PLANNING REPORT NO. 13

A COMPREHENSIVE PLAN FOR THE MILWAUKEE RIVER WATERSHED

volume one

INVENTORY FINDINGS AND FORECASTS

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NUMBER 13

volume one

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INVENTORY FINDINGS AND FORECASTS

Southeastern Wisconsin Regional Planning Commission
Milwaukee River Watershed Study
Old Courthouse
Waukesha, Wisconsin
53186

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December 1970

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STATEMENT OF THE CHAIRMAN

The Southeastern Wisconsin Regional Planning Commission has, since its inception, recognized the importance of water and water-related resource problems within the rapidly urbanizing Southeastern Wisconsin Region. The Commission, after careful consideration, concluded that such problems could best be addressed within the framework of comprehensive watershed planning programs and, therefore, agreed to undertake a series of such watershed planning programs, with the individual programs, however, being initiated only upon the specific request of the local units of government concerned. The resulting comprehensive watershed plans are intended to provide the basic regional storm water drainage plan element and the basic regional water pollution abatement plan element of a comprehensive plan for the physical development of the Region, as well as to provide important inputs to the regional sanitary sewerage system, regional water supply system, and regional park and related open-space system plan elements.

Pursuant to the Commission's established policy in this respect, on December 15, 1964, the Common Council of the City of Milwaukee formally requested the Southeastern Wisconsin Regional Planning Commission to undertake a comprehensive study of the Milwaukee River watershed looking to the ultimate resolution of the serious and costly flooding and water pollution problems within that watershed which affect the property and general welfare of its citizens and which can only be properly resolved within the context of a long-range comprehensive watershed planning effort. On February 2, 1965, the Board of Supervisors of Milwaukee County formally adopted a similar request. The Commission accordingly on September 14, 1965, formed the Milwaukee River Watershed Committee, a Committee comprised of 26 local public officials and citizen leaders drawn from throughout the watershed to assist the Commission in its study of the watershed. That Committee prepared a Prospectus for a comprehensive study of the Milwaukee River watershed, a Prospectus which, with the formal approval of the five county boards concerned, became the basis for the conduct of the actual watershed planning program. The ultimate purpose of that program was to prepare a comprehensive plan for the physical development of the watershed designed not only to solve the pressing problems of flooding, water pollution, and changing land use which exist within that watershed, but to most advantageously develop the total land and water resources of that watershed and thereby provide an environment for human life within the watershed which is attractive, as well as safe and healthful.

This study represents the first planning program to be conducted by the Commission which includes considerable portions of counties lying outside the seven-county Southeastern Wisconsin Planning Region. It is gratifying that the County Boards of Fond du Lac and Sheboygan Counties, which contain the headwater portions of this watershed, have cooperated in this work both as to funding and the conduct of this very important watershed study.

The final planning report for this study will consist of two volumes. This, the first volume, presents a summary of the required inventory findings, as well as forecasts of future growth and development within the watershed. These inventories and forecasts provide the basis for an in-depth analysis of the resource-related problems and, as such, the basis for the preparation of alternative watershed plan elements and for the selection, after public hearings, of a final plan from among these alternatives. The inventories also provide for all time an invaluable bench mark of historic data upon which future studies of the watershed can be built.

In accordance with the advisory role of the Commission, this volume is transmitted herewith to the governmental agencies operating within the watershed and within the Region. Consideration and careful review of this volume by all responsible public officials concerned is urged, since out of this volume, as previously indicated herein, will grow definitive plans and specific recommendations for the resolution of the resource-related problems of the Milwaukee River watershed. During the next few months, many meetings and hearings on the contents of this volume and on the available alternative solutions to the problems of the watershed will be held. The results of these meetings and hearings and the reactions of public officials and interested citizens will weigh heavily on the effectiveness of the solutions proposed to meet the growing resource problems of the watershed. These proposed solutions will be set forth and documented in the second volume of this report.

With the assistance of concerned public officials and interested citizens, lasting guidelines for the abatement of detrimental land and water resource uses and for the proper development of these resources can be provided and the protection and wise use of the natural resource base of the watershed assured.

Respectfully submitted,

George Berteau

George C. Berteau
Chairman

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Chapter I

INTRODUCTION

The Milwaukee River watershed study is the third comprehensive watershed planning program to be carried out by the Southeastern Wisconsin Regional Planning Commission. Since this watershed study is an integral part of the Commission work program, an understanding of the need for, and objectives of, regional planning and the manner in which these needs and objectives are being met in southeastern Wisconsin is necessary to a proper appreciation of the Milwaukee River watershed study and its findings and recommendations.

NEED FOR REGIONAL PLANNING

Regional planning is herein defined as comprehensive planning for a geographic area larger than a county but smaller than a state, united by economic interests, geography, or common areawide development problems. The need for such planning has been brought about by certain important social and economic changes which, while national phenomena, have far-reaching impacts on the problems facing local government. These changes include: unprecedented population growth and urbanization; increasing agricultural and industrial productivity, income levels, and leisure time; generation of mass recreational needs and pursuits; increasingly intensive use and consumption of natural resources; development of private water supply and sewage disposal systems; development of far-flung electric power and communications networks; and development of limited-access highway systems and mass automotive transportation.

Under the impact of these changes, entire regions, such as southeastern Wisconsin, are becoming mixed rural-urban areas. This, in turn, is creating new and intensified areawide development problems of an unprecedented scale and complexity. Rural, as well as urban, people must increasingly concern themselves with these problems or face irreparable damage to their land and water resources.

The areawide problems which necessitate a regional planning effort in southeastern Wisconsin all have their source in the unprecedented population growth and urbanization occurring within the Region. These areawide problems include, among others: inadequate drainage and mounting flood damages; underdeveloped sewerage and inadequate sewage disposal facilities; impairment of water supply and increasing pollution; deterioration and destruction of the natural resource base; rapidly increasing demand for outdoor recreation and for park and open-space reservation; inadequate transportation facilities; and, underlying all of the foregoing problems, rapidly changing and unplanned land use development. These problems are all truly regional in scope since they transcend the boundaries of any one municipality and can only be resolved within the context of a comprehensive regional planning effort involving, on a cooperative basis, all levels of government concerned.

THE REGIONAL PLANNING COMMISSION

The Southeastern Wisconsin Regional Planning Commission (SEWRPC) represents an attempt to provide the necessary areawide planning services for one of the large urbanizing regions of the nation. The Commission was created in August 1960, under the provisions of Section 66.945 of the Wisconsin Statutes, to serve and assist the local, state, and federal units of government in planning for the orderly and economical development of southeastern Wisconsin. The role of the Commission is entirely advisory; and participation by local units of government in the work of the Commission is on a voluntary, cooperative basis. The Commission itself is composed of 21 citizen members, who serve without pay, three from each county within the Region.

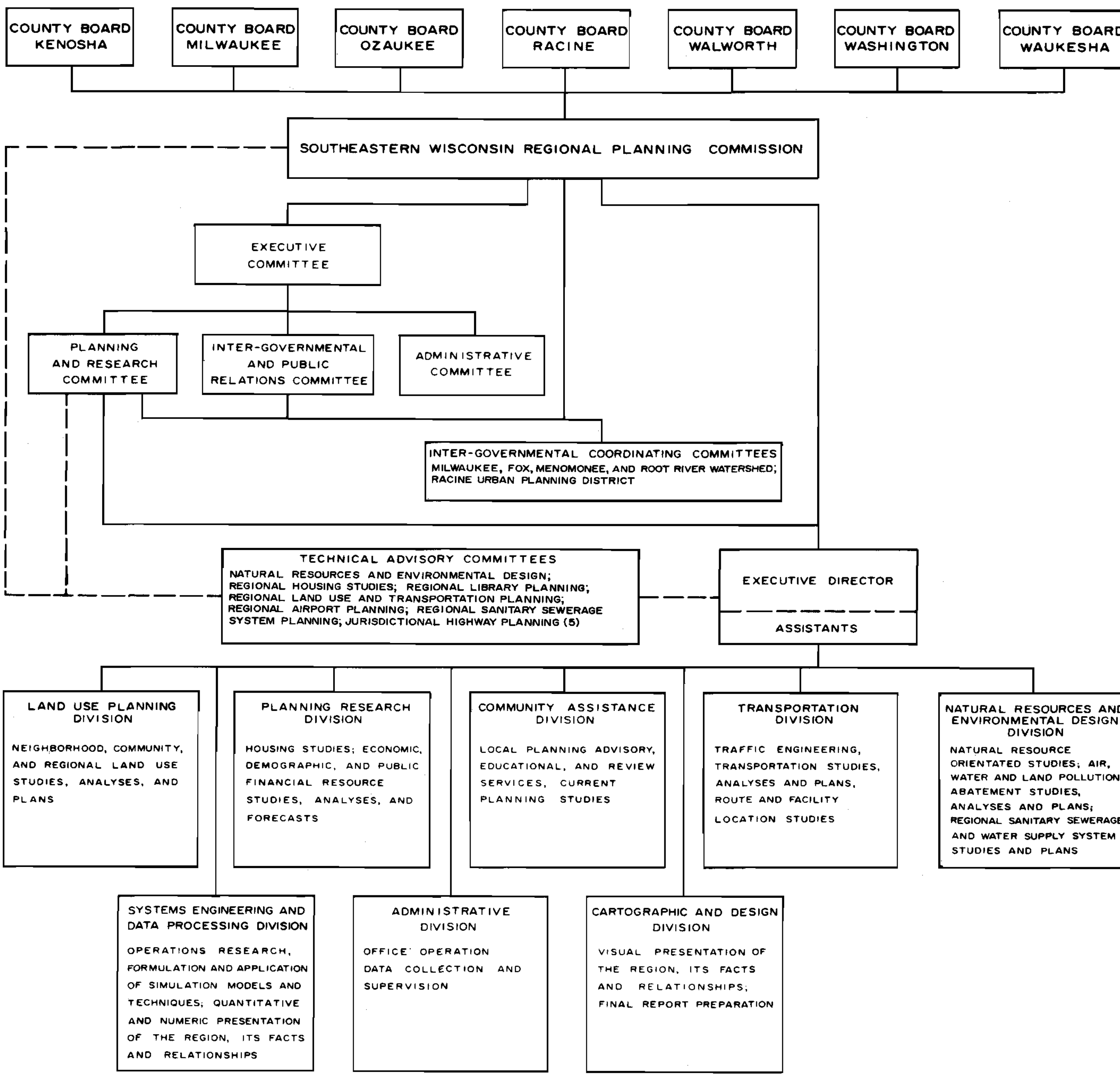
The powers, duties, and functions of the Commission and the qualifications of the Commissioners are carefully set forth in the state enabling legislation. The Commission is authorized to employ experts and a staff as necessary for the execution of its responsibilities. Basic funds necessary to support Commission operations are provided by the member counties, the budget being apportioned among the several counties on the basis of relative equalized valuation. The Commission is authorized to request and accept aid in any form from all levels and agencies of government for the purpose of accomplishing its objectives and is authorized to deal directly with the state and federal governments for this purpose. The Commission, its committee structure, and its staff organization, together with its relationship to the constituent counties, are shown in Figure 1.

THE REGIONAL PLANNING CONCEPT IN SOUTHEASTERN WISCONSIN

Regional planning, as conceived by the Commission, is not a substitute for, but a supplement to, local, state, and federal planning efforts. Its objective is to aid the various levels and units of government in finding solutions to areawide devel-

Figure 1

SOUTHEASTERN WISCONSIN REGIONAL PLANNING COMMISSION
EXISTING STAFF AND COMMITTEE STRUCTURE



Source: SEWRPC.

opmental and environmental problems which cannot be properly resolved within the framework of a single municipality or a single county. As such, regional planning has three principal functions:

1. Inventory—the collection, analysis, and dissemination of basic planning and engineering data on a uniform, areawide basis so that, in light of such data, the various levels and agencies of government and private investors operating within the Region can better make decisions concerning community development.

2. Plan Design—the preparation of a framework of long-range plans for the physical development of the Region, these plans being limited to those functional elements having areawide significance. To this end the Commission is charged by law with the function and duty of "making and adopting a master plan for the physical development of the Region." The permissible scope and content of this plan, as outlined in the enabling legislation, extend to all phases of regional development, implicitly emphasizing, however, the preparation of alternative spatial designs for the use of land and for the supporting transportation and utility facilities.

3. Plan Implementation—promotion of plan implementation through the provision of a center for the coordination of the many planning and plan implementation activities carried on by the various levels and agencies of government operating within the Region.

The work of the Commission is, therefore, visualized as a continuing planning process providing outputs of value to the making of development decisions by public and private agencies and to the preparation of plans and plan implementation programs at the local, state, and federal levels of government. The work of the Commission emphasizes close cooperation between the governmental agencies and private enterprise responsible for the development and maintenance of land uses within the Region and for the design, construction, operation, and maintenance of their supporting public works facilities. All of the Commission work programs are intended to be carried out within the context of a continuing planning program which provides for the periodic reevaluation of the plans produced, as well as for the extension of planning information and advice necessary to convert the plans into action programs at the local, regional, state, and federal levels.

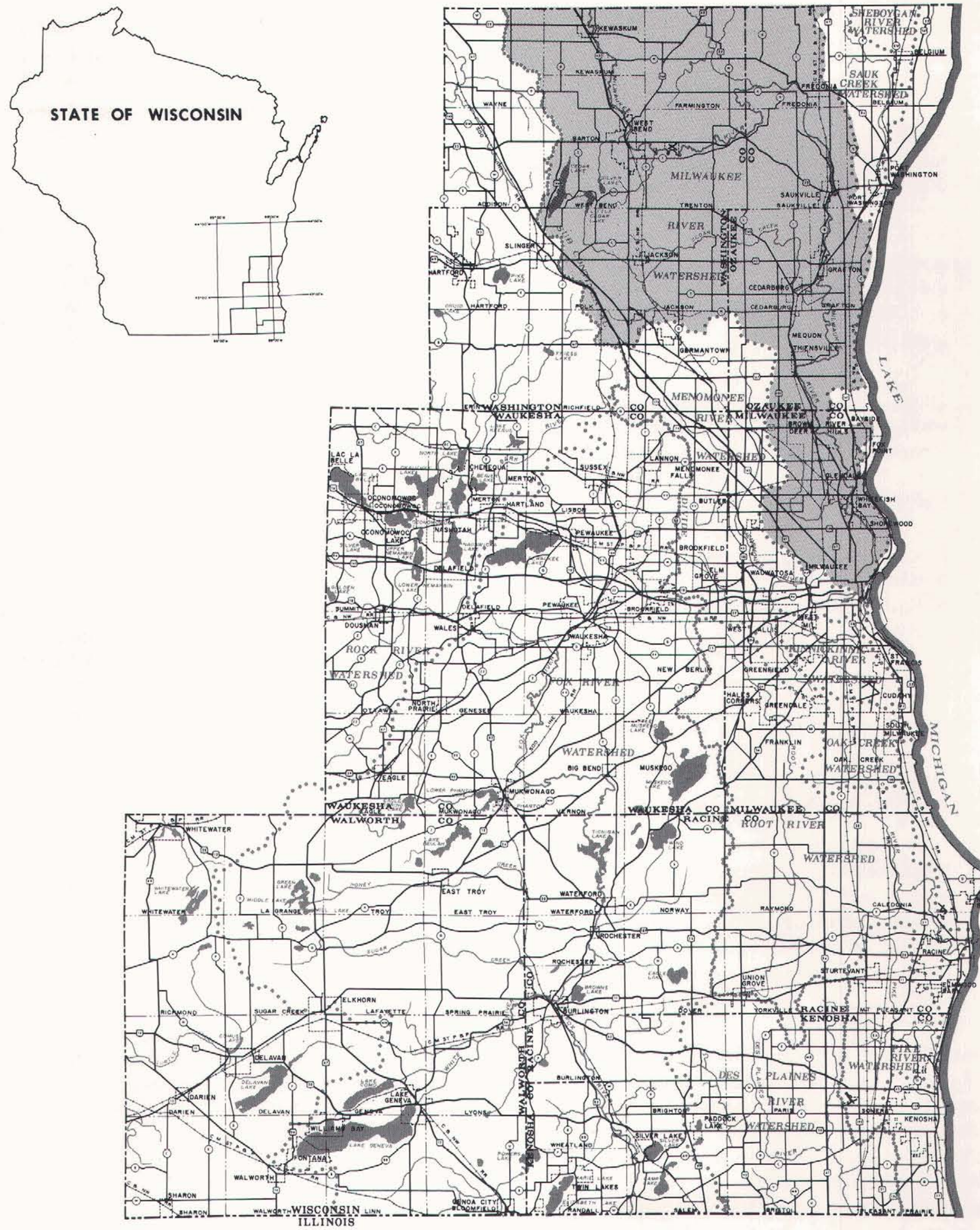
THE REGION

The Southeastern Wisconsin Planning Region, as shown on Map 1, is comprised of Kenosha, Milwaukee, Ozaukee, Racine, Walworth, Washington, and Waukesha Counties in southeastern Wisconsin. Exclusive of Lake Michigan, these seven counties have a total area of 2,689 square miles and together comprise about 5 percent of the total area of the State of Wisconsin. About 40 percent of the state population, however, resides within these seven counties, which contain three of the five and one-half standard metropolitan statistical areas in the state. The Region contains approximately one-half of all the tangible wealth in the State of Wisconsin as measured by equalized valuation and represents the greatest wealth-producing area of the state, about 42 percent of the state labor force being employed within the Region. It contributes about twice as much in state taxes as it receives in state aids. The seven-county Region contains 153 local units of government exclusive of school and other special-purpose districts and encompasses all or parts of 11 major watersheds. The Region has been subject to rapid population growth and urbanization and, in the decade from 1950 to 1960, accounted for 64 percent of the population increase of the entire state.

Geographically the Region is located in a relatively good position with regard to continued growth and development. It is bounded on the east by Lake Michigan, which provides an ample supply of fresh water for both domestic and industrial use, as well as being an integral part of a major international transportation network. It is bounded on the south by the rapidly expanding northeastern Illinois metropolitan region and on the west and north by the fertile agricultural lands and desirable recreational areas of the rest of the State of Wisconsin. Many of the most important industrial areas and heaviest population concentrations in the Midwest lie within a 250-mile radius of the Region, and over 31 million people reside within this radius.

Map I

LOCATION OF THE MILWAUKEE RIVER WATERSHED IN THE SOUTHEASTERN WISCONSIN REGION



The Milwaukee River watershed is an integral part of the rapidly urbanizing seven-county Southeastern Wisconsin Region. This Region, while comprising only 5 percent of the total area of the state, contains over 40 percent of the state's population, provides employment for almost one-half of the state's labor force, and contains over one-half of all the tangible wealth of the state. The Milwaukee River watershed is the third largest natural surface water drainage basin in the Region. About 31 percent of the current (1967) population of the Region resides within the watershed, which comprises about 16 percent of the area of the Region. In the lower reaches of the watershed are found some of the most intensely urbanized portions of the Region, including the largest city in the Region, the City of Milwaukee.

Source: SEWRPC.

COMMISSION WORK PROGRAMS

Initial Work Program

The initial work program of the Commission was directed entirely toward basic data collection. It included six basic regional planning studies, which were initiated in July 1961 and completed by July 1963: a statistical program and data processing study, a base mapping program, an economic base and structure study, a population study, a natural resources inventory, and a public utilities study.

All of these initial studies were directed toward providing a basic foundation of planning and engineering data for regional planning and were documented in six published planning reports. None of these studies involved the preparation of plans. Their findings, however, provided a valuable point of departure for all subsequent Commission work, including the Milwaukee River watershed planning program.

Also as a part of its initial work program, the Commission adopted a policy of community planning assistance wherein functional guidance and advice on planning problems are extended to local units of government and through which regional planning studies are interpreted locally and regional plans may be integrated with local plans. Six local planning guides have been prepared to date under this community assistance program to provide municipalities throughout the Region with information helpful in the preparation of sound local planning and plan implementation codes and ordinances. These guides will aid in implementing regional, as well as local, plans and will further assist local public officials in carrying out their day-to-day planning functions. The subjects of these guides are: subdivision control, official mapping, zoning, organization of local planning agencies, floodland and shoreland development, and use of soil survey data in planning and development. All include model ordinances, and all provide a framework for plan implementation through local land use control measures.

Land Use-Transportation Study

The first major work program of the Commission actually directed toward the preparation of long-range development plans was a regional land use-transportation study, which was initiated in January of 1963 and completed in December of 1966. This program produced two of the key elements of a comprehensive plan for the physical development of the Region: a land use plan and a transportation plan. The findings and recommendations of the regional land use-transportation study, which has provided many important inputs to the comprehensive watershed planning programs of the Commission, have been published in the three-volume SEWRPC Planning Report No. 7, Regional Land Use and Transportation Plans; in SEWRPC Planning Report No. 8, Soils of Southeastern Wisconsin; and in five supporting technical reports, including SEWRPC Technical Report No. 4, Water Quality and Flow of Streams in Southeastern Wisconsin.

Root River Watershed Study

The Root River watershed study was the first comprehensive watershed planning program and the second major work program actually directed toward the preparation of long-range development plans to be undertaken by the Commission. This program was initiated in July of 1964 and completed in July of 1966. The results of the Root River watershed study have been published in SEWRPC Planning Report No. 9, entitled A Comprehensive Plan for the Root River Watershed, and in supporting SEWRPC Technical Report No. 2, Water Law in Southeastern Wisconsin.

The study embodied an analysis and evaluation of three alternative land use plans: 1) an uncontrolled existing trend plan, which would, in effect, continue the recent trends to a highly dispersed pattern of low-density residential development throughout the watershed, impose no regulations on land use in the floodways and floodplains of the streams and watercourses, and require no adjustment of development to soil capabilities or sanitary sewer service areas; 2) a controlled existing trend plan, which would require land use regulation at the local level of government to ensure protection of the floodplains and floodways from urban encroachment and which would guide new urban development into those areas of the watershed which can be readily served by extension of existing centralized public sanitary sewerage systems; and 3) a controlled existing trend-parkway and recreation land development plan, which would, in addition to the second alternative, provide for the acquisition and development of certain urbanizing portions of the river floodways and floodplains for public parkway use. These three land use alternatives were accompanied by, and combined with, six different water control facility plans directed at flood control and four water control facility plans directed at pollution abatement.

The Commission adopted the comprehensive plan for the Root River watershed on September 22, 1966. The plan has been enthusiastically received to date by the local units of government and full implementation is anticipated. The recommended plan has been formally adopted by the Milwaukee and Racine County Boards of Supervisors; by the Common Councils of the Cities of Franklin, Oak Creek, and Racine; and by the Town Board of the Town of Mt. Pleasant. The Metropolitan Sewerage Commission of the County of Milwaukee has formally acted to change its sanitary sewer service areas to conform to the watershed plan recommendations and has indicated its intent within the watershed to depart from its historic channel improvement approach to flood abatement in accordance with the plan. The Milwaukee County Park Commission is proceeding with the recommended parkway land acquisition and has formally expressed its intent to construct the recommended multi-purpose reservoir. The Cooper-Dixon Duck Farm and the Wisconsin Southern Colony have initiated recommended improvements in waste treatment facilities. The Racine County Board has, upon recommendations contained in the final planning report, retained a full-time park planner and administrator with specific responsibilities for implementation of the park and parkway elements of the recommended plan in Racine County.

Fox River Watershed Study

The Fox River watershed study was the second comprehensive watershed planning program and the third major work program directed toward the preparation of long-range development plans to be undertaken by the Commission. This program was initiated in November of 1965 and completed in February 1970. The results of the Fox River watershed study have been published in SEWRPC Planning Report No. 12, A Comprehensive Plan for the Fox River Watershed, Volume 1, Inventory Findings and Forecasts, and Volume 2, Alternative Plans and Recommended Plan.

The Fox River watershed study differed from the Root River study as it was not conducted for an entire watershed but only for the headwater portion of the Fox River basin. The attention of the Commission was focused primarily on the 942 square miles of the watershed lying in Wisconsin, but the Commission remained cognizant of the relationship of this area with the 1,640 square mile portion of the Fox River watershed located in Illinois.

Unlike the Root River watershed study but like the Milwaukee River watershed study, the Fox River watershed study embodied analysis and evaluation of only two alternative land use plans: 1) an uncontrolled existing trend plan, and 2) a controlled existing trend plan, the latter encompassing, however, several alternative recreation and recreation-related resource conservation elements. These two basic land use alternatives were accompanied by, and combined with, six different water control facility plan elements directed at flood control, four water control facility plan elements directed at pollution abatement, and three water supply facility plan elements. The Commission adopted the comprehensive plan for the Fox River watershed on June 4, 1970.

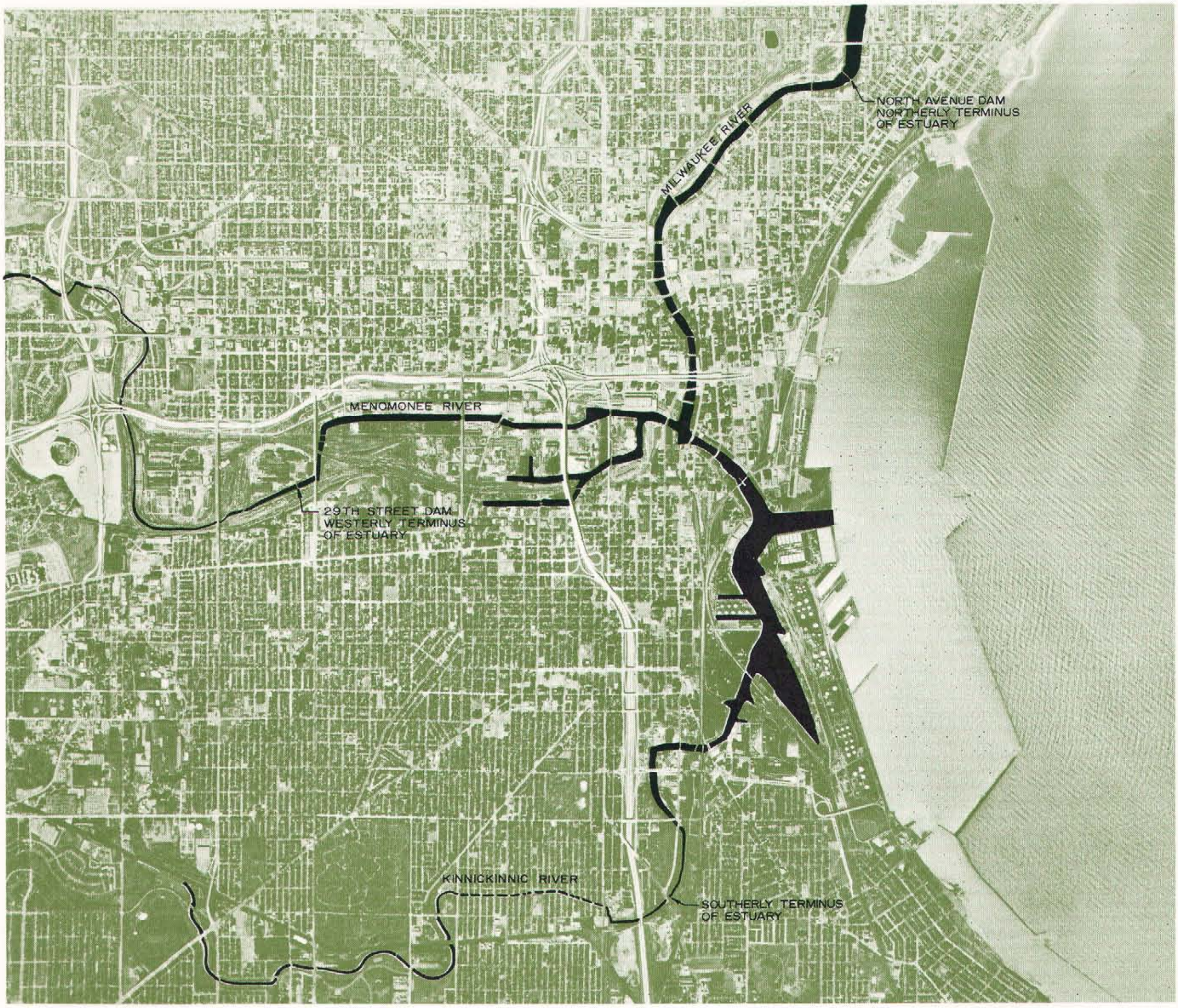
THE MILWAUKEE RIVER WATERSHED STUDY

The Milwaukee River watershed study is the third comprehensive watershed planning program to be undertaken by the Commission. It is, however, the first such study to be conducted by the Commission for a watershed, a significant portion of which lies outside the boundaries of the Southeastern Wisconsin Region. As shown on Map 2, approximately 264 square miles, or about 38 percent of the total area of the Milwaukee River watershed, is located in Dodge, Fond du Lac, and Sheboygan Counties, counties which lie outside the jurisdictional boundaries of the seven-county Southeastern Wisconsin Planning Region.

Although the entire Milwaukee River watershed, from its headwater area to its mouth on Lake Michigan, was to be included in the comprehensive watershed planning program with respect to the land use and flood control plan elements of the study, primary attention with respect to the pollution abatement elements of the study was to be centered on the 688 square mile watershed area situated upstream from the North Avenue Dam in the City of Milwaukee. That portion of the Milwaukee River below the North Avenue Dam acts as an estuary of Lake Michigan; and it is the Commission opinion that, with respect to pollution abatement, this estuary should be studied separately from not only the Milwaukee but also from the Menomonee and Kinnickinnic Rivers, which also discharge to this estuary below the North Avenue Dam. The Menomonee River joins the Milwaukee River estuary at a distance of only 5,200 feet from the mouth of the estuary on the shore of Lake Michigan, while the Kinnickinnic River joins the estuary at a distance of only 1,800 feet from the mouth of the estuary (see Figure 2).

Figure 2

THE LAKE MICHIGAN ESTUARY AS FORMED BY THE CONFLUENCE OF THE MILWAUKEE, MENOMONEE, AND KINNICKINNIC RIVERS



Source: SEWRPC.

As already noted, the Commission believes that the delineation of watersheds as planning areas must recognize not only the physical features influencing a technically sound watershed planning operation but also the existence of a significant community of interest upon which the active participation of local officials and citizen leaders in the planning effort can be obtained. Because the Menomonee and Kinnickinnic Rivers join the Milwaukee River in its estuary portion and do so virtually at the Lake Michigan shoreline, any attempt to relate the water resource-related problems of the Menomonee and Kinnickinnic River basins to those of the Milwaukee River basin would be tenuous even from a purely physical standpoint. More importantly, however, the promotion of a single community of interest throughout all three of these river basins would be most difficult. Residents of the Menomonee and Kinnickinnic River basins have little in common with respect to land and water resource problems with residents of the Milwaukee River basin. The three rivers do little more than share a common estuary, which estuary should, in accordance with the Commission position as stated above, be studied separately, as should each of the three tributary watersheds.

Thus, while the Menomonee and Kinnickinnic River basins would, under a strictly physical definition, be a part of the Milwaukee River basin, these two basins do not rationally form integral parts of the latter basin for planning purposes. The planning area of the Milwaukee River basin chosen for study by the Commission, therefore, excludes the basins of the Menomonee and Kinnickinnic Rivers. The excluded area totals about 19 percent of the approximately 856 square mile combined drainage area of the Milwaukee, Menomonee, and Kinnickinnic Rivers. The area chosen is a rational and viable planning unit for the following reasons:

1. The watershed planning area adopted for land use and flood control planning comprises all of the watershed, including the headwater areas lying outside the Region, thus assuring that water resource-related problems which emanate from the upper watershed reaches, but are capable of being transmitted downstream, can be effectively resolved within the framework of the watershed study.

2. The watershed planning area adopted for water quality control planning comprises all of the watershed above the North Avenue Dam. The Dam provides a sharp break in the hydraulic grade line of the Milwaukee River and thereby clearly and sharply defines the upper limits of the estuary portion of the Milwaukee River. The water quality conditions of this estuary are determined by flow and water quality conditions in the Menomonee and Kinnickinnic Rivers, as well as by level and water quality conditions in Lake Michigan.

3. The watershed planning area adopted for water quality control planning comprises all of the watershed wherein water pollution sources are located exclusively within the watershed. Due to the configuration of existing sewerage systems, as well as to the natural stream and lake network configuration, that portion of the watershed below the North Avenue Dam is subject to pollution from sources outside the Milwaukee River watershed, and, therefore, cannot be effectively studied within the framework of the watershed study.

The Milwaukee River watershed study was initiated upon the specific request of local units of government within the watershed as a result of a growing concern on the part of local public officials and citizen leaders over increasing problems of flood damage, water pollution, soil erosion, deteriorating fish and wildlife habitat, and the complex effects of changing land use. Concern over what seemed at first to be local problems was followed by a growing awareness among public officials that the causes and effects of these problems transcend local municipal boundaries and are related to the entire stream network and tributary drainage areas. Recognizing the Commission as the logical and best equipped agency to find practical and permanent solutions to these problems, the Common Council of the City of Milwaukee on December 15, 1964, formally requested the Commission to undertake a comprehensive planning study of the Milwaukee River, looking to the ultimate resolution of the serious and costly flooding and water pollution problems within that watershed, which affect the property and general welfare of its citizens and which can only be properly resolved within the context of a long-range comprehensive watershed planning effort. On February 2, 1965, the Board of Supervisors of Milwaukee County formally adopted a similar request.

The Commission accordingly on September 14, 1965, formed the Milwaukee River Watershed Committee, comprised of state and local public officials and citizen leaders from throughout the watershed. This Committee was created to assist the Commission in its study of the problems of the Milwaukee River watershed, and the Committee began at once to prepare a Prospectus for the necessary comprehensive watershed planning program.

It was evident from the beginning that the entire watershed should be included in any comprehensive planning program. This meant the inclusion in the study of the considerable portions of the watershed lying in Fond du Lac and Sheboygan Counties, as well as the very small area of the watershed lying in Dodge County. All of these counties lie outside the Southeastern Wisconsin Planning Region. Fond du Lac and Sheboygan

Counties were requested to join in the work of the Watershed Committee; and on May 12, 1966, the Sheboygan County Board formally acted to appoint representatives to the Watershed Committee, followed on June 14, 1966, by similar action of the Fond du Lac County Board.

The expanded Committee identified and described, in a watershed planning program Prospectus, seven basic problems within the watershed that required careful areawide study for sound resolution. These problems relate to water pollution, inadequate soil and water conservation and management practices, deteriorating fish and wildlife habitat, ground water supply, flood damage, open-space and recreation needs, and changing land use. All of these problems are inextricably interrelated, and this fact precludes their study and resolution on an individual basis.

The Prospectus prepared by this Committee was endorsed by the Commission on September 15, 1966; published; and in accordance with the advisory role of the Commission, transmitted to the governmental agencies concerned for their consideration and action. All five county boards concerned—Fond du Lac, Milwaukee, Ozaukee, Sheboygan, and Washington—as well as the Wisconsin Department of Natural Resources, formally endorsed the Prospectus and agreed to provide the state and local funds necessary for execution of the indicated planning program. The U. S. Department of Housing and Urban Development and the U. S. Department of the Interior, Federal Water Pollution Control Administration, also endorsed the Prospectus and agreed to provide the federal funds necessary for execution of the program.

In order to accomplish the financing of the study, as outlined in the Prospectus, it was necessary for the Commission to effect separate contractual agreements with the U. S. Department of Housing and Urban Development; the U. S. Department of the Interior, Federal Water Pollution Control Administration; the Wisconsin Department of Natural Resources; and the five counties containing major portions of the watershed. Under the contracts between the federal and state agencies and the Commission, the latter agreed to complete the necessary planning work in accordance with the Prospectus, while the former agreed to provide, respectively, Section 701 planning grant funds, Public Law 84-660 comprehensive water pollution control planning funds, and state water pollution abatement planning funds in partial support of the study. Under the contracts between the five counties concerned and the Commission, the latter agreed to complete the necessary planning work; and the former agreed to provide the local funds necessary to support the work. Pursuant to the state regional planning enabling act, the local study costs, amounting to 14.69 percent of the total study costs, were allocated to the respective counties, including Fond du Lac and Sheboygan Counties, on the basis of each county's proportionate share of the 1965 state equalized assessed valuation of the watershed. The percentage share of the total study costs agreed upon in the contracts were: U. S. Department of Housing and Urban Development, 29.40 percent; U. S. Department of the Interior, Federal Water Pollution Control Administration, 22.79 percent; State Department of Resource Development (now the Wisconsin Department of Natural Resources), 33.12 percent; Fond du Lac County, 0.54 percent; Milwaukee County, 10.63 percent; Ozaukee County, 1.38 percent; Sheboygan County, 0.93 percent; and Washington County, 1.21 percent.

The Prospectus, as prepared by the Watershed Committee and published by the Commission, was not a finished study design. It was a preliminary design prepared to obtain support and financing for the necessary study, an objective which was fully achieved. Major work elements, a staff organization, a time schedule, and cost estimates were set forth in the Prospectus. Work on the study, as outlined in the Prospectus, began in October 1967.

Study Objectives

The primary objective of the Milwaukee River watershed planning program, as set forth in the Prospectus, is to assist in abating the serious resource-related problems of the Milwaukee River basin by developing a workable plan to guide the staged development of multi-purpose water resource-related facilities and related resource conservation and management programs for the watershed. This plan, to be effective, must be amenable to cooperative adoption and joint implementation by all levels and agencies of government concerned. It must be capable of functioning as a practical guide for the making of development decisions concerning both land use and water control facility development within the watershed so that, through such implementation, the major water resource-related problems within the watershed may be abated and the full development potential of the watershed realized.

More specifically, the objectives of the planning program are to:

1. Prepare a plan for improved drainage and effective flood damage abatement in and along the major waterways and adjacent floodlands of the Milwaukee River basin.

2. Prepare a plan for water quality management and pollution abatement for the Milwaukee River, for its major tributaries, and for the major lakes of the watershed.

3. Prepare a plan for the protection and conservation of the quality and quantity of the basin ground water supplies.

4. Prepare a plan for the preservation and enhancement of fish and wildlife habitat.

5. Prepare a plan for public open-space reservation and for recreational development.

6. Refine and adjust the regional land use plans to reflect the conveyance, storage, and waste assimilation capabilities of the perennial waterways and floodplains of the watershed; to include feasible water control facilities; and generally to promote the adjustment of land uses in the basin to the surface and ground water resources.

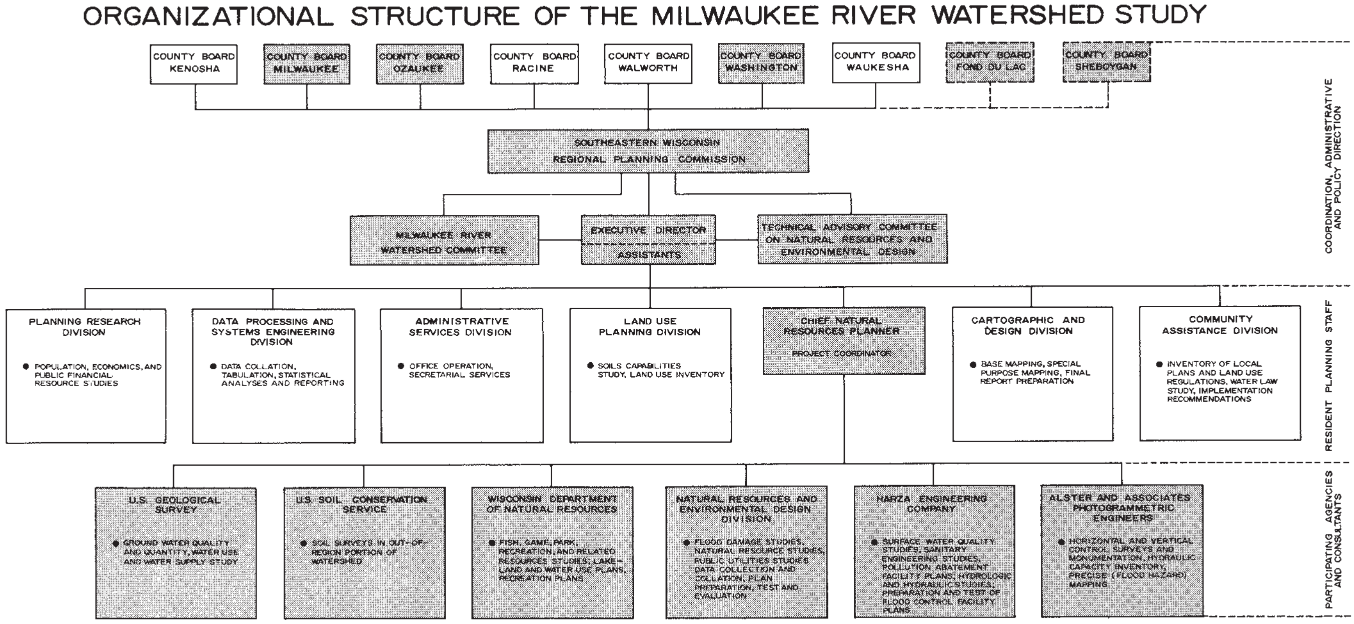
<u>Staff, Cooperating Agency, Consultant, and Committee Structure</u>

The basic organizational structure for the study is outlined in Figure 3 and consists of the cooperating state and federal agencies, consultants, and Commission staff reporting to the Chief Natural Resources Planner as the inter-staff project coordinator, who reports to the Executive Director, who, as a professional engineer, serves as the project sponsor. The Executive Director, in turn, reports to the Southeastern Wisconsin Regional Planning Commission. The responsibilities of the cooperating federal and state agencies, consultants, and Commission staff for the conduct of major elements of the planning study are also indicated in Figure 3.

A comprehensive watershed planning program necessarily covers a broad spectrum of related governmental and private development programs; and no agency, whatever its function or authority, can "go it alone" in the conduct of such a study. The basic Commission organization provides for the attainment of the necessary interagency coordination through the establishment of advisory committees, as well as through interagency staff

Figure 3

ORGANIZATIONAL STRUCTURE OF THE MILWAUKEE RIVER WATERSHED STUDY



NOTE: *SEE ACCOMPANYING TEXT FOR DISCUSSION OF THOSE WORK ELEMENTS ACCOMPLISHED JOINTLY BY THE STUDY STAFF.*

Source: SEWRPC.

assignment; and two types of such committees are provided as integral parts of the organization for the watershed planning work.

The first type of advisory committee, which functions as a part of the organization created by the Commission for watershed planning, is the Technical Advisory Committee on Natural Resources and Environmental Design. This Committee was established in January 1962 and includes representatives from governmental agencies with active resource planning, development, research, or management programs in southeastern Wisconsin. The full Committee membership is listed in Appendix A. The basic purpose of this Committee is to place the experience, knowledge, and resources of the represented federal, state, and local agencies at the disposal of the study and to ensure that the planning objectives and design criteria of these agencies are recognized and incorporated to the fullest extent possible into the watershed planning work.

The second type of advisory committee, which functions as a part of the organization created by the Commission for watershed planning, is the Milwaukee River Watershed Committee. This important Committee was established in September 1965, and the full membership is listed in Appendix B. The basic purpose of this Committee is to actively involve the various governmental bodies, technical agencies, and private interest groups within the watershed in the planning study. The Committee assists the Commission in determining and coordinating basic policies involved in the conduct of the study and in the resultant plans and plan implementation programs. Active involvement of local public officials in the watershed planning program through this Committee is particularly important to any ultimate implementation of the watershed plans in light of the advisory role of the Commission in shaping regional and subregional development. The Watershed Committee performs an important function in familiarizing local leadership within the watershed with the study and its findings and in generating an understanding of basic watershed development objectives and implementation procedures. The Watershed Committee has proven to be a very valuable advisory body to the Commission and its staff throughout the conduct of the Milwaukee River watershed planning program.

The watershed planning work program has been conducted by the small resident SEWRPC staff heavily supplemented by contractual services provided by two federal agencies, one state agency, and two consulting engineering firms. The SEWRPC staff assumed direct responsibility for all those work elements of a general regional planning nature. These elements included the land use inventory; population, economic, and public financial resource studies; flood damage inventory; public utilities inventory; inventory of local plans and land use regulations; and the formulation of plan implementation recommendations.

Services of specialists in the disciplines of soil science, ground water and surface water hydrology, hydraulics, recreation, resource conservation, sanitary engineering, surveying, and photogrammetry were necessary to the successful completion of the complex, interdisciplinary planning program. Contractual agreements were, therefore, executed with the U. S. Soil Conservation Service; the U. S. Geological Survey; the Wisconsin Department of Natural Resources; the Harza Engineering Company of Chicago, Illinois; and Alster & Associates, Inc., of Madison, Wisconsin. Each of these organizations was selected by the Commission for participation in the study by virtue of their exceptional skills and experience in specialized phases of watershed planning.

Under the study the U. S. Soil Conservation Service was responsible for those elements of the study which were related to delineation of types and identification of the properties and capabilities of soils located in that portion of the watershed lying outside the Region. The U. S. Geological Survey was responsible for those elements of the study which related to ground water resources, ground water-surface water relationships, and water supply. The Wisconsin Department of Natural Resources was responsible for those elements of the study which were related to recreation and resource conservation-related problems and their solution. The Harza Engineering Company was responsible for those elements of the study which were related to the surface water hydrology and hydraulics of the watershed, hydrologic and water quality simulation, and surface water-related problems and the formulation of alternative recommendations for their solution, including: economic analyses related to flood damage abatement, recreational development, water utilization, pollution abatement, and land use. Alster & Associates, Inc., was responsible for the horizontal and vertical control surveys and monumentation within the watershed, the hydraulic capacity inventory, and the preparation of large-scale topographic maps to be used for flood hazard mapping purposes.

As the planning effort and this report are both the result of the joint efforts of the Commission, the U. S. Geological Survey, the Wisconsin Department of Natural Resources, and Harza Engineering Company, it is difficult to ascribe a precise delineation of responsibilities for several work elements. These work elements included the detailed study design; formulation of watershed development objectives, principles, and standards; analysis of resource problems and capabilities; determination of resource requirements; plan synthesis, test, and evaluation; and report writing.

Scheme of Presentation

The major findings and recommendations of the Milwaukee River watershed planning program are documented and presented in this report, which consists of two volumes. The first volume of the report sets forth the basic concepts underlying the study and the factual findings of the extensive inventories conducted under the study. It identifies and, to the extent possible, quantifies the developmental and environmental problems of the watershed and sets forth forecasts of future economic activity, population growth, and concomitant land use and natural resource demands. The second volume explores alternative plan elements relating to land use, flood control, pollution abatement, and water supply and sets forth a recommended plan for the development of the watershed based upon regional and watershed development objectives adopted by the Watershed Committee and the Commission. In addition, it contains a financial analysis and specific recommendations for implementation. This report is intended to allow careful, critical review of the alternative plan elements by public officials, agency staff personnel, and citizen leaders within the watershed and to provide the basis for plan adoption and implementation by the federal, state, and local agencies of government concerned.

This report can only summarize in brief fashion the large volume of information assembled in the extensive data collection, analysis, and forecasting phases of the Milwaukee River watershed study. Although the reproduction of all of this information in report form is impractical, due to the sheer magnitude, as well as complexity, of the data collected and analyzed, all of the basic data are on file in the Commission Offices and available to member units and agencies of government and to the public in general upon specific request. This report, therefore, serves the additional purpose of indicating the types of data which are available from the Commission and which may be of value in assisting federal, state, and local units of government and private investors in making better decisions about community development within the Region.

Chapter II

BASIC PRINCIPLES AND CONCEPTS

Watershed planning is not new. Plans have been developed in the past for many river basin watersheds, both large and small, throughout the United States. Most of these plans, however, have been developed either to meet the needs of one or more specific revenue-producing functions, such as irrigation, power, or municipal water supply, or to fulfill a single-purpose requirement for which specific benefits are assignable to existing properties, such as flood control or soil and water conservation.

The application of comprehensive planning principles and practices to watersheds, as defined herein, however, is a relatively new concept. Consequently, at the time that the Commission undertook its first comprehensive watershed planning program, that for the Root River watershed, little practical experience had been accumulated in such comprehensive watershed planning; and widely accepted principles governing such planning had not been established. Moreover, the need to carry out comprehensive watershed planning as an integral part of a broader regional planning effort required the adaptation and modification of even the very limited body of comprehensive watershed planning experience to the specific needs of the Root River watershed planning program.

These factors occasioned, as a part of the Root River watershed study, the development of a unique approach to watershed planning, an approach which proved to be sound and was, therefore, adopted for use in subsequent studies for the Fox and Milwaukee River watersheds. This approach can only be explained in terms of the conceptual relationships existing between watershed planning and regional planning and of the basic principles applicable to watershed planning set within the framework of regional planning. Only after this foundation of conceptual relationships and applicable principles has been established can the specific problems of the Milwaukee River watershed and the recommended solutions to these problems, as presented herein, be properly understood.

THE WATERSHED AS A PLANNING UNIT

Resources planning could conceivably be carried out on the basis of various geographic units, including areas defined by governmental jurisdictions, economic linkages, or watershed boundaries. None of these are perfect as a resources planning unit. There are many advantages to selection of the watershed as a resources planning unit, however, since many resource problems and solutions are water-oriented.

Storm water drainage and flood control facilities should form a single integrated system over an entire watershed. This system must be capable of carrying both present and future runoff loads generated by changing land use and water control facility patterns within the watershed. Therefore, storm water drainage and flood control problems and facilities can best be considered on a watershed basis. Drainage and flood control problems, however, are closely related to other land and water use problems. Consequently, floodplain protection, park and related open-space reservation, and recreational facilities that are related to surface water resources also can best be studied on a watershed basis.

Water supply and sewerage frequently involve problems that cross watershed boundaries, but strong watershed implications are involved if the source of water supply comes from the surface water resources of the watershed or if the sewerage systems discharge pollutants into the surface water system. Changes in land use and transportation requirements are ordinarily not controlled primarily by watershed factors but can have a great effect on watershed problems. The land use and transportation pattern affects the amount and spatial distribution of the hydraulic and pollution loadings to be accommodated by water control facilities. In turn, the water control facilities and their effect upon the historic floodways and floodplains determine to a considerable extent the use to which such land areas may be put. Finally, the related physical problems of a watershed tend to create a strong community of interest among the residents of the watershed; and citizen action groups can readily be formed to assist in solving water-related problems.

It may be concluded, therefore, that the watershed is a logical areal unit to be selected for resources planning purposes, provided that the relationships existing between the watershed and the surrounding region are recognized. Accordingly, the SEWRPC regional planning program embodies a recognition of the need to consider watersheds within the Region as rational planning units in rapidly urbanizing areas if workable solutions are to be found to intensifying interrelated land and water use problems.

The foregoing discussion implies that the term watershed may have two meanings. Defined in a strictly physical sense, a watershed is simply a geographic area of overland drainage contributing surface runoff to the flow of a particular stream or watercourse at a given point. Under this definition the terms watershed and drainage basin are synonymous. The meaning of the term watershed may be expanded, however, to include planning concepts by adding to the above definition the phrase: whose natural and man-made features are so interrelated and mutually interdependent as to create a significant community of interest among its residents. This expanded definition of the term watershed contains within it the characteristics which a drainage basin, such as that of the Milwaukee River, must exhibit if it is to form a rational unit for comprehensive water resources planning. This expanded definition, moreover, had a particularly important impact upon the geographic area to be encompassed in a study of the Milwaukee River watershed by the Regional Planning Commission, for careful consideration of the communities of interest involved led the Commission to exclude from its delineation of the Milwaukee River watershed the drainage areas of the Menomonee and Kinnickinnic Rivers.

Thus, it is recognized that a watershed is far more than a system of interconnected waterways and floodplains, which, in fact, comprise only a small proportion of the total watershed area. Land treatment measures, soil and water management practices, and land use over the entire watershed, as well as all related water resource problems, are of major importance in the proper development of watershed resources.

RELATIONSHIP OF WATERSHED TO REGION

Although recognizing the importance of the watershed as a rational planning unit within the Region, the SEWRPC planning program also recognizes the necessity to conduct individual watershed planning programs within the broader framework of areawide, comprehensive regional planning. This is essential for two reasons. First, areawide urbanization indiscriminately crosses watershed boundaries and exerts an overwhelming external influence on the physical development of the affected watershed. Second, the meandering pattern of natural watershed boundaries rarely, if ever, coincides with the artificial, generally rectangular boundaries of minor civil divisions and special-purpose districts.

Important elements of the necessary areawide planning program have been provided by the regional land use-transportation study completed earlier and by other ongoing areawide planning programs of the Commission. Conversely, within the context of the regional planning program, the comprehensive watershed planning programs provide, within the limits of each watershed, one of the key elements of a comprehensive regional development plan; namely, a long-range plan for water-related community facilities. While the proposed watershed plans may be centered on water quality and flood control facilities, it must be recognized that these facility plans must be prepared in consideration of the related problems of land and water use and park and public open-space reservation. Recognition of the need to relate these facility plans to areawide regional development plans is the primary factor which determines the unique nature of the SEWRPC watershed planning efforts. Ultimate completion of planning studies covering all of the watersheds within the Region will provide the Commission with a framework of community facility plans encompassing drainage, flood control, and pollution control and abatement facilities properly related to areawide development plans and will make significant contributions to the preparation of a framework of regional community facility plans for parks and related open spaces and for water supply and sewerage facilities.

THE WATERSHED PLANNING PROBLEM

Although the water-related resource planning efforts of the Commission are focused on the watershed as a rational planning unit, the watershed planning problem is closely linked to the broader problem of resource conservation. Society has always had need to be concerned with resource conservation; but the need for such concern is greater today than ever before and grows, as does the need for regional planning, out of the unprecedented population growth and urbanization of the nation, the state, and the Region. Increasing urbanization has, moreover, changed the nature of the resource conservation problem.

In the past conservation was largely concerned with the protection of wilderness areas and possible future shortages of some resources through chronic mismanagement. The new problem which conservation now faces has to do mainly with the kind of environment being created by the ever increasing areawide diffusion of urban development over large regions and the relentless pursuit of an ever higher material standard of living. Regional settlement patterns so far have not been determined by design but by economic expedience and have failed to recognize the existence of a limited resource base to which urban development must be carefully adjusted if severe environmental problems are to be avoided. If increasing areawide urbanization is to work for the benefit of man and not to his detriment, adjustment of such urban development to the ability of the resource base to sustain and support it, thereby maintaining the quality of the environment, must become a major physical development objective for urbanizing regions.

Enlightened public officials and citizen leaders are becoming increasingly aware of this new and pressing need for conservation. This growing awareness is often accelerated as the result of a major disaster or of the imminent threat of such a major disaster. Even in such cases, however, the magnitude and degree of the interrelationship of resource problems may not always be fully realized. In many cases, such as in the Milwaukee River watershed, the initial concern with the growing resource problems is centered in such highly visible problems as flooding and water pollution.

Growing urbanization is causing increasing concern on the part of public officials, citizen leaders, and technicians with these and other water-related problems; and the manner in which these problems are ultimately resolved will involve many important public policy determinations. These determinations must be made in view of an urbanizing Region which is constantly changing and, therefore, should be based upon a comprehensive planning process able to objectively scale the changing resource demands against the ability of the limited natural resource base to meet these demands. Only within such a planning process can the effect of different land and water use and water control facility construction proposals be evaluated, the best course of action intelligently selected, and the available funds most effectively invested.

The ultimate purposes of such a planning process are twofold: 1) to permit public evaluation and choice of alternative resource conservation and development policies and plans; and 2) to provide—through the medium of a long-range plan for water-related community facilities—for the full coordination of local, state, and federal resource development programs within the Region and within the various watersheds of the Region. Important among goals to be achieved by this process are the protection of floodways and floodplains; the protection of water quality and supply; the preservation of land for park and open space; and, in general, promotion of the wise and judicious use of the limited land and water resources of the Region and its watersheds.

BASIC PRINCIPLES

Based upon the foregoing considerations, eight basic principles were developed under the Root River watershed study, which together form the basis for the specific watershed planning process applied by the Commission in that study. These same principles provide the basis for the planning process applied in the Milwaukee River watershed study:

1. Watersheds must be considered as rational planning units if workable solutions are to be found to water-related resource problems.

2. A comprehensive, multi-purpose approach to water resource development and to the control and abatement of the water-related problems is preferable to a single-purpose approach.

3. Watershed planning must be conducted within the framework of a broader areawide regional planning effort; and water-

shed development objectives must be compatible with, and dependent upon, regional development plans and objectives.

4. Water control facility planning must be conducted concurrently with, and cannot be separated from, land use planning.

5. Both land use and water control facility planning must recognize the existence of a limited natural resource base to which urban and rural development must be properly adjusted to ensure a pleasant and habitable environment.

6. The capacity of each water control facility in the integrated watershed system must be carefully fitted to the present and probable future hydraulic loads, and the hydraulic performance and hydrologic feasibility of the proposed facilities must be determined and evaluated.

7. Primary emphasis should be placed on in-watershed solutions to water resource problems, and the export of water resource problems to downstream areas is unwise on a long-range and regional basis.

8. Plans for the solution of watershed problems and development of resources should offer as flexible an approach as possible in order to avoid "dead-end" solutions and provide latitude for continued adaptation to changing conditions.

THE WATERSHED PLANNING PROCESS

Based upon the foregoing principles, the Commission has developed a seven-step planning process by which the principal functional relationships existing within a watershed can be accurately described, both graphically and numerically; the hydrologic and hydraulic characteristics of the basin simulated; and the effect of different courses of action with respect to land use and water control facility development evaluated. The seven steps involved in this planning process are: 1) study design, 2) formulation of objectives and standards, 3) inventory, 4) analysis and forecast, 5) plan design, 6) plan test and evaluation, and 7) plan selection and adoption. Plan implementation, although necessarily beyond the foregoing planning process, must be considered throughout the process if the plans are to be realized.

The principal end results of the above process are land use and water control facility plans scaled to future land use and resource demands and consistent with regional development objectives. In addition, the process represents the beginning of a continuing planning effort that permits modification and adaptation of the plans and the means of implementation to changing conditions. Each step in this planning process includes many individual operations which must be carefully designed, scheduled, and controlled to fit into the overall process; and an understanding of this planning process is essential to an appreciation and understanding of the results. Each step in the process, together with its major component operations, is diagrammed in Figure 4 and described briefly below.

Study Design

Every planning program must embrace a formal structure or study design so that the program can be carried out in a logical and consistent manner. This study design must: specify the content of the fact-gathering operations, define the geographic area for which data will be gathered and plans prepared, outline the manner in which the data collected are to be processed and analyzed, specify requirements for forecast and for forecast accuracy, and define the nature of the plans to be prepared and the criteria to be used in their evaluation and adoption.

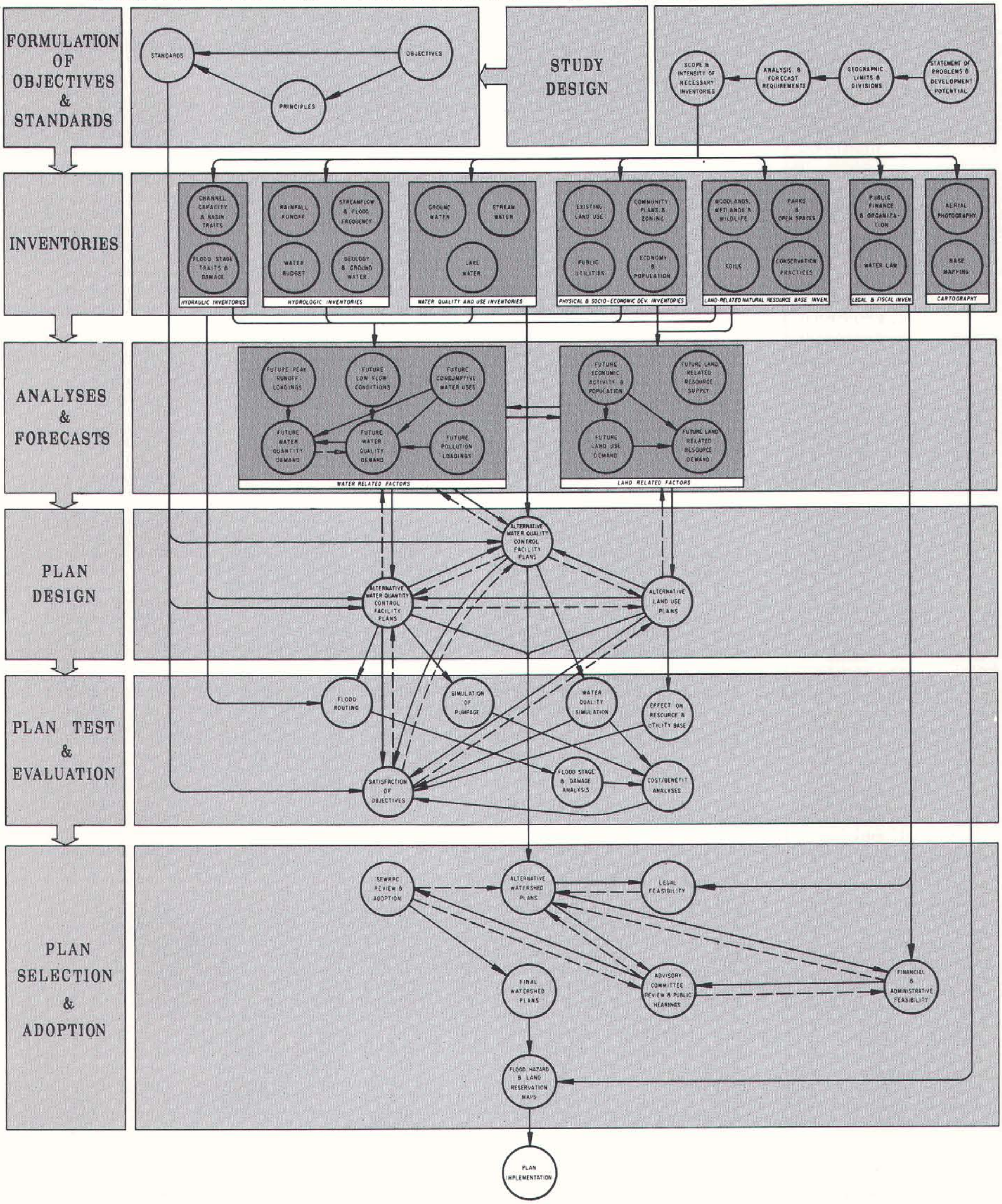
In the Milwaukee River watershed program, the study design was prepared jointly by the staffs of the Southeastern Wisconsin Regional Planning Commission, U. S. Soil Conservation Service, U. S. Geological Survey, Wisconsin Department of Natural Resources, and Harza Engineering Company and presented to the Milwaukee River Watershed Committee for review and approval.

Formulation of Objectives and Standards

In its most basic sense, planning is a rational process for establishing and meeting objectives. The formulation of objectives is, therefore, an essential task to be undertaken before plans can be prepared. In order to be useful in the regional and watershed planning process, the objectives to be defined must not only be stated clearly and be sound logically but must also be related in a demonstrable way to alternative physical development proposals. This is necessary because it is the duty and function of the Commission to prepare a comprehensive plan for the physical development of the Region and its component parts and,

Figure 4

GENERAL STEPS IN A COMPREHENSIVE WATERSHED PLANNING STUDY



Source: SEWRPC.

more particularly, because it is the objective of the Milwaukee River watershed planning study to prepare one of the key elements of such a physical development plan—a long-range plan for water-related community facilities. Only if the objectives are clearly relatable to physical development and subject to objective test can a choice be made from among alternative plans in order to select that plan which best meets the needs of agreed-upon objectives. Finally, logically conceived and well-expressed objectives must be translated into detailed design standards to provide the basis for plan preparation, test, and evaluation. Because the formulation of objectives and standards involves many nontechnical, as well as technical, policy determinations, all objectives and standards were carefully reviewed and adopted by the Milwaukee River Watershed Committee and the Commission. The objectives and standards ranged from general development goals for the watershed as a whole to detailed planning and engineering criteria covering rainfall intensity–duration–frequency relationships, rainfall-runoff relationships, channel capacity formulae, backwater computations, water quality parameters, recreational facilities, and economies.

Inventory

Reliable basic planning and engineering data collected on a uniform, areawide basis are absolutely essential to the formulation of workable development plans. Consequently, inventory becomes the first operational step in any planning process, growing out of the study design. The crucial nature of factual information in the planning process should be evident since no intelligent forecasts can be made or alternative courses of action selected without knowledge of the current state of the system being planned.

The sound formulation of comprehensive watershed development plans requires that factual data must be developed on the quantity of surface and ground water, precipitation, hydraulic characteristics of the stream channels, historic flooding, flood damages, water quality, water use, soil capabilities, land use, economic activity, population, recreation facilities, fish and wildlife, public utilities, and water law.

In the Milwaukee River study, the most expedient methods of obtaining adequate information of the necessary quality were followed; and the means of data collection included review of prior publications, perusal of agency files, personal interviews with private citizens and public officials, committee meetings of staff and technical advisors, and postal questionnaire surveys, as well as original field investigations.

Analysis and Forecast

Inventories provide factual information about historic and present situations; but analyses and forecasts are necessary to provide estimates of future needs for land, water, and water control facilities. These future needs must be determined from a sequence of interlocking forecasts. Economic activity and population forecasts enable determination of future growth within the watershed, which, in turn, can be translated into future demands for land use, resources, and water control facilities. These future demands can then be scaled against the existing supply and plans formulated to meet deficiencies.

To illustrate the complexity of this task in comprehensive watershed planning, consider that to prepare a forecast of future drainage and flood control needs it was necessary to analyze and to interrelate the following factors: precipitation characteristics, relationship between precipitation and runoff, relationship between basin morphology and runoff, effect of urbanization and soils on runoff, effect of the hydraulic characteristics of the stream network on streamflow, relationship of peak volumes of streamflow to stage heights and frequency of occurrence, relationship of differences between winter and summer runoff and streamflow characteristics, extent and depth of inundation on floodplains, and the horizontal and vertical location of possible future development in floodplains.

Two important considerations involved in the preparation of the necessary forecasts are the forecast target date and the forecast accuracy requirements. Both the land use pattern and the water control facilities must be planned for anticipated demand at some future point in time. In the planning of water control facilities, this "design year" is usually established by the expected life of the first facilities to be constructed in implementation of the plan. Although it may be argued that the design year for land use development should be extended further into the future than that for facilities because of the basic irreversibility of many land development decisions, practical considerations dictate that the land use planning design year be scaled to the facility design year requirement. In the Milwaukee River watershed study, the necessary forecast period was set as 20 years, both as a very conservative approximation of facility life and as a means for locking the watershed forecast periods into the previously determined regional land use and transportation study forecast periods.

Forecast accuracy requirements depend on the use to be made of the forecasts; and as applied to land use and water control facility planning, the critical question relates to the effect of any forecast inaccuracies on the basic structure of the plans to be produced. It is important to keep the forecast tolerances within that range wherein only the timing and not the basic structure of the plans will be affected.

Plan Design

Plan synthesis or design forms the heart of the planning process. The most well-conceived objective; the most sophisticated data collection, processing, and analysis operations; and the most accurate forecasts are of little value if they do not ultimately result in sound plans. The outputs of each of the three previously described planning operations—formulation of objectives and standards, inventory, and forecast—become inputs to the design problems of plan synthesis.

The land use plan design problem consists essentially of determining the allocation of a scarce resource—land—between competing and often conflicting demands. This allocation must be accomplished so as to satisfy the aggregate needs for each land use and comply with all of the design standards derived from the plan objectives, all at a feasible cost. The water control facility plan design problem requires a similar reconciliation between hydrologic and hydraulic loading derived from the land use plan, adopted facility design standards, existing facilities, and new facility costs.

Plan Test and Evaluation

If the plans developed in the design stage of the planning process are to be realized in terms of actual land use and water control facility development, some measures must be applied to quantitatively test alternative plans in advance of their adoption and implementation. The alternative plans must be subjected vigorously to all the necessary levels of review and inspection, including: 1) engineering performance, 2) technical feasibility, 3) economic feasibility, 4) legality, and 5) political reaction. Devices used to test and evaluate the plans range from the assignment of hydraulic loadings to the existing and proposed system of water control facilities through interagency meetings and public hearings. Plan test and evaluation should demonstrate clearly which alternative plan or portions of plans are technically sound, financially feasible, legally possible, and politically realistic.

Plan Selection and Adoption

It is proposed in the Milwaukee River watershed study to develop two alternative land use plans, one representing a refinement of the adopted regional land use plan and the other representing a forecast of continued unplanned and uncontrolled existing trend development within the watershed. Each of these two alternative land use plans will be supported by various combinations of water control facility system plans for both flood control and pollution abatement, thus providing a number of alternative watershed development plans. The general approach contemplated for the selection of one plan from among these alternatives is to proceed through the use of the Milwaukee River Watershed Committee structure, interagency meetings, and hearings to a final decision and plan adoption by the Commission in accordance with the provisions of the state enabling legislation. The role of the Commission is to recommend to federal, state, and local units of government and private investors the final plan for their consideration and action. The final decisive step to be taken in the process is the acceptance or rejection of the plan by the local governmental units concerned and subsequent plan implementation by public and private action. Therefore, plan selection and adoption must be founded in the active involvement of the various governmental bodies, technical agencies, and private interest groups concerned with development in the watershed. The use of advisory committees and both formal and informal hearings appears to be the most practical and effective procedure for achieving such involvement in the planning process and of openly arriving at agreement among the affected governmental bodies and agencies on objectives and on a final watershed plan which can be cooperatively adopted and jointly implemented.

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Chapter III

DESCRIPTION OF THE WATERSHED—MAN-MADE FEATURES

INTRODUCTION

A watershed is a complex of natural and man-made features which interact to comprise a changing environment for human life. The man-made features of a watershed, which are important to any consideration of its future development, include its public utility network, its transportation system, and its land use pattern. Together with the population residing in, and the economic activities taking place within, the watershed, these features may be thought of as the socioeconomic base of the watershed. A description of this base is essential to sound watershed planning for, any attempt to improve the environment must be founded in an understanding of not only the various demands for land, public facilities, and resources generated by the population and economic activities of an area but also of the ability of the existing land use pattern and public facility systems to meet these demands.

In order to facilitate such understanding, a description of the socioeconomic base of the watershed is herein presented in five sections. The first section places the watershed into proper perspective as a rational planning unit within a regional setting by delineating its internal political and governmental boundaries and relating these boundaries to the Region as a whole. The second section describes the demographic and economic base of the watershed in terms of population size, distribution, and composition and in terms of employment levels and distribution. The third section describes the patterns of land use in the watershed in terms of historical development and existing (1967) conditions. The fourth and fifth sections describe the public utility and transportation facility systems within the watershed. A final section summarizes the material in the chapter.

REGIONAL SETTING OF THE WATERSHED

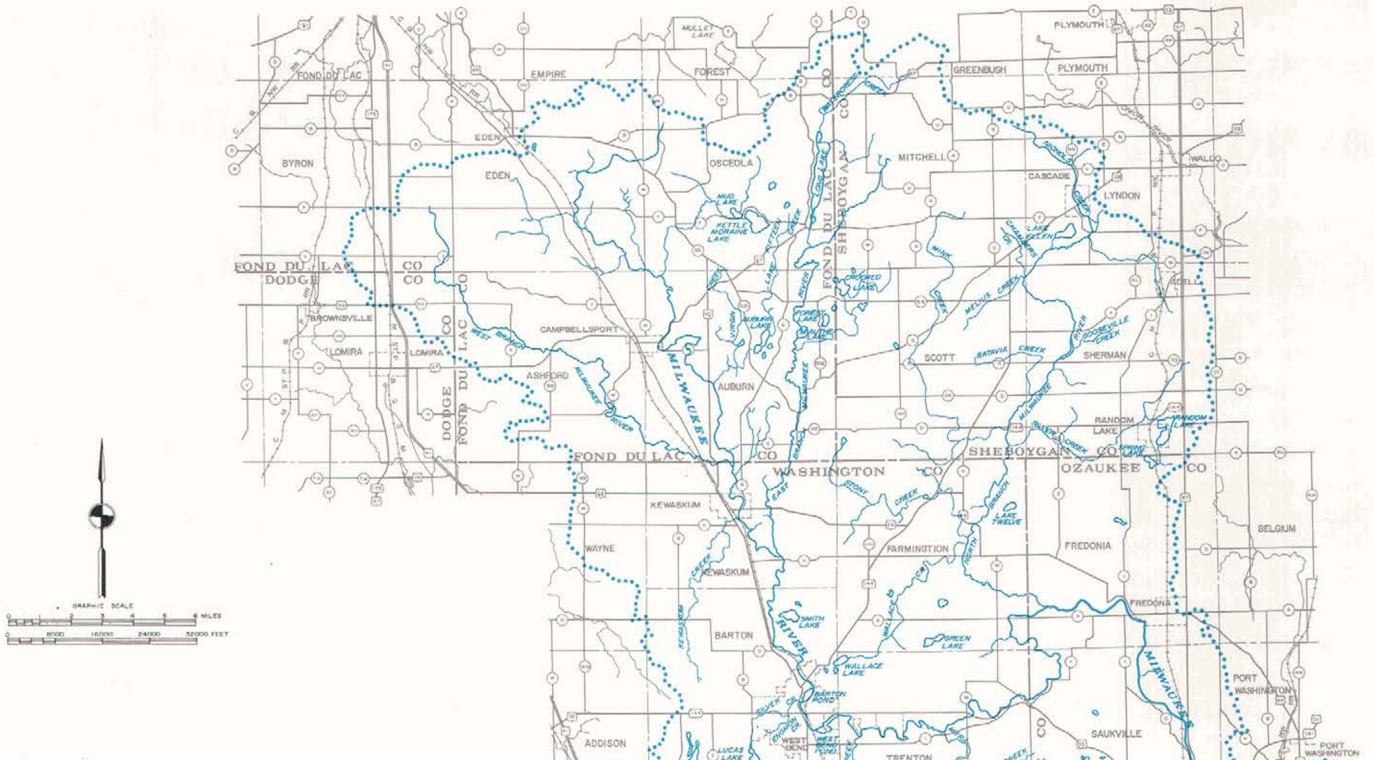
The Milwaukee River watershed, as shown on Map 2, is a surface water drainage unit, 693.8 square miles in areal extent, discharging to Lake Michigan within the City of Milwaukee. Approximately 62 percent of the total watershed area, or 430.3 square miles, lie within the seven-county Southeastern Wisconsin Planning Region. The remaining 38 percent, consisting of the head-water portions of the watershed, lies adjacent to the Region in adjoining Dodge, Fond du Lac, and Sheboygan Counties. The watershed is the third largest of the 11 major natural surface water drainage units within the Region and comprises approximately 16 percent of the total land and water area of the Region.

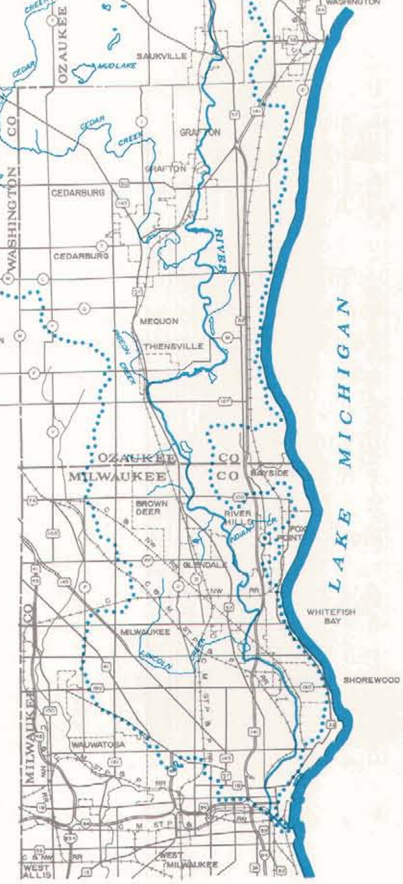
Political Boundaries

Superimposed upon the natural, meandering watershed boundary is a rectangular pattern of local political boundaries, as shown on Map 2. The watershed occupies portions of three of the seven counties comprising the Southeastern Wisconsin Region: Milwaukee, Ozaukee, and Washington; parts of three counties outside of the Southeastern Wisconsin Region: Dodge, Fond du Lac, and Sheboygan; and portions or all of five cities, 18 villages, and 28 towns. The area and proportion of the watershed lying within the jurisdiction of each local unit of government as of January 1, 1967, are set forth in Table 1.

In Wisconsin the boundaries of the Soil and Water Conservation Districts, which Districts are special-purpose units of government having responsibilities for the promotion of good soil and water conservation practices, are coterminous with county boundaries. Therefore, six such soil and water conservation districts have jurisdiction over portions of the watershed. In addition, another special-purpose unit of government having important responsibilities for drainage and flood control, for the provision of sanitary sewerage service and sewage treatment, and for water pollution control, the Metropolitan Sewerage District of the County of Milwaukee, exists within the watershed. This District, while legally empowered to serve all of the Milwaukee River watershed, has to date confined its activities within the Milwaukee River watershed to all of Milwaukee County and all of the City of Mequon in Ozaukee County. The service area of the Metropolitan Sewerage District within the watershed is shown on Map 44.

Map 2
THE MILWAUKEE RIVER WATERSHED





The Milwaukee River watershed is a natural surface water drainage basin about 693 square miles in extent, of which about 62 percent, or 430 square miles, are located within the jurisdiction of the seven-county Southeastern Wisconsin Planning Region. The remaining 38 percent, or about 264 square miles, are located in Dodge, Fond du Lac, and Sheboygan Counties. A sound approach to the growing environmental and developmental problems of the watershed requires that the entire watershed, including the headwater protions beyond the geographic boundaries of the Region, be included in the comprehensive planning program.

Source: SEWRPC.

TABLE 1

AREAL EXTENT OF COUNTIES AND CIVIL DIVISIONS IN THE MILWAUKEE RIVER WATERSHED- JANUARY 1, 1967

COUNTY OR CIVIL DIVISION	TOTAL COUNTY AND CIVIL DIVISION AREA (SQUARE MILES)	COUNTY AND CIVIL DIVISION AREA INCLUDED WITHIN WATERSHED (SQUARE MILES)	PERCENT OF COUNTY AND CIVIL DIVISION AREA WITHIN WATERSHED	PERCENT OF WATERSHED AREA WITHIN COUNTY AND CIVIL DIVISION
DODGE COUNTY........	909.97	4.66	0.51	0.67
TOWNS				
LOMIRA..........	35.70	4.66	13.05	0.67
FOND DU LAC COUNTY..	764.94	136.17	17.80	19.63
VILLAGES				
CAMPBELLSPORT...	0.78	0.78	100.00	0.11
EDEN............	0.29	0.05	17.24	0.01
TOWNS				
ASHFORD.........	36.02	28.96	80.40	4.17
AUBURN..........	36.47	36.47	100.00	5.26
BYRON...........	36.55	8.98	24.57	1.30
EDEN............	36.36	29.78	81.90	4.29
FOREST..........	35.94	0.84	2.34	0.12
OSCEOLA.........	36.61	30.31	82.79	4.37
MILWAUKEE COUNTY....	242.19	56.97	23.52	8.21
CITIES				
GLENDALE........	5.93	5.85	96.65	0.84
MILWAUKEE.......	95.96	37.50	39.08	5.41
VILLAGES				
BAYSIDE.........	2.31	0.63	27.27	0.09
BROWN DEER......	4.37	4.37	100.00	0.63
FOX POINT.......	2.87	1.21	42.16	0.17
RIVER HILLS.....	5.32	4.11	77.26	0.59
SHOREWOOD.......	1.58	1.45	91.77	0.21
WHITEFISH BAY...	2.12	1.85	87.26	0.27
OZAUKEE COUNTY......	234.49	150.54	64.20	21.69
CITIES				
CEDARBURG.......	2.20	2.20	100.00	0.32
MEQUON..........	46.88	31.57	67.34	4.54
VILLAGES				
FREDONIA........	1.05	0.93	88.57	0.13
GRAFTON.........	1.70	1.70	100.00	0.25
SAUKVILLE.......	1.29	1.29	100.00	0.19
THIENSVILLE.....	1.03	1.03	100.00	0.15
TOWNS				
CEDARBURG.......	27.93	27.93	100.00	4.03
FREDONIA........	35.18	28.18	80.10	4.06
GRAFTON.........	21.98	18.13	82.48	2.61
PORT WASHINGTON.	20.09	2.49	12.39	0.36
SAUKVILLE.......	35.10	35.09	99.97	5.05
SHEBOYGAN COUNTY....	508.03	122.73	24.16	17.69
VILLAGES				
ADELL...........	0.42	0.42	100.00	0.06
CASCADE.........	0.75	0.75	100.00	0.11
RANDOM LAKE.....	0.66	0.66	100.00	0.10
TOWNS				
GREENBUSH.......	35.36	3.54	10.01	0.51
LYNDON..........	33.67	12.72	37.78	1.83
MITCHELL........	36.42	33.75	92.67	4.86
SCOTT...........	36.94	36.94	100.00	5.32
SHERMAN.........	35.44	33.95	95.80	4.90
WASHINGTON COUNTY...	435.50	222.76	51.15	32.11
CITIES				
WEST BEND.......	4.55	4.55	100.00	0.66
VILLAGES				
GERMANTOWN......	34.33	4.49	13.08	0.65
JACKSON.........	0.51	0.51	100.00	0.07
KEWASKUM........	1.01	1.01	100.00	0.15
TOWNS				
ADDISON.........	36.02	0.12	0.33	0.02
BARTON..........	21.32	20.01	93.86	2.88
FARMINGTON......	36.77	36.77	100.00	5.30
GERMANTOWN......	1.77	0.97	54.80	0.14
JACKSON.........	36.07	36.07	100.00	5.20
KEWASKUM........	23.32	23.32	100.00	3.36
POLK............	34.59	24.39	70.51	3.52
RICHFIELD.......	36.34	4.32	11.89	0.62
TRENTON.........	35.73	35.73	100.00	5.15
WAYNE...........	35.77	8.62	24.10	1.24
WEST BEND.......	22.93	21.88	95.42	3.15
TOTAL	--	693.83[a]	--	100.00

[a] THIS FIGURE REPRESENTS THE TOTAL AREA OF THE WATERSHED AS DETERMINED BY MAP DELINEATION AND MEASUREMENT. EXISTING LAND USE DATA AS USED THROUGHOUT THIS REPORT HAVE BEEN DETERMINED THROUGH APPROXIMATING THE WATERSHED BOUNDARY BY U. S. PUBLIC LAND SURVEY QUARTER SECTION AND SUMMING THE QUARTER SECTION TOTALS. THE ACTUAL MEASURED WATERSHED TOTAL IS 693.83 SQUARE MILES, OR 444,051 ACRES. THE APPROXIMATED WATERSHED TOTAL IS 695.24 SQUARE MILES, OR 444,951 ACRES (SEE TABLE 7).

SOURCE- SEWRPC.

There are also a total of eight legally established drainage districts in the Milwaukee River watershed, special-purpose units of government having responsibilities for the carrying out of agricultural and urban drainage improvements. These districts encompass a total area of about 28.5 square miles and are: Ozaukee County Drainage Districts, Numbers 1 (City of Mequon—2.0 square miles), 4 (City of Mequon—3.5 square miles), 6 (Town of Cedarburg—2.5 square miles), 8 (Town of Port Washington—4.0 square miles), 10 (City of Mequon—1.5 square miles), 11 (Town of Cedarburg—2.0 square miles), and 12 (City of Mequon—2.0 square miles), and the Jackson-Germantown Drainage District, encompassing about 11.0 square miles, in the Towns of Germantown and Jackson and the Village of Germantown in Washington County. The Jackson-Germantown Drainage District is, however, the only one of the eight districts in the watershed which is still active. The location and service areas of these districts are shown on Map 3.

There are a total of six town sanitary and utility districts in the Milwaukee River watershed, another type of special-purpose unit of government created to provide various urban-type services, such as the provision of sanitary sewerage, water supply, and solid waste collection and disposal services, to designated portions of towns. These districts, encompassing a total area of 4.9 square miles, are: Big Cedar Lake Sanitary District in the Towns of Polk and West Bend, Washington County (2.1 square miles); Little Cedar Lake Sanitary District in the Towns of Polk and West Bend, Washington County (0.9 square mile); Newburg Sanitary District in the Town of Trenton, Washington County (0.8 square mile); Sanitary District No. 1 (Lake Ellen area) in the Town of Lyndon, Sheboygan County (0.4 square mile); Silver Lake Sanitary District in the Town of West Bend, Washington County (0.4 square mile); and Wallace Lake Sanitary District in the Town of Trenton, Washington County (0.3 square mile). The location and service areas of these sanitary districts are shown on Map 4.

Superimposed upon these local and areawide units and agencies of government are the state and federal governments, certain agencies of which also have important responsibilities for resource conservation and management. These include the Wisconsin Department of Natural Resources; the University Extension of the University of Wisconsin; the Soil Conservation Board of Wisconsin; the U. S. Department of the Interior, Geological Survey and Federal Water Pollution Control Administration; the U. S. Department of Agriculture, Soil Conservation Service; and the U. S. Army Corps of Engineers.

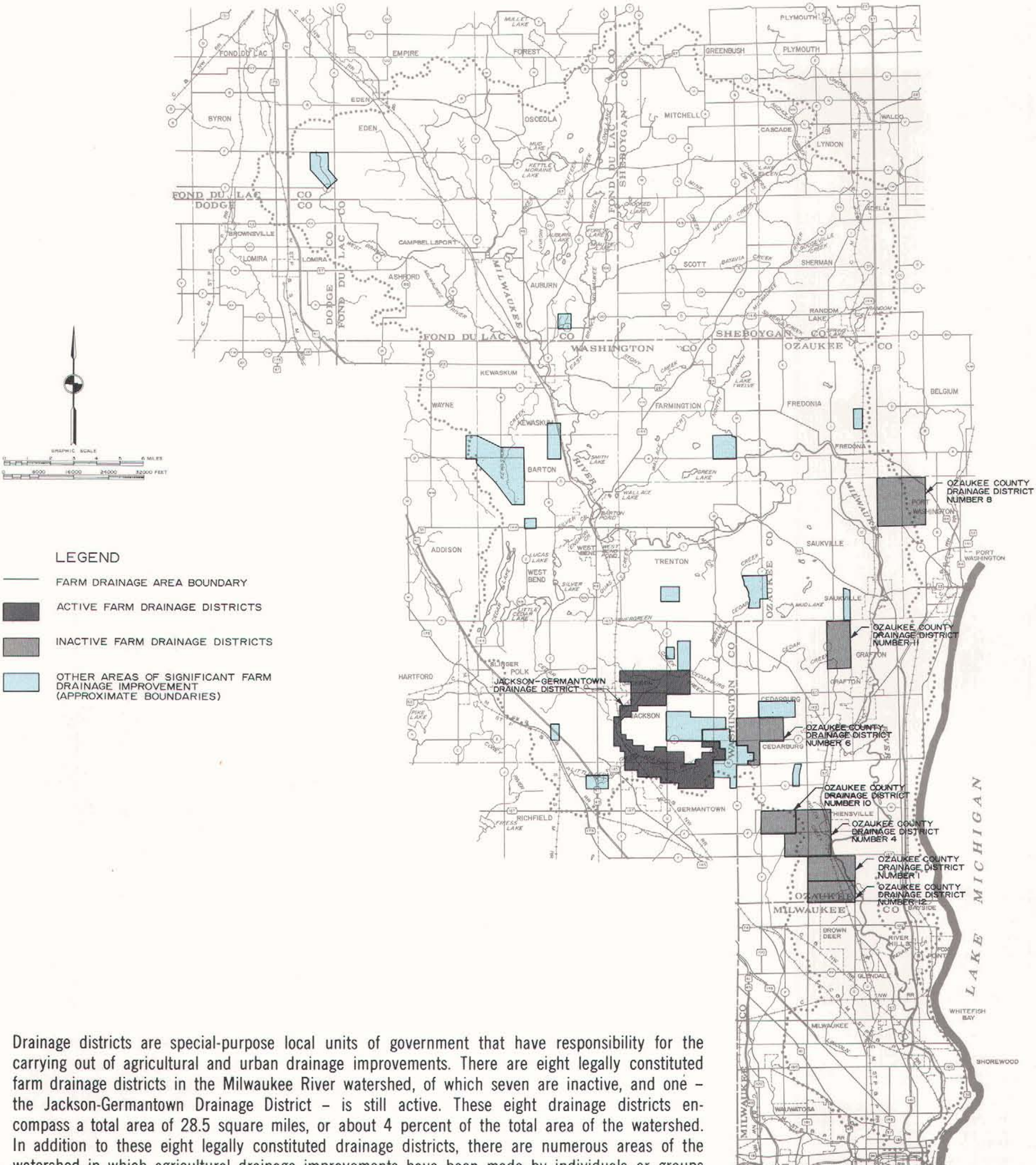
DEMOGRAPHIC AND ECONOMIC BASE

Since the ultimate purpose of the watershed planning effort is to improve the environment in which the resident population lives, an understanding of the size, characteristics, and spatial distribution of this population is basic to any sound public planning effort. The population must also be studied because of the direct relationships existing between population levels and the demand for soil, water, open space, and other elements of the natural resource base, as well as the demand for various kinds of transportation, utility, and community facilities and services. The size and characteristics of the population of an area are greatly influenced by growth and change in economic activity. Population and economic activity must, therefore, be considered together. It is important to note, however, that, because the Milwaukee River watershed is an integral part of a larger urbanizing Region, many of the economic forces that influence population growth within the watershed are centered outside the watershed proper. Thus, any economic analysis for watershed planning purposes must relate the economic activity within the watershed to the economy of the larger Region. Similarly, the size, characteristics, and distribution of the population residing within the watershed must be viewed in relation to the population size, characteristics, and distribution within the Region as a whole.

Population

Population Size: The present (1967) population of the watershed is estimated at 543,790 persons, of which 531,680 persons reside within the Region and 12,110 persons reside outside the Region. The portion of the watershed population within the Region comprises about 30 percent of the total regional population. The population of the watershed has increased steadily since 1850. From 1940 to 1950, the rate of population increase within the watershed was below that of the Region as a whole, which, in turn, however, was higher than the rate of population increase of both the state and the nation. From 1950 to 1960, the population of the watershed increased by 32 percent, somewhat more than the 27 percent increase experienced by the Region as a whole during this same decade. Since 1960,

Map 3
DRAINAGE DISTRICTS
IN THE MILWAUKEE RIVER WATERSHED

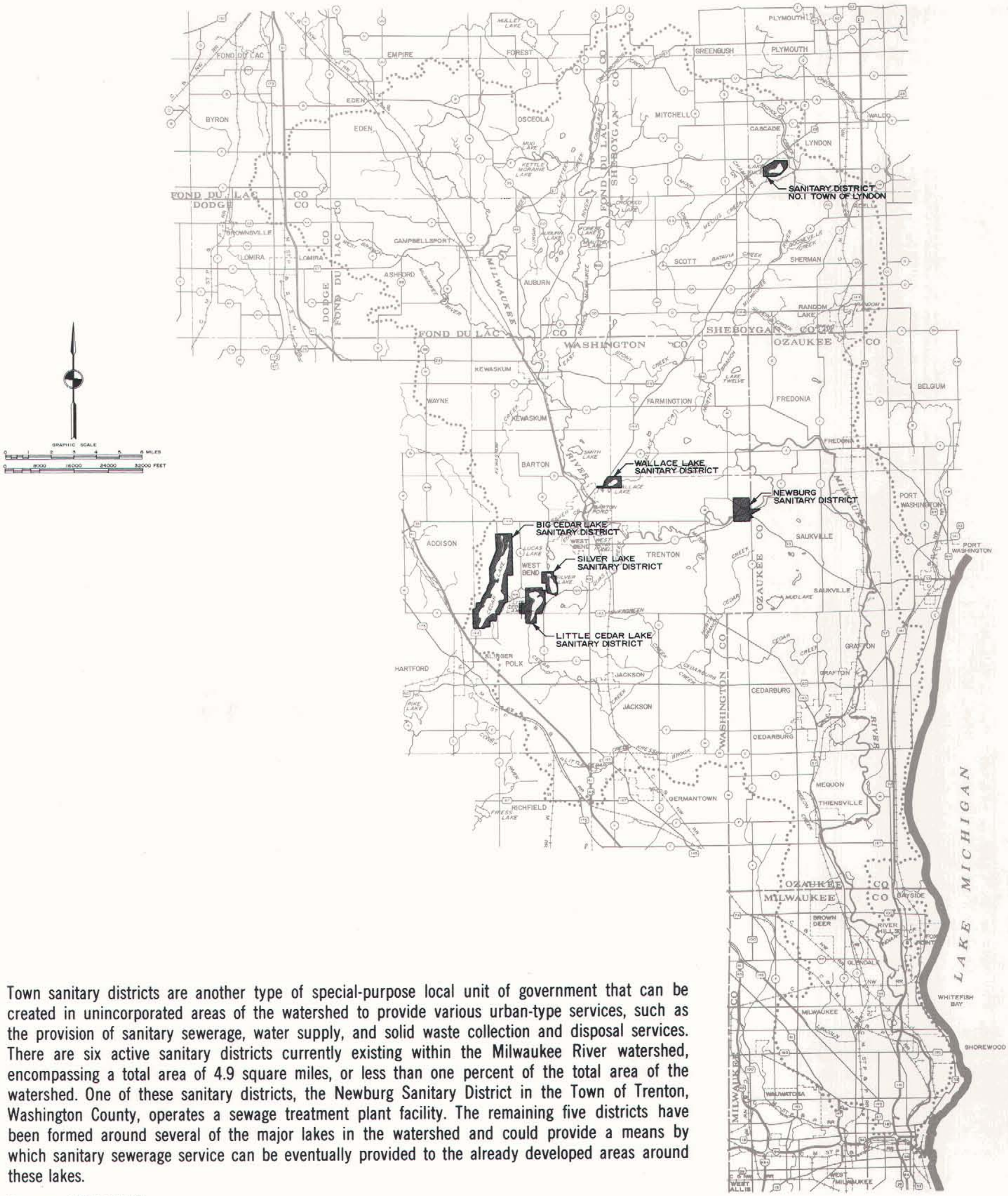


Drainage districts are special-purpose local units of government that have responsibility for the carrying out of agricultural and urban drainage improvements. There are eight legally constituted farm drainage districts in the Milwaukee River watershed, of which seven are inactive, and one – the Jackson-Germantown Drainage District – is still active. These eight drainage districts encompass a total area of 28.5 square miles, or about 4 percent of the total area of the watershed. In addition to these eight legally constituted drainage districts, there are numerous areas of the watershed in which agricultural drainage improvements have been made by individuals or groups of individuals on an informal basis as a private endeavor.

Source: SEWRPC.

Map 4

SANITARY DISTRICTS IN THE MILWAUKEE RIVER WATERSHED



Town sanitary districts are another type of special-purpose local unit of government that can be created in unincorporated areas of the watershed to provide various urban-type services, such as the provision of sanitary sewerage, water supply, and solid waste collection and disposal services. There are six active sanitary districts currently existing within the Milwaukee River watershed, encompassing a total area of 4.9 square miles, or less than one percent of the total area of the watershed. One of these sanitary districts, the Newburg Sanitary District in the Town of Trenton, Washington County, operates a sewage treatment plant facility. The remaining five districts have been formed around several of the major lakes in the watershed and could provide a means by which sanitary sewerage service can be eventually provided to the already developed areas around these lakes.

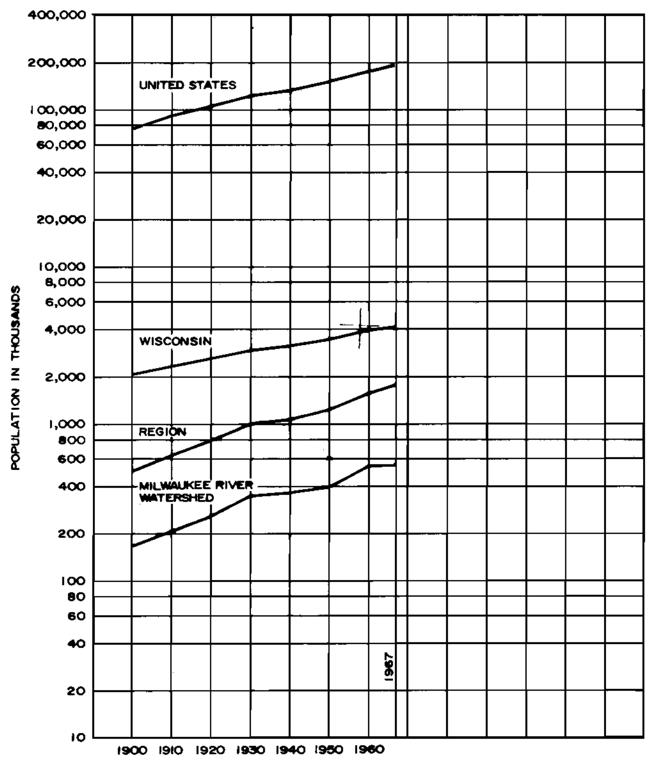
Source: SEWRPC.

however, the rate of population increase within the Region has exceeded the rate of increase within the watershed. The trend in population levels within the watershed from 1900 to 1967, along with regional, state, and national trends, is set forth in Table 2 and graphically illustrated in Figure 5. Watershed population growth rates since 1940 can be attributed primarily to natural increase, that is, to an excess of births over deaths, and this indicates that migration from other parts of the nation, state, and Region has not been a significant factor in the recent (1940-1967) population increase of the watershed.

Population Distribution: The Milwaukee River watershed, in common with much of the Region, is becoming increasingly urban, particularly in the middle and lower reaches of the watershed. The more recently urbanizing areas lie in Ozaukee and Washington Counties and adjacent to the Cities of Cedarburg and West Bend and the Village of Grafton. In 1967 about 94 percent of the residents of the watershed lived in incorporated cities and villages, the combined areas of which comprise about 15 percent of the total area of the watershed (see Tables 3 and 4). The headwater reach, located entirely outside the Region in Dodge, Fond du Lac, and Sheboygan Counties, contains approximately two-fifths (38 percent) of the total watershed area but only 2 percent of the population of the watershed. Ninety-eight percent of the residents of the watershed reside in the remaining three-fifths (62 percent) of the watershed area, which includes the lower reaches of the Milwaukee River in the City of Milwaukee and the most highly urbanized areas of the watershed. The present spatial distribution of the population within the watershed is indicated on Map 5. The very heavy, although decreasing, concentration of population in the lower reaches of the watershed, the rapid transition from rural to urban land use taking place in the middle reaches of the watershed with the concomitant increasing concentration of population in this portion of the watershed, and the increase in recreational demand being exerted in

Figure 5

POPULATION TRENDS FOR THE MILWAUKEE RIVER WATERSHED, THE REGION, WISCONSIN, AND THE UNITED STATES 1900-1967



Source: U.S. Bureau of the Census and SEWRPC.

TABLE 2

POPULATION SIZE OF THE MILWAUKEE RIVER WATERSHED, THE REGION, WISCONSIN, AND THE UNITED STATES- 1900-1970

YEAR	RESIDENT POPULATION OF WATERSHED	PERCENT INCREASE OVER PRECEDING DECADE	RESIDENT POPULATION OF WATERSHED WITHIN REGION	PERCENT INCREASE OVER PRECEDING DECADE	POPULATION OF REGION	PERCENT INCREASE OVER PRECEDING DECADE	POPULATION OF WISCONSIN	PERCENT INCREASE OVER PRECEDING DECADE	POPULATION OF UNITED STATES	PERCENT INCREASE OVER PRECEDING DECADE	WATERSHED POPULATION WITHIN THE REGION AS A PERCENT OF THE REGIONAL POPULATION
1900	165,580	--	155,560	--	501,808	--	2,069,042	--	75,994,575	--	31
1910	208,280	26	199,030	28	631,161	26	2,333,860	13	91,972,266	21	32
1920	266,090	28	256,160	29	783,681	24	2,632,067	13	105,710,620	15	33
1930	346,040	30	336,560	31	1,006,118	28	2,939,006	12	122,775,046	16	34
1940	362,080	5	352,330	5	1,067,699	6	3,137,587	7	131,669,270	7	33
1950	399,040	10	388,930	10	1,240,618	16	3,434,575	9	151,325,798	15	31
1960	526,823	32	515,906	32	1,573,620	27	3,952,771	15	179,323,175	18	33
1967	543,790	--	531,680[a]	--	1,809,500[a]	--	4,188,000	--	198,852,000	--	31
1970	527,652[b]	--[c]	514,791[b]	--[d]	1,742,883[b]	11	4,366,766[b]	10	203,675,000[e]	14	30

[a]ESTIMATE BASED ON SYMPTOMATIC INDICATORS OF POPULATION CHANGE BETWEEN 1960 AND 1967.

[b]BASED UPON PRELIMINARY REPORTS OF 1970 U.S. CENSUS OF POPULATION.

[c]LESS THAN ONE PERCENT INCREASE.

[d]LESS THAN ONE PERCENT DECREASE.

[e]ESTIMATED BY U.S. BUREAU OF THE CENSUS, CURRENT POPULATION REPORTS, SERIES P-25, NO. 445.

SOURCE- U. S. DEPARTMENT OF COMMERCE, BUREAU OF THE CENSUS, AND SEWRPC.

TABLE 3

ESTIMATED POPULATION IN THE MILWAUKEE RIVER WATERSHED BY COUNTY AND CIVIL DIVISION- 1960, 1967, AND 1970

CIVIL DIVISION[a]	1960[b]		1967[c]		1970[d]	
	POPULATION WITHIN WATERSHED	PERCENT OF WATERSHED POPULATION	POPULATION WITHIN WATERSHED	PERCENT OF WATERSHED POPULATION	POPULATION WITHIN WATERSHED	PERCENT OF WATERSHED POPULATION
DODGE COUNTY..........	160	0.03	160	0.03	160	0.03
TOWNS						
LOMIRA............	160	0.03	160	0.03	160	0.03
FOND DU LAC COUNTY....	5,417	1.03	5,970	1.10	6,295	1.19
VILLAGES						
CAMPBELLSPORT.....	1,472	0.28	1,590	0.29	1,677	0.32
EDEN..............	50	0.01	50	0.01	60	0.01
TOWNS						
ASHFORD...........	1,020	0.19	1,160	0.21	1,210	0.23
AUBURN............	1,025	0.20	1,170	0.22	1,238	0.23
BYRON.............	280	0.05	300	0.06	330	0.06
EDEN..............	810	0.15	850	0.16	870	0.16
FOREST............	20	0.01	20	0.00	20	0.01
OSCEOLA...........	740	0.14	830	0.15	890	0.17
MILWAUKEE COUNTY......	464,307	88.13	464,540	85.43	441,782	83.73
CITIES						
GLENDALE..........	9,537	1.81	12,800	2.35	13,415	2.54
MILWAUKEE.........	404,540	76.79	400,300	73.62	375,940	71.25
VILLAGES						
BAYSIDE...........	1,530	0.29	2,080	0.38	2,420	0.46
BROWN DEER........	11,280	2.14	11,600	2.13	12,647	2.40
FOX POINT.........	3,510	0.67	3,800	0.70	3,830	0.73
RIVER HILLS.......	1,010	0.19	1,300	0.24	1,320	0.25
SHOREWOOD.........	15,180	2.88	15,650	2.88	15,480	2.93
WHITEFISH BAY.....	17,720	3.36	17,010	3.13	16,730	3.17
OZAUKEE COUNTY........	26,038	4.94	34,840	6.40	37,787	7.16
CITIES						
CEDARBURG.........	5,191	0.99	7,000	1.29	7,630	1.45
MEQUON............	5,980	1.14	8,330	1.53	8,450	1.60
VILLAGES						
FREDONIA..........	710	0.13	900	0.16	972	0.18
GRAFTON...........	3,748	0.71	5,100	0.94	5,980	1.13
SAUKVILLE.........	1,038	0.20	1,200	0.22	1,350	0.26
THIENSVILLE.......	2,507	0.47	3,000	0.55	3,183	0.60
TOWNS						
CEDARBURG.........	2,248	0.43	3,300	0.61	3,869	0.73
FREDONIA..........	1,270	0.24	1,540	0.28	1,570	0.30
GRAFTON...........	1,860	0.35	2,840	0.52	2,940	0.56
PORT WASHINGTON...	180	0.03	230	0.04	270	0.05
SAUKVILLE.........	1,306	0.25	1,400	0.26	1,573	0.30
SHEBOYGAN COUNTY......	5,340	1.02	5,980	1.10	6,406	1.21
VILLAGES						
ADELL.............	398	0.08	380	0.07	380	0.07
CASCADE...........	449	0.09	500	0.09	585	0.11
RANDOM LAKE.......	858	0.16	950	0.17	1,053	0.20
TOWNS						
GREENBUSH.........	100	0.02	350	0.06	360	0.07
LYNDON............	390	0.07	500	0.09	530	0.10
MITCHELL..........	680	0.13	690	0.13	700	0.13
SCOTT.............	1,255	0.24	1,280	0.24	1,418	0.27
SHERMAN...........	1,210	0.23	1,330	0.25	1,380	0.26
WASHINGTON COUNTY.....	25,561	4.85	32,300	5.94	35,222	6.68
CITIES						
WEST BEND.........	11,538	2.19	15,100	2.78	16,516	3.13
VILLAGES						
GERMANTOWN[e].......	---	---	160	0.03	170	0.03
JACKSON...........	458	0.09	500	0.09	564	0.11
KEWASKUM..........	1,572	0.30	1,800	0.33	1,905	0.36
TOWNS						
ADDISON...........	---	---	---	---	---	---
BARTON............	1,170	0.22	1,370	0.25	1,520	0.29
FARMINGTON........	1,433	0.27	1,600	0.29	1,728	0.33
GERMANTOWN[e].......	150	0.03	20	0.01	30	0.00
JACKSON...........	1,576	0.30	2,600	0.48	2,835	0.54
KEWASKUM..........	897	0.17	1,100	0.20	1,143	0.22
POLK..............	1,570	0.30	2,010	0.37	2,270	0.43
RICHFIELD.........	300	0.06	360	0.07	400	0.08
TRENTON...........	2,657	0.50	3,100	0.57	3,171	0.60
WAYNE.............	270	0.05	280	0.05	290	0.05
WEST BEND.........	1,970	0.37	2,300	0.42	2,680	0.51
TOTAL	526,823	100.00	543,790	100.00	527,652	100.00

[a]IT IS IMPORTANT TO NOTE THAT MINOR CIVIL DIVISION BOUNDARIES MAY CHANGE OVER TIME AS A RESULT OF ANNEXATIONS, CONSOLIDATIONS, AND INCORPORATIONS.

[b]1960 U. S. CENSUS OF POPULATION

[c]CURRENT POPULATION ESTIMATES BY CIVIL DIVISION PREVIOUSLY PREPARED BY THE REGIONAL PLANNING COMMISSION UNDER ITS CONTINUING LAND USE-TRANSPORTATION PLANNING PROGRAM UTILIZING SYMPOMATIC INDICATORS, SUCH AS BIRTHS, DEATHS, AUTOMOBILE REGISTRATIONS, AND RESIDENTIAL BUILDING AND DEMOLITION PERMITS, WERE INITIALLY USED IN THE MILWAUKEE RIVER WATERSHED PLANNING PROGRAM. THESE CURRENT ESTIMATES PLACED THE 1967 POPULATION OF THE WATERSHED AT 570,790 PERSONS AND WERE PREPARED PRIOR TO THE RELEASE OF THE 1970 PRELIMINARY POPULATION COUNTS TAKEN BY THE U. S. BUREAU OF THE CENSUS. UPON RELEASE OF THE PRELIMINARY 1970 CENSUS DATA, THE 1967 POPULATION ESTIMATES FOR THOSE CIVIL DIVISIONS CONTAINED EITHER WHOLLY OR PARTIALLY WITHIN THE MILWAUKEE RIVER WATERSHED WERE ADJUSTED BASED ON THE ACTUAL ENUMERATED POPULATION INCREASE OR DECREASE WHICH OCCURRED BETWEEN THE 1960 AND 1970 PRELIMINARY CENSUS WITHIN THE WATERSHED, AND A REVISED 1967 WATERSHED POPULATION ESTIMATE OF 543,790 PERSONS WAS SELECTED TO BE USED AS THE FINAL BASE YEAR POPULATION FOR THE WATERSHED STUDY. THIS WAS 27,000 OR NEARLY 5 PERCENT LESS THAN THE INITIAL 1967 ESTIMATE. THE MAJOR DIFFICULTIES BETWEEN THE EARLIER 1967 BASE YEAR ESTIMATE AND THE REVISED 1967 BASE YEAR ESTIMATE FOR THE MILWAUKEE RIVER WATERSHED WERE CENTERED WITHIN THE CITY OF MILWAUKEE, AND, THEREFORE, ALMOST ENTIRELY WITHIN THE LOWER REACHES OF THE WATERSHED. PART OF THIS DIFFERENCE MAY BE ATTRIBUTED TO FREEWAY CONSTRUCTION WITHIN THE DEVELOPED LOWER REACHES OF THE WATERSHED, AND PART TO URBAN RENEWAL ACTIVITIES, AS WELL AS TO CERTAIN CHANGES IN DEMOGRAPHIC CHARACTERISTICS, SUCH AS FAMILY SIZE AND COMPOSITION. THE CITY OF MILWAUKEE HAS HAD UNDERWAY FOR SEVERAL YEARS EIGHT URBAN RENEWAL PROJECTS, SEVEN OF WHICH ARE LOCATED WHOLLY OR PARTIALLY WITHIN THE WATERSHED. THE RESIDENTIAL AREA IN THESE PROJECTS PRIOR TO SITE CLEARANCE WAS APPROXIMATELY 168 ACRES AND THE RESIDENT POPULATION WAS APPROXIMATELY 9,771. THE URBAN RENEWAL PROJECT PROPOSALS PROVIDE FOR THE REDEVELOPMENT OF ABOUT 162 ACRES OF THE CLEARED LAND FOR RESIDENTIAL USE, AND THE PLANNED DENSITIES WOULD RESULT IN THE REPOPULATION OF THE SITES AT DENSITIES AT LEAST EQUAL TO THOSE WHICH EXISTED PRIOR TO SITE CLEARANCE.

[d]1970 U. S. CENSUS OF POPULATION (PRELIMINARY ESTIMATE).

[e]IN A SERIES OF ANNEXATIONS BETWEEN 1963 AND 1968 ABOUT 30 SQUARE MILES OF THE TOWN OF GERMANTOWN WERE ADDED TO THE VILLAGE OF GERMANTOWN.

SOURCE- SEWRPC.

TABLE 4

TOTAL POPULATION AND POPULATION DENSITY IN THE MILWAUKEE RIVER WATERSHED BY CITIES, VILLAGES, AND TOWNS- 1967

CIVIL DIVISION	POPULATION WITHIN WATERSHED	PERCENT OF WATERSHED POPULATION	AREA INCLUDED IN WATERSHED (SQUARE MILES)	PERCENT OF AREA IN WATERSHED	AVERAGE GROSS POPULATION DENSITY (PER SQUARE MILE)
CITIES.....	443,530	82	81.67	12	5,431
VILLAGES...	67,570	12	22.75	3	2,970
TOWNS......	32,690	6	589.41	85	55
TOTAL	543,790	100	693.83	100	784

SOURCE- SEWRPC.

the upper reaches of the watershed are significant factors contributing to a number of serious environmental and resource-related problems existing within the watershed, problems which will be discussed in greater detail in subsequent chapters of this report.

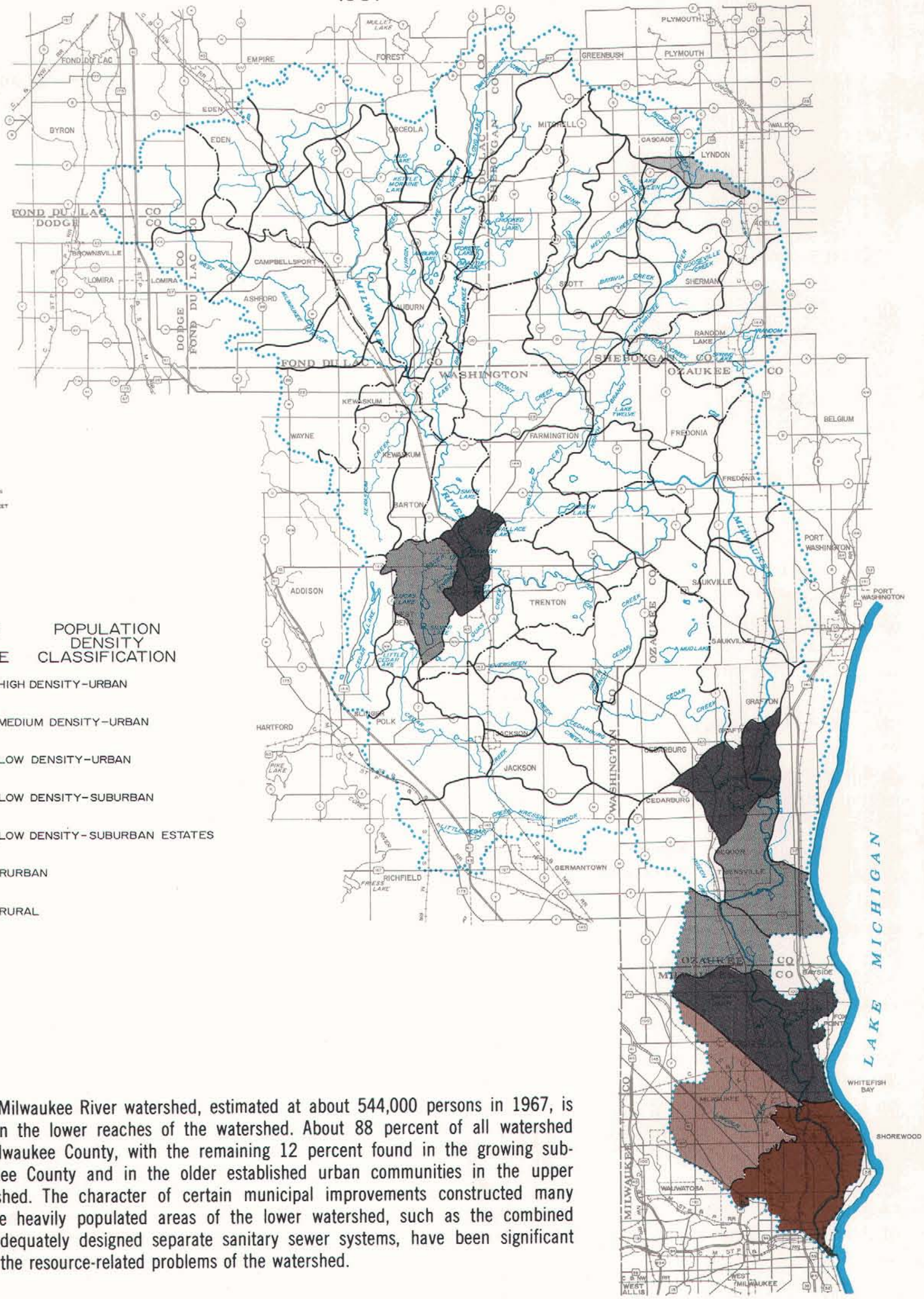
Population Composition: The estimated geographic distribution in 1967 of the resident population of the watershed by median age is shown on Map 6. This map indicates a concentration of older people in the middle and lower reaches of the watershed, particularly in the east side of the City of Milwaukee. Map 7 shows the estimated geographic distribution in 1967 of average household sizes in the watershed. The geographic distribution of both the residential population by median age and the average household size in the watershed did not change measurably between 1963 and 1967. As in the Region, the smaller average household sizes occur in the central cities and in smaller outlying cities and villages, with the larger average household sizes occurring in suburban and rural farm areas. The average household size in the watershed in 1967 was 3.16 persons, with an average of 3.34 persons for the headwater area and an average of 3.16 persons within the regional extent of the watershed. The average household size in 1967 for the Region as a whole was 3.38 persons. The average household income within that portion of the watershed inside the Region in 1967 was estimated at $9,500. This compares with a regional average household income in 1967 of $9,750. Average household income in 1967 for the entire watershed was $9,475, due to the influence of the lower incomes of households in the rural and semirural middle and upper reaches of the watershed.

Preliminary 1970 Census of Population: In April of 1970, the U. S. Bureau of the Census conducted the regular federal decennial census of population and housing. Preliminary civil division population estimates became available from this census in June 1970 as the Milwaukee River watershed study was entering the alternative plan preparation stage and after the basic data inventories and analyses had been completed. The preliminary 1970 census results, however, were considered to be of great significance to the watershed study and are set forth by civil division in the Milwaukee River watershed in Table 3.

The 1970 estimated watershed population, based upon the preliminary census figures, is 527,652, as compared to the 1960 estimated watershed population of 526,823. Thus, the total watershed population grew only by about 0.2 percent in the 1960-1970 decade. A closer inspection of the preliminary 1970 census results reveals, however, a pattern that includes substantial growth of population in the middle and upper reaches of the watershed combined with substantial losses of population in the lower watershed consisting of Milwaukee County communities and, more particularly, the City of Milwaukee itself. The 1960 City of Milwaukee population in the Milwaukee River watershed was estimated at about 405,000. By 1970 this figure had dropped to about 376,000, a 7 percent decline. Although many factors contributed to this decline, it is clear that at least three factors were of particular significance; namely, urban renewal activities involving wholesale clearance of housing units with little or no replacement by April 1970, essential freeway and other public works construction involving a loss of housing units, and a reduction in the average

Map 5

EXISTING POPULATION DENSITIES
IN THE MILWAUKEE RIVER WATERSHED BY HYDROLOGIC SUB-BASIN
1967



LEGEND

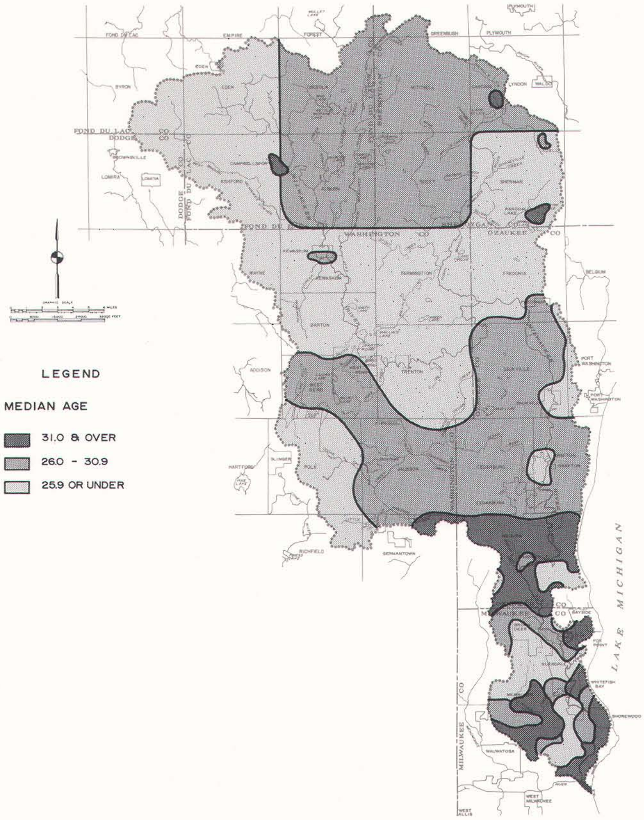
AVERAGE NUMBER OF PERSONS PER GROSS SQUARE MILE	POPULATION DENSITY CLASSIFICATION
10,000-25,000	HIGH DENSITY-URBAN
3,500- 9,999	MEDIUM DENSITY-URBAN
2,500- 3,499	LOW DENSITY-URBAN
650- 2,499	LOW DENSITY-SUBURBAN
350- 649	LOW DENSITY-SUBURBAN ESTATES
200- 349	RURBAN
0- 199	RURAL

The population of the Milwaukee River watershed, estimated at about 544,000 persons in 1967, is heavily concentrated in the lower reaches of the watershed. About 88 percent of all watershed residents reside in Milwaukee County, with the remaining 12 percent found in the growing suburban areas of Ozaukee County and in the older established urban communities in the upper reaches of the watershed. The character of certain municipal improvements constructed many years ago to serve the heavily populated areas of the lower watershed, such as the combined sewer system and inadequately designed separate sanitary sewer systems, have been significant factors contributing to the resource-related problems of the watershed.

Source: SEWRPC.

Map 6

MEDIAN AGE DISTRIBUTION
IN THE MILWAUKEE RIVER WATERSHED
1967

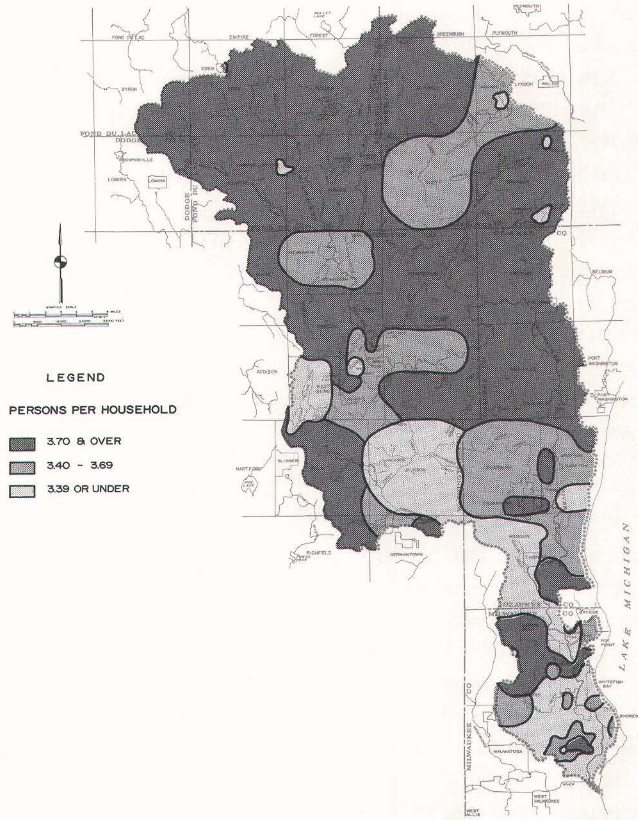


The median age distribution within the watershed, as depicted above, indicates that older people are concentrated more in the central city and older villages located in the lower reaches of the watershed, with young families concentrated more in the outlying urban and rural areas of the middle and upper reaches of the watershed. A particularly heavy concentration of older people in the watershed is found in the east side of the City of Milwaukee. The median age of the watershed population dropped from 32 years in 1950 to 29 years in 1967, reflecting, in part, the rapid growth of suburban communities in the middle reaches of the watershed.

Source: SEWRPC.

Map 7

AVERAGE HOUSEHOLD SIZE
IN THE MILWAUKEE RIVER WATERSHED
1967



The average household size within the Milwaukee River watershed was 3.16 persons in 1967, as compared to 3.38 persons per household in 1967 for the Region as a whole. The household size distribution pattern depicted above follows the normal pattern of an increasing household size, with an increasing distance from the larger, older urban areas of the Region.

Source: SEWRPC.

household size. A more complete analysis of these factors could not be made within the context of the Milwaukee River watershed study, since the essential detailed census data were not to be available until after completion of the study and since the socioeconomic changes evidenced in the watershed are part of a set of complex factors at work throughout the Southeastern Wisconsin Region, the State of Wisconsin, and the nation and, hence, can only be properly studied after more detailed comparative data become available on a nation and statewide, as well as a regionwide, basis.

At the same time that the City of Milwaukee was exhibiting a rather sharp decline in population within the Milwaukee River watershed, however, the remainder of the watershed continued to grow in close accord with the population forecasts prepared by the Commission under its regional land use-transportation study (see Table 3). Thus, while total watershed growth was very small in the 1960-1970 decade, the substantial population loss in the City of Milwaukee was more than offset by rapid growth in the middle reaches of the watershed and, in particular, the urbanizing portions of Ozaukee and Washington Counties. Heavy demands are, therefore, continuing to be placed upon the limited land use, natural resource, and public utility base of the watershed despite the fact that total watershed population growth has slowed.

The rather sudden cessation of overall population growth in the Milwaukee River watershed roughly parallels a similar period in the 1930's when growth slowed throughout the watershed, Region, state, and nation. Unlike the decade of the 1930's, however, the growth rates of the Region, state, and nation, while exhibiting slowdowns, did not exhibit the same drastic slowdown in the 1960's as the watershed. The overall watershed growth pattern in the 1960's masks, however, as noted above, a true pattern of substantial growth in the middle reaches of the watershed combined with housing stock depletion and consequent population loss in the lower, older, more urban reaches of the watershed. If the urban renewal activities are successfully completed in the lower watershed according to planned densities, it is likely that the population decline will cease and that population levels will stabilize or actually increase in the lower watershed.

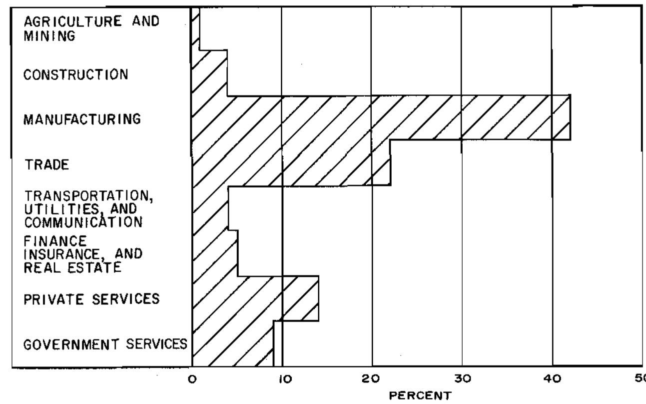
The Economy

Increases in the population levels of the watershed are closely related to increases in the amount of economic activity within the Milwaukee urbanized area, almost all of which lies within commuting distance of major portions of the watershed. This is true not only because population migration into the watershed is dependent upon the availability of jobs within the Milwaukee urbanized area, but also because jobs must ultimately be available to hold the natural increase and prevent the out-migration of young people entering the labor force. Population growth in the watershed may, therefore, be attributed basically to increasing economic activity within the Milwaukee urbanized area. As shown in Figures 6 and 7, employment within the Milwaukee urbanized area is heavily concentrated in the manufacturing of durable goods—primarily in machinery, electrical equipment, and transportation equipment—and in printing and publishing and food and beverage products manufacturing.

The largest concentration of industry within the watershed is in the City of Milwaukee and is comprised of 62 of the total of 75 industrial firms within the watershed which employ 150 or more persons each. It includes the six largest industries within the watershed—American Motors Corporation, A. O. Smith Corporation, The Journal Company, Globe Union Corporation, Joseph Schlitz Brewing Company, and the Pabst Brewing Company. Other major industrial concentrations within the watershed are located in the Cities of Cedarburg, Glendale, and West Bend and in the Village of Grafton.

Figure 6

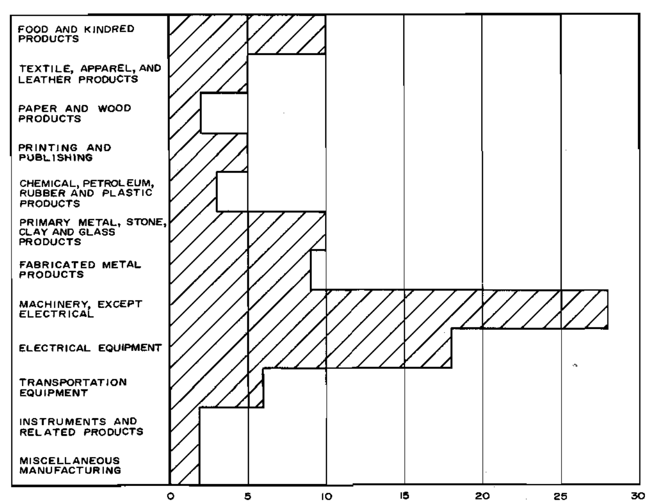
PERCENTAGE DISTRIBUTION OF TOTAL EMPLOYMENT IN MILWAUKEE, OZAUKEE, AND WASHINGTON COUNTIES BY MAJOR INDUSTRIAL GROUP 1967



Source: SEWRPC.

Figure 7

PERCENT DISTRIBUTION OF MANUFACTURING EMPLOYMENT IN MILWAUKEE, OZAUKEE, AND WASHINGTON COUNTIES BY TYPE OF MANUFACTURING 1967



Source: SEWRPC.

Due to these employment concentrations, much of the working population of the watershed maintains residence in, and works within, the watershed, primarily in the urbanized areas of the watershed in Milwaukee County. Although the watershed within the Region contains approximately 30 percent of the regional population, it accounts for more than 42 percent of the total regional jobs.

It is important to note, also, that agriculture is still an important component of the economy of the watershed. Although the number of farms in operation, the number of acres being farmed, and the number of farm operators have been declining within the counties containing the watershed in accord with state and national trends, the average farm size and the total value of farm products sold have increased in all but Milwaukee County. As indicated in Table 5, the 1959 to 1964 trend in agricultural indicators for Fond du Lac, Milwaukee, Ozaukee, Sheboygan, and Washington Counties shows a decline in the number of farms and farm operators from 8,931 to 8,069, or by 9.7 percent, and a decline in the number of acres farmed from 1,053,220 to 1,018,377, or by 3.3 percent. The average farm size has increased from 117.9 acres to 126.2 acres between 1959 and 1964, and the value of farm products sold has increased by more than $12 million, from about $71.6 million in 1959 to approximately $84.2 million in 1964. As indicated in Table 6, there has been a slight shift in farm product emphasis within these five counties between 1959 and 1964. In 1959 approximately 84 percent of the total sales value of farm products was accounted for by dairy products, livestock products other than poultry, and by field crops. By 1964 these three product categories accounted for 87 percent of the total sales of farm products, but the sale of field crops has taken on added importance and the proportionate sales of livestock products decreased. Also, the sale of poultry products decreased proportionately from 4.5 percent of the total to 2.9 percent of the total. It is probable that increasing urbanization within, and adjacent to, the watershed will result in additional shifts in agricultural product output in an attempt by the farm operators to capture a greater share of the local produce market. Although the foregoing discussion refers to the five counties containing the major portions of the Milwaukee River watershed and not to the watershed itself, about 15 percent of the agricultural lands of Fond du Lac County; about 10 percent of the agricultural lands of Milwaukee County; about 60 percent of the agricultural lands of Ozaukee County; about 20 percent of the agricultural lands of Sheboygan County; and about 50 percent of the agricultural lands of Washington County lie within the Milwaukee River watershed. About 26 percent of the agricultural lands of the five counties containing the major portions of the watershed lies within the watershed. Because of these facts and the general homogeneity of farm operations within each of the counties involved, it is likely that the trends in agricultural indicators within the watershed will closely parallel those of the six-county area for which data are available.

LAND USE

An important concept underlying the watershed planning effort is that an adjustment must be effected between land use development and the ability of the underlying natural resource base to sustain such development. The type, intensity, and spatial distribution of land uses determine, to a large extent, the resource demands within a watershed. Water resource demand can be correlated directly with the quantity and type of land use. Similarly, water resource deterioration can be correlated with the quantity and type of land use. The existing land use pattern can best be understood within the context of its historical

TABLE 5

AGRICULTURAL INDICATORS IN FOND DU LAC, MILWAUKEE, OZAUKEE, SHEBOYGAN, AND WASHINGTON COUNTIES- 1959 AND 1964

INDICATOR	FOND DU LAC COUNTY		MILWAUKEE COUNTY		OZAUKEE COUNTY		SHEBOYGAN COUNTY		WASHINGTON COUNTY		TOTAL OR AVERAGE	
	1959	1964	1959	1964	1959	1964	1959	1964	1959	1964	1959	1964
NUMBER OF FARMS................	3,029	2,768	557	409	989	871	2,506	2,306	1,850	1,715	8,931 (TOTAL)	8,069 (TOTAL)
ACREAGE FARMED................	409,776	407,688	32,848	25,670	116,827	108,205	275,649	266,258	218,120	211,556	1,053,220 (TOTAL)	1,019,377 (TOTAL)
NUMBER OF FARM OPERATORS......	3,029	2,768	557	409	989	871	2,506	2,306	1,850	1,715	8,931 (TOTAL)	8,069 (TOTAL)
AVERAGE FARM SIZE (ACRES).....	135.3	147.3	59.0	62.8	118.1	124.2	110.0	115.5	117.9	123.4	108.0 (AVERAGE)	114.6 (AVERAGE)
VALUE OF FARM PRODUCTS SOLD (THOUSANDS OF DOLLARS)........	25,643	31,539	5,932	5,292	7,853	9,262	18,618	22,086	13,541	15,986	71,587 (TOTAL)	84,165 (TOTAL)
AVERAGE VALUE OF FARM PRODUCTS SOLD PER FARM (DOLLARS).......	8,463	11,407	10,175	12,938	8,173	10,634	7,230	9,614	7,360	9,335	8,280 (AVERAGE)	10,786 (AVERAGE)

SOURCE- U.S. CENSUS OF AGRICULTURE AND SEWRPC.

TABLE 6

VALUE OF FARM PRODUCTS SOLD IN FOND DU LAC, MILWAUKEE, OZAUKEE, SHEBOYGAN, AND WASHINGTON COUNTIES BY PRODUCT 1959 AND 1964 (THOUSANDS OF DOLLARS)

PRODUCT	FOND DU LAC COUNTY			MILWAUKEE COUNTY		
	1959	1964	PERCENT CHANGE 1959-1964	1959	1964	PERCENT CHANGE 1959-1964
DAIRY.............	$14,832	$18,600	+25.4	$ 683	$ 398	-41.7
LIVESTOCK (NOT POULTRY)...	6,682	7,044	+ 5.4	552	482	-12.7
FIELD CROPS.......	1,432	2,596	+81.3	492	509	+ 3.5
POULTRY...........	1,089	895	-17.8	202	114	-43.6
VEGETABLES........	1,059	1,823	+72.1	361	283	-21.6
FOREST............	505	549	+ 8.7	3,550	3,445	- 3.0
FRUITS AND NUTS...	44	32	-27.3	92	61	-33.7
TOTAL	$25,643	$31,539	+23.0	$5,932	$5,292	-10.8

PRODUCT	OZAUKEE COUNTY			SHEBOYGAN COUNTY		
	1959	1964	PERCENT CHANGE 1959-1964	1959	1964	PERCENT CHANGE 1959-1964
DAIRY.............	$4,214	$4,744	+ 12.6	$11,135	$12,295	+10.5
LIVESTOCK (NOT POULTRY)...	1,709	2,123	+ 24.2	4,444	6,400	+44.0
FIELD CROPS.......	569	1,306	+129.5	994	1,817	+82.8
POULTRY...........	354	239	- 32.5	970	584	-39.8
VEGETABLES........	622	383	- 38.4	767	680	-11.3
FOREST............	230	300	+ 30.4	178	253	+42.1
FRUITS AND NUTS...	155	167	+ 7.7	130	57	-56.2
TOTAL	$7,853	$9,262	+ 15.2	$18,618	$22,086	+18.6

PRODUCT	WASHINGTON COUNTY			TOTAL				
				1959		1969		
	1959	1964	PERCENT CHANGE 1959-1964	VALUE	PERCENT DISTRIBUTION	VALUE	PERCENT DISTRIBUTION	PERCENT CHANGE 1959-1964
DAIRY.............	$ 8,076	$ 9,978	+ 23.6	$38,940	54.3	$46,015	54.7	+18.2
LIVESTOCK (NOT POULTRY)...	3,325	2,604	- 21.7	16,712	23.3	18,653	22.2	+11.6
FIELD CROPS.......	1,017	2,067	+103.2	4,504	6.3	8,295	9.9	+84.2
POULTRY...........	594	648	+ 9.1	3,209	4.5	2,480	2.9	-22.7
VEGETABLES........	390	550	+ 41.0	3,199	4.5	3,719	4.4	+16.3
FOREST............	91	83	- 8.8	4,554	6.4	4,630	5.5	+ 1.7
FRUITS AND NUTS...	48	56	+ 16.7	469	0.7	373	0.4	-20.5
TOTAL	$13,541	$15,986	+ 18.1	$71,587	100.0	$84,165	100.0	+17.6

SOURCE- U. S. CENSUS OF AGRICULTURE AND SEWRPC.

development. Thus, attention is focused herein upon historic, as well as existing, land use development and upon region-wide, as well as watershed-wide, factors influencing land use.

Historical Development

The historic settlement by Europeans of what is now the Southeastern Wisconsin Region had its beginning following the Indian-cessions of 1829 and 1833, which transferred to the Federal Government all of what is now the State of Wisconsin south of the Fox River and east of the Wisconsin River. Initial urban development occurred along the Lake Michigan shoreline at the ports of Milwaukee, Port Washington, Racine, and Southport (now Kenosha), as these settlements were more directly accessible to immigration from the East Coast through the Erie Canal-Great Lakes transportation route. The settlement of the watershed, which constituted a rich farm hinterland to the northwest of the port city of Milwaukee, followed soon afterward. Federal surveyors, after the close of the Black Hawk War of 1832, began to survey, subdivide, and monument the federal lands; and by 1836 the U. S. Public Land Surveys had been essentially completed in southeastern Wisconsin. In 1838 a federal land office was opened at Milwaukee, from which nearly 500,000 acres of farm land were sold at the minimum price of $1.25 per acre during the great land sale of February and March of 1839. Significantly, most of this land was not sold to speculators but to farmers who sought the land for permanent homesteads. Most of the settlers within the watershed had been farming and living on the land with only squatter rights prior to the federal land sale.

Almost without exception the pioneer villages of the watershed were located along the Milwaukee River or on major tributaries at natural waterfalls or rapids, where small water-powered grist mills and sawmills could be built. The early settlers had to have flour, meal, feed, and lumber; so these millsites were the logical locations for the development of urban settlements. Information pertinent to the watershed planning effort concerning the milldams remaining within the watershed is presented in Chapter V of this volume.

The period from 1840 to 1860 was one of rapid settlement of the rural area of the watershed, while the villages sustained relatively little growth. Immigrants from northern Europe, New England, and New York State settled in the watershed in increasing numbers and occupied most of the good farm land by 1860. This was an era of enormous wheat production within the watershed, even though the crop had to be hauled long distances by wagon over extremely poor roads to markets in the ports of Milwaukee, Port Washington, and Sheboygan. Sheep raising was also important to the agricultural economy of the watershed until about 1880. Most of the wool produced was marketed at the major port cities. After 1880 both wheat and wool production declined rapidly, being supplanted by dairy farming. By 1900, as today, dairy farming was the most important agricultural industry in the watershed.

Industrial development began to grow rapidly in the watershed following the completion in 1855 of the Chicago and Milwaukee Railroad connecting the Cities of Chicago and Milwaukee. Milwaukee became a major urban center and the most important manufacturing center within the watershed, primarily due to the immigration of skilled artisans and mechanics from Germany. Nearly all of the city's major industrial plants can trace their beginnings to the small backyard shops of these immigrants. The rapidly expanding manufacturers had their foundations in the raw materials supplied by the farms and forests of the watershed, the state, and its neighbors. Some well-known Milwaukee companies developed from small local plants within the watershed, including the Pabst Brewing Company, Joseph Schlitz Brewing Company, and the Pfister and Vogel Leather Company.

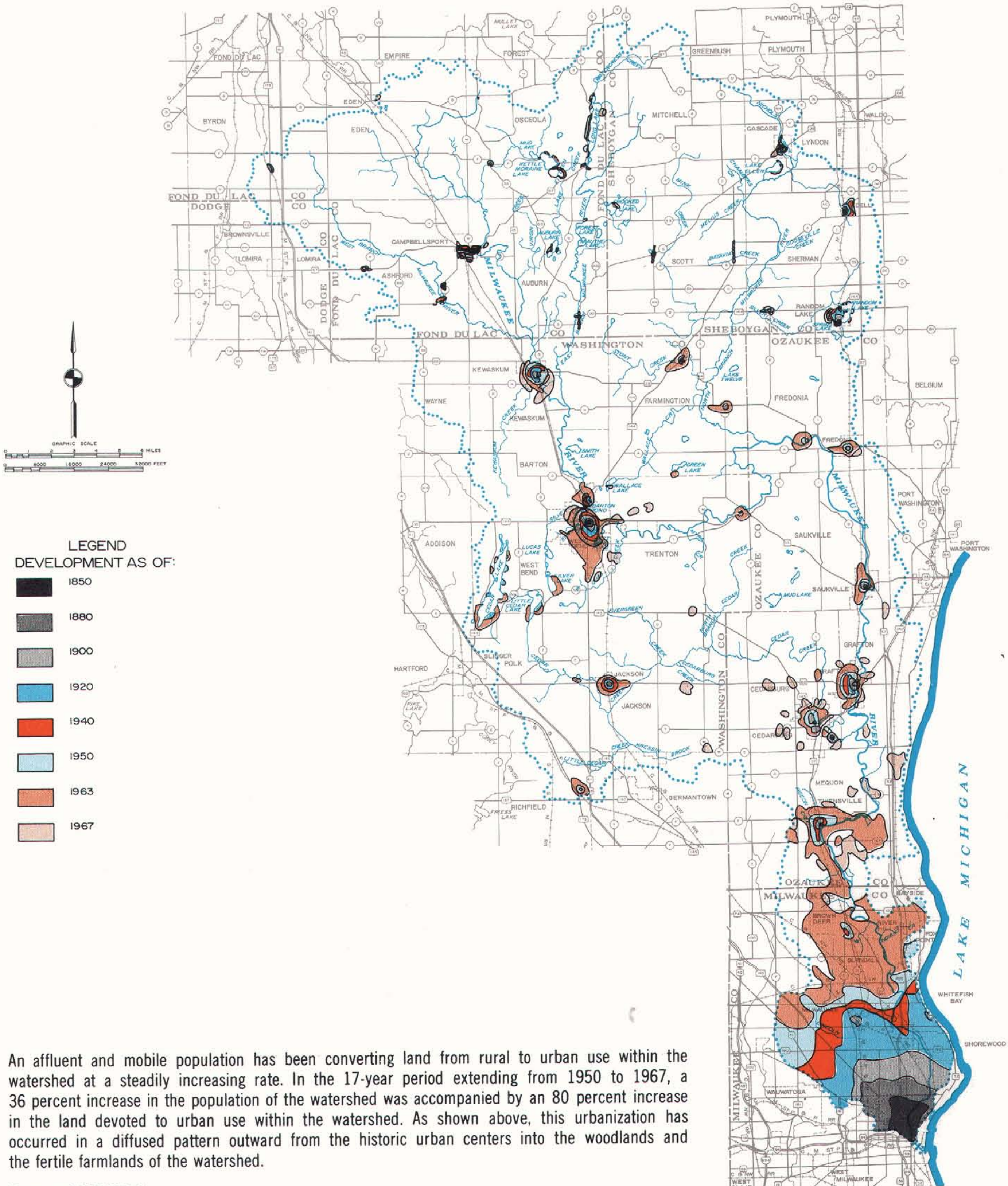
During the 35-year period from 1910 to the end of World War II in 1945, the trend toward more intensive land use continued, marked particularly by the increasing mechanization of farming and the introduction of a modern, all-weather highway system. During the 20 years since the end of World War II, land use has changed more than in the entire previous 115-year history of the watershed. An affluent and mobile population has been converting land from rural to urban use for residential, commercial, institutional, and transportation purposes at an unprecedented rate. In the 17-year period extending from 1950 to 1967, a 36 percent increase in the population of the watershed was accompanied by an 80 percent increase in the land devoted to urban use within the watershed. As shown on Map 8, this urbanization occurred in a diffused pattern outward from the historic urban center into the woodlands and the fertile farm lands of the watershed.

Present Land Use

The generalized pattern of present (1967) land use within the Milwaukee River watershed is shown on Map 9 and is summarized in Table 7. Although Map 9 illustrates the still predominately rural character of the headwaters, it also illustrates the diffused pattern of medium- to high-density urban development which has occurred in the basin portion and surrounding the satellite villages and cities of the watershed. Agricultural land use is still the predominant land use in the watershed, occupying 61.0 percent of the total watershed area. Urban land uses within the watershed presently occupy only 14.7 percent of the total watershed area. Residential development, consisting mainly of single-family dwellings, accounts for 6.1 percent of the total urban land use.

Although only 1.1 percent of the watershed area is presently devoted to active outdoor recreational land use, a high potential for development of additional recreational land exists. While over 62 percent of the Milwaukee River watershed lies within the Region, only 57 percent of the woodlands and

Map 8
HISTORIC URBAN GROWTH
IN THE MILWAUKEE RIVER WATERSHED
1850-1967

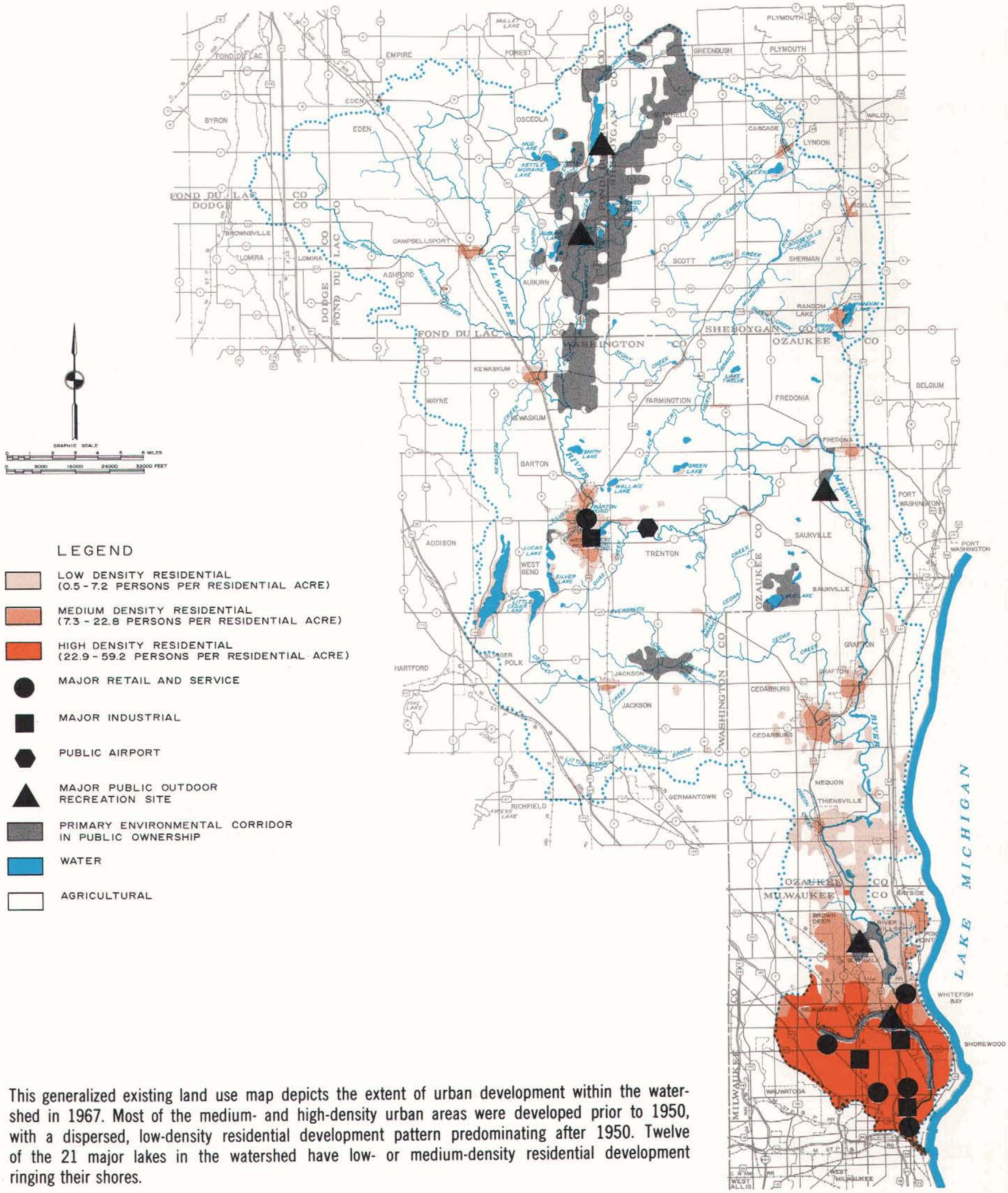


An affluent and mobile population has been converting land from rural to urban use within the watershed at a steadily increasing rate. In the 17-year period extending from 1950 to 1967, a 36 percent increase in the population of the watershed was accompanied by an 80 percent increase in the land devoted to urban use within the watershed. As shown above, this urbanization has occurred in a diffused pattern outward from the historic urban centers into the woodlands and the fertile farmlands of the watershed.

Source: SEWRPC.

Map 9

GENERALIZED EXISTING LAND USE IN THE MILWAUKEE RIVER WATERSHED 1967



This generalized existing land use map depicts the extent of urban development within the watershed in 1967. Most of the medium- and high-density urban areas were developed prior to 1950, with a dispersed, low-density residential development pattern predominating after 1950. Twelve of the 21 major lakes in the watershed have low- or medium-density residential development ringing their shores.

Source: SEWRPC.

TABLE 7

SUMMARY OF EXISTING LAND USE IN THE MILWAUKEE RIVER WATERSHED- 1967

LAND USE CATEGORY	AREA IN ACRES	AREA IN SQUARE MILES	PERCENT OF MAJOR CATEGORY	PERCENT OF WATERSHED AREA
URBAN LAND USE				
RESIDENTIAL				
UNDER DEVELOPMENT.............	2,176	3.40	3.3	0.5
DEVELOPED....................	24,844	38.82	38.0	5.6
SUBTOTAL	27,020	42.22	41.3	6.1
COMMERCIAL......................	1,368	2.14	2.1	0.3
INDUSTRIAL......................	1,763	2.76	2.7	0.4
MINING..........................	1,113	1.74	1.7	0.3
TRANSPORTATION AND UTILITIES[a]...	25,511	39.86	39.1	5.7
GOVERNMENTAL AND INSTITUTIONAL..	3,452	5.39	5.3	0.8
RECREATIONAL[b]....................	5,081	7.94	7.8	1.1
TOTAL URBAN LAND USE	65,308	102.05	100.0	14.7
RURAL LAND USE				
AGRICULTURAL....................	271,370	424.01	71.5	61.0
OPEN LAND				
WATER AND WETLAND[c].............	65,050	101.64	17.1	14.6
WOODLAND[c]......................	35,032	54.74	9.2	7.9
UNUSED LAND..................	8,191	12.80	2.2	1.8
TOTAL RURAL LAND USE	379,643	593.19	100.0	85.3
TOTAL LAND USE	444,951	695.24[d]	--	100.0

[a]INCLUDES OFF-STREET PARKING.

[b]INCLUDES MAJOR AND NEIGHBORHOOD PARKS.

[c]THE WETLAND AND WOODLAND AREA DATA PRESENTED IN THIS TABLE WAS DETERMINED THROUGH AIR PHOTO INTERPRETATION, DELINEATION, AND MEASUREMENT BY THE SEWRPC AS PART OF THE WATERSHED LAND USE INVENTORY AND, AS SUCH, IS NOT STRICTLY COMPARABLE TO THE WETLAND AND WOODLAND AREA DATA PRESENTED AS PART OF THE NATURAL RESOURCE INVENTORY IN CHAPTERS IV AND XIII OF THIS VOLUME. THE LATTER DATA WERE COMPILED BY THE WISCONSIN DEPARTMENT OF NATURAL RESOURCES THROUGH FIELD INTERPRETATION TECHIQUES AND GENERALLY INCLUDE ONLY CONTIGUOUS WETLAND AREAS OF AT LEAST 50 ACRES AND ONLY CONTIGUOUS WOODLAND AREAS OF AT LEAST 20 ACRES.

[d]THIS FIGURE REPRESENTS THE TOTAL AREA OF THE WATERSHED AS DETERMINED THROUGH APPROXIMATING THE WATERSHED BOUNDARY BY U. S. PUBLIC LAND SURVEY QUARTER-SECTION AND SUMMING THE QUARTER-SECTION TOTALS. THE ACTUAL MEASURED WATERSHED TOTAL IS 693.83 SQUARE MILES, OR 444,051 ACRES, REPRESENTING A DIFFERENCE OF 1.41 SQUARE MILES, OR ABOUT 900 ACRES, FROM THE APPROXIMATED WATERSHED TOTAL (SEE TABLE 1).

SOURCE- SEWRPC.

51 percent of the water and wetlands of the watershed lie within the Region. That part of the Milwaukee River watershed within the Region accounts for 18.5 percent of the water and wetlands and 15.2 percent of the woodlands of the Region, while comprising 25.8 percent of the total area of the Region.

The existing land uses are summarized in Appendix C by the major areas of the watershed tributary to the existing stream gages located at Milwaukee (Estabrook Park), Cedarburg, Fredonia, North Branch, New Fane (East Branch), and Kewaskum.

PUBLIC UTILITY BASE

Sanitary Sewerage Service

Within the watershed the construction of public sanitary sewerage facilities has not fully kept pace with the rapid urbanization of the watershed, with the result that much suburban development is presently dependent upon individual septic tank sewage disposal systems. Presently (1967), about 64 percent of the developed area of the watershed, 9 percent of the total watershed area, and about 92 percent of the total watershed population are served by public sanitary sewerage facilities. The existing public sanitary sewerage service areas within the watershed are shown on Map 10, together with the locations of the 14 municipal sewage treatment plants within the watershed. Detailed information on the treatment provided by, and the loading and efficiency of, these sewage treatment plants is presented in Chapter IX of this volume.

Of special significance, and also shown on Map 10, are the areas within the basin and outside Milwaukee County which are included in the planned service area of the Metropolitan Sewerage Commission of the County of Milwaukee. Within this service area, which comprises about 32 square miles, or nearly 5 percent of the total watershed area, sanitary sewage will be collected and transmitted to plants located directly on the shore of Lake Michigan for treatment and disposal.

Water Supply Service

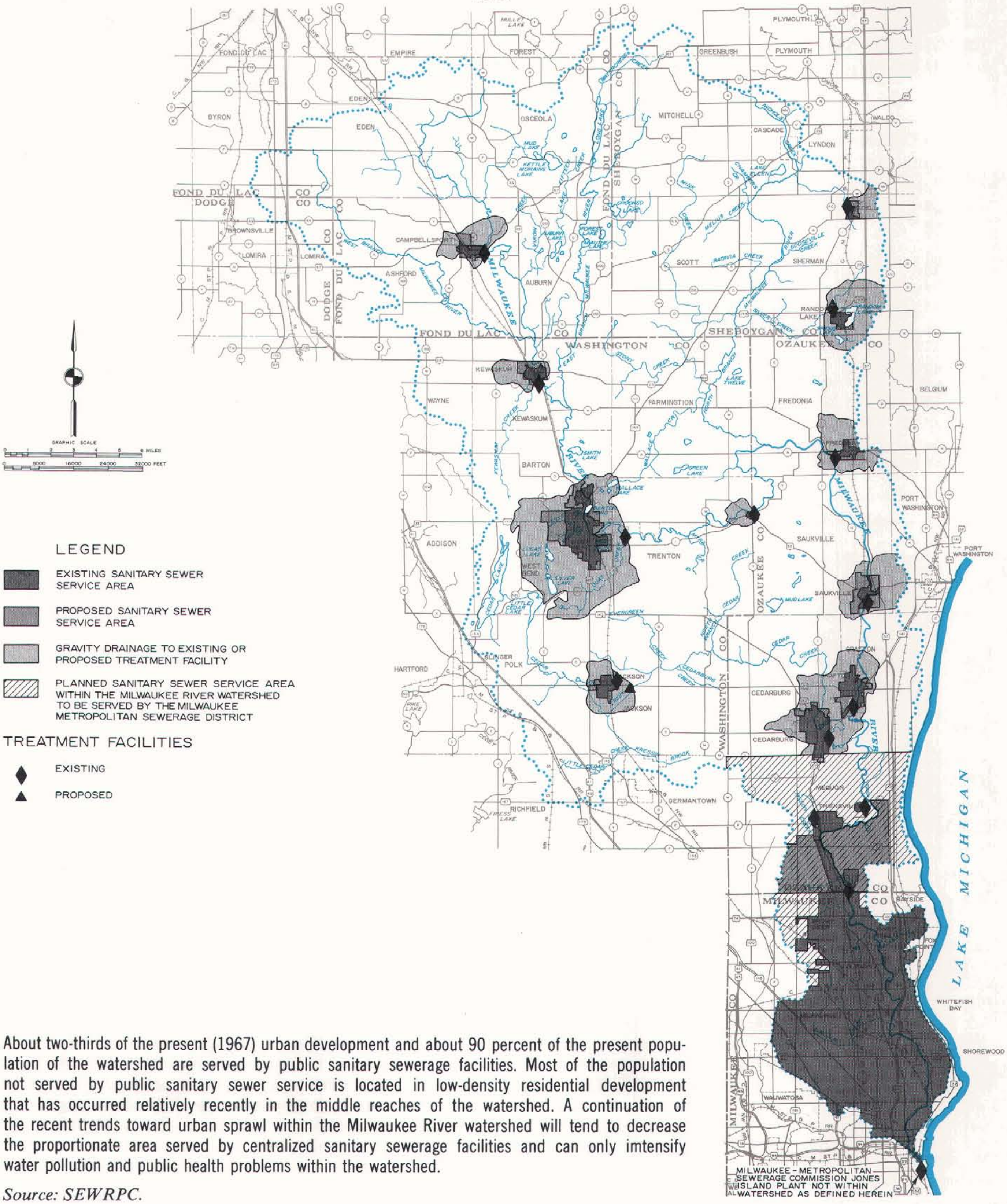
Public water supply systems serve a somewhat smaller proportion of the watershed area than do public sanitary sewerage systems. Presently (1967) about 60 percent of the total developed area of the watershed, 9 percent of the total watershed area, and about 91 percent of the total watershed population are served by public water supply systems. The existing service areas of public and privately operated water systems are shown on Map 11. Two major publicly owned and operated water supply systems in the watershed—the Milwaukee water utility, serving the City of Milwaukee and the Villages of Brown Deer and Shorewood, and the North Shore water utility, serving the City of Glendale and the Villages of Fox Point and Whitefish Bay—utilize Lake Michigan as their source for domestic water supply. All other public and privately operated water systems, as well as individual water supplies, depend entirely upon ground water resources for domestic water supply. Except for the relatively large public water service areas of the Cities of Glendale and Milwaukee and the Villages of Brown Deer, Fox Point, Shorewood, and Whitefish Bay in Milwaukee County; the City of Cedarburg and the Village of Grafton in Ozaukee County; and the City of West Bend in Washington County, the public and privately owned water supply systems serve small and scattered areas of urban development.

Electric and Gas Utility Service

An adequate supply of electric power is available to all portions of the watershed. Residential service is available anywhere within the watershed, and low-voltage lines are in place along nearly every rural highway. Electric power adequate to meet any commercial or industrial need could and would, as a matter of established utility corporation policy, be extended to any customer requesting electric service, with the sole limitation being that the anticipated earnings from a particular customer must, over a four-year period, be equal to, or greater than, the cost of extending such service.

As a matter of established utility corporation policy, any major natural gas customer can obtain gas service anywhere within the franchise portions of the watershed; but extensions to serve small potential customers in areas remote from existing gas mains must be deferred until the number of such customers economically justifies the necessary extension. Gas service within the watershed is provided by three utilities: the Wisconsin Gas Company, the Wisconsin Power and Light Company, and the Wisconsin Public Service Corporation. No gas utility franchise exists in the watershed within the Town of Wayne in Washington County and the Town of Scott in Sheboygan County.

Map 10
PUBLIC SANITARY SEWER SERVICE AREAS IN THE MILWAUKEE RIVER WATERSHED 1967

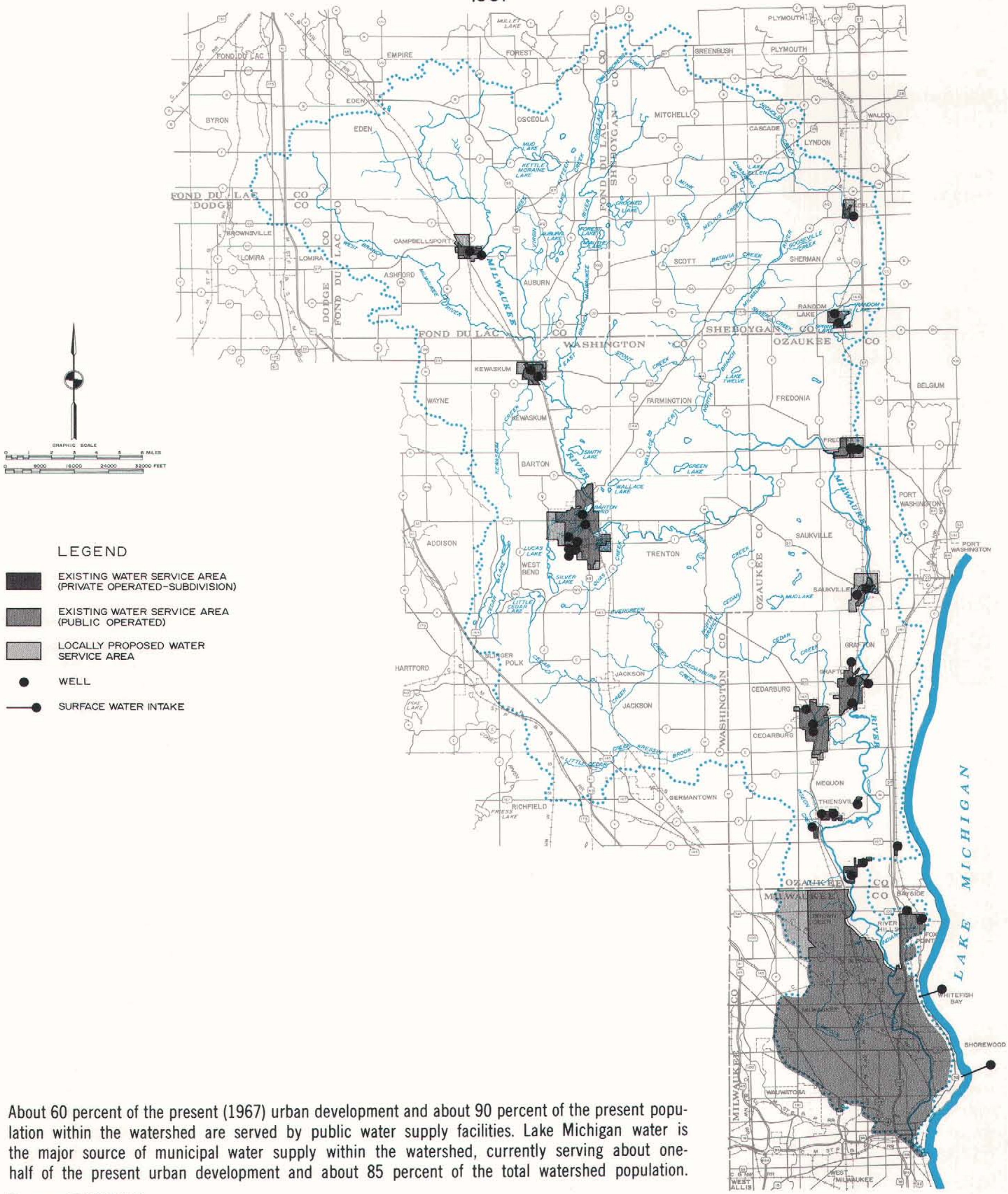


About two-thirds of the present (1967) urban development and about 90 percent of the present population of the watershed are served by public sanitary sewerage facilities. Most of the population not served by public sanitary sewer service is located in low-density residential development that has occurred relatively recently in the middle reaches of the watershed. A continuation of the recent trends toward urban sprawl within the Milwaukee River watershed will tend to decrease the proportionate area served by centralized sanitary sewerage facilities and can only imtensify water pollution and public health problems within the watershed.

Source: SEWRPC.

Map 11

PUBLIC WATER SUPPLY SERVICE AREAS IN THE MILWAUKEE RIVER WATERSHED 1967



About 60 percent of the present (1967) urban development and about 90 percent of the present population within the watershed are served by public water supply facilities. Lake Michigan water is the major source of municipal water supply within the watershed, currently serving about one-half of the present urban development and about 85 percent of the total watershed population.

Source: SEWRPC.

TRANSPORTATION SYSTEM

The extensively developed, all-weather, high-speed highway system within the watershed has had a marked influence on the spatial location of urban development. This influence has, however, been significantly modified by the location within the watershed of such natural resources as lakes, streams, woodland, and fertile farm lands.

The major transportation network within the watershed, as shown on Map 12, consists of a radial pattern of major arterial highways interconnecting the urban and rural areas of the watershed. Most of the arterial highways presently (1967) carrying over 4,000 vehicles per average weekday are either major intercity and interregional routes through the watershed or radiate from the Milwaukee urbanized area.

Intercity bus service is provided (1967) between several communities within the watershed and other urban centers, such as Milwaukee, West Bend, Fond du Lac, Port Washington, and Sheboygan. The Wisconsin Coach Lines of Waukesha serves communities within the watershed by one route along STH 33, 57, and 145 and USH 41 and 45 and by another route along STH 57, 60, and 175 and USH 41 and 141.

Intra-urban bus service within Milwaukee County is provided (1967) by the Milwaukee and Suburban Transport Corporation. Rail service in the watershed is limited to freight hauling, except for scheduled passenger service to the Cities of Milwaukee and West Bend by the Chicago and Northwestern Railway Company (C&NW). Two other major railway lines operating within the watershed but providing freight service only are: The Chicago, Milwaukee, St. Paul and Pacific Railroad Company (Milwaukee Road) and the Minneapolis, St. Paul and Sault Ste Marie Railroad Company (Soo Line).

SUMMARY

This chapter has described the man-made features of the Milwaukee River watershed, which together constitute the socioeconomic base of the watershed. The description has included the historic trends and the present size, composition, and distribution of the resident population; the general interdependence of economic activity within the watershed to that of the Region; the historic development of land use and the general pattern of existing land use within the watershed; and the transportation and public utility systems existing within the watershed. The findings contained in this chapter, which have particular significance to the comprehensive planning study of the Milwaukee River watershed, are summarized in the following paragraphs.

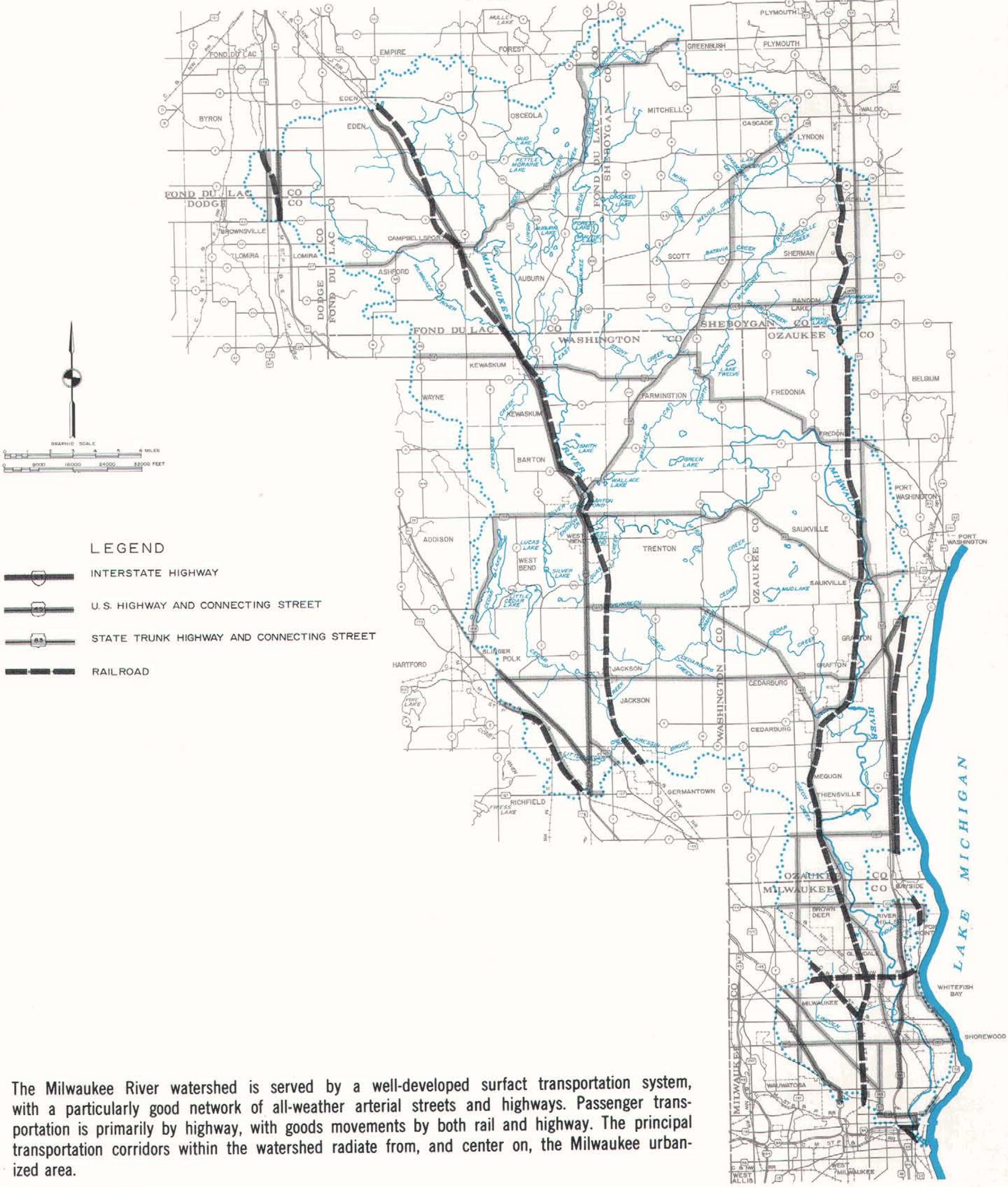
The Milwaukee River watershed is the third largest of the 11 major natural surface water drainage units located within the rapidly urbanizing Southeastern Wisconsin Region. A complex pattern of general and special-purpose units of government, including federal, state, regional, and local levels, is superimposed upon this drainage unit, complicating comprehensive watershed planning and plan implementation activities.

The present (1967) population of the watershed is estimated at 543,790 persons, of which 531,680 persons reside within the Region and 12,110 persons reside outside the Region. The population of the watershed has increased steadily since 1850, although preliminary 1970 U. S. Census of Population and Housing results reveal a less than 1 percent increase in total watershed population during the 1960-1970 decade, as compared to a 32 percent increase in watershed population during the 1950-1960 decade. Closer inspection of the preliminary 1970 census results reveals, however, a combination of substantial population growth and development in the middle, urbanizing reaches of the watershed, combined with an actual decline in population in the City of Milwaukee portion of the lower, urban reach of the watershed. The City of Milwaukee watershed population dropped 7 percent in the 1960-1970 decade, from about 405,000 to about 376,000, the decline being attributed primarily to a substantial loss of housing units due to extensive urban renewal activities and essential freeway and other public works construction and to a reduction in the average household size due to changing patterns of family composition. This substantial population loss was more than offset by rapid growth in the middle reaches of the watershed.

The economic forces which promote this population growth and urbanization in the middle and upper portions of the watershed are largely centered inside the watershed in the major urban center of Milwaukee. Land areas in the lower and center reaches of the watershed are undergoing a particularly rapid conversion from rural to urban use. Moreover, recent urban develop-

Map 12

FEDERAL AND STATE HIGHWAY AND TRUNK LINE RAILROAD FACILITIES IN THE MILWAUKEE RIVER WATERSHED 1967



The Milwaukee River watershed is served by a well-developed surfact transportation system, with a particularly good network of all-weather arterial streets and highways. Passenger transportation is primarily by highway, with goods movements by both rail and highway. The principal transportation corridors within the watershed radiate from, and center on, the Milwaukee urbanized area.

Source: SEWRPC.

ment has consisted primarily of a scattered, low-density type, with many isolated enclaves of residential development away from established communities. This type of urban development is placing a particularly heavy strain on the natural resource base of the watershed.

The construction of public sanitary sewer and water facilities has not fully kept pace with the rapid urban growth in the watershed, necessitating the widespread use of individual private wells and on-site sewage disposal systems (septic tanks) in the middle and upper reaches of the watershed. Presently, about 64 percent of the developed urban land area and 92 percent of the total watershed population is served by public sewerage systems, while about 60 percent of the developed urban land area and 91 percent of the total watershed population is served by public water supply systems.

The extensively developed, high-speed, all-weather highway system within the watershed has had a marked influence on the spatial location of urban development from West Bend to Milwaukee. This influence has, however, been significantly modified by the location within the watershed of such natural resources as lakes, streams, woodland, and fertile farm lands.

Chapter IV

DESCRIPTION OF THE WATERSHED—NATURAL RESOURCE BASE

INTRODUCTION

The natural resource base is a primary determinant of the development potential of a watershed and of its ability to provide a pleasant and habitable environment for all forms of life. The principal elements of the natural resource base are climate, physiography, geology, soils, vegetation, water resources, and wildlife. Without a proper understanding and recognition of these elements and of their interrelationships, human use and alteration of the natural environment proceeds at the risk of excessive costs in terms of both monetary expenditures and the destruction of nonrenewable or slowly renewable resources. In this age of high resource demand and rapidly changing technology, it is especially important that the natural resource base be a primary consideration in any areawide planning effort, since these aspects of contemporary civilization make the underlying and sustaining resource base highly vulnerable to misuse and destruction.

CLIMATE

The Milwaukee River watershed is subject to a semi-humid continental-type climate which is characterized by the extremes in weather common to its latitude and interior position on the North American Continent. Cyclonic activity is the main cause of the weather conditions over the watershed, which lies in the path of frontal systems moving across the continent in a generally easterly and southeasterly direction. Lake Michigan has a moderating effect on the climate of the watershed, which effect, although generally limited to a narrow band within five miles of the Lake Michigan shoreline, may extend as far as 30 miles inland under some conditions.

The climate spans the four seasons, each succeeding one another through varying periods of unsteady transition. Summer generally spans the months of June, July, and August. The summers are relatively warm, with occasional periods of hot, humid weather and sporadic periods of very cool weather. Precipitation experienced during this season is usually convectional in origin due to diurnal heating. Winter generally spans the months of December, January, and February but may, in some years, be lengthened to include all or parts of the months of November and March. Winters tend to be cold, cloudy, and snowy. There is often a short mid-winter thaw occasioned by brief periods of unseasonably warm weather. Streams and lakes begin to freeze over in November, with the larger and deeper bodies of water being usually covered with ice by mid-December. Lake and stream ice breakup occurs in late March or early April due to increasing solar radiation.

Autumn and spring in the watershed, being transitional times of year between the dominant seasons, are usually periods of unsettled weather conditions. Temperatures are extremely varied, and relatively long periods of precipitation are common during these two seasons. Early spring is marked by a moderation of the low temperature of winter, and by late March rainfall replaces snow as the predominant form of precipitation. Typical spring weather may extend from March through May and is characterized by cool, wet weather. Typical autumn weather may extend from September through November and is characterized by pleasant, mild, sunny days and cool nights.

Air temperatures within the watershed are subject to large seasonal and yearly variations. Air temperatures for both winter and summer generally lag about three weeks behind their respective solstice, resulting in July being the warmest month and January, the coldest. The number of days within the watershed with temperatures of 0^{o}F or less has ranged from none in 1921 and 1931 to 41 in 1963, as determined by the records for the two stations from 1871 to 1969. The number of days with temperatures of 90^{o}F or more has ranged from zero in 1950 and 1951 to 31 in 1941. The lowest temperature recorded within the watershed was -29^{o}F in January 1951. The highest temperature recorded was 107^{o}F in July 1936. The mean daily temperature of the hottest month, July, is 70.3^{o}F; and the mean daily temperature of the coldest month, January, is 20.4^{o}F. The mean annual temperature for the watershed ranges from 45.1^{o}F in the lower watershed to 46.4^{o}F in the upper watershed.

The growing season, which is defined as the number of days between the last 32°F frost in spring and the first 32°F frost in fall, averages about 164 days within the watershed. The average date of the first 32°F freeze occurs during the second week of October, and the average date of the last 32°F freeze in the spring occurs during the first week of May.

Precipitation within the watershed takes the form of rain, sleet, hail, and snow and ranges from gentle showers of trace quantities to destructive thunderstorms, causing property and crop damage, inundation of poorly drained areas, and stream flooding. As indicated in Table 8, the average annual precipitation for the watershed is 29.51 inches at Milwaukee and 29.76 inches at West Bend[1] and has varied from a low of 19.10 inches to a high of 41.86 inches, as determined by the

[1] *The average annual precipitation for the watershed as a whole, determined by the Thiessen (Polygon) Network method, is 29.35 inches.*

TABLE 8

PRECIPITATION MEANS AND EXTREMES
AT MILWAUKEE AND WEST BEND, WISCONSIN 1931-1960[a]

MONTH	PRECIPITATION (INCHES)					
	MEANS		GREATEST DAILY			
	MILWAUKEE	WEST BEND	MILWAUKEE	YEAR	WEST BEND	YEAR
JANUARY.....	1.83	1.68	1.71	1960	2.35	1938
FEBRUARY....	1.40	1.36	1.67	1960	1.52	1937
MARCH.......	2.31	2.01	2.57	1960	1.74	1943
APRIL.......	2.53	2.54	2.11	1956	2.42	1955
MAY.........	3.16	2.98	2.06	1948	2.52	1936
JUNE........	3.64	3.96	3.13	1950	3.78	1940
JULY........	2.95	3.34	4.35	1959	4.24	1952
AUGUST......	3.06	2.89	4.05	1953	2.58	1945
SEPTEMBER...	2.72	3.16	5.28[b]	1941	2.09	1941
OCTOBER.....	2.10	2.21	2.60	1959	3.10	1954
NOVEMBER....	2.18	2.13	2.18	1943	1.39	1931
DECEMBER....	1.63	1.50	1.93	1942	2.20	1942
	29.51	29.76	5.28	1941 SEPT	4.24	1952 JULY

[a] THE 30-YEAR PERIOD, 1931-1960, IS THE 'STANDARD NORMAL' PERIOD, WHICH CONFORMS TO THE WORLD METEOROLOGICAL ORGANIZATION STANDARD FOR CLIMATOLOGICAL NORMALS. FOR A MORE COMPLETE PERIOD OF ANNUAL PRECIPITATION SEE CHAPTER VI, TABLE 24, OF THIS REPORT VOLUME.

[b] THE MAXIMUM RECORDED 24-HOUR RAINFALL IN THE WATERSHED --7.58 INCHES-- OCCURRED AT WEST BEND IN AUGUST 1924 (SEE CHAPTER VI OF THIS VOLUME).

SOURCE- U. S. WEATHER BUREAU AND SEWRPC.

records for the two stations from 1931 to 1960, which 30-year period is the "standard normal" period conforming to the World Meteorological Organization standard for climatological normals. Approximately 55 percent of the average annual precipitation occurs as rainfall during the growing season. Snowfall accounts for approximately 14 percent of the average annual precipitation and has ranged from a minimum cumulative seasonal snowfall of 12.1 inches (water equivalent of one inch) in the winter of 1967-1968 to a maximum cumulative seasonal snowfall of 93.3 inches (water equivalent of 7.75 inches) in the winter of 1959-1960. The maximum recorded 24-hour rainfall was 5.28 inches in 1941, and the maximum recorded 24-hour snowfall was 16.7 inches in 1960.

Summaries of precipitation and temperature data for the Milwaukee, and West Bend, Wisconsin, weather stations are presented in Tables 8 and 9; and graphic presentations for each are shown in Figure 8. These climatological summaries closely approximate temperature and precipitation characteristics within the watershed. They also indicate differences between a geographic location in the lower watershed on the Lake Michigan shoreline and a location in the middle or upper watershed at a distance of about 15 miles inland from the Lake Michigan shoreline.

Northwesterly winds prevail during the winter, whereas southwesterly winds prevail during the summer. The windiest months are March, April, and November, when the wind velocities have averaged about 14 miles per hour out of the west-northwest during the 30-year period of record from 1931 to 1960. Wind velocities in the range of 13 to 31 miles per hour have occurred about 40 percent of the time. Wind velocities exceeding 31 miles per hour have occurred less than 1 percent of the time.

The percent of maximum possible sunshine averages about 51 percent during the year, ranging from 40 percent from November through February, 55 percent from March through May and during October, to 60 percent from June through September.

TABLE 9

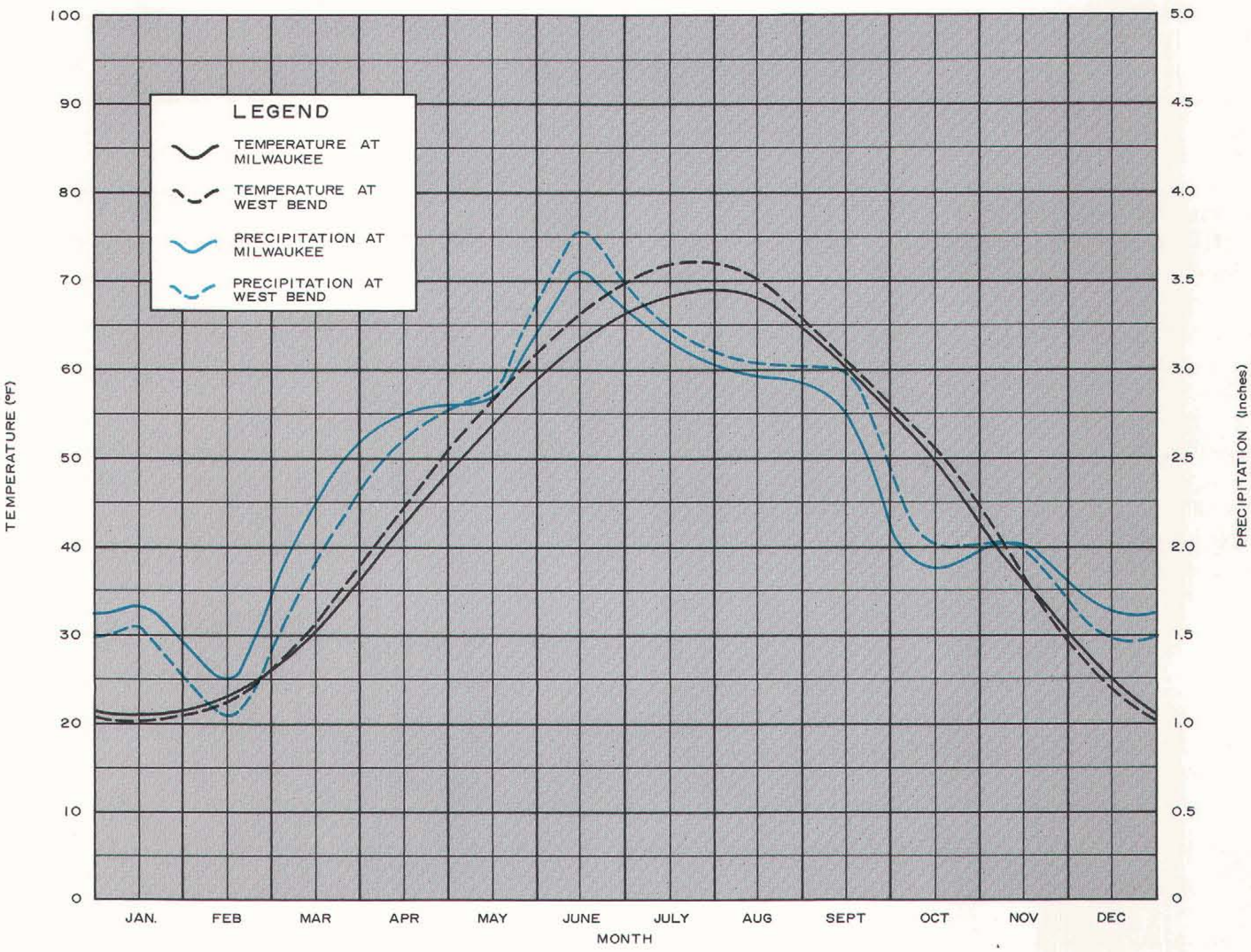
TEMPERATURE MEANS AND EXTREMES AT MILWAUKEE AND WEST BEND, WISCONSIN 1931-1960[a]

MONTH	MEANS (°F)						EXTREMES (°F)							
	DAILY MAXIMUM		DAILY MINIMUM		MONTHLY		RECORD HIGH				RECORD LOW			
	MILWAUKEE	WEST BEND	MILWAUKEE	WEST BEND	MILWAUKEE	WEST BEND	MILWAUKEE	YEAR	WEST BEND	YEAR	MILWAUKEE	YEAR	WEST BEND	YEAR
JANUARY....	28.3	28.6	12.8	11.7	20.6	20.2	62	1944	60	1944	-24	1951	-29	1951
FEBRUARY...	30.2	31.0	14.6	13.5	22.4	22.3	60	1954	63	1930	-19	1951	-28	1933
MARCH......	38.8	39.9	23.2	23.0	31.0	31.5	77	1943	79	1945	-9	1960	-9	1943
APRIL......	53.1	54.9	34.1	34.6	43.6	44.8	85	1939 1960	88	1930	13	1954	8	1954
MAY........	63.9	67.5	42.9	45.4	53.4	56.5	90	1939 1950 1956 1959	100	1934	29	1943	20	1935
JUNE.......	73.9	77.4	52.6	55.8	63.3	66.6	99	1953	103	1934	33	1945	30	1945
JULY.......	78.9	82.9	58.4	60.7	68.7	71.8	102	1940	107	1936	45	1945	42	1945
AUGUST.....	77.7	80.8	57.8	59.5	67.8	70.2	100	1948 1955	99	1934	44	1950	37	1934
SEPTEMBER..	70.7	72.4	49.9	51.3	60.3	61.9	99	1939	98	1931	31	1942	28	1942
OCTOBER....	60.1	60.8	39.9	41.1	50.0	51.0	86	1947	84	1938	21	1942 1948 1960	19	1954
NOVEMBER...	44.1	44.1	27.5	27.8	35.8	36.0	77	1944	77	1933	-5	1950	-10	1958
DECEMBER...	32.0	32.0	17.1	16.7	24.6	24.4	60	1946 1949 1960	60	1946	-12	1950	-17	1940
	54.3	56.0	35.9	36.7	45.1	46.4	102	1940 JULY	107	1940 JULY	-24	1951 JANUARY	-29	1951

[a]THE 30-YEAR PERIOD, 1931-1960, IS THE 'STANDARD NORMAL' PERIOD WHICH CONFORMS TO THE WORLD METEOROLOGICAL ORGANIZATION STANDARD FOR CLIMATOLOGICAL NORMALS, AND, MOREOVER, CONFORMS TO THE DECENNIAL CENSUS OF THE UNITED STATES CLIMATE, U. S. WEATHER BUREAU.

SOURCE- U.S. DEPARTMENT OF COMMERCE, WEATHER BUREAU, AND SEWRPC.

Figure 8
AVERAGE MONTHLY TEMPERATURE AND PRECIPITATION AT MILWAUKEE AND WEST BEND, WISCONSIN 1931-1960



Source: U.S. Department of Commerce, Weather Bureau.

PHYSIOGRAPHY

The Milwaukee River watershed is an irregularly shaped drainage basin, with its major axis oriented approximately north and south. Its area is approximately 694 square miles and its length approximately 46 miles. Its width varies from 26 miles in the northern portions of the watershed to approximately four miles in the lower watershed.

The western boundary of the Milwaukee River watershed forms a major subcontinental divide between the upper Mississippi River drainage basin and the Great Lakes-St. Lawrence River drainage basin. On the north the Milwaukee River watershed adjoins the Sheboygan and Wolf-Fox River watersheds; on the west, the Rock River watershed; and on the south, the Menomonee River watershed. On the east the Milwaukee River watershed shares a common boundary with the Sauk Creek watershed and with various minor unnamed tributaries to Lake Michigan. In the lower portion of the basin, the eastern boundary lies very close to and parallels the Lake Michigan shoreline.

Topography

The Milwaukee River watershed lies within the Niagara cuesta section of the Eastern Ridges and Lowlands physiographic province of Wisconsin, and its topography is controlled together by the bedrock and overlying glacial deposits. The Niagara cuesta, on which the watershed lies, is a gently eastward sloping bedrock surface. The topography in this section is asymmetrical, with the eastern border of the watershed being generally lower in elevation than the western border. The bedrock formations underlie glacial deposits, which form the irregular surface topography characterized by rounded hills or groups of hills, ridges, broad undulating plains, and poorly drained wetlands. In particular, the interlobate deposits left between the Green Bay and Lake Michigan lobes of the continental glacier, known as the Kettle Moraine, give the watershed its highest elevations and areas of greatest local relief. This complex system of moraines, kames, kettle holes, and abandoned drainageways forms some of the most attractive and interesting landscapes within the watershed. Surface elevations within the watershed range from a high of approximately 1,311 feet above sea level at Parnell Lookout Tower in the Town of Mitchell, Sheboygan County, to approximately 580 feet at the entrance to the Milwaukee Harbor, a maximum relief of 731 feet. The areas of greatest local relief are located northwest of West Bend in Washington County and northeast of Long Lake in Sheboygan County and, although generally less than 100 feet, in some places exceed 200 feet (see Map 13).

Surface Drainage

Surface drainage is poorly developed but highly diverse within the Milwaukee River watershed due to the effects of the relatively recent glaciation. The land surface is complex, containing thousands of closed depressions that range in size from mere pits to large areas up to 100 acres in size. Significant areas of the watershed are covered by wetlands, and many streams are mere threads of water through these wetlands. Even the main avenues of drainage in the watershed formed by the Milwaukee River and its major tributaries have a very disordered pattern. The flow of the Milwaukee River from its origin in Kettle Moraine Lake, located in Section 27, Town 14 North, Range 19 East, Town of Osceola, Fond du Lac County, is generally southerly to West Bend. At West Bend the river turns eastward and flows generally easterly down the dip slope of the Niagara cuesta to Fredonia. Here it turns and again flows in a generally southerly direction parallel and very close to the Lake Michigan shoreline to its mouth on the Lake Michigan shore in Milwaukee. A relatively complex pattern of major tributaries includes the North, the East, and the West Branches of the Milwaukee River and Cedar Creek.

GEOLOGY—A STRATIGRAPHIC AND HISTORIC OVERVIEW

The geology of the Milwaukee River watershed is a complex system of various layers and ages of rock formations. The type and extent of the various bedrock formations underlying the watershed was determined primarily by the environments in which the sediments forming the various rock layers were deposited. The surface of this varied system of rock layers was, moreover, deeply eroded prior to being buried in a blanket of glacial deposits consisting of unconsolidated sand, clay, gravel, and boulders.

The geologic units underlying the Milwaukee River watershed, in ascending order, consist of Pre-Cambrian crystalline rocks, layered Paleozoic sedimentary rocks, and unconsolidated Pleistocene glacial deposits. Only the glacial deposits and the youngest sedimentary rocks are exposed in the watershed. The subsurface stratigraphy of the Milwaukee River watershed is summarized in Table 10. Geologic sections through the watershed are shown in Figure 9, and the locations of these sections are shown on Map 14.

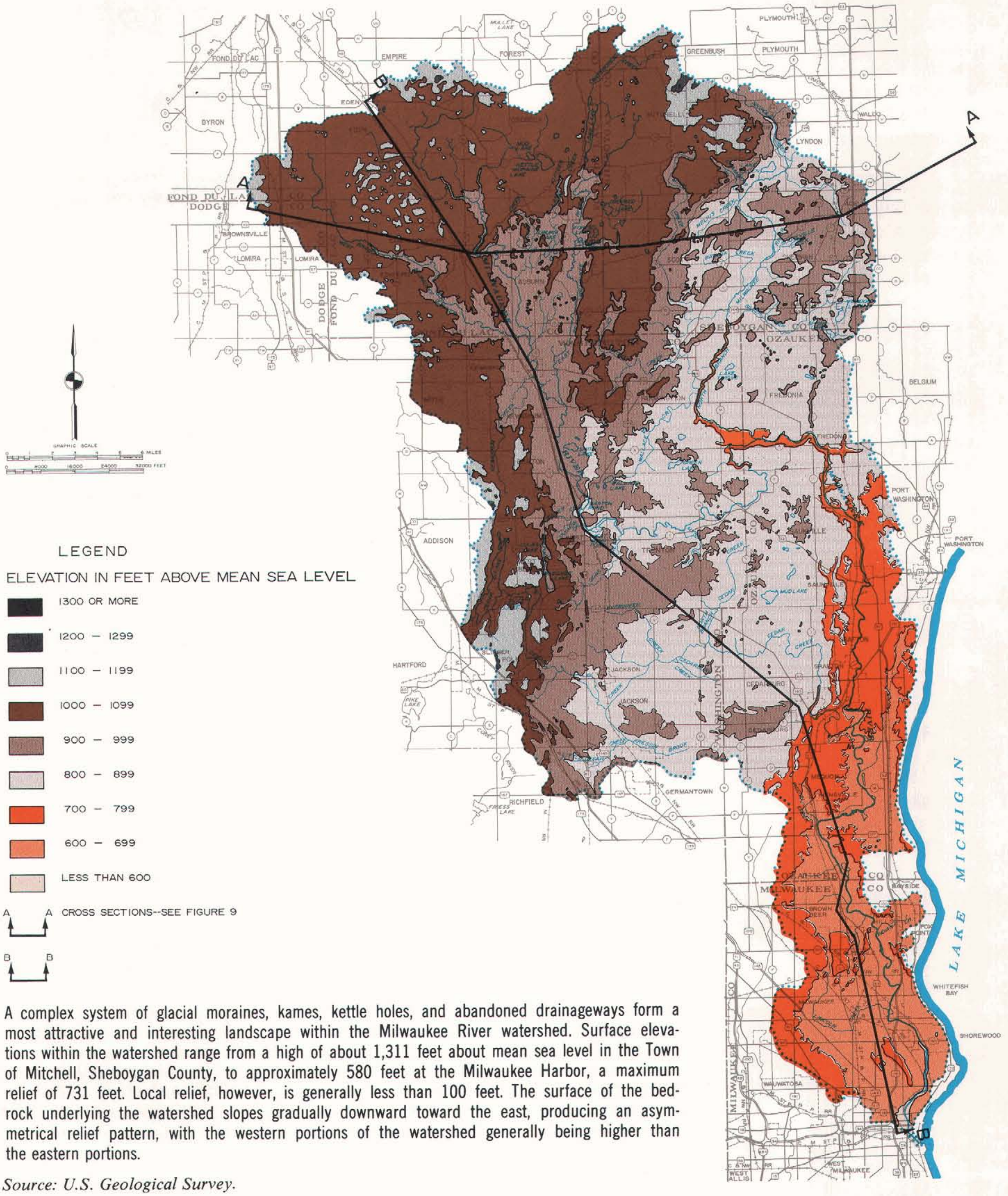
Pre-Cambrian Rock Units

Pre-Cambrian crystalline rocks, thousands of feet thick, form the basement on which younger rocks were deposited. Little is known of their origin; but, in three wells that reach the Pre-Cambrian basement, the rock types are quartzite and granite.

The Pre-Cambrian rocks were extensively eroded to an uneven surface before the overlying sedimentary formations were deposited. A striking feature of this eroded surface is a buried Pre-Cambrian hill near West Bend in Washington County. At the crest of the hill, the Pre-Cambrian rocks are about 950 feet below land surface, while in Milwaukee County to the southeast, these rocks are estimated to be over 2,600 feet below land surface. The slope of this hill is steepest to the east and south.

Map 13

GENERALIZED RELIEF
IN THE MILWAUKEE RIVER WATERSHED



A complex system of glacial moraines, kames, kettle holes, and abandoned drainageways form a most attractive and interesting landscape within the Milwaukee River watershed. Surface elevations within the watershed range from a high of about 1,311 feet about mean sea level in the Town of Mitchell, Sheboygan County, to approximately 580 feet at the Milwaukee Harbor, a maximum relief of 731 feet. Local relief, however, is generally less than 100 feet. The surface of the bedrock underlying the watershed slopes gradually downward toward the east, producing an asymmetrical relief pattern, with the western portions of the watershed generally being higher than the eastern portions.

Source: U.S. Geological Survey.

TABLE 10

STRATIGRAPHY OF THE MILWAUKEE RIVER WATERSHED

GEOLOGIC AGE	STRATIGRAPHIC UNIT	THICKNESS RANGE (FEET)	LITHOLOGY	AREAL EXTENT
HOLOCENE	ALLUVIUM	0-25(?)	PEAT, CLAY, SILT, SAND, AND GRAVEL.	OCCURS ONLY LOCALLY IN STREAMS, VALLEYS, AND MARSHES.
PLEISTOCENE	GLACIAL DEPOSITS	0-400(+)	PEAT, CLAY, SILT, SAND, AND GRAVEL.	UNDERLIES ENTIRE WATERSHED EXCEPT ON ROCK OUT-CROPS.
DEVONIAN	MILWAUKEE FORMATION	0-110	DOLOMITE, GRAY AND BROWN SHALE, GRAY.	THESE UNITS OCCUR ONLY IN THE SOUTHEASTERN PART OF THE WATERSHED.
	THIENSVILLE FORMATION	0-80	DOLOMITE, LIGHT TO DARK BROWN AND GRAY MODERATELY THICK-BEDDED, DENSE.	
	LAKE CHURCH FORMATION	0-35	DOLOMITE.	
SILURIAN	DOLOMITE UNDIFFERENTIATED	0-646	DOLOMITE, LIGHT GRAY UPPER PART, MASSIVE MIDDLE PART CHERTY, LOWER PART LESS MASSIVE SOME CORAL REEFS.	UNDERLIES ENTIRE WATER-SHED WITH THE POSSIBLE EXCEPTION OF SMALL AREA NORTH OF SLINGER.
ORDOVICIAN	NEDA FORMATION	0-35	SHALE, RED, OLITIC, HEMATIC.	IDENTIFIED ONLY LOCALLY IN THE WATER-SHED.
	MAQUOKETA SHALE	90-265	SHALE, BLUE GRAY TO GRAY, DOLOMITIC WITH INTER-BEDDED DOLOMITE LAYERS.	UNDERLIES ENTIRE WATERSHED.
	GALENA DOLOMITE DECORAH FORMATION PLATTEVILLE FORMATION	200-305	DOLOMITE, LIGHT GRAY TO BLUE SANDY DOLOMITE OR DOLOMITIC SANDSTONE AT BASE.	UNDERLIES ENTIRE WATERSHED.
	ST. PETER SANDSTONE	95-270	SANDSTONE, MEDIUM TO FINE GRAINED, WHITE TO LIGHT GRAY, DO-LOMITIC.	UNDERLIES ENTIRE WATERSHED.
	PRAIRIE DU CHIEN GROUP	0-(?)	DOLOMITE CHERTY, LIGHT GRAY TO WHITE, DENSE, WITH THIN BEDS OF SHALE.	MAY OCCUR LOCALLY IN NORTHWEST CORNER OF WATERSHED.
CAMBRIAN	TREMPEALEAU FORMATION	0-55	SANDSTONE, VERY FINE TO MEDIUM-GRAINED, DOLOMITE LIGHT GRAY, INTERBEDDED WITH SILTSTONE.	THESE UNITS ARE RECOGNIZED ONLY WITHIN THE NORTHERN PART OF THE WATERSHED.
	FRANCONIA SANDSTONE	0-95	SANDSTONE, VERY FINE- TO MEDIUM GRAINED SILTSTONE OR DOLOMITE IN LOWER PART.	
	GALESVILLE SANDSTONE	0-75(+)	SANDSTONE FINE TO MEDIUM GRAINED, LIGHT GRAY.	
	EAU CLAIRE SANDSTONE	0-390(?)	SANDSTONE FINE TO MEDIUM GRAINED, DOLOMITE, LIGHT GRAY.	THESE UNITS ARE PRESENT IN ALL BUT THE WEST-CENTRAL PART OF THE WATERSHED.
	MT. SIMON SANDSTONE	0-770(+)	SANDSTONE FINE TO COARSE GRAINED, WHITE OR LIGHT GRAY.	
PRECAMBRIAN	UNDIFFERENTIATED	(THOUSANDS OF FEET)	CRYSTALLINE ROCKS IN-CLUDING GRANITE AND QUARTZITE.	UNDERLIES ENTIRE WATERSHED.

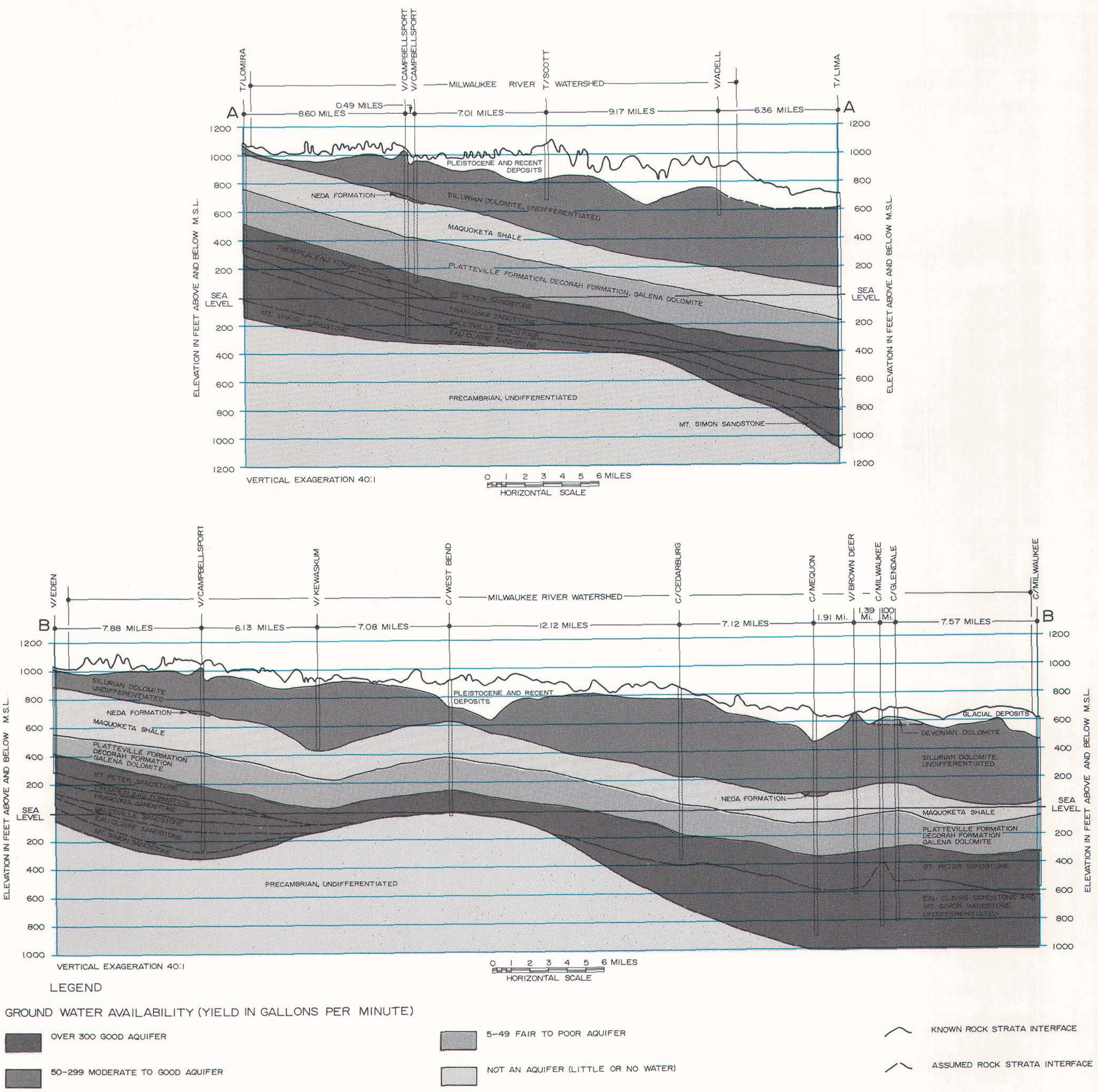
SOURCE- U.S. GEOLOGICAL SURVEY.

Layered sedimentary rocks overlie the Pre-Cambrian rocks and consist primarily of sandstone, shale, and dolomite. These rocks were deposited during the Cambrian, Ordovician, Silurian, and Devonian geologic time periods, in seas that covered much of the present North American continent.

During early stages of deposition, the Pre-Cambrian hill probably was an island in the ancient

Figure 9

STRATIGRAPHIC CROSS SECTIONS THROUGH THE MILWAUKEE RIVER WATERSHED SHOWING THE GENERAL AVAILABILITY OF GROUND WATER FROM THE BEDROCK UNITS



Source: U.S. Geological Survey.

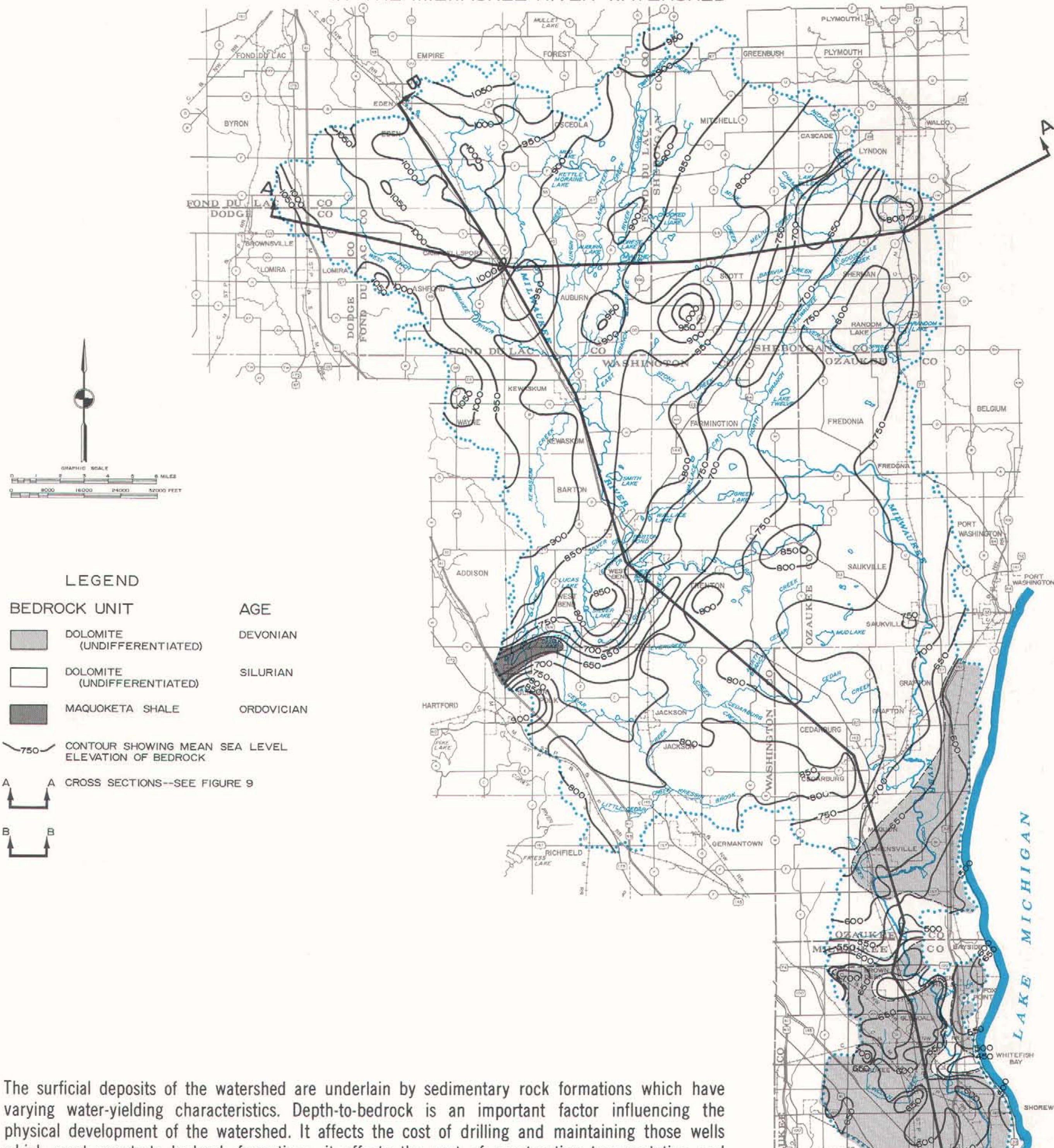
sea, as is suggested by the absence of Cambrian formations near its summit. Ordovician, Silurian, and probably younger sediments were later deposited over the entire hill.

Cambrian Rock Units

Cambrian rocks in the watershed are primarily sandstone but contain some siltstone, dolomite, and shale. These rocks are thin or absent near the buried Pre-Cambrian hill in Washington County. The lowermost Mount Simon sandstone and the Eau Claire sandstone are present throughout the rest of the watershed. The overlying Galesville and Franconia sandstones are absent in the southeastern area, probably because they were eroded during Ordovician time. The Trempealeau formation occurs only locally in the northwestern part of the watershed.

Map 14

GENERALIZED TOPOGRAPHY AND GEOLOGY OF THE BEDROCK BENEATH THE GLACIAL DEPOSITS IN THE MILWAUKEE RIVER WATERSHED



The surficial deposits of the watershed are underlain by sedimentary rock formations which have varying water-yielding characteristics. Depth-to-bedrock is an important factor influencing the physical development of the watershed. It affects the cost of drilling and maintaining those wells which must penetrate bedrock formations, it affects the cost of constructing transportation and utility systems and foundations for engineering structures, it affects the susceptibility of certain ground water supplies to pollution, and it determines the availability of certain construction materials and suitable space for solid water disposal. Only the glacial deposits and the youngest sedimentary rocks are exposed in the watershed.

Source: U.S. Geological Survey.

Cambrian rocks are thickest in the Milwaukee County area, where the Mount Simon sandstone is more than 770 feet thick. Northward toward the Pre-Cambrian hill, the Mount Simon sandstone thins and is generally less than 120 feet thick. The Eau Claire sandstone ranges between 140 and 190 feet thick in the north and between 200 and 300 feet thick in the south. The younger Cambrian formations are present only in the northern part of the watershed and do not exceed a combined thickness of 225 feet.

Ordovician Rock Units

Ordovician rocks in the watershed consist of sandstone, dolomite, and shale. Dolomitic rocks of the Prairie du Chien group are generally absent but may be present locally in the northwestern area, where they occur as remnants of Ordovician erosion. Ordovician formations younger than the Prairie du Chien group are present throughout the watershed.

The St. Peter sandstone was deposited on an irregular erosion surface that cut deeply into the underlying Prairie du Chien group and the Cambrian formations. As a result the thickness of the St. Peter sandstone is not uniform. The overall thickness is generally greatest in the east and southeast, where it ranges between 190 and 250 feet, and is least in the north and west, where it ranges between 95 and 170 feet.

The Platteville formation, Decorah formation, and Galena dolomite were deposited in succession on top of the St. Peter sandstone but are not differentiated in the watershed. The combined thickness of these dolomitic units is generally between 220 and 260 feet. Above these is the Maquoketa shale, which ranges generally between 140 and 200 feet thick in the south and between 230 and 250 feet thick in the north. The Neda formation, which lies above the Maquoketa shale, is a distinctive iron-rich red shale that has a maximum thickness of 35 feet. The Neda formation has been identified only locally from wells in Fond du Lac and Ozaukee Counties.

Silurian Rock Units

Silurian rocks consisting of undifferentiated dolomitic strata overlie the Maquoketa shale and the Neda formation. They form the bedrock beneath the glacial deposits in most of the watershed. The Silurian dolomite crops out and is quarried at several localities within the watershed.

In Sheboygan County the Silurian dolomite locally is more than 600 feet thick; southward its thickness ranges between 450 and 550 feet. It thins toward the western side of the watershed and may be absent near Slinger in Washington County. Large local differences in the thickness of the Silurian dolomite are probably due to preglacial and glacial erosion.

Devonian Rock Units

Rocks of Devonian age, predominantly dolomite, overlie the Silurian dolomite in the southeastern part of the watershed. Devonian rocks are thickest along the easternmost edge of this area and are absent throughout the remainder of the watershed. The Lake Church and Thiensville formations closely resemble the Silurian dolomite, but the Milwaukee formation is less massive and contains some shale.

The upper bedrock surface, consisting of Silurian and Devonian rocks covering over 99 percent of the watershed, was shaped by preglacial erosion. The major preglacial topographic feature is a valley that trends southwest from northeastern Washington County toward the Village of Slinger. A shallow saddle in Washington County separates this buried valley from a similar valley that trends northeast toward the Village of Cascade in Sheboygan County. A few deep preglacial valleys which drained to Lake Michigan are also present in the Milwaukee and Ozaukee County area.

Pleistocene and Recent Deposits

Unconsolidated deposits of boulders, gravel, sand, silt, and clay overlie the sedimentary rocks. These were deposited during the Pleistocene age by continental glaciers that covered the Region intermittently between 1 million and possibly as recently as 5,000 years ago. These deposits can be classified according to their origin into stratified drift and till. Stratified drift consists primarily of sand and gravel that was sorted and deposited as outwash by glacial melt water. A small area of glacial lakebeds, consisting of clay, silt, and sand, occurs near West Bend and grades north into outwash. Till, a mixture of clay, silt, sand, gravel, and boulders, was deposited from ice without the sorting action of water.

End-moraine and ground-moraine deposits are composed mainly of till but may locally contain stratified drift. Clayey till is predominant in the eastern one-third and the northwestern corner of the watershed, but sandy tills are present in the rest of the area.

The Kettle Moraine is a complex moraine that formed between two glacial ice lobes—the Green Bay and the Lake Michigan lobes—and it consists of intermixed stratified drift and till deposits. The layering in many of the exposed stratified drift deposits in this moraine is folded and faulted and shows evidence of collapse as the supporting ice melted. Map 15 shows the approximate areal distribution of the glacial deposits in the watershed.

Table 11 summarizes the water-yielding characteristics of the unconsolidated deposits of Pleistocene and recent ages in the Milwaukee River watershed.

TABLE 11

LITHOLOGY AND WATER-YIELDING CHARACTERISTICS OF THE UNCONSOLIDATED DEPOSITS OF PLEISTOCENE AND RECENT AGES IN THE MILWAUKEE RIVER WATERSHED

UNIT	GENERAL DESCRIPTION	WATER-YIELDING CHARACTERISTICS
ORGANIC DEPOSITS	PEAT AND MUCK	GENERALLY SATURATED. NOT USED AS A SOURCE OF WATER FOR WELLS. PITS ARE SOMETIMES DUG TO EXPOSE GROUND WATER FOR USE IN IRRIGATION.
GLACIAL LAKE DEPOSITS (LACUSTRINE) AND STREAM ALLUVIUM	CLAY, SILT, SAND, AND MARL. SORTED AND STRATIFIED	SAND MAY YIELD SMALL QUANTITIES OF WATER.
OUTWASH	MOSTLY SAND AND GRAVEL. SORTED AND STRATIFIED	YIELD SMALL TO LARGE QUANTITIES OF WATER. DEPOSITS ADJACENT TO PERENNIAL STREAMS ARE MOST FAVORABLE FOR OBTAINING LARGE YIELDS.
ICE-CONTACT DEPOSITS	CLAY, SILT, SAND, GRAVEL, AND BOULDERS. UNSTRATIFIED TO STRATIFIED AND UNSORTED TO SORTED	YIELD SMALL QUANTITIES OF WATER. THICK SECTIONS OF SAND AND GRAVEL IN BURIED VALLEYS MAY YIELD MODERATE TO LARGE QUANTITIES OF WATER.
GLACIAL TILL	CONSISTING OF CLAY, SILT, SAND, GRAVEL, AND BOULDERS. UNSORTED AND UNSTRATIFIED	PERMEABILITY LOW TO VERY LOW. ISOLATED LENSES OF SAND AND GRAVEL MAY YIELD SMALL QUANTITIES OF WATER TO WELLS.
LOESS	SILT WITH SOME CLAY AND A LITTLE SAND. UNSTRATIFIED. BLANKETS GLACIAL DEPOSITS.	GENERALLY UNSATURATED. DOES NOT YIELD WATER TO WELLS.

SOURCE- U.S. GEOLOGICAL SURVEY.

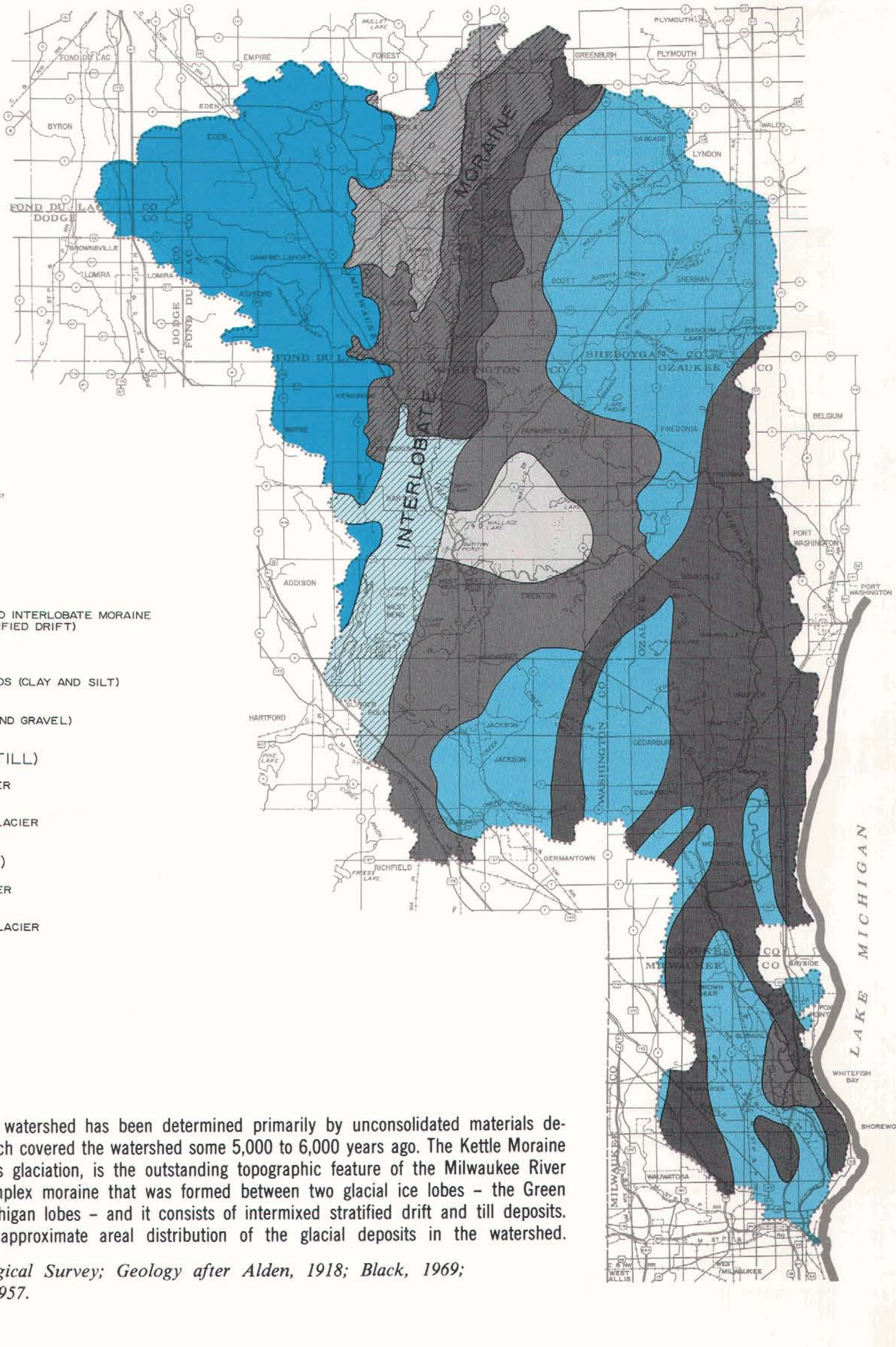
SOILS

The nature of soils within the watershed has been determined primarily by the interaction of the Pleistocene and recent deposits, topography, climate, plants, animals, and time. Within each soil profile, the effects of these soil-forming factors are reflected in the transformation of soil material in place; chemical removal of soil components by leaching or physical removal of erosion; additions by chemical precipitation or by physical deposition; and transfer of some soil components from one part of the soil profile to another. There are literally hundreds of soil types that have been developed within the watershed from a variety of parent glacial or glacial-related material, and these represent an exceedingly complex soil pattern.

In order to assess the significance of the diverse soil types to sound regional development, the SEWRPC in 1963 negotiated a cooperative agreement with the U. S. Soil Conservation Service for the completion of a detailed operational soil survey of the entire Region. This soil survey has now been completed for the entire Region, and the results have been published in SEWRPC Planning Report No. 8, Soils of Southeastern Wisconsin. The regional soil survey has not only resulted in the mapping of the soils within the Region in great detail and in the provision of data on the physical, chemical, and biological properties of the soils but also in the provision of interpretations of the soil properties for engineering, agricultural, conservation, and planning purposes.

Particularly important to comprehensive watershed planning are the soil suitability interpretations for specified types of urban development. These are: residential development with public sanitary sewer service, residential development without public sanitary sewer service on lots smaller than one acre in size, and residential development without public sanitary sewer ser-

Map 15
GENERALIZED GLACIAL GEOLOGY OF THE MILWAUKEE RIVER WATERSHED



LEGEND

UNDIFFERENTIATED INTERLOBATE MORAINE (TILL AND STRATIFIED DRIFT)

STRATIFIED DRIFT

GLACIAL LAKE BEDS (CLAY AND SILT)

OUTWASH (SAND AND GRAVEL)

GROUND MORAINE (TILL)

GREEN BAY GLACIER

LAKE MICHIGAN GLACIER

END MORAINE (TILL)

GREEN BAY GLACIER

LAKE MICHIGAN GLACIER

The topography of the watershed has been determined primarily by unconsolidated materials deposited by glaciers which covered the watershed some 5,000 to 6,000 years ago. The Kettle Moraine area, a product of this glaciation, is the outstanding topographic feature of the Milwaukee River watershed. It is a complex moraine that was formed between two glacial ice lobes – the Green Bay and the Lake Michigan lobes – and it consists of intermixed stratified drift and till deposits. This map shows the approximate areal distribution of the glacial deposits in the watershed.

Source: U.S. Geological Survey; Geology after Alden, 1918; Black, 1969; and Thwaites, 1956-1957.

vice on lots one acre or larger in size. Approximately 205 square miles, or about 30 percent of the watershed, are covered by soils which have severe or very severe limitations for residential development, even when such development is provided with public sanitary sewer service or, more precisely, are poorly suited for residential development of any kind. The distribution of these soils is shown on Map 16. Approximately 386 square miles, or about 56 percent of the watershed, are covered by soils which have severe or very severe limitations for residential development without public sanitary sewer service on lots smaller than one acre in size. The distribution of these soils is shown on Map 17. Approximately 319 square miles, or about 46 percent of the watershed, are covered by soils which have severe or very severe limitations for residential development without public sanitary sewer service on lots one acre or larger in size. The distribution of these soils is shown on Map 18.

It should be noted that the use suitability ratings are empirical, being based upon the performance of similar soils elsewhere for the specified uses, as well as upon such physically observed conditions as high water table, slow permeability, high shrink-swell potential, low bearing capabilities, frost heave, and frequent flood overflow.

Soils are an important factor in the determination and delineation of prime agricultural lands. Approximately 83 square miles, or about 12 percent of the watershed, are designated as prime agricultural lands (see Map 19). It is important to note that, in addition to soil characteristics, these prime agricultural areas are based upon the size and extent of the area farmed; the historic capability of the area to consistently produce better than average crop yields; and the relationship of such lands to important high-value recreational, cultural, or scientific resource areas.

VEGETATION

Presettlement Vegetation

According to the records of the U. S. Public Land Survey carried out within the Region in 1836, the Milwaukee River watershed originally was almost completely timbered with a dense hardwood forest. Exceptions to this cover consisted of wetlands and of small areas of oak savanna and white pine forest and of prairie. The upland timber consisted primarily of the hardwood species—sugar maple, oaks, elms, ashes, hickories, beech, linden, walnut, and ironwood—and one coniferous species—white pine. The first surveyors found three Indian sugar camps located in one section alone, Section 10, Town 11 North, Range 21 East (Town of Saukville, Ozaukee County). The hardwood stands were part of the primeval sugar maple forest which attracted the early settlers, particularly those from Germany and the Scandinavian countries. These settlers were not only aware that the sugar maples were an excellent source of fuel, raw material for cabinet and furniture construction, and sugar but also an indicator of good soil as well. Some beautiful stands of white pine also were established. Cutting began in these stands as early as 1834 in order to provide lumber for the developing nation. In 40 years most of the stands had been depleted. In the wetlands not only were good cedar and tamarack available but also good quality elm and black ash, the latter being a particularly good source of wood for fence rails.

Examples of this presettlement vegetation are preserved in four scientific areas within the watershed. Spruce Lake Bog in Fond du Lac County and Cedarburg Bog in Ozaukee County are representative of the lowland conifer forest. Cedarburg Beech Woods in Ozaukee County and Haskell Noyes Memorial Forest in Fond du Lac County represent the upland hardwood types. No remaining prairie or savannas are known to exist in the watershed.

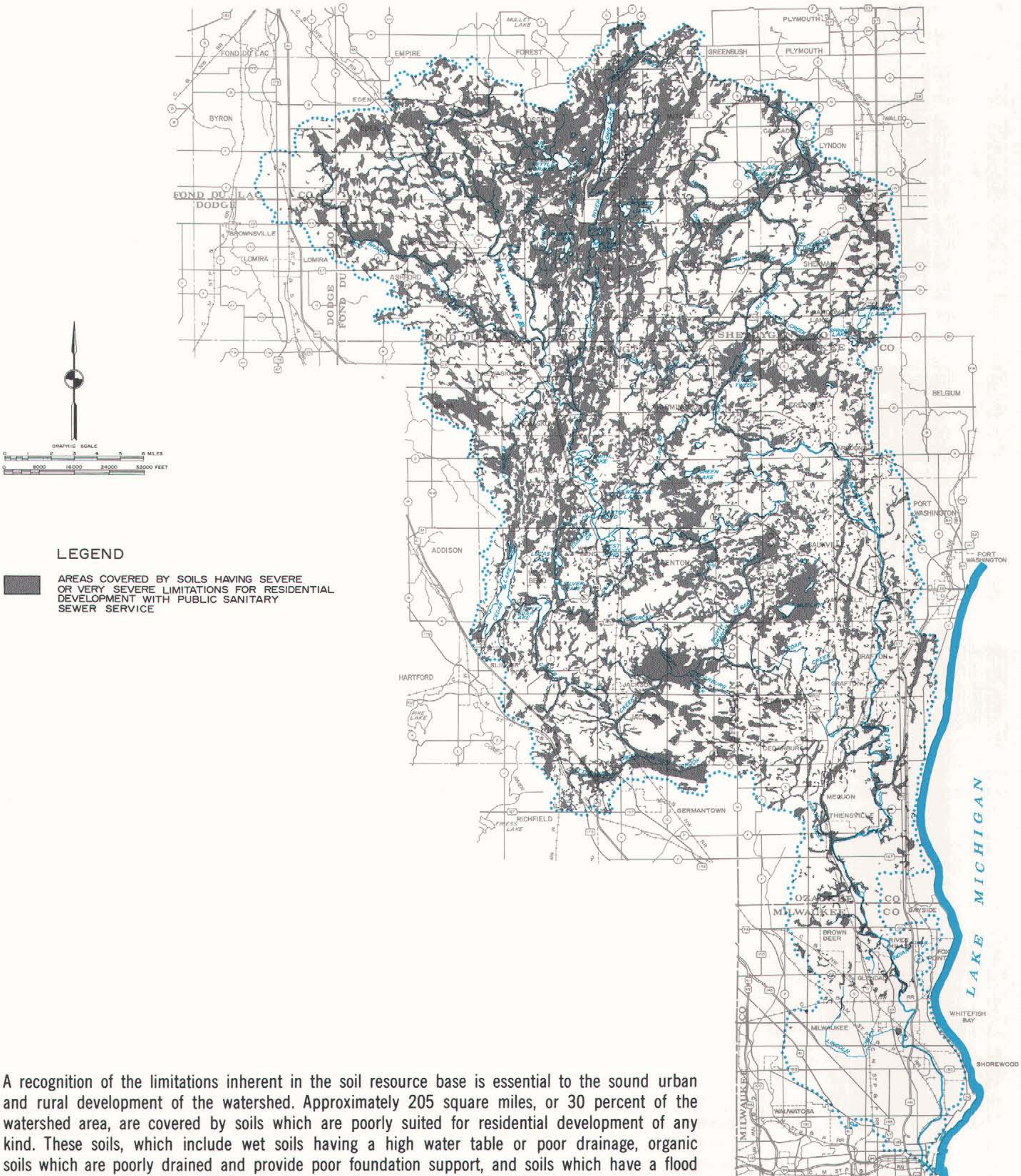
Woodlands

Woodlands in the Milwaukee River watershed presently cover a total combined area of 70,885 acres, or approximately 16 percent of the watershed area. Located primarily on morainal hills and slopes, along streams and lakeshores, and in wetlands, these woodlands provide an attractive natural resource of immeasurable value. Not only is the beauty of the lakes, streams, and glacial topography of the watershed accentuated by the woodlands, but these woodlands are essential to the maintenance of the overall environmental quality of the watershed.

Classified in accordance with their primary values, woodlands fall into two specific groups: aesthetic and commercial. Aesthetic woodlands comprise 96 percent; and commercial woodlands, the remaining 4 percent of the existing woodlands. Of the aesthetic group, 76 percent have a high-value rating and 24 percent a medium-value rating (see Map 20).

Map 16

SOIL SUITABILITY INTERPRETATION MAP FOR THE MILWAUKEE RIVER WATERSHED RESIDENTIAL DEVELOPMENT WITH PUBLIC SANITARY SEWER SERVICE 1967

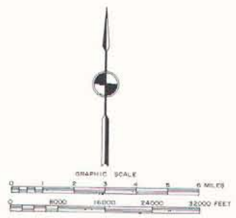


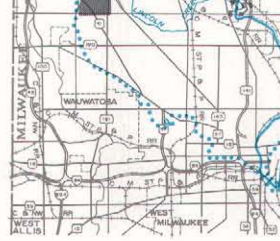
A recognition of the limitations inherent in the soil resource base is essential to the sound urban and rural development of the watershed. Approximately 205 square miles, or 30 percent of the watershed area, are covered by soils which are poorly suited for residential development of any kind. These soils, which include wet soils having a high water table or poor drainage, organic soils which are poorly drained and provide poor foundation support, and soils which have a flood hazard, are especially prevelent in the riverine and wetland areas of the watershed.

Source: SEWRPC.

Map 17

SOIL SUITABILITY INTERPRETATION MAP FOR THE MILWAUKEE RIVER WATERSHED SMALL LOT RESIDENTIAL DEVELOPMENT WITHOUT PUBLIC SANITARY SEWER SERVICE 1967





LEGEND

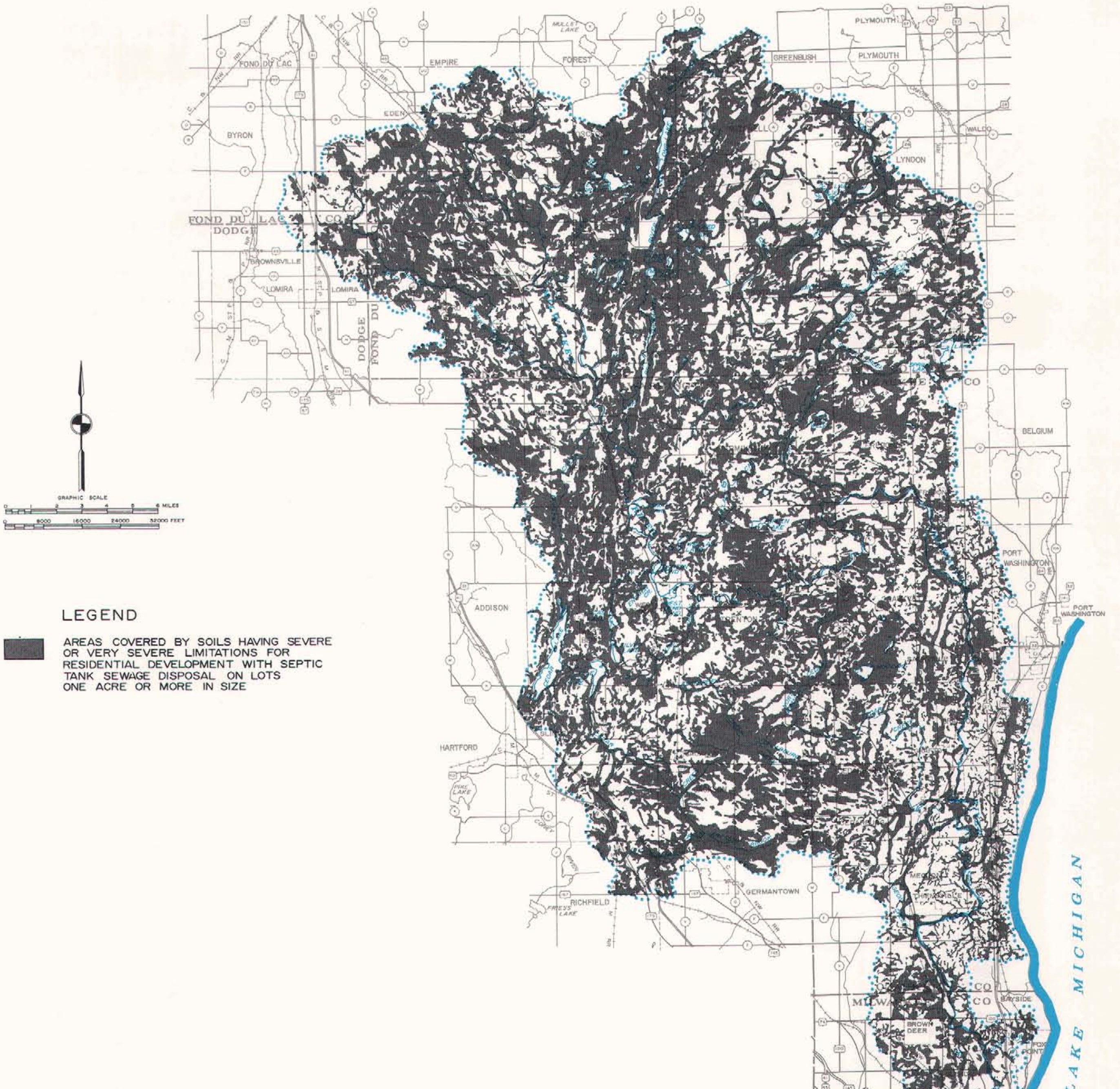
AREAS COVERED BY SOILS HAVING SEVERE OR VERY SEVERE LIMITATIONS FOR RESIDENTIAL DEVELOPMENT WITH SEPTIC TANK SEWAGE ON LOTS LESS THAN ONE ACRE IN SIZE

Approximately 386 square miles, or 56 percent of the watershed area, are covered by soils poorly suited for residential development on lots having an area smaller than one acre and not served by public sanitary sewerage facilities. Reliance on private on-site soil absorption (septic tank) sewage disposal systems in these areas, which are covered by relatively impervious soils or are subject to seasonally high water tables, can only result in eventual malfunctioning of such systems and the consequent intensification of water pollution and public health problems in the watershed.

Source: SEWRPC.

Map 18

SOIL SUITABILITY INTERPRETATION MAP FOR THE MILWAUKEE RIVER WATERSHED LARGE LOT RESIDENTIAL DEVELOPMENT WITHOUT PUBLIC SANITARY SEWER SERVICE 1967

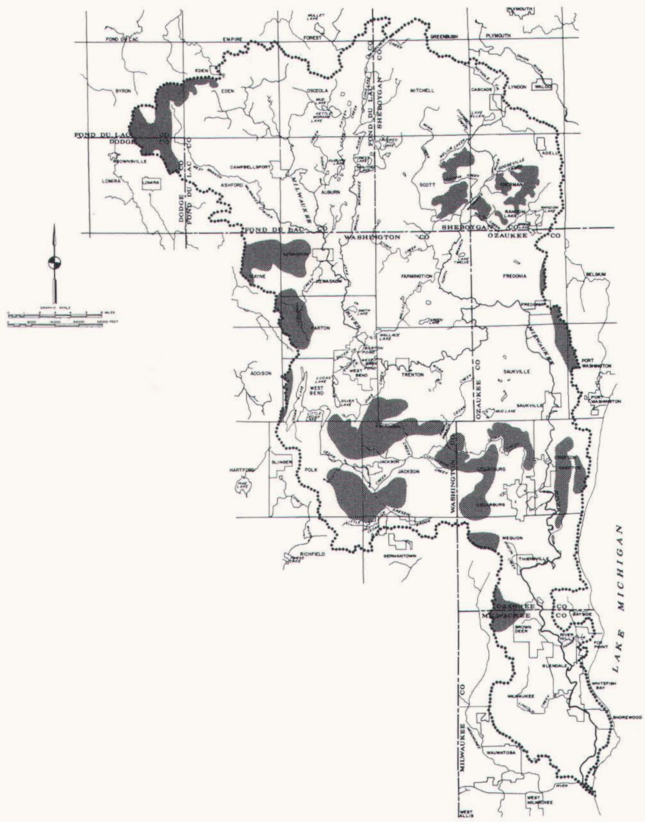


Approximately 319 square miles, or 46 percent of the watershed area, are covered by soils poorly suited for residential development on lots having an area of one acre or more and not served by public sanitary sewerage facilities. The inherent limitations for septic tank sewage disposal systems cannot always be overcome by the provision of larger lots, since many soil types simply cannot absorb the sewage effluent, resulting in surface ponding and runoff of partially treated wastes into nearby watercourses.

Source: SEWRPC.

Map 19

PRIME AGRICULTURAL AREAS
IN THE MILWAUKEE RIVER WATERSHED
1967



Approximately 83 square miles, or about 12 percent of the watershed area, have been identified in the watershed study as prime agricultural lands. In addition to being covered by highly fertile soils, these prime agricultural areas are held in farms of sufficient size to be economically viable units and have consistently produced better than average crop yields. The preservation of these prime agricultural areas in agricultural use will, in addition to providing food and fibre, contribute significantly to maintaining the ecological balance between plants and animals; provide locations proximal to urban centers for the production of certain food commodities which may require nearby population concentrations for an efficient production-distribution relationship; and provide open spaces which give form and structure to urban development.

Source: SEWRPC.

Principally because of location, aesthetic woodlands have their highest potential in a combination of multiple-use values which include recreation, scenic and property value enhancement, watershed protection, wildlife production, and only incidentally the production of forest products. Their land values, chiefly because of nearness to population centers, along lakes and streams, and within environmental corridors, are considered too high to use primarily for commercial lumbering purposes. Commercial woodlands, on the other hand, have their highest potential value presently directed toward the production of forest products. Scenic, wildlife, and watershed protection values are of secondary importance. Through good management, commercial woodlands can produce a continuous crop of forest products. Through the application of balanced-use and sustained-yield management, woodlands, whether commercial or aesthetic, can serve a combination of productive uses simultaneously and continuously.

The woodlands of the watershed can be classified into five forest types: 1) central hardwoods, 2) northern hardwoods, 3) oak, 4) upland conifers, and 5) wetland conifer-hardwoods. The central hardwoods type is most common, with the northern hardwoods type the next most common. Of the natural stands, the most productive for commercial forest products, when managed, are the central and northern hardwoods types. It is of special interest that the tamarack, which has gradually regressed over the centuries from the upland areas to the wetlands, is today the only tree species growing naturally on the watershed which survived from the original forest cover that was established as the last glacier slowly retreated.

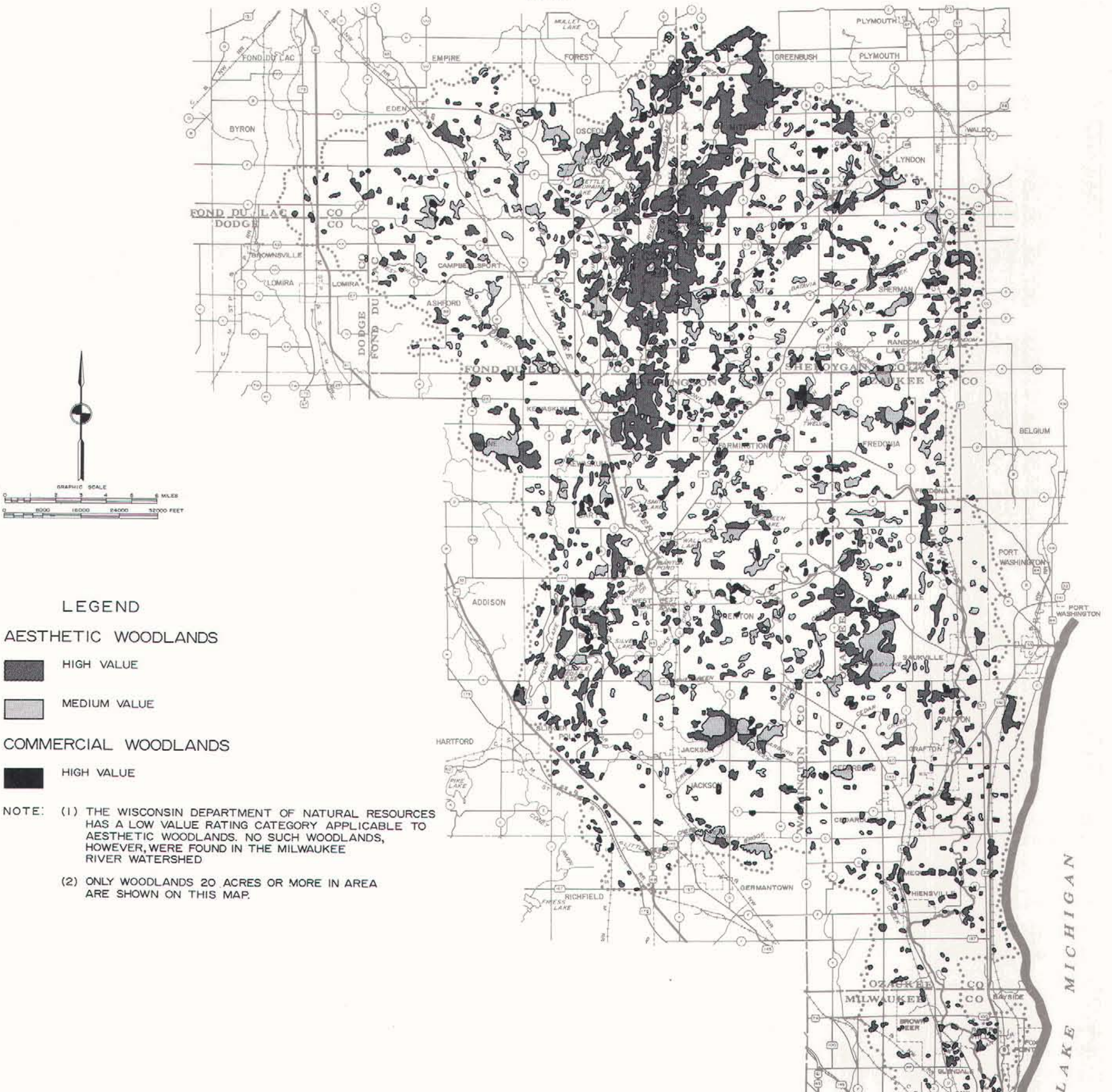
The existing woodlands are only poorly-to-moderately well stocked for commercial use, due principally to the lack of good management. The unmanaged stands have had the more valuable tree species and better grades of timber removed; thus, principally low–value species and poor grades remain.

Forest plantations, classified as upland conifers forest type, comprise 4,977 acres, or 7.0 percent of the woodland cover. Of this amount, 3,841 acres were planted by the Wisconsin Department of Natural Resources on the Kettle Moraine State Forest and 1,136 acres, by individuals on privately owned lands. During the past 10 years, approximately 250 acres of conifers have been planted within the watershed each year. Plantations consist principally of white and red pine and white and Norway spruce, trees that add greenery to the countryside during the winter when deciduous species have no foliage. Plantations on the Kettle Moraine State Forest also include a few other species, such as white cedar, black spruce, jack pine, white ash, and sugar maple. Trees within a given plantation normally are the same age and generally are planted with tree-planting machines on open land. Tree survival has been extraordinary; and, as a consequence, thinning in the older plantations is urgently needed.

Natural stands of trees within the watershed consist largely of even-aged mature, or nearly mature specimens, with insufficient reproduction

Map 20

WOODLANDS
IN THE MILWAUKEE RIVER WATERSHED
1967



Woodlands in the Milwaukee River watershed presently cover a total combined area of about 71,000 acres, or approximately 16 percent of the total watershed area. These woodlands assist in maintaining a unique natural relationship between plants and animals; reduce storm water runoff; contribute to atmospheric oxygen and water supply; aid in reducing soil erosion and stream sedimentation; provide the resource base for the forest product industries; and provide valuable recreational opportunities, as well as a desirable aesthetic setting for attractive rural and planned urban development. Woodlands within the watershed are presently being lost at the rate of approximately 400 acres per year, and less than 60 percent of the original woodland cover of the watershed remains.

Source: Wisconsin Department of Natural Resources.

and saplings to maintain the stands when the old trees are harvested or die of disease or age. This lack of young growth is an unnatural condition brought about by mismanagement and associated with many years of excessive grazing by livestock.

Woodlands within the watershed are presently being lost at the rate of approximately 400 acres per year. These losses are due to land clearing, highway construction, drainage of wetlands, and degeneration and neglect. These forces of destruction will rapidly and appreciably reduce the woodland acreage unless corrective measures are taken. Moreover, the present rate of loss may be expected to accelerate rapidly in the foreseeable future unless management, balanced use, and sustained yield management are applied. The changes in woodland area within the watershed since 1900 are shown in Table 12.

TABLE 12

WOODLAND AREAS IN THE MILWAUKEE RIVER WATERSHED FOR THE YEARS 1900, 1939, 1958, AND 1967

YEAR	CONIFEROUS		DECIDUOUS		TOTAL WOODLANDS	
	ACRES	PERCENT OF TOTAL WOODLANDS	ACRES	PERCENT OF TOTAL WOODLANDS	ACRES	PERCENT OF TOTAL WATERSHED
1900(C)	5,051	4	114,843	96	119,894	27
1939	5,270	5	96,862	95	102,132	23
1958	8,393	10	71,536	90	79,929	18
1967	8,598	12	62,287	88	70,885	16

SOURCE- WISCONSIN DEPARTMENT OF NATURAL RESOURCES.

An estimated 45 percent of the privately owned upland forest land is being grazed by livestock. Reproduction of the most desirable hardwood species is prevented by grazing which destroys the young growth needed to sustain the stands through browsing and trampling. With no young growth in the stand, a woodland cannot perpetuate itself.

Woodlands in the Milwaukee River watershed, even in their present condition, have many values beyond monetary returns for their forest products. Under balanced and sustained yield management, woodlands can provide a variety of benefits compatible with other uses. Conversely, the deforestation of hillsides contributes to the siltation of lakes and streams and the destruction of wildlife habitat. Woodlands can and should be maintained for scenic, wildlife, open-space, recreation, and watershed protection, as well as for forest product values.

No direct correlation exists between the various values associated with woodlands. A poorly stocked woodland may have a low value for commerical wood production, but at the same time may have superlative scenic value if located so as to enhance the beauty of a lake, stream, or hillside. Strategic location, accessibility, and heavy ground cover are factors which contribute to the aesthetic value rating of a woodland.

An increasing demand for woodland areas has arisen within the watershed, especially for such areas located on ridge tops and slopes, by persons who wish to leave urban and suburban centers and live closer to nature. Real estate interests also have acquired scenic woodland areas for development, and this trend is expected to accelerate. Untold damage to the wooded areas has resulted where developers have subdivided woodlands into small lots and removed trees to develop the subdivisions. If any trees remained, moreover, they usually were seriously weakened through loss of a large portion of their root systems. Woodlands may be substantially preserved during land subdivision if lots are made one acre or larger in size and if careful attention is paid to construction practices, as well as to subdivision layout and design.

Whether the land values placed on forest land in the watershed are always economically sound or not, they do command respect in the current respect in the current marketplace. A large and increasing proportion of people in our affluent society, for various tangible or intangible reasons, are eager to own forested land. These reasons include privacy, bird watching, hunting, growing trees as a hobby, as well as a business venture, or merely for aesthetic appreciation.

It is becoming more apparent that the interaction between man and his environment is intensifying and becoming critical. The quality of life within an area is greatly influenced by the overall quality of the environment, as measured in terms of clean air, clean water, scenic beauty, and diversity. In addition to contributing to clean air and water, the maintenance of woodlands within the watershed can contribute to the maintenance of a diversity of plant and animal life in association with human life. The existing woodlands of the watershed, which required a century or more to develop, can be destroyed through mismanagement within a comparatively short period of time. A new dimension in forest management is needed to retain the woodlands of the Milwaukee River watershed as an essential element of the natural resource base.

Wetlands

Wetlands are defined as areas where the ground water table is at, or very near, the surface and may represent a variety of stages in the natural filling of lake and pond basins, as well as floodplain areas. Wetlands are generally unsuited for most agricultural uses requiring cultivation. Wetlands are composed of organic soils, silts, and marl deposits. Included in the composition of wetlands are numerous types of terrestrial and emergent aquatic vegetation, the dominant plant species of which help to further classify these areas.

Wetlands within the Milwaukee River watershed have been classified by the Wisconsin Department of Natural Resources according to a National Wetland Classification System.[2] There are seven major classes of wetlands under this system: potholes, fresh meadows, shallow marshes, deep marshes, shrub swamps, timber swamps, and bogs.

The wetlands with standing water are well suited for waterfowl and marsh furbearers, while drier types support upland game due to the protection afforded by the vegetative cover. Shallow water wetlands are subject to winter freeze and summer drought and, therefore, are considered to be lower in value than the deepwater types of wetlands.

An inventory of all wetland areas 50 acres or more in size, termed wetland units, was made as a part of the Milwaukee River watershed study. Smaller areas were inventoried if they were considered to have a particularly high recreational or wildlife habitat value. Small, noncontiguous wetland areas were also inventoried if such areas enhanced a lake, stream, or other nearby recreational area. In all, 199 wetland units were identified in the Milwaukee River watershed, as shown on Map 21. These wetland units comprise a total of 39, 652 acres.[3] The drier types of wetlands greatly predominated over the wetter types, totaling about 90 percent of the total wetland area. This category includes meadows, shrub swamps, and timber swamps, while the wet types include the shallow and deep marshes, potholes, and bogs.

Wetlands within the watershed are presently being lost at the rate of about 200 acres per year. Most of the loss in wetland area has been the result of conversion to agricultural uses through extensive drainage ditching. Other reclaimed areas have been developed for urban and recreational uses. In recent years, however, there has been a slight increase of the more desirable open-water wetland areas, brought about by public acquisition and improved management of these valuable natural resource areas. The changes in wetland area within the watershed since 1900 are shown in Table 13.

TABLE 13

WETLAND AREA WITHIN THE MILWAUKEE RIVER WATERSHED[a] 1900, 1939, 1958, AND 1967

YEAR	OPEN WATER WETLANDS		SHALLOW WETLANDS[b]		TOTAL WETLANDS	
	ACRES	PERCENT OF TOTAL WETLANDS	ACRES	PERCENT OF TOTAL WETLANDS	ACRES	PERCENT OF TOTAL WATERSHED
1900	--	--	--	--	80,000(EST)	18.0(EST)
1939	--	--	--	--	46,000(EST)	10.5(EST)
1958	--	--	--	--	42,000(EST)	9.5(EST)
1967	3,972	10.0	35,680	90.0	39,652[c]	8.93

[a]EXCLUDING MILWAUKEE COUNTY.

[b]WATER TABLE GENERALLY BELOW GROUND LEVEL.

[c]INCLUDES ONLY THOSE SIGNIFICANT WETLAND AREAS OCCURRING IN UNITS OF 50 ACRES MORE. AN ADDITIONAL 29,416 ACRES OF MINOR WETLANDS WERE IDENTIFIED IN THE WATERSHED LAND USE INVENTORY.

SOURCE- WISCONSIN DEPARTMENT OF NATURAL RESOURCES AND SEWRPC.

Aquatic Vegetation

An aquatic plant survey involving the 21 major lakes of the Milwaukee River watershed was conducted during the summer of 1968. Of the lakes surveyed, six were resurveyed in late summer to determine if seasonal change in the aquatic plant communities was apparent. The lakes which were resurveyed included: Ellen, Green, Long, Mauthe, Random, and Seven. The primary purpose of the aquatic plant survey was to determine the distribution and abundance of aquatic plants, to identify some of the factors affecting distribution and abundance, and to establish a record of the present status of aquatic plants for future reference.

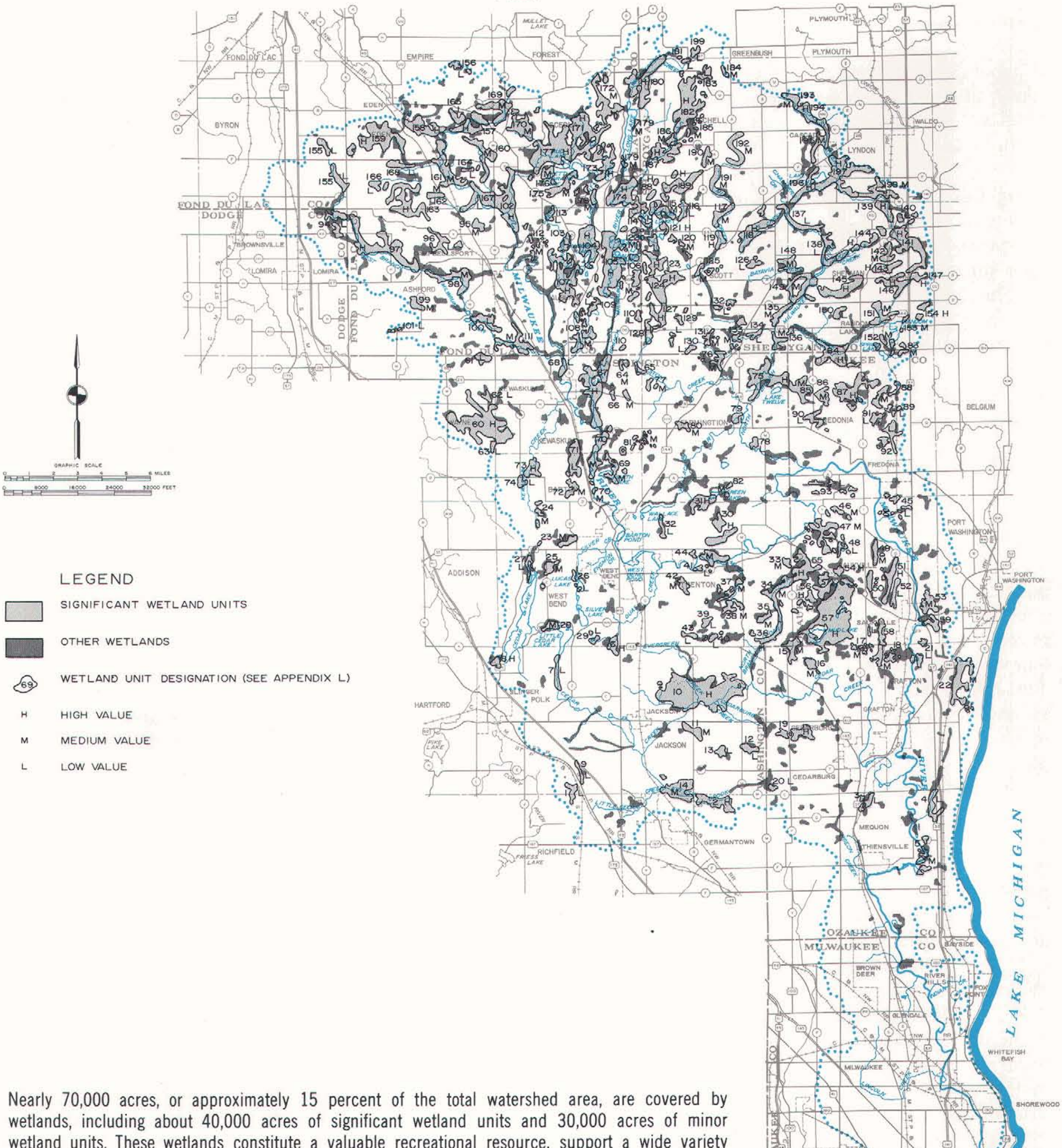
Plants representing 26 families were encountered; and within these, 39 genera and 45 species were identified. Pondweed (Potamogeton), bulrush

[2]*Classification of Wetlands of the United States, Special Scientific Report: Wildlife No. 20, Fish and Wildlife Service, 1953.*

[3]*It is important to note that an additional 29,416 acres of minor wetlands (areas less than 50 acres in size) were inventoried by the SEWRPC in the watershed land use inventory. Thus, the total amount of wetlands in the Milwaukee River watershed, including both the significant wetland units and the minor wetlands, is 69,068 acres.*

Map 21

WETLAND AREAS
IN THE MILWAUKEE RIVER WATERSHED
1967



Nearly 70,000 acres, or approximately 15 percent of the total watershed area, are covered by wetlands, including about 40,000 acres of significant wetland units and 30,000 acres of minor wetland units. These wetlands constitute a valuable recreational resource, support a wide variety of desirable forms of plant and animal life, and assist in reducing storm water runoff and stabilizing streamflows. Wetlands within the watershed are presently being lost at the rate of about 200 acres per year, and less than 50 percent of the original significant wetland area of the watershed remains.

Source: Wisconsin Department of Natural Resources.

(Scirpus), and white water lily (Nymphaea), found in all the lakes, were the most widely distributed genera of aquatic plants. Cattail (Typha) was observed in 96 percent of the lakes. Other widely distributed genera included musk grass (Chara), water milfoil (Myriophyllum), and spatterdock (Nuphar). A complete list of the aquatic plants found in the 21 lakes of the watershed and their relative abundance on a percentage basis is set forth in Table 116.

Long Lake in Fond du Lac County contained the greatest diversity of plants encountered, with 34 species observed. Big Cedar Lake, the largest lake surveyed, contained 30 species. In both lakes the submergent aquatics were in greatest abundance. Lake Twelve contained the lowest number of species, with only 16 species observed. Gilbert Lake, part of the Big Cedar Lake complex, had the largest population of floating aquatics, most of which were white water lilies.

Most of the lakes displayed moderate-to-abundant vegetation in areas from the shore zone to depths as great as 20 feet. In general, situations of extensive shallows, clear water, and muck bottoms supported the highest densities of aquatic vegetation. Situations of limited shallow areas, either turbid or tea-colored water, and marl, sand, gravel, or suspended ooze bottoms, supported lower densities of aquatic vegetation. Lakes varied in abundance of aquatic vegetation from Ellen Lake, with a relatively low abundance, to Crooked Lake, which displayed a profusion of aquatic vegetation.

Seasonal changes of abundance and dominance were brought to light by the resurvey of the six earliest surveyed lakes. An average of 58 days passed between the initial survey and the resurvey. This span of time showed the change in dominance of narrow leaf pondweed (Potamogeton) to bushy pondweed (Najas). This change was very obvious in Seven Lake, Mauthe Lake, and Long Lake. Eelgrass (Vallisneria), found to be very abundant in Green Lake and Mauthe Lake, was hardly noticed during the first survey. Changes in the emergent population were very difficult to determine. As the season progressed, however, various species which were unnoticed in early summer became apparent because of their production of flowers. Lesser duckweed (Lemna minor) was found to increase substantially in late summer. Watermeal (Wolffia), which was very abundant in early summer, was almost absent; and the area it once covered was taken over by lesser duckweed. Apparently water lilies die off earlier than spatterdock, since spatterdock becomes dominant where water lilies had been dominant. In all the lakes resurveyed, beds of water lilies were observed in various stages of die-off. The most drastic change in abundance was noticed in Seven Lake, the first lake surveyed. Here vegetation increased from an abundant condition to an overabundant condition in 69 days.

Within the Milwaukee River watershed, the distribution and accumulation of aquatic plants tended to vary, depending upon the character of the lake. All of the lakes studied could be described as hard-water lakes. Certain definite associations were apparent, however, with respect to the occurrence of aquatic vegetation with water transparency, bottom sediments, water fertility, and man's weed control activities. A definite correlation was found between the maximum depth at which the vegetation occurred and the Secchi depth.[4] In many cases cutting operations and algal blooms altered conditions. Tea-colored lakes contained a sparse-to-scattered abundance of submergents. The color tends to reduce rapidly the quality of solar radiation causing the restriction of plant life to the shallower waters. Lakes or portions of lakes that contain sediments formed from suspended ooze normally have very few submergents. Some of the lakes displayed unusual rank aquatic plant growth or extensive algal blooms. Included in such lakes were: Big Cedar, Crooked, Kettle Moraine, Long, Lucas, Seven, and West Bend Pond.

WATER RESOURCES

The surface water resources, consisting of lakes and streams, form the singular most important natural landscape feature within the watershed and serve to enhance all proximate uses. The water resources contribute both directly and indirectly to the regional economy. Moreover, water resources contribute immeasurably to total resource conservation and recreation within the

[4] *The secchi depth is the depth of water at which a Secchi disk lowered into the water can no longer be seen. This depth is also the maximum depth at which aquatic plants can live due to lack of light for the photosynthetic process. A Secchi disk is a circular metal plate 20 centimeters in diameter, the upper surface of which is divided into four equal quadrants and so painted that two quadrants directly opposite each other are black and the intervening ones, white.*

watershed. The ground water resources of the watershed are closely interrelated with the surface water, sustaining lake levels and providing the base flow of streams. The ground water resources, along with Lake Michigan, comprise the major sources of supply for municipal, industrial, and domestic water users. Indeed, the protection, enhancement, and proper development of these invaluable water resources were three primary reasons for mounting the Milwaukee River watershed study.

Surface Water Resources

Major Lakes: Major lakes are defined herein as those having 50 acres or more of surface water area. Lakes of this size are capable of supporting reasonable recreational use with little degradation of the resource. Within the watershed there are 21 major lakes, as listed in Table 14, having a combined surface water area of 3,438 acres and providing a total of 59 miles of shoreline.

TABLE 14

MAJOR LAKES IN THE MILWAUKEE RIVER WATERSHED 1967

RANK	NAME	ACREAGE	COUNTY
1	CEDAR	932	WASHINGTON
2	LONG	427	FOND DU LAC
3	LITTLE CEDAR	246	WASHINGTON
4	MUD	245	OZAUKEE
5	KETTLE MORAINE	227	FOND DU LAC
6	RANDOM	209	SHEBOYGAN
7	ELLEN	121	SHEBOYGAN
8	SILVER	118	WASHINGTON
9	AUBURN (FIFTEEN)	107	FOND DU LAC
10	CROOKED	91	SHEBOYGAN [a]
11	SMITH (DRICKENS)	86	WASHINGTON
12	MAUTHE	78	FOND DU LAC
13	LUCAS	78	WASHINGTON
14	GREEN	71	WASHINGTON
15	BARTON POND	67	WASHINGTON
16	WEST BEND POND	67	WASHINGTON
17	SPRING	57	OZAUKEE [b]
18	MUD	55	FOND DU LAC
19	TWELVE	53	WASHINGTON
20	WALLACE	52	WASHINGTON
21	FOREST	51	FOND DU LAC
	TOTAL	3,438	

[a] PARTLY CONTAINED IN FOND DU LAC COUNTY.

[b] PARTLY CONTAINED IN SHEBOYGAN COUNTY.

SOURCE- WISCONSIN DEPARTMENT OF NATURAL RESOURCES.

The lakes are mostly of glacial origin, being depressions in gravelly outwash, moraine, or ground moraine deposits. By virtue of their origin, these lakes are fairly regular in shape, with their deepest points predictably near the center of the basin or near the center of each of several connected basins. The beaches are characteristically gravel or sand on the wind-swept north, east, and south shores, while fine sediments and encroaching vegetation are common on the protected west shores and in the bays.

Minor Lakes: There are 50 minor lakes within the watershed having surface water areas of less than 50 acres in extent. These minor lakes have a combined surface water area of 732 acres and provide 41 miles of shoreline. These minor lakes generally have few riparian owners and only marginal fisheries. In most cases the value of the minor lakes is largely aesthetic, a value which these lakes are incapable of retaining with any degree of development.

Major Streams: Major streams are defined herein as perennial streams which maintain, at a minimum, a small continuous flow throughout the year except under unusual drought conditions. Within the watershed there are approximately 330 lineal miles of such major streams, as listed in Table 15. The study of these major streams comprises an important element of the watershed planning effort, and subsequent chapters of this report will develop and describe the important interrelationships existing between the major streams and other natural and man-made elements of the watershed.

Ground Water Resources

The Milwaukee River watershed is richly endowed with ground water resources. Ground water is the source of water supply for many industries and for approximately 15 percent of the 543,790 people who reside in the watershed. The amount of ground water stored in the rocks beneath the Milwaukee River valley is enormous and is estimated to exceed 1.5×10^{11} gallons. This is enough water to fill the largest lake in the watershed—Big Cedar Lake—nearly 15 times. In addition, ground water contributes approximately 23 billion gallons annually to the flow of the Milwaukee River.

The rock units within the watershed differ widely in the yield of stored water. Rock units that yield water in usable amounts to pumping wells and in important amounts to lakes and streams

TABLE 15

MAJOR STREAMS IN THE MILWAUKEE RIVER WATERSHED- 1967

NAME	LENGTH[a] (MILES)	COUNTY
BATAVIA CREEK....................	5.0	SHEBOYGAN
CEDAR CREEK......................	31.5	OZAUKEE AND WASHINGTON
CEDARBURG CREEK..................	3.0	WASHINGTON
CHAMBERS CREEK...................	2.9	SHEBOYGAN
EAST BRANCH MILWAUKEE RIVER......	14.3	FOND DU LAC, SHEBOYGAN, AND WASHINGTON
ENGMON CREEK.....................	1.5	WASHINGTON
EVERGREEN CREEK..................	4.9	WASHINGTON
GOOSEVILLE CREEK.................	1.8	SHEBOYGAN
INDIAN CREEK.....................	1.9	MILWAUKEE
KEWASKUM CREEK...................	6.4	WASHINGTON
KRESSIN BROOK....................	4.7	WASHINGTON
LAKE FIFTEEN CREEK...............	7.4	FOND DU LAC
LINCOLN CREEK....................	7.1	MILWAUKEE
LITTLE CEDAR CREEK...............	6.0	WASHINGTON
MELIUS CREEK.....................	3.3	SHEBOYGAN
MILWAUKEE RIVER[b]................	101.0	FOND DU LAC, MILWAUKEE, OZAUKEE, AND WASHINGTON
MINK CREEK.......................	17.3	SHEBOYGAN
MYRA CREEK.......................	2.6	WASHINGTON
NICHOLS CREEK....................	3.3	SHEBOYGAN
NORTH BRANCH CEDAR CREEK.........	7.3	WASHINGTON AND OZAUKEE
NORTH BRANCH MILWAUKEE RIVER.....	30.0	SHEBOYGAN, WASHINGTON, AND OZAUKEE
PIGEON CREEK.....................	2.4	OZAUKEE
QUAS CREEK.......................	5.9	WASHINGTON
SILVER CREEK.....................	7.1	SHEBOYGAN
SILVER CREEK.....................	4.0	WASHINGTON
STONY CREEK......................	10.0	WASHINGTON, FOND DU LAC, AND SHEBOYGAN
VIRGIN CREEK.....................	4.5	FOND DU LAC
WALLACE CREEK....................	8.6	WASHINGTON
WATER CRESS CREEK................	6.5	FOND DU LAC AND SHEBOYGAN
WEST BRANCH MILWAUKEE RIVER......	20.1	FOND DU LAC AND WASHINGTON
TOTAL............................	332.3	

[a]TOTAL PERENNIAL STREAM LENGTH AS SHOWN ON U. S. GEOLOGICAL SURVEY QUADRANGLE MAPS. DOES NOT INCLUDE MILES THROUGH LAKES.

[b]LENGTH OF RIVER FROM ORIGIN TO LAKE MICHIGAN.

SOURCE- WISCONSIN DEPARTMENT OF NATURAL RESOURCES.

are called aquifers. Three major aquifers exist in the Milwaukee River watershed; and these are, in order from land surface downward: 1) the sand and gravel deposits in the glacial drift; 2) the shallow dolomite strata in the underlying bedrock; and 3) the Cambrian and Ordovician strata, composed of sandstone, dolomite, siltstone, and shale. Because of their relative nearness to the land surface, the first two aquifers are sometimes called "shallow aquifers" and the latter, the "deep aquifers." Wells tapping these aquifers are referred to as shallow or deep wells, respectively.

The occurrence, distribution, movement, use, and quality of these important ground water resources and their interrelationship with surface water resources and other elements of the planning study are discussed in considerable detail in subsequent chapters of this report.

FISHERY RESOURCE

A high demand for fishing presently exists within the watershed even though the watershed supports only a limited fishery. Of the 21 major lakes within the watershed, only Mud Lake in Ozaukee County is considered incapable of supporting significant fish populations under existing conditions. Several other lakes experience periodic winterkills but sustain a limited fishery nearly every year. The remaining lakes sustain a moderate fishery and must support the major proportion of the heavy fishing demand.

Dominant fish species of lakes within the watershed in order of importance to its fishery include bluegill, largemouth bass, northern pike, walleye, bullhead, black crappie, yellow perch, and carp. Other fish species existing in the lakes and streams, but of lesser importance to the fisherman, are pumpkinseed, warmouth, white sucker, and green sunfish. Nearly every lake capable of supporting a fishery has a fish population comprised of northern pike, largemouth bass, bluegill, and bullhead. Little Cedar, Long, Mauthe, Random, and Silver Lakes, however, support good walleye populations; and Big Cedar Lake supports a population of cisco.

Stream fisheries are limited in the watershed to only five major streams—the Milwaukee River and its four tributaries—the East, North, and West Branches, and Cedar Creek. The Milwaukee River and its main tributaries support fisheries of smallmouth bass, northern pike, bullheads, carp, and white suckers. Small populations of bluegills, black crappies, and walleyes are also present in limited quantities. Cedar Creek has small populations of walleyes, panfish, and smallmouth bass and large populations of bullheads and carp. These streams have additional northern pike during the spring spawning migration period. The minor streams of the watershed support high populations of forage minnows and crayfish, with the exceptions of Water Cress Creek, Melius Creek, and the North Branch of the Milwaukee River above Cascade Pond. Water Cress Creek has a good population of brook trout, while the North Branch of the Milwaukee River and Nichols Creek have a limited number of brown, brook, and rainbow trout. Melius Creek is stocked with brown trout but is considered to be only a marginal trout stream. Gooseville Creek has a natural population of brook trout but is stocked with brown trout, while Lake Fifteen Creek is stocked with brook trout.

Lake fisheries are sustained primarily by natural spawning areas within the lakes. Presently, there are adequate shallow weedbed areas available for fish spawning within most major lakes. Other factors, however, such as deteriorating water quality, fluctuating water quantity, and the lack of adequate boating regulations to protect spawning areas, tend to limit the effectiveness of these areas for natural spawning. In many instances, therefore, the natural lake fisheries must be supplemented with fish stocking operations.

WILDLIFE

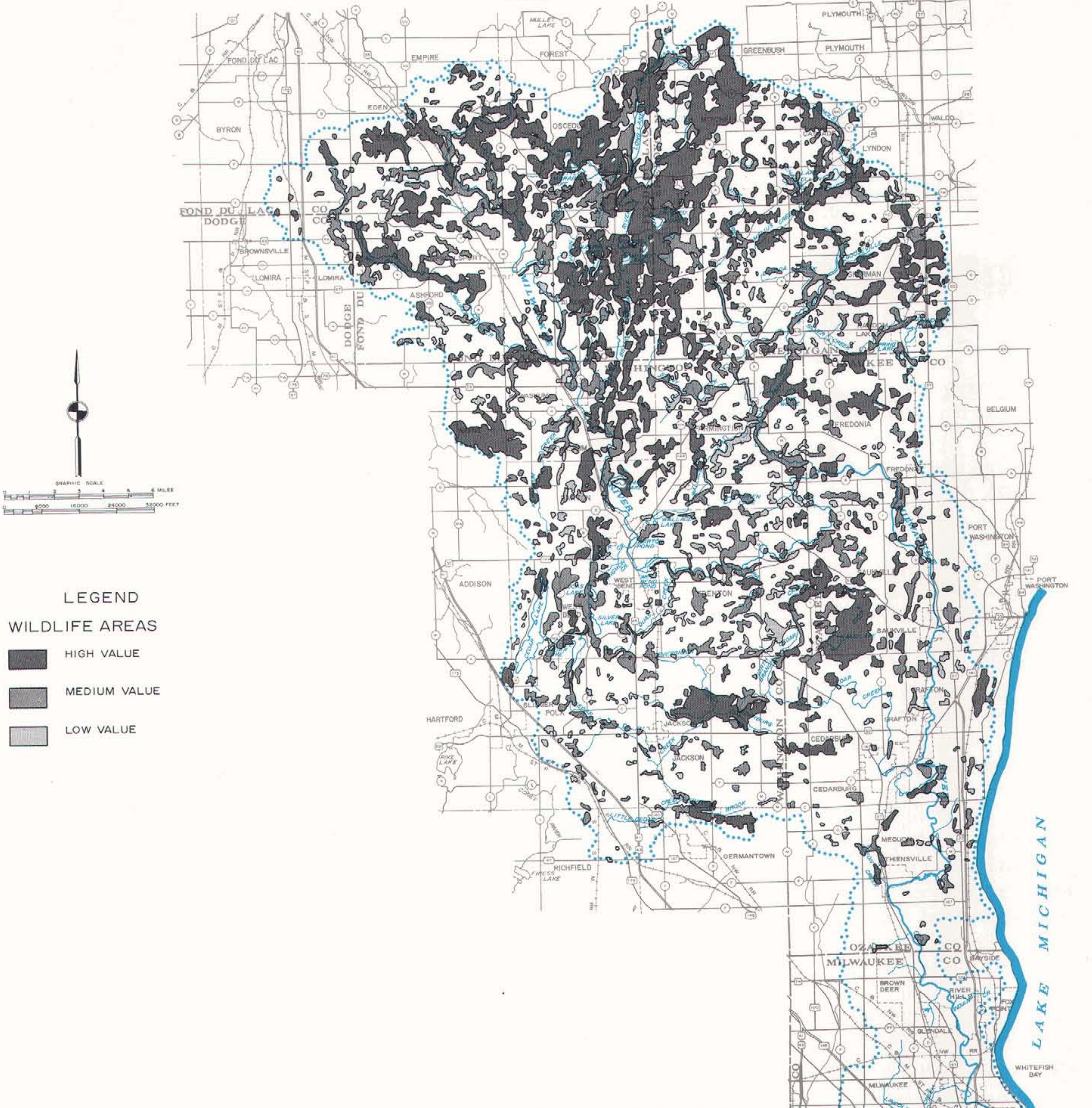
Since the early settlement of the Milwaukee River watershed by Europeans, there has been a sharp decrease in the variety and quantity of wildlife. This is a loss not only to hunters and other sportsmen, but to the health and diversity of the total environment. An inventory of the present wildlife populations of the watershed was made to ascertain the need to protect this important element of the resource base. The remaining prime wildlife areas of the watershed are shown on Map 22 and are summarized by value rating in Table 16.

Mammals

Mammals, common or fairly common in the less densely populated parts of the watershed, include white-tailed deer, cottontail rabbit, gray squirrel, fox squirrel, muskrat, mink, weasel, raccoon, red fox, gray fox, skunk, and opossum. The first four listed above are considered game mammals, while the balance are fur-bearing mammals.

In the watershed the greatest number of deer inhabit the larger wooded areas of the kettle moraine. The larger wooded and shrub swamps are also utilized by the deer, especially in snowy winters. It is estimated that there are 2,400 to 3,000 deer within the watershed, the higher figure including the new fawn crop. The cottontail rabbit is abundant throughout the watershed, even in urbanized areas; and rabbit hunting and observation are enjoyed by many. Similarly, there is also an abundance of gray and fox squirrels in the watershed. The gray squirrel is primarily found in dense mixed hardwood forests, while the fox squirrel is characteristic of the more open woods and countryside. Both require trees of some maturity because the natural cavities in such trees are of considerable importance for rearing of young and winter protection.

Map 22
WILDLIFE HABITAT
IN THE MILWAUKEE RIVER WATERSHED
1970



Wildlife habitat areas provide an important recreational resource and aid in controlling harmful insects and other noxious pests. Unless consciously protected, these areas will decrease rapidly in both quantity and quality as urbanization proceeds within the watershed. Of the approximately 67,700 acres of wildlife habitat remaining in the Milwaukee River watershed, about 29,300 acres are rated as having high value and about 28,400 acres are rated as having medium value. In the absence of a sound watershed plan and its subsequent implementation, further urban development in the watershed may be expected to destroy this important natural asset.

Source: Wisconsin Department of Natural Resources.

TABLE 16

WILDLIFE HABITAT AREA IN THE MILWAUKEE RIVER WATERSHED- 1967

COUNTY	WILDLIFE HABITAT (ACRES) HIGH VALUE	PERCENT OF TOTAL	MEDIUM VALUE	PERCENT OF TOTAL	LOW VALUE	PERCENT OF TOTAL	TOTAL
DODGE........	185	100	--	--	--	--	185
FOND DU LAC..	12,367	62	5,877	30	1,590	8	19,834
OZAUKEE......	5,284	42	6,267	50	978	8	12,529
SHEBOYGAN....	883	13	5,015	73	997	14	6,895
WASHINGTON...	10,605	38	11,273	40	6,341	22	28,219
TOTAL	29,324	43	28,432	42	9,906	15	67,662

SOURCE- WISCONSIN DEPARTMENT OF NATURAL RESOURCES.

Although there are no detailed data on the actual number of fur-bearing mammals in the watershed, rough population estimates for the fall of the year set the number of muskrats at about 25,000; mink at 2,000; raccoon at 5,000; and red and gray fox at 2,000, most of which are red fox.

The muskrat is the most abundant and widely distributed fur-bearing mammal in the watershed and brings the greatest economic return to trappers. Any significant water area in the watershed may attract muskrats. Lakeshores, marshes, small ponds, and the banks of rivers, creeks, and drainage ditches provide good homesites for muskrats. In marshes the familiar muskrat house contributes a certain amount of interest to the landscape. These houses are also used by other wildlife. Waterfowl make use of the houses as "loafing," or protective, areas and to a lesser extent for nesting. Mink and raccoon use muskrat houses as denning areas. Preservation and improvement of muskrat habitat would, therefore, automatically benefit waterfowl, the mink, and the raccoon.

The raccoon is usually associated with the woodland areas of the watershed; however, much of the raccoon's food is water-based, so it makes much transient use of wetland areas. Raccoon hunting with dogs is considered an important sport within the watershed. Both the red and gray fox are common in the watershed. The red fox is more characteristic of mixed habitat and farmland, while the gray fox inhabits hilly, wooded areas. Many people are tolerant of the fox due to its aesthetic appeal, while others, less well informed, consider it a marauding threat to other wildlife. Ecologically, foxes are part of the natural fauna and, therefore, have a role in the balance of nature, as do all wildlife species.

Skunks and opossums are common furbearers in the watershed; however, their pelts are of little commercial value. Both use woodland areas bordering farmlands for homes and venture into the wetlands in search of food. Both tend to become inactive in cold weather, although neither is a true hibernator. Skunks are the major carrier of rabies in Wisconsin.

Birds

Game birds which are found in the watershed include the pheasant, Hungarian partridge, woodcock, jacksnipe, rail, dabbling duck, diving duck, coot, and a variety of geese. Pheasant and Hungarian partridge are upland game birds and provide the best bird hunting. Waterfowl hunting is also good, as the watershed lies within the "Mississippi Flyway."

The fall pheasant population within the watershed is estimated to total about 35,000. The pheasant population is annually supplemented by the release of state-propagated birds, consisting largely of cocks, through local cooperator clubs and on public hunting grounds. The Hungarian partridge, although less important than the pheasant as a game bird, is abundant enough to be of interest to the public and sportsmen alike. The Hungarian partridge is a coveying bird sometimes seen in larger flocks in winter. Ruffed grouse occur in many wooded locations in the watershed but not in great numbers. The bobwhite quail have been virtually eliminated within the watershed; however, in a few areas, the range potential still exists for their reintroduction.

There is a significant production of waterfowl in the watershed, especially the mallard and the teal. The annual production of ducks averages about 10,000. Migratory waterfowl populations, both spring and fall, vary greatly. The peak waterfowl population reaches about 50,000 birds annually, while the total migratory passage may be twice this amount.

Other species of water-based birds within the watershed include the loon, heron, sandpiper, gull, plover, and tern. A major site for these species is Jackson Marsh on Cedar Creek, as well as other wetland areas, lakes, and streams. Because of the admixture of lowland and upland forest, meadows, and agricultural lands, along with favorable warm-season climate, the watershed supports many other species of birds, including the bald eagle, turkey vulture, hawk, owl, swallow, kingfisher, woodpecker, robin, whip-poor-will, and mourning dove. Pest bird species of the watershed may be considered to include the English sparrow, starling, and red-winged blackbird.

EXISTING AND POTENTIAL PARKS AND RELATED RECREATION SITES

An inventory of existing parks, outdoor recreation areas, and related open-space sites was conducted within the Region and the watershed during 1967. This inventory revealed that there are a total of 186 park, outdoor recreation, and related open-space sites within the watershed, totaling 29,065 acres. The distribution of these sites by ownership category is shown in Table 17 and by county in Table 18. The geographic distribution thereof is shown on Map 23.

Less than one-tenth of the total watershed acreage is in public park and recreation use. About 90 percent of that publicly owned land is state owned, consisting of the large Kettle Moraine forest areas (Northern Unit), wildlife areas, and seven small park sites. The local government acreage, while small in comparison to the state acreage, consists mainly of intensively used parks and active outdoor recreation areas within the urban centers of the watershed.

The nonpublic recreation sites, consisting of private, organizational, and commercially operated recreation lands, account for about one-third of

TABLE 17

EXISTING PARK, OUTDOOR RECREATION, AND RELATED OPEN-SPACE SITES AND ACREAGE IN THE MILWAUKEE RIVER WATERSHED BY OWNERSHIP CATEGORY- 1967

OWNERSHIP	NUMBER OF		PERCENT OF PUBLIC		PERCENT OF NONPUBLIC		PERCENT OF TOTAL	
	SITES	ACRES	SITES	ACREAGE	SITES	ACREAGE	SITES	ACREAGE
PUBLIC								
STATE..............	14	22,402	10.8	89.3	--	--	7.4	77.1
COUNTY.............	41	2,196	30.8	8.7	--	--	21.2	7.6
CITY OR VILLAGE...	71	519	57.7	1.9	--	--	39.7	1.6
TOWN...............	1	3	0.7	0.1	--	--	0.5	0.1
SUBTOTAL........	127	25,120	100.0	100.0	--	--	68.8	86.4
NONPUBLIC								
PRIVATE...........	14	1,385	--	--	23.7	35.1	7.4	4.8
ORGANIZATIONAL....	22	1,517	--	--	37.3	38.5	11.6	5.2
COMMERCIAL........	23	1,043	--	--	39.0	26.4	12.2	3.6
SUBTOTAL........	59	3,945	--	--	100.0	100.0	31.2	13.6
TOTAL	186	29,065	--	--	--	--	100.0	100.0

SOURCE- WISCONSIN DEPARTMENT OF NATURAL RESOURCES AND SEWRPC.

TABLE 18

EXISTING PARK, OUTDOOR RECREATION, AND RELATED OPEN-SPACE SITES AND ACREAGE IN THE MILWAUKEE RIVER WATERSHED BY OWNERSHIP CATEGORY BY COUNTY- 1967

OWNERSHIP	DODGE COUNTY		FOND DU LAC COUNTY		MILWAUKEE COUNTY		OZAUKEE COUNTY		SHEBOYGAN COUNTY		WASHINGTON COUNTY		WATERSHED TOTAL	
	SITES	ACRES	SITES	ACRES	SITES	ACRES	SITES	ACRES	SITES	ACRES	SITES	ACRES	SITES	ACRES
PUBLIC														
STATE............	--	--	1	8,805	1	1	5	1,002	1	8,211	6	4,383	14	22,402
COUNTY..........	--	--	--	--	35	1,741	4	353	1	2	1	100	41	2,196
CITY OR VILLAGE..	--	--	2	16	39	177	15	85	3	56	12	185	71	519
TOWN............	--	--	--	--	--	--	--	--	--	--	1	3	1	3
SUBTOTAL	--	--	3	8,821	75	1,919	24	1,440	5	8,269	20	4,671	127	25,120
NONPUBLIC														
PRIVATE..........	--	--	2	116	7	566	3	624	--	--	2	79	14	1,385
ORGANIZATIONAL...	--	--	4	390	1	24	8	392	--	--	9	711	22	1,517
COMMERCIAL.......	--	--	1	156	6	50	5	109	--	--	11	728	23	1,043
SUBTOTAL	--	--	7	662	14	640	16	1,125	--	--	22	1,518	59	3,945
TOTAL	--	--	10	9,483	89	2,559	40	2,565	5	8,269	42	6,189	186	29,065

SOURCE- WISCONSIN DEPARTMENT OF NATURAL RESOURCES AND SEWRPC.

the number of sites in the watershed but for only 13 percent of the acreage. Over one-third of the nonpublic acreage, or 1,517 acres, is owned by organizations such as church groups, Boy Scouts and Girl Scouts, and hunting clubs who maintain a number of recreational camps. Nearly 1,050 acres are operated on a profit-making commercial basis.

An inventory of potential park and related open-space sites was conducted within the Region during 1964 and within the out-of-Region portion of the Milwaukee River watershed during 1967. The results of these inventories with respect to the watershed are summarized in Table 19. Of the 131 sites identified (see Map 24) slightly less than one-half are considered to be of high recreational resource value. These high-value sites, however, do comprise over one-half of the total identified and delineated potential park site acreage. In general, the study revealed that the Milwaukee River watershed has some of the best remaining recreational resources in the Region, including areas within, and in close proximity to, the Kettle Moraine State Forest in Fond du Lac, Sheboygan, and Washington Counties.

TABLE 19

POTENTIAL PARK SITES AND ACREAGE IN THE MILWAUKEE RIVER WATERSHED BY COUNTY AND VALUE CATEGORY- 1967

COUNTY		SITE VALUE			
		HIGH	MEDIUM	LOW	TOTAL
DODGE..........	SITES	--	--	--	--
	ACRES	--	--	--	--
FOND DU LAC....	SITES	3	4	5	12
	ACRES	435	228	224	887
MILWAUKEE......	SITES	--	1	--	1
	ACRES	--	290	--	290
OZAUKEE........	SITES	20	7	14	41
	ACRES	4,582	1,750	1,315	7,647
SHEBOYGAN......	SITES	10	11	4	25
	ACRES	1,673	1,627	142	3,442
WASHINGTON.....	SITES	26	11	15	52
	ACRES	6,096	1,556	2,017	9,669
TOTAL..........	SITES	59	34	38	131
	ACRES	12,786	5,451	3,698	21,935

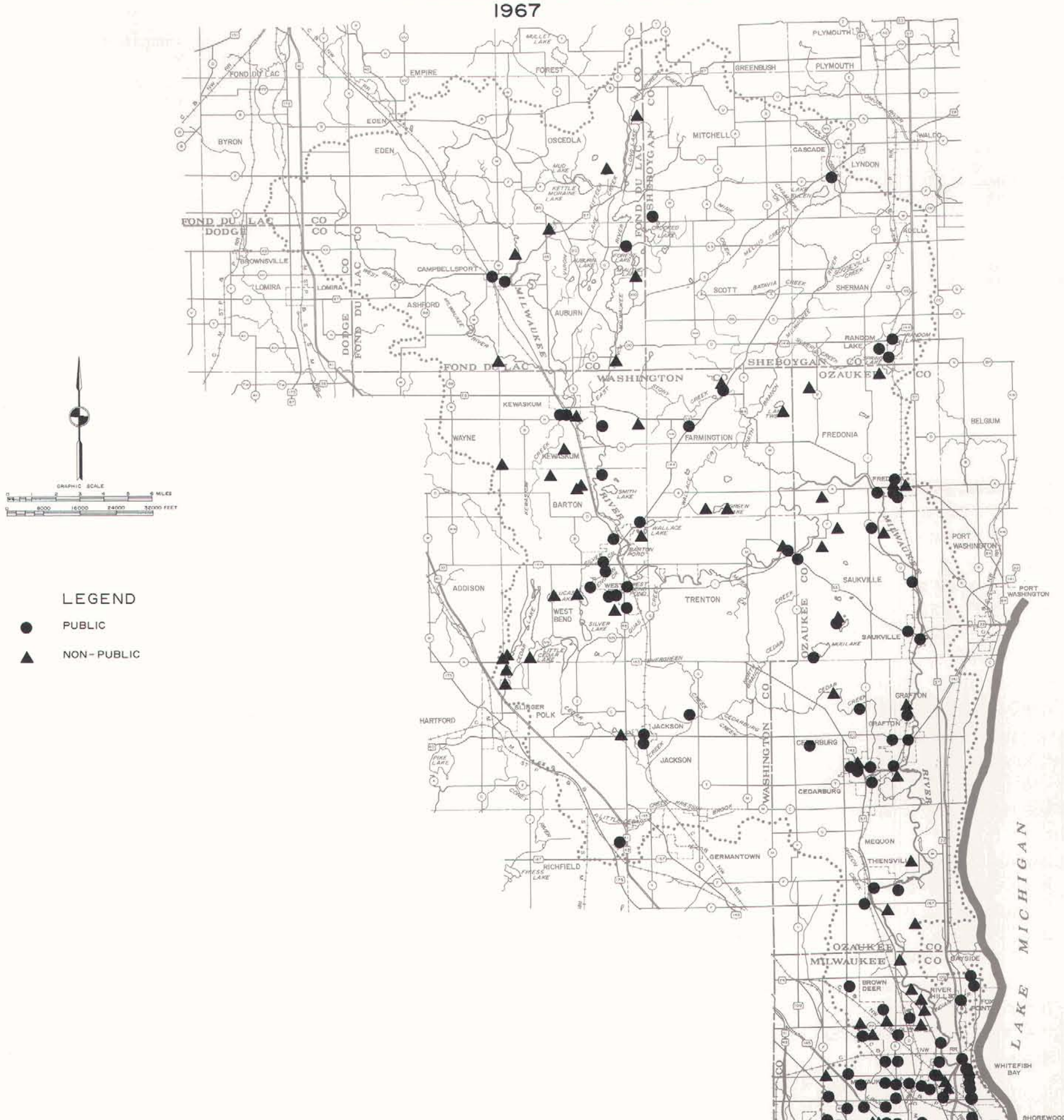
SOURCE- WISCONSIN DEPARTMENT OF NATURAL RESOURCES AND SEWRPC.

ENVIRONMENTAL CORRIDORS

One of the most important tasks which was completed as part of the regional land use planning effort was the identification and delineation of those areas of the Region in which concentrations of scenic, recreational, and historic resources occur and which, therefore, should be preserved and protected. Such areas include those elements of the natural resource base which are essential to the maintenance of both the ecological balance and natural beauty of the watershed and include lakes and streams and their associated floodlands, wetlands, forests, woodlands, wildlife habitat areas, high-relief topography, and significant geological formations. Although the foregoing elements comprise the integral parts of the natural resource base, there are certain additional elements which, although not a part of the natural resource base per se, are closely related to, or centered on, that base. These additional elements include existing outdoor recreation sites, potential outdoor recreation and related open-space sites, historic sites and structures, and significant scenic areas and vistas.

Map 23

EXISTING PARK, OUTDOOR RECREATION, AND RELATED OPEN-SPACE SITES IN THE MILWAUKEE RIVER WATERSHED 1967

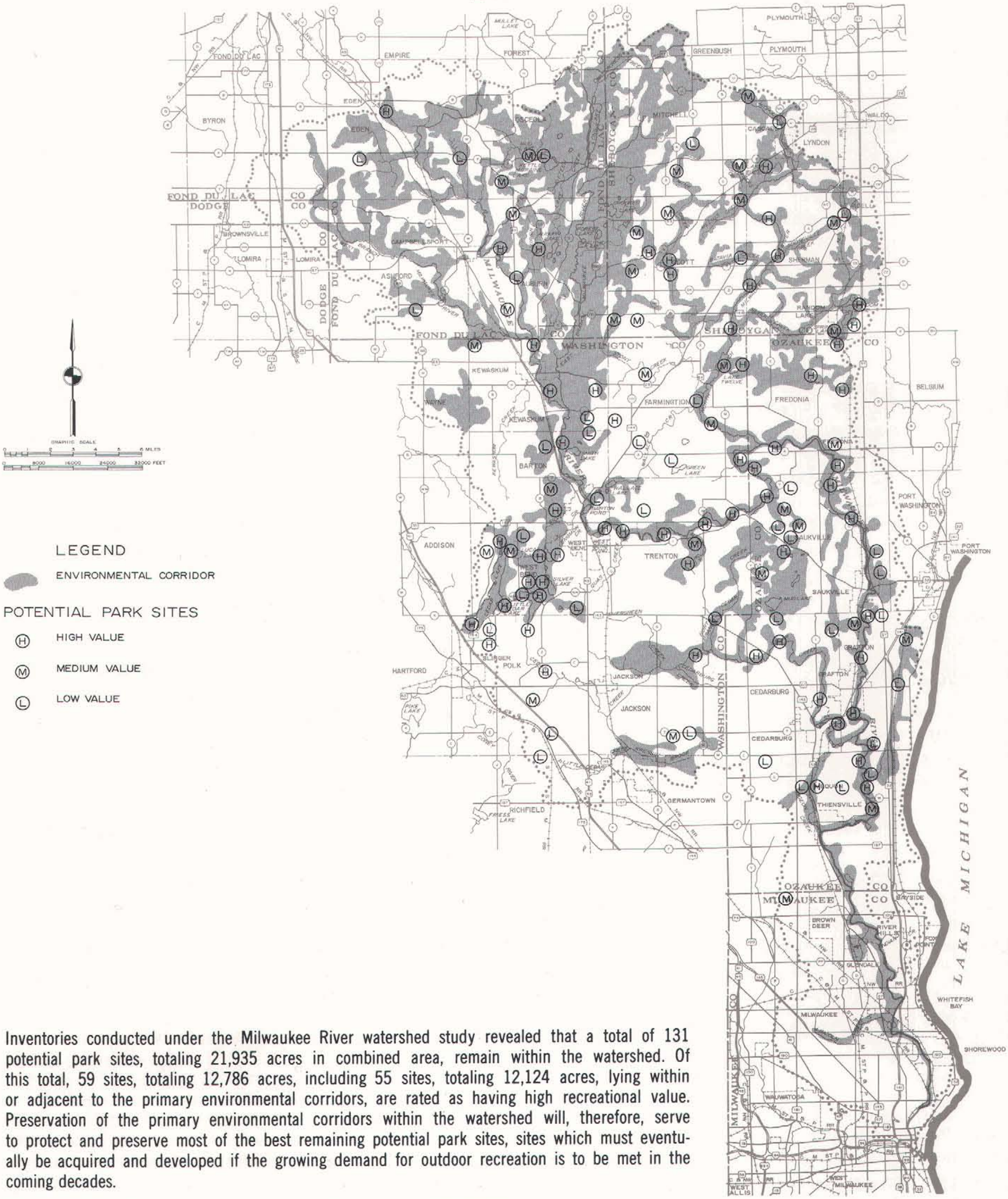


There are a total of 186 existing outdoor recreation sites in the Milwaukee River watershed, totaling about 29,100 acres. About 86 percent of this total acreage is in public ownership, consisting mainly of nearly 20,000 acres of land in state ownership as part of the Northern Unit of the Kettle Moraine State Forest. The local government acreage, while small in comparison to the state acreage, consists mainly of intensively used parks and active outdoor recreation areas within the urban centers of the watershed.

Source: Wisconsin Department of Natural Resources and SEWRPC.

Map 24

POTENTIAL PARK SITES IN THE MILWAUKEE RIVER WATERSHED 1967



Inventories conducted under the Milwaukee River watershed study revealed that a total of 131 potential park sites, totaling 21,935 acres in combined area, remain within the watershed. Of this total, 59 sites, totaling 12,786 acres, including 55 sites, totaling 12,124 acres, lying within or adjacent to the primary environmental corridors, are rated as having high recreational value. Preservation of the primary environmental corridors within the watershed will, therefore, serve to protect and preserve most of the best remaining potential park sites, sites which must eventually be acquired and developed if the growing demand for outdoor recreation is to be met in the coming decades.

Source: Wisconsin Department of Natural Resources and SEWRPC.

The delineation of these natural resource and natural resource-related elements on a map of the watershed results in an essentially lineal pattern encompassed in narrow, elongated areas which have been termed "environmental corridors" by the Commission. Primary environmental corridors which encompass three or more environmental elements are shown on Map 25. These primary environmental corridors occupy approximately 157 square miles, or 23 percent of the total watershed area. Most of the primary environmental corridors within the watershed lie in the Kettle Moraine area, surrounding major lakes, and along major stream valleys.

It is important to note that the primary environmental corridors contain almost all of the remaining high-value wildlife habitat and forest areas within the watershed in addition to most of the wetlands, lakes, and streams and associated floodlands. These corridors also contain many of the best remaining potential park sites. The preservation of these corridors in a natural state or in park and related open-space uses, including limited agricultural and county estate uses, will serve to maintain a high level of environmental quality in the watershed and protect its natural beauty.

The existing land uses within the primary environmental corridors include 6,554 acres of surface water; 46,884 acres of wetlands; 44,951 acres of woodlands; 3,851 acres of unused lands; 22,537 acres of cropland; and 1,397 acres of agricultural-related land. The primary environmental corridors within the watershed are more fully discussed in Chapter XIII of this report.

Recent trends within the watershed have resulted in the encroachment of urban development into the primary environmental corridors. Unfortunately, unplanned or poorly planned intrusion of urban development into these corridors not only tends to destroy the very resources and related amenities sought by the development but also tends to create severe environmental problems having areawide effects.

SUMMARY

This chapter has described the natural resource base of the Milwaukee River watershed which, together with the socioeconomic base, comprises the complex and changing environment of the rapidly urbanizing watershed. Certain natural resource factors have particular significance to the comprehensive planning study of the Milwaukee River watershed, and these factors are summarized in the following paragraphs.

The climate of the watershed is marked by diurnal and seasonal extremes of the climatic elements characteristic of a mid-continental region. Summers are hot, relatively short, and humid. Winters are relatively cold and long. Winter seasons occasionally give way to a mid-winter thaw in January, but the spring thaw occurs in late March or early April.

The topography of the watershed is marked by gently rolling hills with some interspersed flat terrain. Local relief is usually less than 100 feet. Relatively recent glacial deposits overlie the older bedrock formations; and, as a result of the recent glacial action, the surface drainage pattern is youthful and poorly developed. Stream density varies throughout the watershed, reflecting differences in the permeability of the surficial glacial deposits.

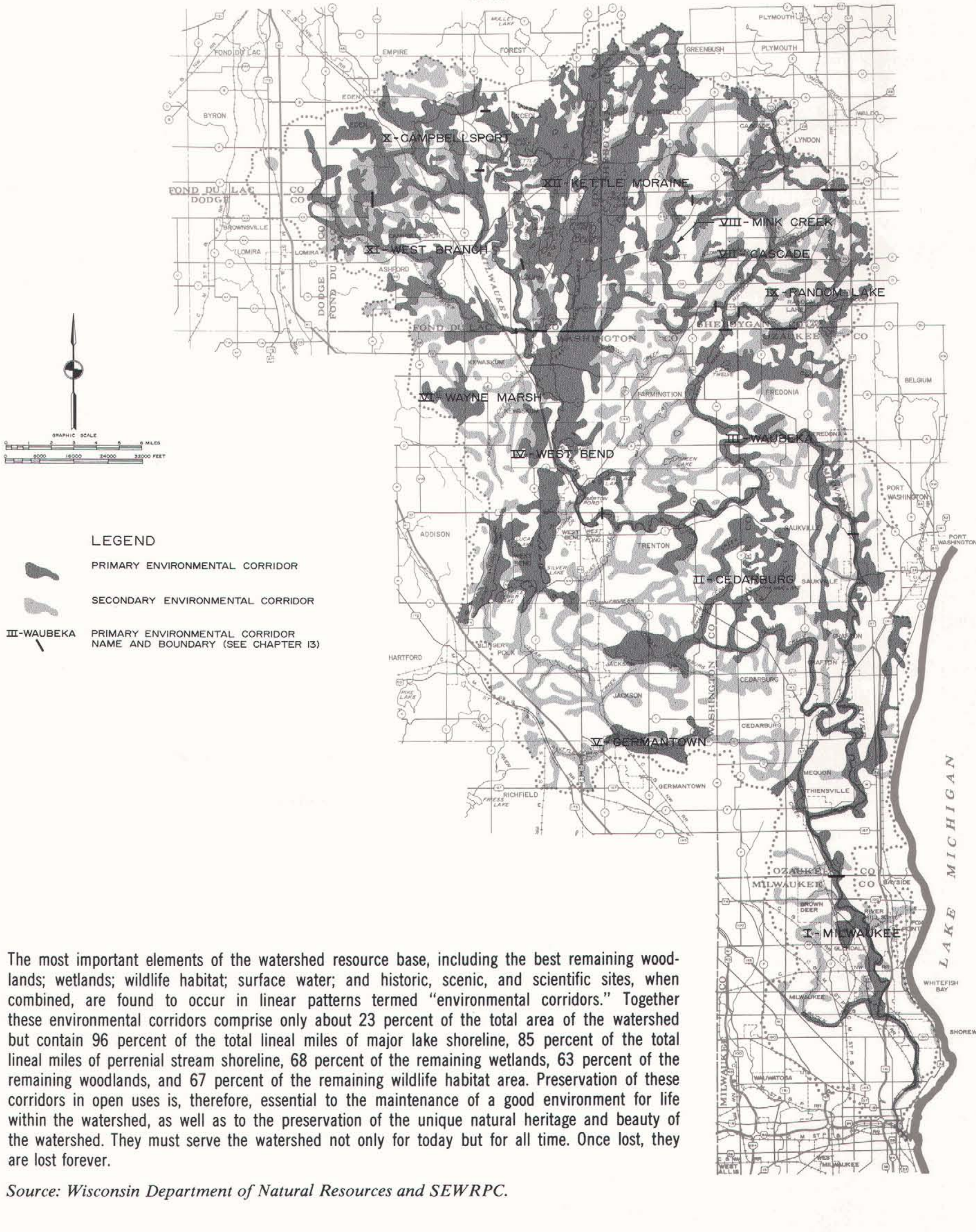
The subsurface geology of the watershed is a particularly important aspect of the resource base because of its relationship to the available ground water supplies. Eight stratigraphic units which have a ground water supply significance have been identified from logs of wells drilled within the watershed. These can be grouped into three major ground water reservoirs or aquifers, which provide nearly all of the water supply for industrial, municipal, and private use within those portions of the watershed lying north of the Ozaukee-Milwaukee County line.

Large areas of the watershed are covered by soils having severe limitations for urban development, particularly for residential development without public sanitary sewer service. These problem areas for urban development, however, comprise much of the remaining area suitable for development of additional wildlife habitat, woodland, and outdoor recreational areas.

Very little of the pre-settlement vegetation pattern remains within the watershed. This change is a testament to the profound effect of human influence upon the natural environment. Open prairie lands have been "turned under" by the plow; forests have been decimated for building materials, fuel, and to provide cropland area; and wetlands have been ditched and tilled to pro-

Map 25

ENVIRONMENTAL CORRIDORS
IN THE MILWAUKEE RIVER WATERSHED
1967



The most important elements of the watershed resource base, including the best remaining woodlands; wetlands; wildlife habitat; surface water; and historic, scenic, and scientific sites, when combined, are found to occur in linear patterns termed "environmental corridors." Together these environmental corridors comprise only about 23 percent of the total area of the watershed but contain 96 percent of the total lineal miles of major lake shoreline, 85 percent of the total lineal miles of perrenial stream shoreline, 68 percent of the remaining wetlands, 63 percent of the remaining woodlands, and 67 percent of the remaining wildlife habitat area. Preservation of these corridors in open uses is, therefore, essential to the maintenance of a good environment for life within the watershed, as well as to the preservation of the unique natural heritage and beauty of the watershed. They must serve the watershed not only for today but for all time. Once lost, they are lost forever.

Source: Wisconsin Department of Natural Resources and SEWRPC.

vide cropland area and filled to provide land for various urban uses.

Lakes and streams are abundant in the watershed and, with the underground water reservoirs, provide the singular most important natural resource values in the basin. There are 71 lakes in the watershed, ranging in size from three acres to 932 acres and comprising a total of 4,170 acres of surface water area, or about 1 percent of the total watershed area. Wetlands, including significant wetland units of at least 50 acres in area, as identified by the Wisconsin Department of Natural Resources, and additional minor wetlands, as identified by the SEWRPC in the watershed land use inventory, comprise a total of 69,068 acres, or about 15 percent of the watershed area. Approximately 330 lineal miles of perennial streams exist within the watershed.

Most of the 21 lakes in the watershed having a surface area of 50 acres or more support at least a limited fishery. Northern pike, largemouth bass, bluegill, and bullhead represent the major fish species present in these lakes. Only five of the major streams—the Milwaukee River and its four main tributaries, including the East, North, and West Branches, and Cedar Creek—support desirable fisheries under present conditions.

As a consequence of the decrease in woodlands and wetlands, the wildlife population within the watershed has decreased with increased urban development. The mammal and bird species once abundant to the watershed have diminished in type and quantity, due to the complex effects of urbanization and changing land use.

Approximately 29,065 acres, or about 7 percent of the watershed area, are devoted to park, outdoor recreation, and related open-space use, including both publicly and privately owned sites. There are 131 identified potential park sites in the watershed, comprising about 21,935 acres, or nearly 5 percent of the watershed area. Of the total 131 sites, 59 sites, totaling 12,786 acres, are rated as having high-value recreational resources.

The delineation on a map of those elements of the natural resource base which are essential to the maintenance of both the ecological balance and the natural beauty of the Region, including the lakes and streams and their associated floodlands; the wetlands, woodlands, and associated wildlife habitat areas; and the high relief topography; significant geological formations; and areas of wet or poorly drained soils, results in a pattern of essentially lineal corridors. These lineal corridors, because of their relationship to the underlying and sustaining natural resource base, have been termed environmental corridors. Such corridors which encompass three or more environmental elements have been termed primary environmental corridors; and such corridors occupy approximately 157 square miles, or 23 percent of the total watershed area. These primary environmental corridors contain almost all of the remaining high-value wildlife habitat and woodland areas within the watershed, in addition to most of the wetlands, lakes and streams, and associated floodlands. These corridors also contain many of the best remaining potential park sites. The preservation of these corridors in a natural state or in park and related open-space uses, including limited agricultural and country-estate residential use, is essential to maintaining a high level of environmental quality in the watershed and to the protection of its natural beauty.

Chapter V

EXISTING STRUCTURES FOR WATER CONTROL AND USE

INTRODUCTION AND OVERVIEW

The Milwaukee River was an important source of power and a major artery of transportation for early settlers in southeastern Wisconsin. Settlements were located at natural waterfalls or rapids where water power could be developed to drive the machinery of mills that produced lumber, flour, woolens, and wood products. To harness the water, power dams were built across the Milwaukee River and its major tributaries beginning in the 1830's. The 48 dams presently existing in the watershed include many of these old power dams, as well as lake level control structures. The use of all of these dams for power, however, has been discontinued, with the use for power of the last one, the Wire and Nail Factory Dam on Cedar Creek, having been discontinued in 1969.

One of the dams, the North Avenue Dam in the City of Milwaukee, was originally built as a part of a proposed major transportation facility—the Milwaukee and Rock River Canal. The approximately one mile reach of canal completed below the Dam was later used as a millrace for water power, being finally abandoned and filled in. The alignment of the lower reaches of the Milwaukee River channel was changed in 1857 to permit development of the river for Great Lakes ship traffic. During the present century, and particularly during the Works Progress Administration era in the 1930's, channel straightening, deepening, and stabilizing were undertaken along the Milwaukee River and major tributaries upstream from the North Avenue Dam. Also, numerous small drainage channel improvement projects were undertaken to drain wetlands and to control the ground water table in agricultural areas. Although these channel improvement works have significant local effects on flood flows and flood stages, the overall effect on the river is hardly measurable.

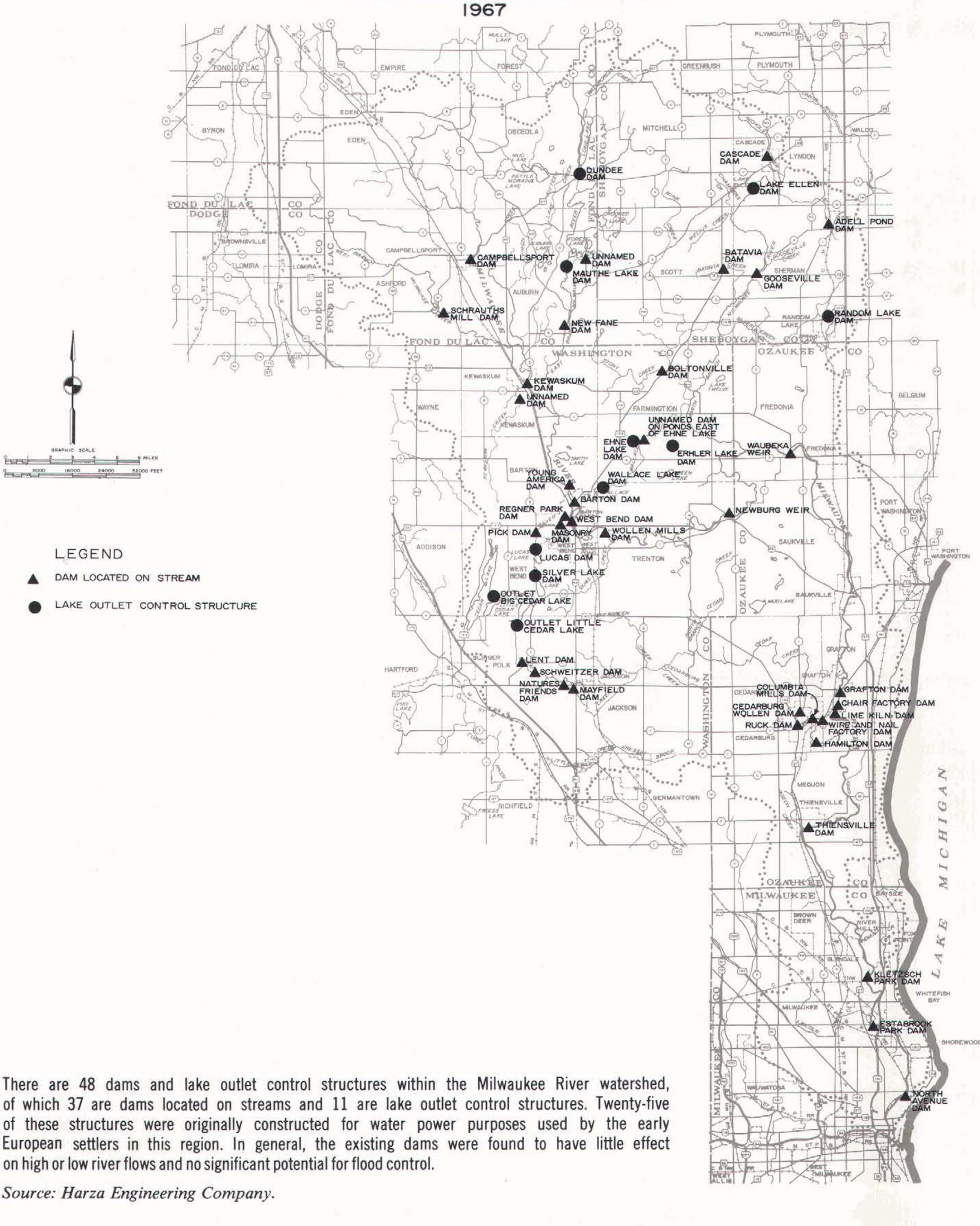
The 48 dams presently located in the watershed were inventoried and visited by an inspection team drawn from the staffs of the Commission and Harza Engineering Company during the fall of 1967, the summer of 1968, and again in the spring of 1970. During the course of these field inspections, the hydraulic characteristics and physical condition of the structures were noted. In general, the existing dams were found to have little effect on high or low river flows and no significant potential for flood control. The small ponds or impoundments created by the dams afford scenic settings for shoreline developments and have a modest potential for water-oriented recreation. Some ponds have a minor potential for emergency use for low-flow augmentation.

All of the dams in the watershed are relatively low, having a height of 25 feet or less, and impound only small volumes of water. Therefore, failure of a dam generally would not be expected to result in significant damage, the most serious consequences of the failure being the unaesthetic conditions resulting from the drainage of the reservoir. It is, however, conceivable that locally serious loss of property and even loss of life could occur with the failure of one of the larger structures. For this reason, several of the larger dams in the watershed require more detailed engineering investigation to determine the need for repair and the character of the needed repair.

The 48 dams in the Milwaukee River watershed are located as shown on Map 26 and control water levels of both natural lakes and man-made ponds. Natural lakes are located on the extreme headwaters of some of its major tributaries. Man-made impoundments are located throughout the watershed. The 11 lakes which are controlled by dams are considerably larger than most of the man-made ponds and impoundments, ranging in size from a maximum of 932 acres for Big Cedar Lake to a minimum of 35 acres for Erhler Lake (see Tables 20-A and 20-B). Six of the 11 natural lakes have a surface area larger than 100 acres, and nine of the 11 have a surface area larger than 50 acres. The 37 man-made impoundments located on the Milwaukee River watershed vary in surface area at normal river flows from a maximum of about 200 acres for the impoundment behind the Thiensville Dam to less than 0.1 acre for the Nature's Friends impoundment in the Town of Polk. Only two of the 37 man-made impoundments—the ponds behind the West Bend and Woolen Mills Dams—are capable of providing any mea-

Map 26

DAMS AND LAKE OUTLET CONTROL STRUCTURES IN THE MILWAUKEE RIVER WATERSHED 1967



LEGEND

▲ DAM LOCATED ON STREAM

● LAKE OUTLET CONTROL STRUCTURE

There are 48 dams and lake outlet control structures within the Milwaukee River watershed, of which 37 are dams located on streams and 11 are lake outlet control structures. Twenty-five of these structures were originally constructed for water power purposes used by the early European settlers in this region. In general, the existing dams were found to have little effect on high or low river flows and no significant potential for flood control.

Source: Harza Engineering Company.

TABLE 20-A

STRUCTURE DATA FOR DAMS AND LAKE OUTLET CONTROL STRUCTURES IN THE MILWAUKEE RIVER WATERSHED- 1967 AND 1968

STRUCTURE IDENTIFICATION				STRUCTURE DATA											
							SPILLWAY				IMPOUNDMENT				
STRUCTURE NAME AND RIVER MILE	SEWRPC CONTROL NO.	WIS DNR NO.	TOWN RANGE AND SECTION	ACCESS	OWNER	TYPE OF DAM	TYPE	APPROXIMATE SIZE	APPROXIMATE DATE OF CONSTRUCTION	HEAD (FT.)	DRAINAGE AREA (SQ.MI.)	SURFACE AREA (ACRES)[a]	DEPTH (FT.)[b]	ORIGINAL PURPOSE	CURRENT PURPOSE
NORTH AVENUE DAM (3.10)	220	40.2	T7N R22E SEC 21	NORTH AVENUE	CITY OF MILWAUKEE	CONCRETE AND MASONRY	OVERFLOW WEIR WITH 2 TAINTER GATES.	WEIR- L=267 FT. GATES-(2) 13 FT. BY 23 FT.	1835, REBUILT 1842 AND 1899	17	690	92	9	FEED MILL. REBUILT AS A NAVIGATION FACILITY	WATER LEVEL CONTROL AND RECREATION
ESTABROOK PARK DAM (6.65) ICE BOOM IN ESTABROOK PARK UPSTREAM FROM CONCRETE DAM	214 AND 215 213	40.8	T7N R22E SEC 5	CENTER OF ESTABROOK PARK SOUTH OF HAMPTON AVENUE	MILWAUKEE COUNTY PARK COMMISSION	CONCRETE, 156 FT LONG WITH VERTICAL LIFT GATES LEFT (EAST) CHANNEL AND A MASONRY WEIR IN THE RIGHT CHANNEL.	CONCRETE WITH 10 GATES LEFT CHANNEL AND S-SHAPED WEIR AT RIGHT.	GATES- 9.5 FT. BY 8.5 FT. CLEAR WEIR LENGTH- 535 FT.	1940	7	686	80	8	WATER LEVEL CONTROL AND RECREATION	WATER LEVEL CONTROL AND RECREATION
KLETZSCH PARK DAM (10.07)	204	40.7	T8N R22E SEC 20	STH-57 AND MILL ROAD	MILWAUKEE COUNTY PARK COMMISSION	MASONRY AND STONE	OVERFLOW WEIR WITH TWO 3 FT. BY 5 FT. GATES CONTROLLED BY STOPLOGS AND 4 SECTIONS OF THE WEIR DEPRESSED 0.24 FT. BELOW THE GENERAL CREST.	WEIR-LENGTH ABOUT 170 FT. ON STRAIGHT LINE AND ABOUT 230 FT. ALONG THE CURVE.	1936	4	631	20	5	WATER LEVEL CONTROL AND RECREATION	WATER LEVEL CONTROL AND RECREATION
THIENSVILLE DAM (19.61)	195	45.1	T9N R21E SEC 23	STH-57 IN THIENSVILLE	VILLAGE OF THIENSVILLE	CONCRETE WEIR	OVERFLOW WEIR ENTIRE DAM. SLOPING CHUTE EAST SIDE.	WEIR-LENGTH= 200 FT. A 6 FT. GATE CONTROLS MILL CHANNEL	1843. REBUILT IN 1886 AND 1913	6	594	204	8	FLOUR AND GRIST MILL	WATER LEVEL CONTROL AND RECREATION
LIME KILN DAM (29.72)	150	45.9	T10N R21E SEC 25	CTH-O SOUTH OF GRAFTON	VILLAGE OF GRAFTON	CONCRETE (MAY BE MASONRY)	OVERFLOW WEIR ENTIRE DAM.	WEIR-LENGTH= 70 FT.	1847. REBUILT IN 1963	10	453	5	8	POWER FOR COMPRESSING AIR FOR QUARRYING OPERATION	WATER LEVEL CONTROL
CHAIR FACTORY DAM (30.10)	149	45.7	T10N R21E SEC 24	AT END OF FALL STREET IN GRAFTON	PORT WASHINGTON CHAIR CO.	CONCRETE AND MASONRY	OVERFLOW WEIR ENTIRE DAM.	WEIR-LENGTH= 100 FT.	1847. REBUILT IN 1914	18	452	8	7	POWER FOR KNITTING COMPANY	WATER LEVEL CONTROL
GRAFTON DAM (30.76)	147	45.8	T10N R21E SEC 24	WASHINGTON STREET IN GRAFTON	VILLAGE OF GRAFTON	CONCRETE (MAY BE MASONRY)	BUTTRESS OVERFLOW.	WEIR-LENGTH= 170 FT.	1847. REBUILT IN 1881	16	451	65	8	GRIST MILL	WATER LEVEL CONTROL
WAUBEKA WEIR (45.61)	141	45.6	T12N R21E SEC 28	STH-84 AT WAUBEKA	JCOSE BROTHERS	CONCRETE	OVERFLOW WEIR ENTIRE DAM. FLOW THROUGH CONCRETE BOX AT LEFT BANK AND MILLRACE RIGHT BANK.	WEIR-LENGTH= 220 FT. BOX-WIDTH = 7 FT. HEIGHT= 5 FT. TWO BAYS OF MILLRACE ARE EACH 5.5 FT. WIDE.	N.A. REBUILT IN 1909	7	412	24	7	FLOUR AND FEED MILL	AESTHETICS
NEWBURG WEIR (54.55)	86	66.7	T11N R20E SEC 12	CTH-MY	NEWBURG FIRE DEPARTMENT	CONCRETE FACING OVER RUBBLE	OVERFLOW WEIR. MILLRACE AND CULVERT (PLUGGED).	WEIR-LENGTH= 150 FT. MILLRACE-11 FT. SECTION WITH 3 GATES. CULVERT-ABOUT 5 FT. WIDE BY 3 FT. HIGH.	1848. REBUILT IN 1913	7	243	33	10	FEED AND SAW MILL	AESTHETICS
WOOLEN MILLS DAM (65.19)	83	66.14	T11N R19E SEC 13	STH-33 AND RIVER ROAD	CITY OF WEST BEND	EARTHFILL	CONCRETE WITH 3 TAINTER GATES, A SLUICE BAY, AND AN UNUSED MILLRACE.	TAINTER GATES-3 EA. 10 FT. WIDE. 1 SLUICE GATE 4 FT. BY 4 FT	1870. REBUILT IN 1913	14	222	67	17	FLOUR AND FEED MILL	POND LEVEL CONTROL
WEST BEND DAM (66.92)	77	66.13	T11N R19E SEC 11	STH-33 IN WEST BEND	WISCONSIN ELECTRIC CO	CONCRETE	CONCRETE OVERFLOW WEIR. TAINTER GATES IN SIDE CHANNEL	WEIR-LENGTH= 180 FT. 2 GATES EA. 14 FT. WIDE	1846	12	219	67	9	FLOUR MILL AND ELECTRIC POWER GENERATION	POND LEVEL CONTROL

TABLE 2C-A (CONTINUED)

STRUCTURE IDENTIFICATION				STRUCTURE DATA											
							SPILLWAY				IMPOUNDMENT				
STRUCTURE NAME AND RIVER MILE	SEWRPC CONTROL NO.	WIS DNR NO.	TOWN RANGE AND SECTION	ACCESS	OWNER	TYPE OF DAM	TYPE	APPROXIMATE SIZE	APPROXIMATE DATE OF CONSTRUCTION	HEAD (FT.)	DRAINAGE AREA (SQ.MI.)	SURFACE AREA (ACRES)[a]	DEPTH (FT.)[b]	ORIGINAL PURPOSE	CURRENT PURPOSE
BARTON DAM (68.26)	59	66.1	T11N R19E SEC 1	STH-144 IN WEST BEND	CITY OF WEST BEND	CONCRETE	CONCRETE OGEE WEIR, VERTICAL GATES, AND MILL-RACE.	WEIR-LENGTH= 120 FT. 4 GATES EA. 4.5 FT. BY 5 FT. LONG. 10.5 FT. MILLRACE	1846. RE-BUILT IN 1908	13	206	18	7	FLOUR AND FEED MILL	POND LEVEL CONTROL
YOUNG AMERICA DAM (69.33)	56	66.2	T11N R19E SEC 2	CTH-D NEAR WEST BEND	MARIAN KAHNT	CONCRETE AND EARTH	CONCRETE WEIR IN NORTHEAST CHAN-NEL. DIVERSION STRUCTURE IN SOUTHWEST CHAN-NEL WITH 2 STRUCTURES SEP-ARATED BY AN 86 FOOT ISLAND.	WEIR-LENGTH= 158 FT. WITH A 4.5 FT. BY 6.5 FT. SLOT. SOUTHWEST CHANNEL BRIDGE 12 FT. WIDE.	1851. RE-BUILT IN 1913	7	204	34	5	FEED MILL	POND LEVEL CONTROL
KEWASKUM DAM (76.86)	30	66.17	T12N R19E SEC 9	STH-28 AT KEWASKUM	VILLAGE OF KEWASKUM	STONE PIERS WITH STEEL PLATES	STEEL PLATES IN STEEL GUIDES WITH A WALKWAY OVER THE TOP.	3 BAYS EACH 30 FT. WIDE EACH WITH 6 GATES.	(C) 1932	9	125	23	8	GRIST MILL	AESTHETICS
CAMPBELLSPORT DAM (87.74)	6	20.12	T13N R19E SEC 18	CTH-Y AT CAMPBELLSPORT	ISADORE FLOOD	GRASSED EARTH FILL	ROCKFILL WEIR CAPPED WITH CON-CRETE, 36 IN. CMP PIPE OUTLET.	WEIR-LENGTH= 108 FT. CLEAR	N.A.	12	54	10	5	N.A.	AESTHETICS
HAMILTON DAM (29.07)	191	45.3	T10N R21E SEC 35	CTH-O AT HAMILTON	DAVE UIHLEIN	MASONRY AND STONE WITH SOME CON-CRETE IN WINGWALLS	OVERFLOW OVER ENTIRE DAM.	WEIR-LENGTH= 84 FT. MILL CHANNEL WITH OPENING 4 FT. WIDE.	1853. RE-BUILT IN 1881	7	125	12	7	FLOUR MILL	AESTHETICS
WIRE AND NAIL FACTORY DAM (31.28)	187	45.5	T10N R21E SEC 26	STH-57 AT CEDARBURG	CEDARBURG WIRE AND NAIL CO.	WOODEN CRIB FACED DOWN-STREAM WITH CONCRETE AND BACKFILLED UPSTREAM WITH CLAY AND GRAVEL	OVERFLOW OVER ENTIRE DAM.	WEIR-LENGTH= 80 FT. MILL-RACE. WIDTH= 10.5 FT.	N.A. RE-BUILT 1882 AND 1930	26	125	3	10	POWER TO RUN NAIL MILL	WATER LEVEL CONTROL
COLUMBIA MILLS DAM (31.59)	186	45.2	T10N R21E SEC 26	OFF STH-57	CEDARBURG WIRE AND NAIL CO.	CRIB TYPE WITH CON-CRETE FACING DOWNSTREAM AND FILL UP-STREAM	OVERFLOW OVER ENTIRE DAM.	WEIR-LENGTH= 78 FT. MILL-RACE-WIDTH= 12.5 FT.	N.A. RE-BUILT IN 1881 AND 1914	11	120	15	7	FLOUR MILL	WATER LEVEL CONTROL
RUCK DAM (32.32)	183	45.4	T10N R21E SEC 27	COLUMBIA AVE. AT CEDARBURG	CEDARBURG SUPPLY COMPANY	MASONRY AND CRIBBING	OVERFLOW OVER WEIR	WEIR-LENGTH= 115 FT. ABAN-DONED 11 FT. MILLRACE AND 22 FT. DIVID-ING SECTION	N.A.	10	120	6	6	FLOUR MILL	WATER LEVEL CONTROL
WOOLEN DAM (32.65)	180	45.1	T10N R21E SEC 27	BRIDGE STREET IN CEDARBURG	CITY OF CEDARBURG	CONCRETE AND MASONRY	OVERFLOW WEIR.	WEIR-LENGTH= 92 FT. ABAN-DONED MILL-RACE CLEAR WIDTH 9 FT.	1864. RE-BUILT IN 1881	12	120	13	5	WOOLEN MILL TURBINE POWER	WATER LEVEL CONTROL
MAYFIELD DAM (52.73)	162A	66.5	T10N R19E SEC 13	SECONDARY ROAD AT MAYFIELD	IVAN KNOLL	SERIES OF 4 MORTARED ROCK FALLS	OVERFLOW OVER ENTIRE STRUC-TURE.	WIDTH OF CREST OF FALLS VARY FROM 8.5 FT. TO 20 FT.	1852. RE-BUILT IN 1954	10 FT. DROP	23	<1	N.A.	N.A.	AESTHETICS
SCHWEITZER DAM (54.23)	159	66.25	T10N R19E SEC 14	CTH-Z	AMOR SCHWEITZER	EARTHFILL	CONCRETE, 2 GATE BAYS WITH STOP-LOGS.	GATES-(2) EACH 5 FT. WIDE	1945	10	20	8	4	N.A.	AESTHETICS
LENT DAM (55.09)	157A	66.29 WAS 66.6	T10N R19E SEC 15	CTH-C	R.W. LENT	EARTHFILL WITH PRIVATE ROAD ACROSS IT	CONCRETE STOP-LOGS	A BOX 10.7 FT. CLEAR WIDTH	1845 AND 1955	5-10	20	8	7	N.A.	AESTHETICS

TABLE 20-A (CONTINUED)

STRUCTURE IDENTIFICATION				STRUCTURE DATA											
							SPILLWAY				IMPOUNDMENT				
STRUCTURE NAME AND RIVER MILE	SEWRPC CONTROL NO.	WIS DNR NO.	TOWN RANGE AND SECTION	ACCESS	OWNER	TYPE OF DAM	TYPE	APPROXIMATE SIZE	APPROXIMATE DATE OF CONSTRUCTION	HEAD (FT.)	DRAINAGE AREA (SQ.MI.)	SURFACE AREA (ACRES)[a]	DEPTH (FT.)[b]	ORIGINAL PURPOSE	CURRENT PURPOSE
LITTLE CEDAR LAKE OUTLET (57.40)	154	66.10	T10N R19E SEC 3	PRIVATE ROAD OFF CTH-Z	WASHINGTON COUNTY FISH AND GAME PROTECTIVE ASSOC.	CONCRETE	CONCRETE BASE WITH STOPLOGS.	WEIR-LENGTH= 20 FT. CLEAR	1868	4	15	246	55	LAKE LEVEL CONTROL	LAKE LEVEL CONTROL
BIG CEDAR LAKE OUTLET (60.29)	151	66.8	T11N R19E SEC 32	SHORELINE ROAD EAST SIDE OF LAKE	CEDAR CREEK HYDRAULIC CO.	CONCRETE	CONCRETE OUTLET	WEIR-LENGTH= 20 FT.	1894	2	10	932	105	LAKE LEVEL CONTROL	LAKE LEVEL CONTROL
NATURE'S FRIENDS DAM (ON TRIBUTARY TO CEDAR CREEK)[c]	261	66.27	T10N R19E SEC 14	STH-60	NATURE'S FRIENDS INC.	EARTHFILL AND CONCRETE	VERTICAL GATES SET IN CONCRETE	GATES-3 AT 3 FT. BYPASS CHANNEL 2.5 FT. WIDE	N.A.	8	2	0.1	9	POWER TO RUN SHOE FACTORY	WATER LEVEL CONTROL
GOOSEVILLE DAM (61.34)	115	59.8	T13N R21E SEC 17	'MAIN' STREET, GOOSEVILLE	GEORGE KNORR	EARTHFILL	CONCRETE WITH 3 SEPARATE SPILLWAY BAYS CONTROLLED BY STOPLOGS AND A TIMBER MILLRACE	3 BAYS WITH 10 FT. WEIRS, 8 FT. MILLRACE	1855	8	8	38	7	FEED MILL	WATER LEVEL CONTROL
CASCADE DAM (69.70)	93	59.1	T14N R21E SEC 20	CTH-NN	H. L. SCHULTZ	EARTHFILL	CONCRETE AND MASONRY WITH MILLRACE	ONE BAY 12.5 FT. CLEAR AND ONE BAY 10 FT. CLEAR, MILLRACE 13.5 FT. CLEAR.	N.A.	2	8	7	3	FEED MILL	WATER LEVEL CONTROL
ERHLER LAKE DAM (TRIBUTARY TO NORTH BRANCH)[c]	262	66.28	T12N R20E SEC 27	CTH-A FROM WAUBEKA	LEONARD YAHR	SMALL CONCRETE DROP INLETS	CONCRETE DROP INLETS CONNECTED BY PIPE (3 FT. DIAMETER)	LENGTH-5 FT.	1942	1	1	35	38	LAKE LEVEL CONTROL	LAKE LEVEL CONTROL
EHNE LAKE DAM (TRIBUTARY OF NORTH BRANCH)[c]	263	66.20	T12N R20E SEC 29	STH-144	ARTHUR J. EHNE	EARTHFILL	CONCRETE	N.A.	N.A.	N.A.	5	18	15	N.A.	AESTHETICS
PONDS EAST OF EHNE LAKE DAM[c]	264	66.21	T12N R20E SEC 29	STH-144	HAROLD H. EMCH	EARTHFILL (2 PONDS)	STEEL PIPE	5-9 INCH	1961	N.A.	5	SMALL PONDS 3 TOTAL	N.A.	N.A.	AESTHETICS
WALLACE LAKE DAM[c]	265	66.19	T11N R20E SEC 6	CTH-MY		CONCRETE	CONCRETE	LENGTH-3-1/2 FT.	1959	1.5	2	52	35	LAKE LEVEL CONTROL	LAKE LEVEL CONTROL
BOLTONVILLE DAM (STONEY CREEK TRIBUTARY TO NORTH BRANCH)[c]	266	66.16	T12N R20E SEC 9	STH-144 NEAR BOLTONVILLE	BOLTONVILLE SPORTSMEN'S CLUB	CONCRETE AND EARTHFILL	CONCRETE SPILLWAY AND LOW LEVEL OUTLET PIPE	WEIR-LENGTH= 15 FT.	N.A. REBUILT IN 1965	N.A.	12	11	N.A.	N.A.	LAKE LEVEL CONTROL
RANDOM LAKE DAM (SILVER CREEK TRIBUTARY TO NORTH BRANCH) (64.92)	124	59.21	T13N R21E SEC 26	STH-144 AT RANDOM LAKE	RANDOM LAKE RESORTERS ASSOCIATION	CONCRETE	CONCRETE WEIR WITH STOPLOGS	WEIR-LENGTH= 11 FT. ENTERING A BOX CULVERT 4 FT. X 3 FT.	N.A.	1.5	6	213	19	FLOUR MILL	LAKE LEVEL CONTROL
TOMBAR DAM (LAKE ELLEN)[c]	111	59.25	T14N R21E SEC 31	STH-28 NEAR CASCADE	CASCADE SAND AND GRAVEL CO.	DIKE AND CONCRETE CULVERT	TWO PIPES 15 FT. LONG WITH STEEL SLOTS.	CULVERT WITH TWO 3 FT. DIAMETER PIPES	1929	3	3	110	48	LAKE LEVEL CONTROL	LAKE LEVEL CONTROL
ADELL DAM[c]	102	--	T13N R21E SEC 2	STH-57 NEAR ADELL	FOREMOST DAIRIES, INC.	EARTHFILL	SHEET PILE SPILLWAY	WEIR 15 FT. LONG WITH 6 FT. CENTER SECTION AND 4 & 5 FT. SECTIONS 1/2 FOOT HIGHER.	N.A.	4	3	9	N.A.	POND LEVEL CONTROL	POND LEVEL CONTROL
CITY PARK DAM (SILVER CREEK WEST BEND) (67.38)	75	66.26	T11N R19E SEC 11	STH-144 IN REGNER PARK AT WEST BEND	CITY OF WEST BEND	CONCRETE WITH FOOTBRIDGE	CONCRETE SPILLWAY	WEIR-LENGTH= 18 FT.	N.A.	3	8	3	3	AESTHETICS AND RECREATION	AESTHETICS AND RECREATION
STONE DAM REGNER PARK (67.51)	73	--[d]	T11N R19E SEC 11	STH-144 IN REGNER PARK	CITY OF WEST BEND	MASONRY	A V-SHAPED WEIR	LENGTH OF CHORD 20 FT.	N.A.	1	8	0.5	1	AESTHETICS AND RECREATION	AESTHETICS AND RECREATION
PICK DAM (69.96)	64	66.24	T11N R19E SEC 15	PARK ROAD NEAR PICK CEMETERY	RIDGE RUN TRUST	TIMBER AND FILL	CONCRETE WITH WOODEN GATE TO BOX CULVERT	WEIR-LENGTH= 4 FT.	1942	8	4	8	N.A.	LAKE LEVEL CONTROL	LAKE LEVEL CONTROL

TABLE 2C-A (CONTINUED)

STRUCTURE IDENTIFICATION				STRUCTURE DATA											
							SPILLWAY				IMPOUNDMENT				
STRUCTURE NAME AND RIVER MILE	SEWRPC CONTROL NO.	WIS DNR NO.	TOWN RANGE AND SECTION	ACCESS	OWNER	TYPE OF DAM	TYPE	APPROXIMATE SIZE	APPROXIMATE DATE OF CONSTRUCTION	HEAD (FT.)	DRAINAGE AREA (SQ.MI.)	SURFACE AREA (ACRES)	DEPTH (FT.)	ORIGINAL PURPOSE	CURRENT PURPOSE
LUCAS LAKE DAM (70.54)	63	66.18	T11N R19E SEC 22	NEAR ACCESS ROAD TO GIRL SCOUT CAMP	GIRL SCOUTS OF MILWAUKEE	EARTHFILL WITH CONCRETE STRUCTURE	CONCRETE WEIR WITH STOPLOGS AT INLET TO BOX CULVERT.	WEIR-LENGTH= 5 FT.	1886 1922-1923	4	3	78	15	LAKE LEVEL CONTROL	LAKE LEVEL CONTROL
SILVER LAKE DAM (71.93)	62	66.22	T11N R19E SEC 27	CTH-NN	SILVER LAKE PROTECTIVE ASSOCIATION	CORRUGATED METAL PIPE SET IN ROAD EMBANKMENT	METAL GATE ON CONCRETE HEADWALL OF PIPE	PIPE, 3 FT. IN DIAMETER	1936	<1	4	118	45	LAKE LEVEL CONTROL	LAKE LEVEL CONTROL
NEW FANE DAM (EAST BRANCH) (80.48)	46	20.17	T13N R19E SEC 35	CTH-DD IN NEW FANE	ELMER WALLEIN	EARTHFILL AND CONCRETE WITH MILL-RACE	CONCRETE BROAD-CRESTED WEIR	WEIR-LENGTH= 47 FT.	1850	8	44	10	7	GRIST MILL	LAKE LEVEL CONTROL AND AESTHETICS
MAUTHE LAKE DAM (85.31)	38	20.16	T13N R19E SEC 14	ACCESS ROAD TO MAUTHE LAKE	WISCONSIN DEPARTMENT OF NATURAL RESOURCES	CONCRETE	CONCRETE SLAB WEIR WITH WOODEN FOOTBRIDGE	LENGTH=100 FT	N.A.	<1	36	78	23	LAKE LEVEL CONTROL	LAKE LEVEL CONTROL
DUNDEE DAM (LONG LAKE) (92.24)	35	20.7	T14N R19E SEC 25	CTH-F AT DUNDEE	LOYD MURPHY	CONCRETE AND EARTHFILL	CONCRETE WITH FLOW OVER ENTIRE CREST AND MILL-RACE CONTROL STRUCTURE	WEIR-LENGTH= 34 FT.	1857. RE-BUILT IN 1901	5	12	409	47	ELECTRIC POWER GENERATION	LAKE LEVEL CONTROL
UNNAMED DAM (CROCKED LAKE CREEK TRIBUTARY TO EAST BRANCH) (86.27)	42	N.A.	T13N R19E SEC 13	EAST SIDE OF CTH-GGG	BAR N RANCH RIDING STABLES	SERIES OF 4 STRUCTURES- UPSTREAM LOW LEVEL WOODEN FOOTBRIDGE- SPAN 24 FT. WOODEN FOOT-BRIDGE AND FILL WITH OPENING-SPAN 10 FT. WOODEN FOOT-BRIDGE WITH WOODEN WEIR 0.8 FT. HIGH & 12 FT. LONG AND CONCRETE WEIR 20 FT. LONG	(SEE TYPE OF DAM DESCRIPTION)	(SEE TYPE OF DAM DESCRIPTION)	N.A.	2	11	0.5	N.A.	LAKE LEVEL CONTROL	LAKE LEVEL CONTROL
UNNAMED DAM (TRIBUTARY OF MILWAUKEE R. 1/2 MI. SOUTH OF KEWASKUM)[c]	31	N.A.	T12N R19E SEC 16	1/2 MI. WEST ON CTH-H OFF OF USH-45	MYRON BELGER	EARTHFILL	CONCRETE WITH STOPLOGS	3 BAYS WITH TOTAL CLEAR WIDTH OF 10.5 FT.	1964	3	8	5	N.A.	LAKE LEVEL CONTROL	LAKE LEVEL CONTROL
SCHRAUTH'S MILL DAM (LAKE BERNICE WEST BRANCH) (85.83)	24	20.9	T13N R18E SEC 26	1/4 MI. SOUTH OF CTH-W	TOWN OF ASHFORD	EARTHFILL AND CONCRETE AND MASONRY WITH ROAD-WAY OVER THE TOP.	CONCRETE AND MASONRY WITH WOODEN GATES.	GATES-43 FT. X 5 FT. AND 33 FT. X 6 FT	1840 AND 1924	9	31	33	12	SAW MILL	LAKE LEVEL CONTROL
BATAVIA DAM[c]	267	--	T13N R20E SEC 13	STH-28	FRANKLIN HELD	EARTHFILL	TWO SPILLWAYS- ONE IS A CONCRETE WEIR AND THE OTHER IS A RECTANGULAR CONCRETE OUTLET WITH STOPLOG PLANKS	CONCRETE WEIR - 15 FT. CONCRETE OUTLET- 1.5 FT.	1857 AND 1924	WEIR- 2 FT. OUTLET- 5 FT.	6	1	5	WATER POWER	LAKE LEVEL CONTROL

[a]AREA WHEN IMPOUNDMENT WATER SURFACE APPROXIMATELY AT CREST OF OUTLET STRUCTURE. AREAS OBTAINED FROM DNR LAKE USE REPORTS AND MEASUREMENTS ON 1 INCH = 400 FEET SCALE AERIAL PHOTOGRAPHY.

[b]MAXIMUM DEPTHS OBTAINED FROM DNR LAKE USE REPORTS AND STREAM BED PROFILES.

[c]NO RIVER MILE ESTABLISHED.

[d]THIS MAY BE THE WEST BEND CARP POND IDENTIFIED BY THE PUBLIC SERVICE COMMISSION AS STRUCTURE NO. 66.23, ALTHOUGH THE SECTION IS 11 INSTEAD OF 14. THE CARP POND COULD BE A SMALL POND AT THE JUNCTION OF SILVER CREEK AND ENGMAN CREEK, A TRIBUTARY OF SILVER CREEK.

N.A.- UNKNOWN OR INFORMATION IS NOT READILY AVAILABLE.

SOURCE- HARZA ENGINEERING COMPANY AND SEWRPC.

TABLE 20-B

INSPECTION RESULTS OF DAMS AND LAKE OUTLET CONTROL STRUCTURES IN THE MILWAUKEE RIVER WATERSHED- 1967 AND 1968

STRUCTURE IDENTIFICATION				SUMMARY OF INSPECTION RESULTS[a]						
							SPILLWAY			
STRUCTURE NAME AND RIVER MILE	SEWRPC CONTROL NO.	WIS. DNR NO.	TOWN RANGE AND SECTION	DATE INSPECTED	DIFFERENCE OF WATER LEVELS (FT.)	CONDITION OF DAM	CONDI-TION	OPERA-BILITY	DEPTH OF OVERFLOW	REMARKS
NORTH AVENUE DAM[b] (3.10)	220	40.2	T7N R22E SEC 21	11/27/67 AND 7/10/68	17	GOOD	GOOD	YES	3 IN.	FALLING WATER DID NOT PERMIT INSPECTION OF MASONRY AND DOWN-STREAM CONDITIONS. OVERFLOW SHOULD BE STOPPED TO PERMIT SOUND-ING DOWNSTREAM FOR SCOUR AND INSPECTION OF DOWNSTREAM MASONRY. AT LEAST FOUR CORE BORINGS SHOULD BE MADE THROUGH THE DAM FROM CREST TO FOUNDATION AND PRESSURE TESTED TO PERMIT CHECK OF THE SOUNDNESS OF THE MORTAR AND STRUCTURE. THERE IS NEED TO REPAIR CRACKS AND UNDERMINING OF THE LEFT DOWNSTREAM TRAINING WALL. GATES SHOULD BE MAINTAINED AND OPERATED REGULARLY AND SEAL OF GATES SHOULD BE CHECKED.
ESTABROOK PARK DAM[b] (6.65)	214 AND 215	40.8	T7N R22E SEC 5	7/10/68	7	GOOD	GOOD	YES	NOT ESTIMATED	THE STRUCTURE IS IN TWO PARTS ON EAST AND WEST CHANNELS. THE GATES SHOULD BE MA[illegible]ED AND KEPT OPERABLE. ALSO GATES SHOULD BE OPENED TO EVENLY DISTRIBUTE FLOW AT LOW WATER TO PREVENT POSS-IBLE SCOUR. AN ICE BOOM IS LOCATED UPSTREAM ON THE EAST CHANNEL.
ICE BOOM IN EST-ABROOK PARK UP-STREAM FROM CON-CRETE DAM	213									
KLETZSCH PARK DAM[c] (10.07)	204	40.7	T8N R22E SEC 20	11/27/67	4	GOOD	GOOD	NO CONTROL	NOT ESTIMATED	
THIENSVILLE DAM[b] (19.61)	195	45.1	T9N R21E SEC 23	7/10/68	6	GOOD	GOOD	NO CONTROL	1 IN. TO 2 IN.	
LIME KILN DAM[c] (29.72)	150	45.9	T10N R21E SEC 25	7/10/68	10	GOOD	GOOD	NO CONTROL	2 IN. TO 3 IN.	SOUNDINGS SHOULD BE MADE DOWNSTREAM TO DETERMINE IF ANY SCOUR IS OCCURRING. AT LOW FLOW THERE IS TURBULENT RAPID FLOW WITH A STANDING WAVE JUST DOWNSTREAM FROM THE WEIR.
CHAIR FACTORY DAM[d] (30.10)	149	45.7	T10N R21E SEC 24	7/10/68	15	FAIR	FAIR	NO CONTROL	1 IN. TO 2 IN.	THE CONCRETE ON THE CREST AND DOWNSTREAM FACE OF THE DAM SHOULD BE REPAIRED AS THE REINFORCING STEEL IS EXPOSED ON THE CREST AND THE DOWNSTREAM FACE IS DETERIORATING. WITH THESE EXCEPTIONS, THE DAM APPEARS TO BE IN GOOD CONDITION. SOUNDINGS SHOULD BE MADE TO CHECK FOR POSSIBLE SCOUR.
GRAFTON DAM[b] (30.76)	147	45.8	T10N R21E SEC 24	7/10/68	16	GOOD	GOOD	NO CONTROL	2 IN.	APPEARS TO BE FOUNDED ON LIMESTONE. MILLRACE HAS BEEN FILLED WITH EARTH. SOUNDINGS SHOULD BE MADE TO CHECK FOR EROSION.
WAUBEKA WEIR[c] (45.61)	141	45.6	T12N R21E SEC 28	11/28/67	7	GOOD	GOOD	NO CONTROL	NOT ESTIMATED	SPALLING OF CONCRETE ALONG WEIR CREST SHOULD BE REPAIRED.
NEWBURG WEIR[c] (54.55)	86	66.7	T11N R20E SEC 12	11/28/67 AND 7/31/68	3	POOR	POOR	NO CONTROL	NONE	A PART OF THE WEIR HAD BEEN WASHED OUT AT THE TIME OF THE NOVEM-BER 1967 INSPECTION. BY THE TIME OF THE JULY 1968 INSPECTION, THE BREACH HAD BEEN FILLED WITH ROUGH IRREGULAR CONCRETE. IT WAS NOT OBVIOUS IF CONCRETE COVERED OTHER MATERIAL. PIPING AT THE RIGHT ABUTMENT SHOULD BE INVESTIGATED. SEALING MAY BE REQUIRED. THE MILLRACE IS OPERATED DURING LOW FLOW AND IS IN GOOD CONDI-TION.
WOOLEN MILLS DAM[c] (65.19)	83	66.14	T11N R19E SEC 13	11/27/67 AND 7/31/68	14	FAIR TO POOR	FAIR	POOR	NOT ESTIMATED	REASON FOR SEEPAGE THROUGH FILL ADJACENT TO LEFT END OF SPILLWAY SHOULD BE INVESTIGATED BY CUTTING BRUSH TO EXPOSE DAM EMBANKMENT AND DRILLING AND SETTING OBSERVATION WELLS. THE SEEPAGE MAY BE DUE TO A CRACK AT THE UPSTREAM JUNCTION OF THE LEFT WINGWALL AND DAM, SEEPAGE THROUGH FILL, OR SEEPAGE THROUGH THE LEFT DOWNSTREAM TRAINING WALL. SOUNDINGS SHOULD BE MADE TO CHECK EROSION OF CHANNEL AT THE APRON AT THE DOWNSTREAM END OF THE STILLING BASIN. FOLLOWING DETAILED INVESTIGATION, REPAIRS SHOULD BE MADE. MAIN-TENANCE AND REPAIRS TO GATES SHOULD INCLUDE TRUNIONS AND COUNTER-WEIGHTS. WINGWALLS SHOULD BE REPAIRED. WATER SHOULD NOT BE AL-LOWED TO FLOW OVER THE TOP OF TAINTER GATES.

TABLE 2C-B (CONTINUED)

STRUCTURE IDENTIFICATION				SUMMARY OF INSPECTION RESULTS[a]						
							SPILLWAY			
STRUCTURE NAME AND RIVER MILE	SEWRPC CONTROL NO.	WIS. DNR NO.	TOWN RANGE AND SECTION	DATE INSPECTED	DIFFERENCE OF WATER LEVELS (FT.)	CONDITION OF DAM	CONDITION	OPERABILITY	DEPTH OF OVERFLOW	REMARKS
WEST BEND DAM[c] (66.92)	77	66.13	T11N R19E SEC 11	11/27/67 AND 7/31/68	7	GOOD	FAIR	FAIR	NOT ESTIMATED	POOL DRAWN DOWN 4 TO 5 FEET IN NOVEMBER 1967. SOUNDINGS SHOULD BE MADE DOWNSTREAM TO CHECK SCOUR.
BARTON DAM[c] (68.26)	59	66.1	T11N R19E SEC 1	11/28/67 AND 8/1/68	11	FAIR	FAIR	POOR	1 IN.	CONCRETE SPALLING AT CREST AND BOTTOM OF WEIR SHOULD BE REPAIRED. GATE HOISTS NEED MAINTENANCE AND REPAIR. SOUNDINGS SHOULD BE MADE TO CHECK FOR SCOUR.
YOUNG AMERICA DAM[c] (69.33)	56	66.2	T11N R19E SEC 2	11/28/67	<1	FAIR	POOR	NO CONTROL	NOT ESTIMATED	CONCRETE BADLY SPALLED IN SOME AREAS NEEDS MAINTENANCE. STREAM IS DIVIDED INTO TWO MAJOR CHANNELS DOWNSTREAM. VEGETATIVE GROWTH AT UPSTREAM SIDE OF WEIR INDICATES THAT FLOW INFREQUENTLY OVERTOPS THE WEIR.
KEWASKUM DAM[c] (76.86)	30	66.17	T12N R19E SEC 9	11/28/67	3	GOOD	GOOD	GOOD	NOT ESTIMATED	THE STRUCTURE GENERALLY APPEARS TO BE IN GOOD CONDITION. HOWEVER, LOCAL OFFICIALS REPORTED THAT CONSIDERATION IS BEING GIVEN TO DEVELOPING BETTER SEAL OF THE STEEL STOP PLATES TO REDUCE LEAKAGE.
CAMPBELLSPORT DAM[c] (87.74)	6	20.12	T13N R19E SEC 18	11/28/67	12	GOOD	GOOD	GOOD	NOT ESTIMATED	SOUNDINGS SHOULD BE MADE TO CHECK FOR SCOUR.
HAMILTON DAM[c] (29.07)	191	45.3	T10N R21E SEC 35	11/27/67 AND 7/10/68	6	FAIR	POOR	NO CONTROL	1/2 IN.	RIGHT WINGWALL NEEDS REPAIR. THERE IS SOME DETERIORATION OF CONCRETE OF THE LEFT WINGWALL AND CREST OF THE WEIR. THIS CONDITION SHOULD BE REGULARLY INSPECTED TO DETERMINE WHEN REPAIRS MAY BE REQUIRED.
WIRE AND NAIL FACTORY DAM[c] (31.28)	187	45.5	T10N R21E SEC 26	11/27/67 AND 7/10/68	24	POOR	POOR	NO CONTROL	NONE	ALL FLOW WAS BEING DIVERTED THROUGH THE MILLRACE FOR USE IN PRODUCTION OF ELECTRICAL POWER. THE DAM IS A CRIB STRUCTURE WITH A CONCRETE FACING DOWNSTREAM AND CLAY AND GRAVEL FILL UPSTREAM. STABILITY OF THE DAM IS PROVIDED BY THE CRIB WHICH HAS TO WITHSTAND THE PRESSURE OF BOTH FILL AND WATER. CONDITION OF THE CRIB IS NOT KNOWN. AT TIME OF INSPECTION, THE OWNER WAS PREPARING TO UNDERTAKE REPAIR OF PIPING THROUGH THE RIGHT SIDE OF THE DAM. A MEDIUM-SIZED TREE ON THE RIGHT BANK SHOULD BE REMOVED. THE PLUNGE POOL SHOULD BE SOUNDED FOR POSSIBLE SCOUR AT THE TOE OF THE DAM.
COLUMBIA MILLS DAM[c] (31.59)	186	45.2	T10N R21E SEC 26	11/27/67 AND 7/10/68	10	POOR	POOR	NO CONTROL	NOT ESTIMATED	THE DAM IS A CRIB STRUCTURE WITH CONCRETE FACING AND FILL ON THE UPSTREAM SIDE. CONDITION OF THE CRIB WHICH SUPPORTS THE STRUCTURE IS NOT KNOWN. THE CREST OF THE DAM IS IN BAD CONDITION AND NEEDS DEWATERING, INSPECTION, AND REPAIR. SOUNDINGS SHOULD BE MADE.
RUCK DAM[c] (32.32)	183	45.4	T10N R21E SEC 27	11/27/67 AND 7/10/68	10	GOOD	GOOD	NO CONTROL	1 IN.	THE WEIR OVERFLOW SECTION APPEARS TO BE MASONRY OR CRIBBING. HOWEVER, WATER IMPINGING ON DOWNSTREAM FACE COULD BE LEAKAGE. FLOW SHOULD BE DIVERTED TO PERMIT INSPECTION OF THE DOWNSTREAM FACE. SOUNDINGS SHOULD BE MADE.
WOOLEN DAM[c] (32.65)	180	45.1	T10N R21E SEC 27	11/27/67 AND 7/10/68	10	GOOD	GOOD	NO CONTROL	1/2 IN.	AN INSPECTION AND SOUNDINGS SHOULD BE MADE TO CHECK FOR POSSIBLE EROSION ALONG THE RIGHT BANK TRAINING WALL AND THE DOWNSTREAM TOE OF THE DAM. THE FOUNDATION OF THE DAM IS APPARENTLY ROCK AS THERE IS AN OUTCROP DOWNSTREAM.
MAYFIELD DAM[c] (52.73)	162A	66.5	T10N R19E SEC 13	7/31/68	10 FT. DROP	GOOD	GOOD	NO CONTROL	NOT ESTIMATED	THIS STRUCTURE IS A SERIES OF FOUR DROPS TOTALING 10 FEET OVER A DISTANCE OF 80 FEET. THERE IS NO IMPOUNDMENT, JUST VERY SMALL SHALLOW POOLS AT EACH STEP. IT WAS DESIGNED AS A FISH HATCHERY.
SCHWEITZER DAM[c] (54.23)	159	66.25	T10N R19E SEC 14	7/31/68	7-10	GOOD	GOOD	GOOD	NOT ESTIMATED	THE OWNER REPORTED THAT SEVERAL YEARS AGO THE CEDAR LAKES' CONTROL STRUCTURES WERE OPENED TWICE WITHOUT ADVANCE WARNING, AND THE EMBANKMENTS ABUTTING THE SPILLWAY WERE BREACHED. SOUNDINGS SHOULD BE MADE DOWNSTREAM FROM THE SPILLWAY TO CHECK FOR POSSIBLE SCOUR.
LENT DAM[c] (55.09)	157A	66.29 WAS 66.6	T10N R19E SEC 15	11/27/67 AND 7/31/68	8	GOOD	GOOD	GOOD-LOW FLOW POOR-HIGH FLOW	NOT ESTIMATED	

TABLE 20-B (CONTINUED)

STRUCTURE IDENTIFICATION				SUMMARY OF INSPECTION RESULTS[a]						
							SPILLWAY			
STRUCTURE NAME AND RIVER MILE	SEWRPC CONTROL NO.	WIS. DNR NO.	TOWN RANGE AND SECTION	DATE INSPECTED	DIFFERENCE OF WATER LEVELS (FT.)	CONDITION OF DAM	CONDI- TION	OPERA- BILITY	DEPTH OF OVERFLOW	REMARKS
LITTLE CEDAR LAKE OUTLET[c] (57.40)	154	66.10	T10N R19E SEC 3	11/27/67	1.5	GOOD	GOOD	GOOD	3/4 IN.	THE STRUCTURE IS USED TO CONTROL THE LEVEL OF LITTLE CEDAR LAKE, WHICH IS A NATURAL LAKE.
BIG CEDAR LAKE OUTLET[c] (60.29)	151	66.8	T11N R19E SEC 32	11/27/67	2	GOOD	GOOD	GOOD	3 IN.	THE STRUCTURE IS USED TO CONTROL THE LEVEL OF BIG CEDAR LAKE.
NATURE'S FRIENDS DAM[c] (ON TRIBUTARY TO CEDAR CREEK)[d]	261	66.27	T10N R19E SEC 14	7/31/68	8	GOOD	GOOD	GOOD	NONE	THE DAM IS USED TO CREATE AN OPEN AIR SWIMMING POOL 20 FT. BY 50 FT. THE HEADWALLS AND WINGWALLS AT THE PIPE (2.5 FT. DIAMETER) INLET TO THE POOL ARE IN NEED OF REPAIR.
GOOSEVILLE DAM[c] (61.34)	115	59.8	T13N R21E SEC 17	11/28/67 AND 7/31/68	7	FAIR TO GOOD	FAIR TO GOOD	GOOD	1 IN.	THE EMBANKMENT SPILLWAY AND MILLRACE ARE IN FAIR TO GOOD CONDITION. HOWEVER, THE MILLRACE PRESENTS A DILAPIDATED APPEARANCE DUE TO LOOSE PLANKING.
CASCADE DAM[c] (69.70)	93	59.1	T14N R21E SEC 20	10/18/67 AND 11/28/67	2	GOOD (EMBANKMENT ONLY)	VERY POOR	DIFFI- CULT	N.A.	THE SPILLWAY REQUIRES REBUILDING. IT IS DETERIORATED MASONRY AND CONCRETE STOPPED BY TWO LARGE STOPLOGS AND DUMPED STONE.
ERHLER LAKE DAM[c] (TRIBUTARY TO NORTH BRANCH)[d]	262	66.28	T12N R20E SEC 27	7/31/68	2 DROPS OF 2 FT. EACH	GOOD	GOOD	GOOD	1/2 IN.	
EHNE LAKE DAM[c] (TRIBUTARY OF NORTH BRANCH)[d]	263	66.20	T12N R20E SEC 29	7/31/68	7	GOOD	GOOD	GOOD	NONE	STRUCTURE OBSERVED ONLY FROM THE DOWNSTREAM SIDE.
PONDS EAST OF EHNE LAKE DAM[c,d]	264	66.21	T12N R20E SEC 29	7/31/68	7	GOOD	GOOD	GOOD	NONE	GOOD CONDITION. SOME PIPING NEAR SPILLWAY TO CREEK FROM LOWER POND. OWNER REPORTED AT THE TIME OF INSPECTION THAT HE PLANNED TO DRAIN THE POOL AND PUT SAND AND POLYETHELENE ON THE BOTTOM.
WALLACE LAKE DAM[b,d]	265	66.19	T11N R20E SEC 6	7/13/70	0	GOOD	GOOD	GOOD	NONE	FLOW OCCURS ONLY IN SPRING.
BOLTONVILLE DAM[c] (STONEY CREEK TRIBUTARY TO NORTH BRANCH)[d]	266	66.16	T12N R20E SEC 9	11/28/67	NOT REPORTED	GOOD	GOOD	GOOD	NONE	
RANDOM LAKE DAM[c] (SILVER CREEK TRIBUTARY TO NORTH BRANCH) (64.92)	124	59.21	T13N R21E SEC 26	11/28/67	1	GOOD	GOOD	GOOD	NONE	
TOMBAR DAM[c] (LAKE ELLEN)[d]	111	59.25	T14N R21E SEC 31	4/2/70	0.5	GOOD	GOOD	NO CONTROL	1.5 FT. (IN PIPE)	CONCRETE CRACKED AT DOWNSTREAM END OF THE RIGHT BARREL.
ADELL DAM[c,d]	102		T13N R21E SEC 2	11/28/67	1.5	GOOD	GOOD	NO CONTROL	1/2 IN.	POND IMPOUNDED BY THE DAM IS USED FOR SEWAGE TREATMENT.
CITY PARK DAM[c] (SILVER CREEK WEST BEND) (67.38)	75	66.26	T11N R19E SEC 11	11/28/67	NOT REPORTED	GOOD	GOOD	GOOD	1 IN.	
STONE DAM REGNER PARK[c] (67.51)	73	--[f]	T11N R19E SEC 11	2/4/70	NOT REPORTED	GOOD		NO CONTROL	1 IN.	THE MASONRY OF THE UPSTREAM WALLS IS CRACKED SLIGHTLY.

TABLE 2C-B (CONTINUED)

STRUCTURE IDENTIFICATION				SUMMARY OF INSPECTION RESULTS[a]						
							SPILLWAY			
STRUCTURE NAME AND RIVER MILE	SEWRPC CONTROL NO.	WIS. DNR NO.	TOWN RANGE AND SECTION	DATE INSPECTED	DIFFERENCE OF WATER LEVELS (FT.)	CONDITION OF DAM	CONDI-TION	OPERA-BILITY	DEPTH OF OVERFLOW	REMARKS
PICK DAM[c] (69.96)	64	66.24	T11N R19E SEC 15	11/27/67 AND 7/31/68	8	GOOD	FAIR	GOOD	2 IN.	THE STOPLOGS TO THE INLET BOX ARE ROTTING. THE LEFT DOWNSTREAM WINGWALL OF THE CONCRETE CULVERT UNDER THE ROAD HAS FAILED AND 3 CORRUGATED METAL PIPES FILLED WITH SAND HAVE BEEN USED FOR TEMPORARY REPAIRS. THE INLET BOX AND CONCRETE CULVERT SHOULD BE REPAIRED. THE ROADWAY FILL SHOULD BE MAINTAINED IN WELL-COMPACTED CONDITION TO PREVENT EROSION.
LUCAS LAKE DAM[c] (70.54)	63	66.18	T11N R19E SEC 22	11/27/67	4	GOOD	GOOD	GOOD	1 IN.	
SILVER LAKE DAM[c] (71.93)	62	66.22	T11N R19E SEC 27	11/27/67	<1	GOOD	FAIR	GOOD	NONE	
NEW FANE DAM[c] (EAST BRANCH) (80.48)	46	20.17	T13N R19E SEC 35	11/28/67	8	GOOD	GOOD	NO CONTROL	1 IN.	SOUNDINGS SHOULD BE MADE DOWNSTREAM TO CHECK FOR SCOUR.
MAUTHE LAKE DAM[c] (85.31)	38	20.16	T13N R19E SEC 14	11/28/67	<1	GOOD	GOOD	GOOD	NOT ESTIMATED	
DUNDEE DAM[c] (LONG LAKE) (92.24)	35	20.7	T14N R19E SEC 25	11/28/67 AND 2/4/70	5	GOOD	GOOD	NO CONTROL	1/2 IN.	
UNNAMED DAM[c] (CROOKED LAKE CREEK TRIBUTARY TO EAST BRANCH) (86.27)	42	--	T13N R19E SEC 13	11/28/67	2	GOOD	GOOD	NO CONTROL	1 IN.	
UNNAMED DAM[c] (TRIBUTARY OF MILWAUKEE R. 1/2 MI. SOUTH OF KEWASKUM)[d]	31	--	T12N R19E SEC 16	7/31/68	3	GOOD	GOOD	GOOD	1/2 IN.	ALTHOUGH THE STRUCTURE APPEARS TO BE IN GOOD CONDITION, THERE WAS SOME MINOR CAVING ALONG THE OUTLET PIPE.
SCHRAUTH'S MILL DAM[c] (LAKE BERNICE-WEST BRANCH) (85.83)	24	20.9	T13N R18E SEC 26	11/28/67, 7/31/68, & 2/4/70	9	FAIR	FAIR	GOOD	3 IN.	REPAIRS ARE NEEDED TO THE RIGHT ABUTMENT AND TO THE WINGWALLS DOWNSTREAM AS THEY ARE CRACKED. THE RIGHT CENTER PILLAR NEEDS REPAIR TO THE DOWNSTREAM NOSE. THESE REPAIRS ARE CONTRACTED TO BE MADE IN EARLY 1970. REPAIRS WERE MADE IN OCTOBER OF 1969 TO GATES AND UPSTREAM CONCRETE. CHANNEL WAS CLEARED OF BOULDERS IN 1969.
BATAVIA DAM[d,e]	267	--	T13N R20E SEC 13	9/17/70	WEIR-2 FT. OUTLET- 5 FT.	POOR	POOR	POOR	1 IN.	FLOW AROUND SPILLWAY IS UNDERMINING THE RIGHT BANK, SOME EFFORT HAS BEEN MADE TO SHORE UP THE BANK BUT NOT TO ALLEVIATE THE FLOW.

[a]THE INSPECTIONS WERE PERFORMED VISUALLY. STREAMFLOW WAS NOT PURPOSELY DIVERTED TO FACILITATE INSPECTION. SOUNDINGS AND BORINGS WERE NOT MADE.

[b]INSPECTED BY SEWRPC AND HARZA STAFF.

[c]INSPECTED BY HARZA STAFF.

[d]NO RIVER MILE ESTABLISHED.

[e]INSPECTED BY SEWRPC STAFF.

[f]THIS MAY BE THE WEST BEND CARP POND IDENTIFIED BY THE PUBLIC SERVICE COMMISSION AS STRUCTURE NO. 66.23, ALTHOUGH THE SECTION IS 11 INSTEAD OF 14. THE CARP POND COULD BE A SMALL POND AT THE JUNCTION OF SILVER CREEK AND ENGMAN CREEK, A TRIBUTARY OF SILVER CREEK.

N.A.- UNKNOWN OR INFORMATION IS NOT READILY AVAILABLE

SOURCE- HARZA ENGINEERING COMPANY AND SEWRPC.

surable degree of floodwater storage, although the amount of floodwater storage behind these two dams would be insignificant for flood control use on a watershed basis.

The dams are about equally divided between dams with free overflow weirs and dams with small spillways controlled by stoplogs or gates. Millrace channels, generally abandoned, are associated with the dams. At least 13 of the 48 dams have had to be rebuilt at least once since original construction because of poor maintenance or structural failure.

FUNCTION, CAPACITY, AND PERFORMANCE POTENTIAL OF DAMS

As already noted, the existing dams in the Milwaukee River watershed do not significantly affect flood flows. The lakes and impoundments controlled by the dams do exert a moderating effect on major flood flows on Silver Creek at West Bend, Silver Creek in Sherman Township, the East Branch of the Milwaukee River, and the reach of Cedar Creek upstream from the Village of Jackson; but the effects do not extend very far downstream from the dams and are not significant for the watershed as a whole. Although there are a total of 37 impoundments on the Milwaukee River stream system, only two, both of which are located on the main stem of the Milwaukee River in the City of West Bend, have any potential for floodwater storage. The surface area of the impoundments behind the Woolen Mills and West Bend Dams is approximately equal, totaling 134 acres at low flows. The water surface in these two pools may be expected to rise about seven feet during a 100-year flood, which indicates a total storage potential of about 1,000 acre-feet. If the full 1,000 acre-feet were stored during the initial three-day period of a 100-year recurrence interval flood, the reduction in flood flow would approximate 170 cfs below West Bend, or only about 2 percent of the peak flow, approximating 8,500 cfs.

The water surface area of the 48 impoundments controlled by all the dams in the watershed totals about 3,200 acres, nearly 40 percent of which is enclosed in Little Cedar and Big Cedar Lakes. Only about 10 percent of this total water surface is located in the 14 impoundments on the main stem of the Milwaukee River above the North Avenue Dam. If it were possible to coordinate operations of all of these 14 pools, the peak flow of a 100-year recurrence interval flood at Estabrook Park of 16,000 cfs might be reduced by about 2 percent. Such basin-wide control would be difficult to effect. Moreover, unless properly effected, any attempts to reduce flood peaks downstream by such a small amount could actually result in increases in downstream flood peaks by delaying the peak runoff on the main stem so that subwatershed peaks would coincide and reinforce main stem flows. This is not intended to deemphasize the importance of floodwater storage which exists in the watershed in the form of lakes, wetlands, and floodland areas, in reducing flood peaks, but rather is intended to illustrate the lack of potential of the existing water control structures for use in controlling major floods in the watershed.

Siltation

Those pools controlled by dams which were originally natural lakes are, in general, quite deep; and, since they are located in the headwater areas of the watershed, the annual inflows are relatively small compared to lake volume. Thus, these headwater pools are not subject to significant siltation. Serious siltation has occurred, however, in the impoundments along the main streams in the lower reaches of the watershed. None of the ponds, however, appear to be fully silted to the crest level of the overflow structure. Hydrographic surveys were made of the West Bend and Barton Ponds and of Little Cedar and Big Cedar Lakes in 1968 and 1969.[1] The West Bend Pond has a mid-channel depth of 10 to 14 feet and is generally three to five feet deep along the shoreline. The depths at the channel indicate that essentially no silting of the pond has occurred behind this 14-foot high dam. The Barton Pond is shallow in the broader upstream reaches but is between five and 10 feet deep in the channel from the dam to the head of the pond. The head on the dam is about 12 feet, which indicates a possible silt accumulation of from two to seven feet in depth.

Hydrographic surveys that were made of the impoundment at the North Avenue Dam show a mid-pond channel from eight to 11 feet deep extending upstream from the Dam beyond the bridge at North Avenue. This depth decreases

[1] *Hydrographic maps of the West Bend and Barton Ponds and the 19 other major lakes in the watershed have been prepared and published in a series of lake use reports. Such reports are available on a limited basis from the Wisconsin Department of Natural Resources and the SEWRPC.*

near the banks where pool depths average about two feet. The difference between the water depth at mid-pond and the 17-foot head on the Dam indicates that the depth of silting may be from six to nine feet.

During the course of the field inspections, the pool of the Wire and Nail Factory Dam in the City of Cedarburg was observed while drawn down. There was no evidence of noticeable siltation. The owners stated during the course of a personal interview that the pond was just as deep as it was 30 years earlier when it was about 10 feet deep at a location about 50 yards upstream from the Dam. The area immediately upstream from the Dam had been filled with clay in an attempt to seal the Dam. At Lake Bernice tree stumps were visible when the pool was drawn down. The current manager of the Schrauth's Mill Dam thought that these trees had been cut in 1840 when the first dam was built. Silt had not yet covered the stumps.

The ability of the ponds within the Milwaukee River watershed to remain relatively free of sediment may be attributed to the fact that most of the pools are only one or two times as wide as the natural river rather than to any lack of sediment in the streamflows. The relatively narrow width of the pools prohibits them from functioning as silt traps during high flows when the sediment-carrying capacity of the Milwaukee River system is greatest. In fact, during very high flows, it is possible that accumulated silt may actually be flushed from some of the ponds and carried downstream.

Flow Augmentation

The potential of a reservoir to augment the flow of a stream is determined by the usable storage capacity in the reservoir and the flow in the stream. The annual flow of the Milwaukee River is greatly in excess of the storage capacity available at any existing reservoir on the main stem of the river. Therefore, since refilling the reservoirs during the annual runoff cycle is no problem, the most important factors relating to use of stored water for streamflow augmentation are the severity and duration of low stream flows, the quantity of water in the impoundments, and the effect of withdrawals on the reservoirs and the surrounding shoreland areas.

The West Bend and Barton Ponds at West Bend both have surface areas of 67 acres at low flows. However, the potential of each of these two pools for use for streamflow augmentation are very different. The West Bend Pond (Woolen Mills Dam) stores about 426 acre-feet of water at low flow. The average depth of the pool is about six feet; and the water along the entire shoreline is about three feet deep. A drawdown of three feet would yield about 190 acre-feet of water, which could sustain a flow of about 13 cfs[2] for one week. Such a flow is nearly twice the seven-day low flow in the most recent 10-year period[3] at West Bend.

The withdrawal of 190 acre-feet of water from behind the Woolen Mills Dam would dewater only about 12 percent of the pool area. The withdrawal of an equivalent of volume of water from the Barton Pond (West Bend Dam) would completely empty the pond. A three-foot drawdown would yield about 140 acre-feet of water but would expose mud flats and debris over 50 percent of the pond. Even a one- or two-foot drawdown would tend to expose mudbanks along the shore and severely reduce the area of the pool.

The potential for occasional augmentation of flow along Cedar Creek and the lower Milwaukee River from the Cedar Lakes is much greater than any potential in the remainder of the watershed. Big Cedar Lake is about 105 feet deep, with a volume of about 32,000 acre-feet. Little Cedar Lake is about 56 feet deep, with a volume of 3,150 acre-feet. A one-foot drawdown of these two lakes would yield a flow of about 500 cfs in one day or could be used to raise the discharge of Cedar Creek and the lower Milwaukee River by 17 cfs for a full month. Such discharge is about 17 times the seven-day low flow in the most recent 10-year period on Cedar Creek and would more than double the low flow in the lower Milwaukee River. The percentage of the lake area that would be dewatered is very small. A one-foot drawdown of Big Cedar Lake, however, represents approximately the average annual water yield for the lake

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[2] *One acre-foot of water provides a uniform flow of about one-half cubic foot per second (cfs) for a 24-hour period. This may be visualized as a stream of water one inch deep and three feet wide flowing at the rate of two feet per second, a typical low-flow velocity of a natural stream in the Milwaukee River basin.*

[3] *Chapter RD 2 of the Wisconsin Administrative Code, entitled "Water Quality Standards for Interstate Waters, 1967," states that "...Available water, when used in evaluating compliance with (water quality) standards, will be based on the lowest average dilution for any period of 7 consecutive days in the most recent 10 years...." See also Chapter IX of this volume.*

drainage area after reduction for lake evaporation. Therefore, if the lake were to be drawn down as much as one foot, the lakeside residents would have to be prepared for a fairly long-term exposure of lake bottom. Although it may be concluded that use of these waters should be relied upon only for emergency conditions, the potential for use of these stored waters is considered in the development of alternatives for water quality control in the upstream reaches of the Milwaukee River, as reported in Chapter V of Volume 2 of this report.

INSPECTION RESULTS

Only visual inspections of the existing dams were made as a part of the watershed study by the field inspection team previously referred to herein. No foundation exploration, tailrace soundings, concrete core drilling, or detailed engineering studies were made. The visual inspections, however, were made by a team of experienced engineers, including a supervising engineer of the Foundations, Soil Mechanics, and Geology Division of the Harza Engineering Company, who visited each of the 48 sites, and the Chief Structural Engineer of the Harza Engineering Company, who inspected most of the larger concrete structures, as well as the several structures with sizable gates. The inspections were performed for the purpose of: 1) appraising the present condition of the structures and their probable safety, 2) evaluating the adequacy of the maintenance of the structures, 3) determining the operational capabilities of the structures, and 4) generally evaluating the potential utility of the structures in the development of the land and water resources of the watershed.

Inspections were made during low streamflow conditions. In some cases operators and owners were interviewed to obtain information related to the construction, operation, and maintenance of the structures. In other cases it was possible to interview knowledgeable local residents in order to obtain this information. As might be expected, these interviewees generally could provide construction information only for dams which had been built relatively recently. Rarely were persons available who witnessed the construction of, or alterations to, the older dams. Due to the lack of complete engineering drawings, witnesses, and records as to how the dams were built and on what material the dams were founded, evaluations of dam condition and safety are qualitative and necessarily generalized. For example, the 24-foot high Wire and Nail Factory Dam initially appeared to be made of concrete in good condition. Closer inspection and discussion with the owner, however, revealed that it was of timber crib construction with concrete facing downstream and on the crest and with a clay seal upstream.

Although it was impossible with the information available to make quantitative structural analyses of the dams and thereby make valid judgments on the safety of each structure, the inspected structures did not, in general, appear to be in danger of failure. Several of the dams appear to be founded on rock, and normal high streamflow entails only a few feet of water over the weirs or spillways.

During the course of the field inspections, notes were made concerning the characteristics and condition of the structures. Photographs were taken of the structures to show both general and specific structural features. The information collected in the field inspections of the 48 dams within the watershed is summarized in Table 20-B. Separate reports for each of the dams inspected are retained in the files of the SEWRPC.

In addition, drawings of each structure prepared by the firm of Alster & Associates, Inc., as a part of the hydraulic capacity inventory carried out under the Milwaukee River watershed study, are on file in the Commission offices. Second order bench marks referred to mean sea level datum were established on or near each structure as a part of the inventory in order to accurately tie each structure into a vertical survey control network. Structure drawings and second order bench marks were not obtained for 10 of the 48 dams, such dams being located on minor tributaries not included in the study for flood simulation purposes.[4]

SAFETY OF DAMS

As already noted, all of the dams in the watershed are relatively low, with a head or height of 25 feet or less, with 37 of the 48 dams having heads of less than 10 feet. Failure of any of the dams generally would not be expected to result in significant damage, as the dams impound only

[4] *These 10 dams are: Nature's Friends Dam, Erhler Lake Dam, Ehne Lake Dam, Adell Dam, Ponds East of Ehne Lake Dam, Wallace Lake Dam, Boltonville Dam, Tombar Dam, and Batavia Pond Dam, and an unnamed dam on a tributary of the Milwaukee River one-half mile southwest of Kewaskum.*

small volumes of water at low heads. More serious local damage and possibly some loss of life could be expected with the failure of one of the larger structures. Of the 11 structures with heads exceeding 10 feet, four are singled out for particular comment due to their importance in the hydraulic system of the watershed or due to the current state of repair. These four dams are the North Avenue Dam in the City of Milwaukee and the Woolen Mills Dam in the City of West Bend, both on the main stem of the Milwaukee River; the Wire and Nail Factory Dam in the City of Cedarburg on Cedar Creek; and the Schrauth's Mill Dam in the Town of Ashford, on the West Branch of the Milwaukee River.

The North Avenue Dam in Milwaukee merits special attention because of its height, its location near the central business district of the City of Milwaukee, and its sizable tainter gates. The visual inspection of the North Avenue Dam indicated that the Dam was generally in good repair and safe condition. To properly ascertain the soundness of this Dam, it would be necessary to conduct a more thorough engineering investigation at the site, including stoppage or diversion of flow, drilling and pressure testing of the masonry, and sounding and probing of the streambed upstream and downstream from the Dam.

The visual inspection of the Woolen Mills Dam indicated that, although the Dam does not appear to be in immediate danger of failure, several serious problems have developed which eventually could lead to failure. These problems include seepage in the vicinity of the left abutment, missing counter weights, and heavy brush along the left embankment. It would be necessary, however, to conduct a detailed engineering investigation at the site to ascertain the severity of problems which have developed and the remedial measures required, as well as to evaluate properly the overall safety of the structure.

The Wire and Nail Factory Dam is an ungated, free overflow weir which impounds only a small pool of water of about 20 acre-feet. The Dam is an old timber crib structure with concrete facing downstream, a concrete cap, and a clay seal upstream. Since the Dam depends on the crib for stability, it would be impossible to assess the condition and strength of the Dam by a drilling program. An extensive engineering investigation is not justified, however, as the potential damage from possible failure of the Dam is small. Should the Dam fail, only a small volume of water would be suddenly released into the creek channel, which is deeply incised and undeveloped immediately downstream. Development of cracks in the downstream face of the Dam probably will be a reliable indicator of the onset of failure of the crib. Therefore, it would be desirable to commence a regular schedule of observations of the downstream concrete facing to detect cracking.

The Schrauth's Mill Dam carries a town road across the channel on its crest, and a sudden washout could conceivably cause fatalities. This structure was in a state of poor repair when initially inspected under the watershed study in 1967. In 1969, however, the new owners, Ashford Township, initiated repairs to the gates and upstream walls, with technical assistance from the Wisconsin Public Service Commission. Further repairs to the downstream walls and piers have been scheduled in 1970. The structure should be in good operable condition following the programmed repairs.

Although the safety considerations and need for repairs for the four most important structures in the watershed have been stressed in this text, repairs which are needed at other dams have been listed in Table 20-B. The comments include particular references to the need for modifications to gates or improvements of access needed at some structures to assure that the gates can be operated during conditions of high flow. Failure of larger gates to operate during a flood can cause overtopping of a structure, with consequent scour and possible failure of the dam or spillway.

While the general safety and reliability of the structures within the watershed is attested to by the fact that many have withstood the test of time, there have been several historic failures of dams within the watershed. None of these failures are known to have resulted in loss of life, but one spectacular failure resulted indirectly in considerable property damage. The failure in 1866 of the timber dam in the City of Milwaukee which controlled the flow of water into the Rock River Canal resulted in refloating of an abandoned vessel which, in turn, contributed to the destruction or damage to five bridges. Failure of this dam, which was the predecessor to the present North Avenue Dam, was described as follows:

> ... As the flood moved downstream, carrying the dam timbers with great force, five Milwaukee River bridges were damaged or destroyed. Austin describes this disaster as follows: 'The Humboldt bridge was the first to give way. The torrent pulled the hulk of the abandoned vessel ILO out of the mud and hurled it against the Cherry Street bridge, which was set afloat. The old ship then hurtled into the Chestnut Street Bridge, turning it completely around, went on to damage the Oneida Street bridge, and finished its last voyage by breaking up against the Spring Street bridge ....[5]

Another dam located on Silver Creek at West Bend was washed away in the summer flood of 1924. The storm which caused this flood is described in Chapter VI of this volume, entitled "Hydrology." The storm centered over the City of West Bend, with 7.58 inches of rain falling in a 24-hour period ending on August 4. This represents a rainfall equal to about one and one-third times the 100-year event, which is the upper limit normally used as the design criterion for the types of small dams now located in the watershed. Thus, it is not surprising that the failure occurred. No record has been located which would indicate the occurrence of either serious property damage or loss of life due to failure of this dam. Two eyewitness observers of the 1924 flood report that the gated section of the present West Bend Dam on the Milwaukee River failed, resulting in a rapid rise of water in the pond of the Woolen Mills Dam so that water flowed over land into the Woolen Mill factory. No other significant water damage was reported as a result of this failure.

The probable flow conditions and performance of the structures located on the more important streams of the watershed are shown in Table 21. It may be concluded from this table and the results of the field inspections that, since most of the dams in the watershed are relatively low and impound only small volumes of water and since there is generally little development along the streambanks downstream from the dams, failure of the dams would generally not result in significant damage. If failure were to occur, it would probably take place during the heights of a flood. In this case the effect downstream would be hardly noticeable, because the downstream areas would be already extensively flooded. If a sudden failure were to occur during the low-flow season, there may be some damage downstream; and it is possible, though not likely, that someone could be trapped in the stream channel and be drowned. A sudden failure during a period of low flow is unlikely, however, since failure of the dams would most probably be caused by overtopping and excessive scour, conditions which are limited to flood periods.

[5] *Milwaukee River Technical Study Committee, The Milwaukee River, An Inventory of Its Problems, An Appraisal of Its Potentials, 1968.*

PROCEDURES AND COSTS FOR DETERMINING AND MONITORING STABILITY OF DAMS

A program of intensive engineering investigation in order to properly determine the stability and safety of all 48 existing dams within the watershed in accordance with present day engineering standards and practices is not warranted. Such a program would be expensive; and, in view of the diffused ownership pattern of the dams and the low replacement value of the smaller structures, it is doubtful that such an investigation program would lead to a practical program of dam rehabilitation, replacement, or removal. Some structures cannot be altered, and the cost in other cases would be prohibitive.

Detailed engineering investigations should be conducted, however, at two large dams within the watershed. The cost of the necessary engineering investigations would be a small percentage of the total value of the structures. Typical costs that might be incurred in the detailed engineering investigations to properly determine the stability and safety of these two dams are shown in Tables 22 and 23. The $6,700 investigation outlined for the Woolen Mills Dam and the $12,400 investigation outlined for the North Avenue Dam would represent probably 1 percent or less of the replacement value of these structures. The recommended engineering investigations would only determine the problems and needs; the design of corrective alterations and improvements following the investigations would entail costs in addition to those cited for the investigations.

It should be noted that, even after completion of a detailed engineering investigation, including testing and theoretical studies, it often will be difficult to assign a numerical factor of safety to an old dam. Most of these dams were not built to present day specifications, and quality con-

TABLE 21

10- AND 100-YEAR RECURRENCE INTERVAL FLOOD CONDITIONS AT EXISTING DAMS AND LAKE OUTLET CONTROL STRUCTURES IN THE MILWAUKEE RIVER WATERSHED--1967 AND 1968[a]

STRUCTURE					100-YEAR FLOOD EVENT CONDITIONS				10-YEAR FLOOD EVENT CONDITIONS			
		ELEVATIONS (FT-MSL)[c]										
RIVER MILE[b]	NAME	WEIR CREST[d]	PARAPET (LOWEST)[d]	GROUND OR FILL[d]	DISCHARGE (CFS)	ELEVATION (FT-MSL)	DEPTH ON CREST (FEET)	SUBMERGENCE[e]	DISCHARGE (CFS)	ELEVATION (FT-MSL)	DEPTH ON CREST (FEET)	SUBMERGENCE[e]
	MILWAUKEE RIVER											
3.10	NORTH AVENUE DAM..........	595.0	607.0	607.0(+)	16,680	600.8	5.8	NO	10,320	599.2	4.2	NO
6.65	ESTABROOK PARK DAM........	615.4	621.0(-)	621.6(+)	16,440	618.0	2.6	YES	10,130	617.2	1.8	NO
10.07	KLETZSCH PARK DAM.........	623.8	625.0	627.0(+)	16,140	631.3	7.5	YES	9,890	629.0	5.2	YES
19.61	THIENSVILLE DAM...........	654.1	659.2	660.0	15,460	661.0	6.9	YES	9,370	659.0	4.9	YES
29.72	LIME KILN DAM.............	703.6(+)	710.1	706.8(+)	11,900	711.9	8.3	PARTIAL	7,130	710.3	6.7	NO
30.10	CHAIR FACTORY DAM.........	718.4(+)	724.7	724.7(+)	11,850	727.2	8.8	NO	7,100	725.1	6.7	NO
30.76	GRAFTON DAM...............	734.0	--	742.4[f]	11,850	740.2	6.2	NO	7,110	738.8	4.8	NO
45.61	WAUBEKA WEIR..............	782.7	785.2	786.7	12,300	789.0	6.3	YES	6,560	786.6	3.9	PARTIAL
54.55	NEWBURG WEIR..............	840.0(+)	844.9[g]	844.6(+)[g]	9,480	848.6	8.6	YES	5,320	847.1	7.1	PARTIAL
65.19	WOOLEN MILLS DAM..........	866.2[h]	883.1	881.9(+)	8,800	884.4	22.2	YES	4,970	878.7	12.5	YES
66.92	WEST BEND DAM.............	890.4	895.1	897.1	8,580	895.1	4.7	YES	4,840	892.1	1.7	PARTIAL
68.26	BARTON DAM................	904.5	908.7	--	8,580	911.2	6.7	PARTIAL	4,840	909.6	5.1	NO
69.33	YOUNG AMERICA DAM.........	914.6(+)	917.3	917.7(+)	8,220	919.9	5.3	YES	4,640	918.9	4.3	PARTIAL
76.86	KEWASKUM DAM..............	927.9	932.8	929.8	6,600	935.6	7.7	YES	3,710	933.4	5.5	YES
87.74	CAMPBELLSPORT DAM.........	893.8	894.4	995.6	3,920	998.1	4.3	NO	1,860	996.6	2.8	NO
	CEDAR CREEK											
29.07	HAMILTON DAM..............	701.8	705.4	706.2	6,310	708.4	6.6	NO	3,460	706.9	5.1	NO
31.28	WIRE AND NAIL FACTORY DAM.	754.3	758.7	760.0(+)	6,310	761.2	6.9	NO	3,450	759.4	5.1	NO
31.59	COLUMBIA MILLS DAM........	765.8	766.8	--	6,310	771.2	5.4	YES	3,450	770.3	4.5	PARTIAL
32.32	RUCK DAM..................	782.6	786.4	--	6,310	787.3	4.7	YES	3,450	786.3	3.7	NO
32.65	WOOLEN DAM................	794.2	499.1	799.0	6,310	800.1	5.9	PARTIAL	3,450	799.0	4.8	NO
52.73	MAYFIELD DAM..............	909.1	--	--[i]	570	911.0	1.9	NO	210	910.2	1.2	NO
54.23	SCHWEITZER DAM............	970.3	976.7	976.7(+)	580	969.6	--	NO	210	969.0	--	NO
55.09	LENT DAM..................	999.9	1,004.7	1,004.7	580	1,000.9	1.0	NO	210	1,000.3	0.4	NO
57.40	LITTLE CEDAR LAKE OUTLET..	1,016.0	1,018.0	1,017.0(+)	580	1,018.1	2.1	YES	200	1,017.6	1.6	PARTIAL
60.29	BIG CEDAR LAKE OUTLET.....	1,030.5	1,034.0	1,031.2(+)	530	1,033.2	2.7	NO	170	1,031.9	1.4	NO
	NORTH BRANCH											
61.34	GOOSEVILLE DAM............	816.0	818.1	818.0(+)	3,820	822.2	6.2	NO	1,940	820.5	4.5	NO
69.70	CASCADE DAM...............	886.7	888.5	889.5	1,000	889.1	2.4	NO	500	888.3	1.6	NO
	SILVER CREEK (SHERMAN)											
64.92	OUTLET OF RANDOM LAKE.....	868.1	870.2	871.7(+)	120	870.9	2.8	YES	100	870.5	2.4	YES
	EAST BRANCH											
80.48	NEW FANE DAM..............	958.3	959.9	959.9	1,940	960.8	2.5	NO	940	960.2	1.9	NO
85.31	MAUTHE LAKE DAM...........	969.6	970.5	970.5	1,940	976.0	6.4	YES	940	973.5	3.9	YES
92.24	DUNDEE DAM................	1,008.0	1,010.3[g]	1,010.0(+)[i]	550	1,009.7	1.7	NO	110	1,008.1	0.1	NO
	CROOKED LAKE CREEK											
86.26	UNNAMED DAM (SPILLWAY #2).	980.0	--	--	900	989.0	9.0	YES	500	985.5	5.5	YES
	UNNAMED DAM (SPILLWAY #1).	981.1	983.3	--	900	989.0	7.9	YES	500	985.5	4.4	YES
	WEST BRANCH											
85.83	SCHRAUTH'S MILL DAM.......	965.2	--	976.6[j]	3,400	978.5	13.3	NO	1,630	977.6	12.4	NO
	SILVER CREEK (WEST BEND)											
67.38	CITY PARK DAM.............	892.9	896.0	896.0(-)	1,140	898.1	5.2	YES	740	897.2	4.3	YES
67.51	STONE DAM IN REGNER PARK..	894.2	895.0	895.2(+)	1,140	898.9	4.7	YES	740	898.4	4.2	YES
69.96	PICK DAM..................	983.9[k]	985.4	--	640	986.8	2.9	NO	250	986.2	2.3	NO
70.54	LUCAS LAKE DAM............	993.8	997.7	998.2	450	998.7	4.9	NO	175	998.4	4.6	NO
71.93	SILVER LAKE DAM...........	998.5	1,001.9	1,002.6	34	1,001.4	2.9	NO	27	1,000.8	2.3	NO

[a] ELEVATIONS AND DISCHARGES OF FLOODS WERE DETERMINED FOR 38 DAMS AND LAKE OUTLET CONTROL STRUCTURES. FLOOD DISCHARGES AND ELEVATIONS WERE NOT CALCULATED FOR THE FOLLOWING TEN SMALL STRUCTURES LOCATED ON MINOR TRIBUTARIES NOT INCLUDED IN THE WATERSHED STUDY FOR FLOOD SIMULATION PURPOSES: NATURE'S FRIENDS DAM, EHRLER LAKE DAM, EHNE LAKE DAM, ADELL DAM, TOMBAR DAM, PONDS EAST OF EHNE LAKE DAM, WALLACE LAKE DAM, BOLTONVILLE DAM, BATAVIA POND DAM, AND AN UNNAMED DAM ON A TRIBUTARY OF THE MILWAUKEE RIVER ONE-HALF MILE SOUTHWEST OF KEWASKUM.

[b] THE RIVER MILE SHOWN IS THE ACTUAL STRUCTURE LOCATION. WATER SURFACE LEVELS, HOWEVER, ARE FOR SECTIONS APPROXIMATELY 50 FEET UPSTREAM FROM THE STRUCTURES.

[c] ALL ELEVATIONS SHOWN IN THIS TABLE ARE EXPRESSED IN FEET ABOVE MEAN SEA LEVEL, 1929 ADJUSTMENT. A DASH INDICATES THAT THE ELEVATION WAS NOT DETERMINED FROM A FIELD SURVEY.

[d] A (+) OR (-) INDICATES THAT THE GROUND SURFACE SLOPES UP OR DOWN FROM THE GIVEN ELEVATION ADJACENT TO THE STRUCTURE.

[e] SUBMERGENCE COMMENCES WHEN THE WATER LEVEL IN THE DOWNSTREAM CHANNEL RISES TO THE CREST OF THE OVERFLOW CONTROL STRUCTURE.

[f] ELEVATION AT ROAD DOWNSTREAM.

[g] ELEVATION AT MILL RACE.

[h] SILL ELEVATION OF OUTLET STRUCTURE.

[i] STEEP BANKS OR SLOPING.

[j] ELEVATION AT ROADWAY.

[k] BOTTOM OF RECTANGULAR ORIFICE.

SOURCE- HARZA ENGINEERING COMPANY AND SEWRPC.

TABLE 22

COST OF SITE INVESTIGATION AND ANALYSES OF STABILITY
OF THE WOOLEN MILLS DAM IN THE CITY OF WEST BEND

WORK ITEM	ESTIMATED COST
FIELD EXPLORATION DRILL 250 LINEAL FEET IN 10 HOLES, DIG 2 TEST PITS, COLLECT 10 BAG SAMPLES, AND SET 6 OBSERVATION WELLS....	$2,000
LABORATORY TESTING PERFORM 31 TESTS-- 20 FOR GRAIN SIZE DETERMINATION, 10 ATTERBERG LIMITS, AND 1 TRIAXIAL TEST (3 POINTS)....	500
SUPERVISION OF EXPLORATION AND PROBING CHANNEL SIX MAN-DAYS, BOAT RENTAL, TRANSPORTATION, AND PER DIEM..	1,200
OFFICE WORK ANALYSES OF RESULTS AND PREPARATION OF REPORT (EXCLUSIVE OF PRINTING COSTS).........................	3,000
TOTAL	$6,700

SOURCE- HARZA ENGINEERING COMPANY.

TABLE 23

COST OF SITE INVESTIGATION AND ANALYSES OF STABILITY
OF THE NORTH AVENUE DAM IN THE CITY OF MILWAUKEE

WORK ITEM	ESTIMATED COST
FIELD EXPLORATION MOBILIZE BARGE AS DRILLING PLATFORM, RENTAL, AND CREW....	$ 5,000[a]
DRILL 90 LINEAL FEET IN 4 HOLES, PRESSURE TEST FOR 4 HOURS..	2,500
SUPERVISION OF EXPLORATION AND PROBING CHANNEL PROBING UPSTREAM SILT AND DOWNSTREAM CHANNEL, DATA PLOTTING, BOAT·RENTAL, PER DIEM, AND TRANSPORTATION......	800
SUPERVISION OF DRILLING--6 MAN-DAYS, AND TRANSPORTATION AND PER DIEM..	1,100
OFFICE WORK ANALYSES OF RESULTS AND PREPARATION OF REPORT (EXCLUSIVE OF PRINTING COSTS)...........................	3,000
TOTAL	$12,400

[a] IF INITIAL PROBING UPSTREAM REVEALS A POSSIBILITY OF USING MEANS OTHER THAN A BARGE FOR A DRILLING PLATFORM, IT MAY BE POSSIBLE TO REDUCE THIS $5,000 COST TO $2,000.

SOURCE- HARZA ENGINEERING COMPANY.

trol exercised over construction probably varied widely. The explorations are needed to identify areas of distress, such as in areas where seepage, scour, or deterioration is observed, and to ascertain the probable overall deterioration of a structure, particularly a large one. At structures, such as the Woolen Mills Dam, investigations initially may be limited to installation, observation, and interpretation of data from a few observation wells. An even more modest program would involve inspection of the Dam twice a year—once in the fall and once in spring—to monitor changes in seepage, slides, scour, or other signs of distress.

RECOMMENDATIONS

Information and recommendations resulting from the initial inspection of the dams are listed in Table 20-B. Present condition and relative importance of the structures lead to the following specific recommendations:

1. Engineering investigations should be undertaken at the following two dams:

   a. North Avenue Dam—This Dam is owned by the City of Milwaukee. The impoundment serves as a source of water for the St. Regis Paper Company, which utilizes about 1.1 million gallons per day in its operations. The flow of water over the crest of this Dam should be stopped by lowering the pool to permit inspection of the downstream face and to facilitate sounding and probing of the area at the toe of the Dam.

      - Soundings should also be made in the upstream pool.
      - About four holes should be drilled through the crest of the Dam to rock or a minimum of five feet into the foundation. The holes should be pressure-tested to aid determination of the probable soundness of the masonry structure and of the foundation.
      - Cores drilled may be subjected to laboratory tests for quantification of structural properties.
      - Analyses and results of the investigations and recommendations for required repairs should be reported for further action.

   b. Woolen Mills Dam—This Dam is owned by the City of West Bend. Flow of water should be stopped to facilitate sounding and probing of the stilling basin and below the downstream apron.

      - Approximately 10 holes should be bored and two test pits opened to determine embankment conditions and to permit collection of samples for laboratory tests.
      - Approximately six observation wells should be set in the bore holes for monitoring purposes.
      - Analyses and results of the investigations and recommendations for required repairs should be reported for further action.

2. Schrauth's Mill Dam—Repairs to the Dam should be completed. These repairs have been contracted by the Town of Ashford and are to be completed during 1970.

3. It is not considered urgent that an engineering investigation be conducted at the Wire and Nail Factory Dam. However, it is important that the remedial measures noted in the inspection report be executed. These are: that repairs be made to correct piping noted during the inspection and that the large tree growing near the right abutment be removed. It is important that soundings be made downstream twice a year to determine if scour and undermining are endangering the stability of the Dam. The concrete facing on the Dam should be frequently observed for cracking which would indicate probable failure of the wooden crib.

4. All other defects noted in the inspection reports should be remedied.

The implementation of the programs of investigations and repair outlined above should be directed by an engineer qualified in the design, construction, and repair of dams.

In addition to these specific findings, it is recommended that the following general inspection procedures and measures for preventative maintenance be observed:

1. The channel immediately downstream from all structures that maintain a head of 10 feet or more at low flow should be sounded annually to permit determination of scour that could undermine the structure. Preferably, soundings would be made during a low-flow period.

2. Trees and brush should not be permitted to grow on the crest or slopes of embankments or at the abutments of dams. This type of growth should be cut periodically, at least once every three or four years.

3. Any signs of structural distress, such as seepage, slides, or scour, should be carefully monitored and measured by the owner; and any unusual occurrences should be reported to an engineer qualified in dam design, construction, and repair for advice as to the corrective measures required.

4. A routine program for maintaining gates and other movable parts of structures should be observed. Where control is by small stop logs, annual maintenance is adequate. Larger control devices, especially larger tainter gates, should be inspected at least quarterly. Chains, cables, trunions, hoists, and gate seal should all be checked, lubricated, and repaired as required.

5. Gates of structures should be operated so that flow does not overtop the gates and so that flow is evenly distributed downstream to minimize the possibility of scour.

6. All structures with movable parts should be accessible and operable during floods.

The above recommendations represent accepted practice in dam inspection and maintenance. The expense and effort involved is justified whenever public safety is involved or where it is desired to extend the useful life of the existing structures.

CHANNEL MODIFICATIONS

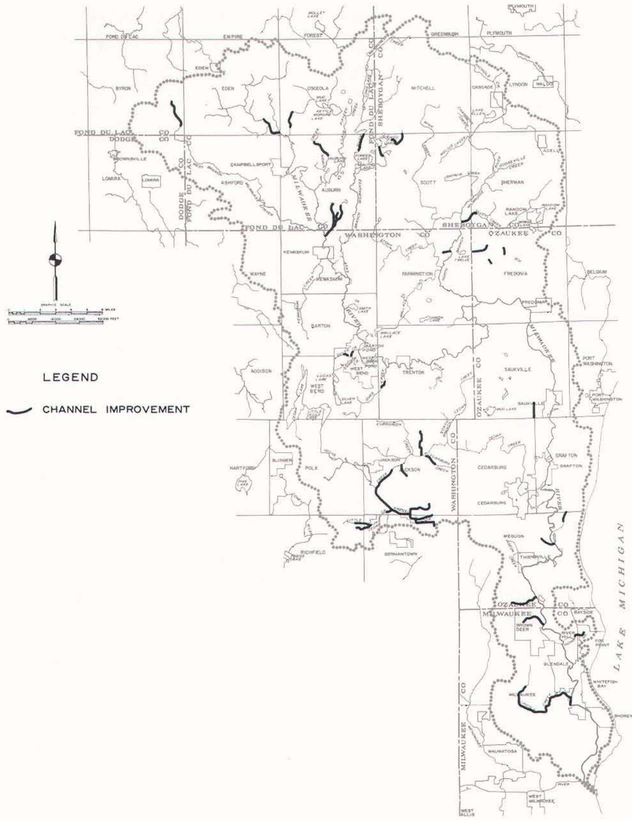
Several miles of the perennial stream system of the Milwaukee River watershed have been intentionally modified in an attempt to improve their hydraulic characteristics. Channel improvement may consist of straightening, deepening, increasing the cross-sectional area, improving the horizontal gradeline, or diking and generally involves all five phases, all of which result in increased velocity of flow and decreased time of concentration. Portions of the Milwaukee River basin were so poorly drained under natural conditions that it was necessary to improve the hydraulic characteristics of the main stream channels in order to provide adequate outlets for agricultural drainage systems, to prevent long periods of inundation in urban areas, and to alleviate conditions which contribute to the formation of ice jams. Because of the individual manner and long period of time over which such channel improvements have been made, it is not possible to determine precisely the history of such operations. It appears, however, that channel straightening and deepening have been carried out through legally organized farm drainage districts, through informally organized citizen action groups, and through individual action since before 1850. The estimated spatial distribution of channel improvements within the Milwaukee River watershed is shown on Map 27 and is summarized in Table 35.

A major program of channel modification of the Milwaukee River was planned and carried out by the U. S. Department of Commerce, Works Progress Administration (WPA), and the Public Service Commission (PSC) of Wisconsin in the Estabrook Park area of the City of Milwaukee. A straight cut of the main Milwaukee River channel was made in the area where the Lincoln Creek tributary joins the main stem of the Milwaukee River. The cut eliminated a bend in the river which retarded streamflow and created problems of flooding both along the main stem and Lincoln Creek, areas which are densely populated. Concrete and masonry-retaining walls also were built along Lincoln Creek to improve its water-carrying capacity and prevent bank erosion.

In 1955 the Milwaukee Sewerage Commissions were given responsibilities for the planning, design, and construction of modifications of natural drainage channels in Milwaukee County, including Lincoln Creek. Modifications have included concreting of the beds and lower slopes of widened stream

Map 27

CHANNEL IMPROVEMENTS
IN THE MILWAUKEE RIVER WATERSHED



As of 1967, approximately 49 miles of stream channel, or 15 percent of the 330 miles of stream channel length in the Milwaukee River watershed, had been subjected to some channel modification or improvement work. Cedar Creek has been subjected to the greatest amount of channel improvement, totaling an estimated 16 miles in length, or about 53 percent of the approximately 30-mile length of the Creek and about 33 percent of the estimated total of 49 miles of channel improvements made within the watershed. Over six miles of urban-type channel improvements have been made along Lincoln Creek by the Metropolitan Sewerage Commission of Milwaukee County.

Source: SEWRPC.

channel reaches, seeding of the higher portions of embankments, and alteration or removal of structures which created significant backwater during high flows. Detailed plans showing these modifications are on file with the Sewerage Commission of the City of Milwaukee. All bridge reconstruction done in conjunction with the channel modifications is the responsibility of the City of Milwaukee or the State of Wisconsin. A channel improvement program is still in progress along Lincoln Creek. Present plans are to widen the channel and to line the streambed between N. 32nd Street and W. Hampton Avenue and N. 63rd Street and W. Hampton Avenue; between N. 55th Street and Thurston Avenue and N. 51st Street and W. Good Hope Road; and between N. 76th Street and Clinton Avenue and N. 59th Street and Clinton Avenue and to modify or replace bridges and culverts at approximately 27 stream crossings in these reaches.

A review of hydrographs and the operation of the flood-routing model described in Chapter XI of this volume, entitled, "River Performance Simulation," indicate that storm water outflow from Lincoln Creek results in sharp, short-based hydrographs. Improved channelization of Lincoln Creek has contributed to this intense runoff pattern. The result is that, although peak flows from Lincoln Creek are now higher than they were before channel modification, they generally do not create flood conditions along the Milwaukee River by their action alone. Since the flows peak very rapidly, the flow from Lincoln Creek is generally in recession when flow from the upstream reaches of the Milwaukee River arrives at the junction of Lincoln Creek and the Milwaukee River. Thus, the channelization of Lincoln Creek has not only reduced flood levels along the urbanized areas of Lincoln Creek but also along the Milwaukee River.

A program of channel modifications in the agricultural area along Cedar Creek in the vicinity of the Jackson Marsh was also initiated during the period in which the WPA and the PSC were executing joint projects. The flow of Cedar Creek spread over a large marshy area, which created poor conditions for drainage in low-lying agricultural lands south of the Village of Jackson. With the straightening and enlarging of the creek channel through the Jackson Marsh, it was possible for improved farm drainage channels to function more efficiently. Even though these modifications undoubtedly have reduced the detention time of floodwaters in the Jackson Marsh, flood routings made under the watershed study show that the storage of floodwaters in the Jackson Marsh continues to reduce significantly high water levels downstream along Cedar Creek. As noted in Table 35, there have been other channel modifications in the watershed; but none of the others have the potential to affect significantly high water flows.

SUMMARY

There are presently 48 man-made water control structures existing in the Milwaukee River watershed. Although most of these structures were built originally as milldams, they are now maintained primarily for aesthetic and recreational purposes. The impoundments are too small to provide any significant reduction of flood peaks along the Milwaukee River, although there is some reduction of flood peaks below the larger natural lakes with controlled outlets. Some of the impoundments have minor potential for augmentation of streamflow. Structural and operational defects of the dams were noted during reconnaissance-type field inspections conducted under the watershed study. Although the inspectors were handicapped in their inspections due to a lack of information concerning foundation conditions, construction materials, construction procedures, and underwater condition of the various structures, it was possible to identify many structural and operational problems, as summarized in Table 20-B of this chapter. The inspection revealed that the most probable consequence of failure of a dam would be development of unaesthetic conditions resulting from draining of the reservoir. It is conceivable, however, although not likely, that serious loss of property and even loss of life could occur with the failure of any of the larger structures. Four of the larger structures—North Avenue Dam, Woolen Mills Dam, Schrauth's Mill Dam, and Wire and Nail Factory Dam—were singled out for special comment, either due to their current state of poor repair or due to their importance and location in the watershed. Estimates of costs that would be incurred in an adequate detailed engineering investigation to obtain data for stability analyses of two of the larger structures, in this case the North Avenue and Woolen Mills Dam, were prepared; and general procedures for owner inspection of dams and measures for preventative maintenance were outlined.

It is extremely difficult to make a meaningful, quantitative evaluation of the overall effect which all existing channel modification projects have had on the surface water characteristics of the Milwaukee River watershed as a whole. Channel modifications have been effected in several areas of the watershed, but only two programs—those along Lincoln and Cedar Creeks—are of any significance to flows in the main channel system. Because of the large amount of natural storage which still exists within the main channel system of the watershed, the net effect of these improvements on the flow regimen at Milwaukee is hardly measurable. Nevertheless, the basic changes that have affected peak flows along Cedar Creek and Lincoln Creek are very real. In the Cedar Creek subwatershed, channel modifications have made possible the drainage of farmland, with the probability that downstream flood peaks are somewhat higher. The channel improvements along Lincoln Creek, which have reduced flood damages along and above the improved reaches, cause staggering of this tributary peak with the peak on the Milwaukee River and have actually decreased the combined discharge rate. Thus, these two channel modification programs probably have resulted in opposite effects on flood peaks in the stream reaches immediately downstream.

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Chapter VI

HYDROLOGY

INTRODUCTION

The hydrologic regimen of the Milwaukee River watershed is conditioned by a combination of influences, some natural and some resulting from human activity. As a result of its glacial origin, the land surface is composed of many different soil types with varying influence upon the relationship of rainfall to runoff, evapotranspiration,[1] and ground water recharge. The natural channels with variable slopes and poorly developed drainage patterns and the numerous kettle lakes and wetland areas also reflect the glacial origin of the topography. Many of the natural drainage courses in the river system have been modified in the agricultural areas by tiles and ditches to drain former wetlands and in the urban areas by conversion into storm sewer receptors and wasteways. Urbanization has reduced the rate of ground water recharge and increased the rate of ground water discharge, with attendant localized lowering of shallow ground water levels and the reduction of the ground water contribution to streamflow. Municipal and industrial liquid waste discharges have significantly altered the low-flow regimen of the tributaries and main stem of the river system in the areas of urbanization. Much of the Milwaukee River watershed thus is greatly changed from its natural condition, generally to the detriment of both the quality and quantity of its water resources. The watershed, however, still retains substantial areas in nearly natural condition and presents a significant potential for beneficial land and water resource development.

Comprehensive planning for the wise use and development of the land and water resources of watershed requires knowledge and understanding of the relationships existing between the many natural and artificial factors that together comprise the hydrologic system of the watershed. Because of the interdependence of streamflow, ground water, and land use, any planned modification or development of one facet of the hydrologic system must consider the resultant effects on all others. Only by considering the hydrologic system as a whole can a sound, comprehensive watershed plan be prepared and the water-related problems of the basin ultimately abated.

HYDROLOGIC CYCLE

Water is not a static,but a dynamic, resource. The quantity and quality of water at a particular place within the Milwaukee River watershed may vary greatly from time to time. These variations may occur rapidly or slowly and may occur on the land surface (surface phase), in the ground water systems (subsurface phase), or in the atmosphere (atmospheric phase). Moreover, these variations may involve water in all its states—solid, liquid, and vapor. This pattern of circulation of the water resource from the atmosphere to the land and, by various processes, back to the atmosphere, is known as the hydrologic cycle.

Precipitation is the primary source of all water in the Milwaukee River watershed. Part of the precipitation runs directly off the land surface into stream channels and is ultimately discharged from the watershed; part is temporarily retained in snow packs, lakes and wetlands, in the soil, or on vegetation and is subsequently transpired or evaporated; and the remainder is retained in the soil and the zone of saturation. Some water is retained in the ground water system; but, in the absence of ground water development, most eventually returns to the surface as seepage or spring discharge into lakes and surface channels. This discharge constitutes the entire natural flow of most streams in the Milwaukee River watershed during extended periods of dry weather.

With the exception of the ground water in the deep sandstone aquifer,[2] all of the water on the land surface and underlying the Milwaukee River basin generally remains an active part of the hydrologic system. In the deep aquifer, water is held in storage beneath the nearly watertight

[1] *The term evapotranspiration as used here is defined as that portion of precipitation returned to the atmosphere through direct evaporation and plant transpiration.*

[2] *The term aquifer is defined as a porous water-bearing geologic formation. As used herein it is a relative term designating geologic formations or deposits that contain significant amounts of ground water which can be used as a principal source of water supply.*

Maquoketa shale and is, therefore, taken into the hydrologic cycle in only a very limited way. Except for a direct natural connection through the recharge areas lying west of the watershed, artificial movement through wells and minor natural amounts of leakage through the shale beds provide the only connection between this water and the surface water and shallow ground water resources of the watershed.

Hydrologic Budget

A quantitative statement of the hydrologic cycle, termed the "hydrologic budget," is commonly used to equate the total gain, loss, and storage change of water resources in a watershed over a given time period. Water is gained by a basin from precipitation and surface and subsurface inflow, and water loss occurs as a result of evapotranspiration and surface and subsurface outflow. A change in surface and ground water storage results from an imbalance between inflow and outflow. Quantitative data, however, are normally available for only a few of the many phases of the complex hydrologic cycle. Quantitative measurements compiled for the Milwaukee River watershed include precipitation, streamflow, evaporation, and ground water levels; but the records of even these phenomena are incomplete and of a relatively short duration.

It is convenient, therefore, to express the hydrologic budget on an average annual basis in a simplified form which includes the significant components of the hydrologic cycle. Moreover, since water in the deep sandstone aquifer is taken into the hydrologic cycle in only a very limited way, a hydrologic budget for the Milwaukee River watershed can be developed considering only the surface and shallow ground water supplies.

In its simplest form, the long-term hydrologic budget for the Milwaukee River watershed may be expressed by the following equation:

$E = P - R \pm \Delta S$ in which

E = average annual evapotranspiration and consumptive use losses over the watershed area, expressed in inches of water loss.

P = average annual precipitation on the watershed area, expressed in inches of rainfall.

R = average annual runoff from the watershed area, expressed in inches of runoff.

ΔS = average annual net change in total surface and ground water storage within the watershed area, expressed in inches of storage.

Average annual values of P and R for the Milwaukee River watershed were compiled and averaged for the 30-year normal period, 1931-1960,[3] for use in the computation of the simplified hydrologic budget of the watershed, as follows:

P = 29.4 inches per year

R = 6.9 inches per year, and

ΔS, assumed to be zero inches per year, because the elevation of the water table[4] has not changed significantly over any large areas of the watershed and because there has been no significant change in surface water storage within the watershed.

Therefore,

$E = 29.4 - 6.9 \pm 0 = 22.5$ inches per year.

The four elements which comprise the simplified hydrologic budget for the Milwaukee River watershed are discussed in the following paragraphs:

1. Evapotranspiration: Evapotranspiration of water from surface water bodies, plants, soil, and ground water is an important element of the hydrologic cycle. Human water uses, such as industrial cooling and domestic consumption, also return water to the atmosphere through evaporation and transpiration processes. The long-term average rate of annual water use through evapotranspiration as estimated above is about 22.5 inches for the Milwaukee River watershed, or approximately 77 percent of the annual precipitation.

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[3] *The 30-year period, 1931 through 1960, is the "standard normal" period used by the World Meteorological Organization in the computation of climatological norms and, moreover, represents a period of time readily comparable to the Decennial Census of the United States Climate, prepared by the U. S. Weather Bureau.*

[4] *The term water table is defined as the upper surface of the zone below which all earth materials are saturated and where the body of ground water is not confined by an overlying impermeable formation.*

2. Precipitation: The average annual precipitation over the watershed is estimated to be 29.4 inches, based upon U. S. Weather Bureau records for rain gages located within and adjacent to the Milwaukee River watershed.

3. Runoff: Runoff is generally measured as streamflow and is discussed in detail in the surface water sections of this chapter. Annual runoff from the Milwaukee River watershed, as measured at the Estabrook Park stream gaging station, was computed to average 6.9 inches per year, or about 23 percent of the precipitation.

4. Storage: Change in storage within the watershed has been estimated as zero in the long-term hydrologic budget for the Milwaukee River watershed. While fluctuations in the amount of water are constantly taking place in the form of increasing and decreasing streamflow, lake levels, and shallow ground water levels, no significant long-term change in storage is apparent for the watershed. Concentrated pumpage of ground water has, however, caused local water level declines and has locally affected stream and lake regimens. Regional changes in storage are taking place in the sandstone aquifer beneath the Milwaukee River watershed, although these changes have only a minor effect on the hydrologic budget because of the poor hydraulic connection of this aquifer with the shallow aquifer and, consequently, the surface hydrologic system.

The approximate seasonal distribution of precipitation, evapotranspiration, and runoff in the Milwaukee River watershed is presented in Figure 10. The distributional pattern of precipitation in the watershed, as shown in the figure, results in the lowest values occurring during mid-winter and the highest values during early and late summer. Average annual runoff, however, does not follow this precipitation pattern. Although runoff is directly proportional to precipitation, all other factors being equal, it is inversely proportional to evapotranspiration, which increases during the growing season. This fact, coupled with the accumulative effect of snowmelt, results in 65 percent of the average annual runoff occurring in the six-month period between November 1 and April 30. In contrast, only 38 percent of the average annual precipitation occurs during this same period.

ATMOSPHERIC PHASE

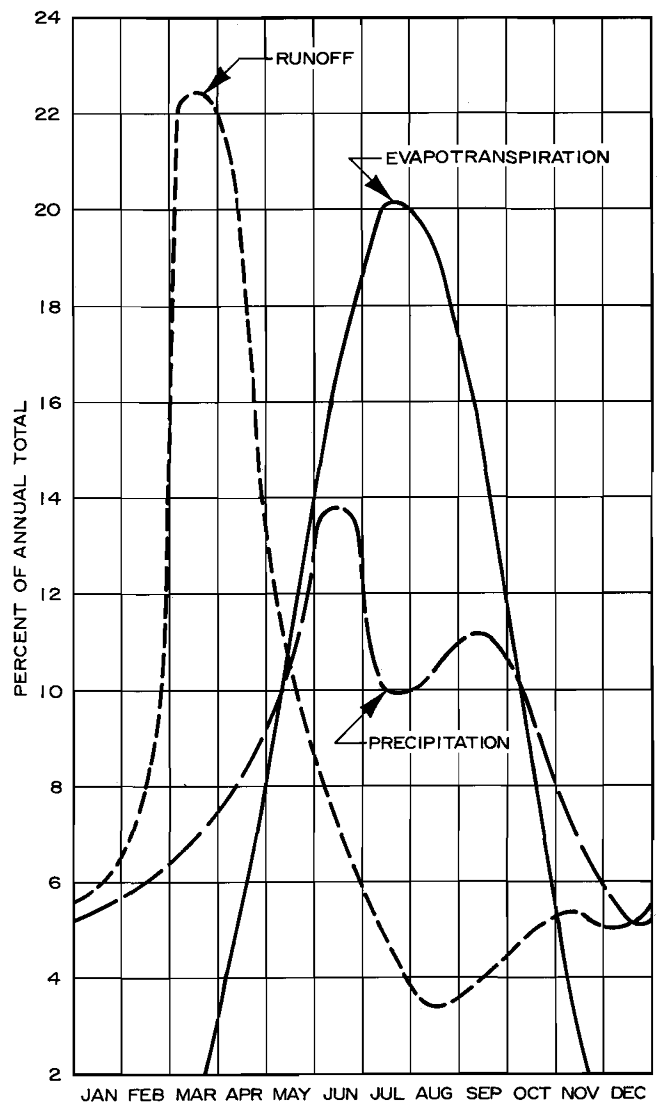
Among the climatic factors that establish the hydrologic features of a region are the amount and distribution of precipitation, the occurrence of snow and ice, and the effects of temperature on evaporation, and snowmelt.

Precipitation

The normal annual precipitation for the Milwaukee River watershed, as represented by the weather

Figure 10

SEASONAL DISTRIBUTION OF PRECIPITATION, EVAPOTRANSPIRATION, AND RUNOFF IN THE MILWAUKEE RIVER WATERSHED



Source: Harza Engineering Company.

observation stations located at Milwaukee, Port Washington, and West Bend, for the period 1931-1960, averaged approximately 29.4 inches. Mean monthly precipitation, based upon weighting by Thiessen polygons, ranged from a minimum of 1.39 inches in February to a maximum of 3.92 inches in June. The normal annual snowfall was about 45 inches. Precipitation and temperature data for these stations are shown in Table 24.

Inventory of Precipitation Data: Sixteen precipitation stations are located within or near the Milwaukee River watershed. Six of these stations are equipped with recording rain gages. Listed in Table 25 are the names of the precipitation stations, the types of gages, and the average annual precipitation. The locations of these stations are shown on Map 28.

Frequency Analyses: As part of the Milwaukee River watershed study, hydrologic criteria for local storm water drainage facility design were established which would be consistent with the design criteria used in the study for the major watercourses of the watershed. In the simulation of river performance under conditions of future land use development within the watershed, it is assumed that local drainage facilities will be designed according to these recommended design criteria. In earlier SEWRPC studies of the Root and Fox River watersheds, rainfall intensity-duration-frequency curves, as reported in the U. S. Weather Bureau Technical Paper No. 25 (TP25),[5] for Milwaukee, Wisconsin, as adapted by the Regional Planning Commission for ready use in urban storm sewer design within the Region, were presented.[6]

The curves were developed from precipitation data collected over the 49-year period extending from 1903 through 1951. Concern has been expressed that several large rainfall events that occurred in the 15-year period of available record since 1951 might change these values if included in the analyses. A review of the rainfall intensity-duration-frequency curves was, therefore, under-

[5] *U. S. Department of Commerce, Weather Bureau, Technical Paper No. 25, Rainfall Intensity-Duration-Frequency Curves for Selected Stations in the United States, Alaska, Hawaiian Islands, and Puerto Rico, December 1955.*

[6] *See SEWRPC Technical Record, Vol. 2, No. 4, "Determination of Runoff for Urban Storm Water Drainage System Design," April-May 1965.*

TABLE 24

MEAN MONTHLY AND ANNUAL PRECIPITATION AND TEMPERATURE DATA AT WEST BEND, MILWAUKEE, AND PORT WASHINGTON

RECORDING STATION	MONTH												ANNUAL
	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	
WEST BEND[a]													
PRECIPITATION (INCHES)	1.69	1.32	2.02	2.53	2.98	3.90	3.45	2.99	3.21	2.21	2.19	1.47	29.96
TEMPERATURE (°F)	20.5	22.0	31.0	45.0	56.3	66.5	71.7	70.1	61.9	51.0	36.2	24.2	46.4
MILWAUKEE[b]													
PRECIPITATION (INCHES)	1.87	1.63	2.40	2.73	3.22	3.52	2.99	2.76	3.10	2.28	2.04	1.75	30.29
TEMPERATURE (°F)	20.4	22.4	31.6	43.6	53.6	63.6	69.5	68.5	61.4	50.4	36.4	25.2	45.6
PORT WASHINGTON[c]													
PRECIPITATION (INCHES)	1.50	1.32	1.81	2.57	2.91	3.52	2.87	2.88	3.00	2.11	2.01	1.46	27.96
TEMPERATURE (°F)	18.5	21.6	32.2	42.1	51.6	61.7	67.8	66.8	60.1	50.7	38.1	24.1	44.6
WATERSHED AVERAGE[d]													
PRECIPITATION (INCHES)	1.73	1.39	2.03	2.36	2.93	3.92	2.86	2.97	3.33	2.07	2.25	1.51	29.35

[a]FIFTY-FIVE YEAR CONTINUOUS TEMPERATURE AND PRECIPITATION RECORDS (1914-1968).

[b]ONE-HUNDRED FIFTEEN YEAR CONTINUOUS PRECIPITATION RECORD (1854-1968). NINETY-EIGHT YEAR CONTINUOUS TEMPERATURE RECORD (1871-1968). STATION MOVED FROM CITY OF MILWAUKEE TO GENERAL MITCHELL AIRPORT IN 1927.

[c]SEVENTY-FOUR YEAR CONTINUOUS PRECIPITATION RECORD (1895-1968). EIGHT YEAR CONTINUOUS TEMPERATURE RECORD (1961-1968).

[d]1931-1960 BY THIESSEN WEIGHTING.

SOURCE- U.S. DEPARTMENT OF COMMERCE, WEATHER BUREAU.

TABLE 25

U. S. WEATHER BUREAU PRECIPITATION STATIONS IN THE MILWAUKEE RIVER WATERSHED AND ENVIRONS

STATION	COUNTY	GAGE TYPE[a]	AVERAGE ANNUAL PRECIPITATION (INCHES)	PERIOD OF RECORD[b] (YEARS)
BURNETT	DODGE	RN	28.70	64
CHILTON	CALUMET	RN	29.76	41
EAGLE	WAUKESHA	R	29.71	20[c]
EL DORADO	FOND DU LAC	RN	27.99	29
FOND DU LAC	FOND DU LAC	N	29.40	83
GERMANTOWN	WASHINGTON	N	27.60	24
HARTFORD	WASHINGTON	RN	30.26	18
MILWAUKEE[d]	MILWAUKEE	RN	30.29	115
		(RN)	(29.51)	(42)
MOUNT MARY COLLEGE	MILWAUKEE	N	30.06	22
PLYMOUTH	SHEBOYGAN	N	28.84	59
PORT WASHINGTON	OZAUKEE	N	27.96	74
SHEBOYGAN	SHEBOYGAN	N	29.83	70
WATERTOWN	JEFFERSON	N	31.49	78
WAUKESHA	WAUKESHA	N	30.62	77
WEST ALLIS	MILWAUKEE	N	29.73	17
WEST BEND	WASHINGTON	N	29.96	55

[a] N = NON-RECORDING
R = RECORDING
RN = RECORDING AND NON-RECORDING

[b] CONTINUOUS RECORD THROUGH 1968.

[c] ALTHOUGH THIS STATION EXISTED PRIOR TO 1949, THE RECORD DURING THOSE YEARS IS INCOMPLETE.

[d] THE STATION AT MILWAUKEE WAS INITIALLY LOCATED IN THE CENTRAL BUSINESS DISTRICT OF THE CITY, BUT WAS MOVED IN 1927 TO GENERAL MITCHELL FIELD AIRPORT. DATA FOR THE PERIOD SINCE 1927 ARE SHOWN IN PARENTHESES.

SOURCE- U. S. WEATHER BUREAU AND SEWRPC.

taken, utilizing the entire period of rainfall records available to the date of the beginning of the Milwaukee River watershed study.

The rainfall intensity-duration-frequency curves for Milwaukee, as published on page 51 of TP25, were derived by application of statistical analyses of frequencies based on a method of determining extreme values proposed by Gumbel.[7] A rainfall frequency analysis was made for at least seven separate series of rainfall values observed during the period 1903 through 1951. The series of values were the maximum rainfall depths that occurred each year during clock periods (durations) of 5, 10, 15, 30, 60, 120, and 1,440 minutes. The rainfall depths for each of the durations were then converted to rainfall depths that would have occurred in 60 minutes, had it rained for 60 minutes at the indicated intensity, for return periods of 2, 5, 10, 25, 50, and 100 years (frequencies).

A similar analysis was made by Harza Engineering Company for the period from 1952 through 1966; and upon request for a check of the results obtained, the U. S. Weather Bureau made analyses using data for the Milwaukee station for the 64-year period of record from 1903 through 1966 and for four 15-year periods from 1907 through 1966.

It was mutually concluded by the Harza Engineering Company and the U. S. Weather Bureau that the values obtained from TP25 for Milwaukee, Wisconsin, would not be significantly changed by including in the analyses data for the additional 15 years of record extending from 1952 through 1966. The plotted points for the 10-year and 100-year return periods, based upon the period of record from 1903 through 1966, indicate no significant change from the points based upon the period of record from 1903 through 1951.

New rainfall intensity-duration-frequency curves, nevertheless, were prepared utilizing the entire 64-year period of rainfall record available for southeastern Wisconsin, extending from 1903 through 1966. These curves are shown in Appendix C of Volume 2 of this report. The new curves are intended to replace those set forth on page 5 of SEWRPC Technical Record, Volume 2, No. 4, "Determination of Runoff for Urban Storm Water Drainage System Design." As noted on page 6 of the above-referenced SEWRPC Technical Record, the curves represent point rainfall and should not be applied to areas larger than 10 square miles in extent. Curves relating the point rainfall depth to rainfall depth over larger areas are provided in SEWRPC Technical Record, Volume 2, No. 4.

Again, for convenience the new rainfall intensity-duration-frequency curves have been presented on two plates—one providing rainfall intensity data for storms of relatively short duration for use in the design of drainage systems having times of concentration ranging up to three hours and the second providing rainfall intensity data for storms of longer duration for use in the design of drainage systems having times of concentration ranging from three to 24 hours.

Evaporation and Evapotranspiration

Annual evaporation from water surfaces, such as lakes and streams, is, within southeastern Wisconsin, about equal to the mean annual precipitation of 29.4 inches. The annual average evapotranspiration, as calculated in the hydrologic budget for the watershed, is about 22.5 inches, or 271 billion gallons. This difference between the potential for evaporation from a free water surface and long-term evapotranspiration over the watershed occurs because evapotranspi-

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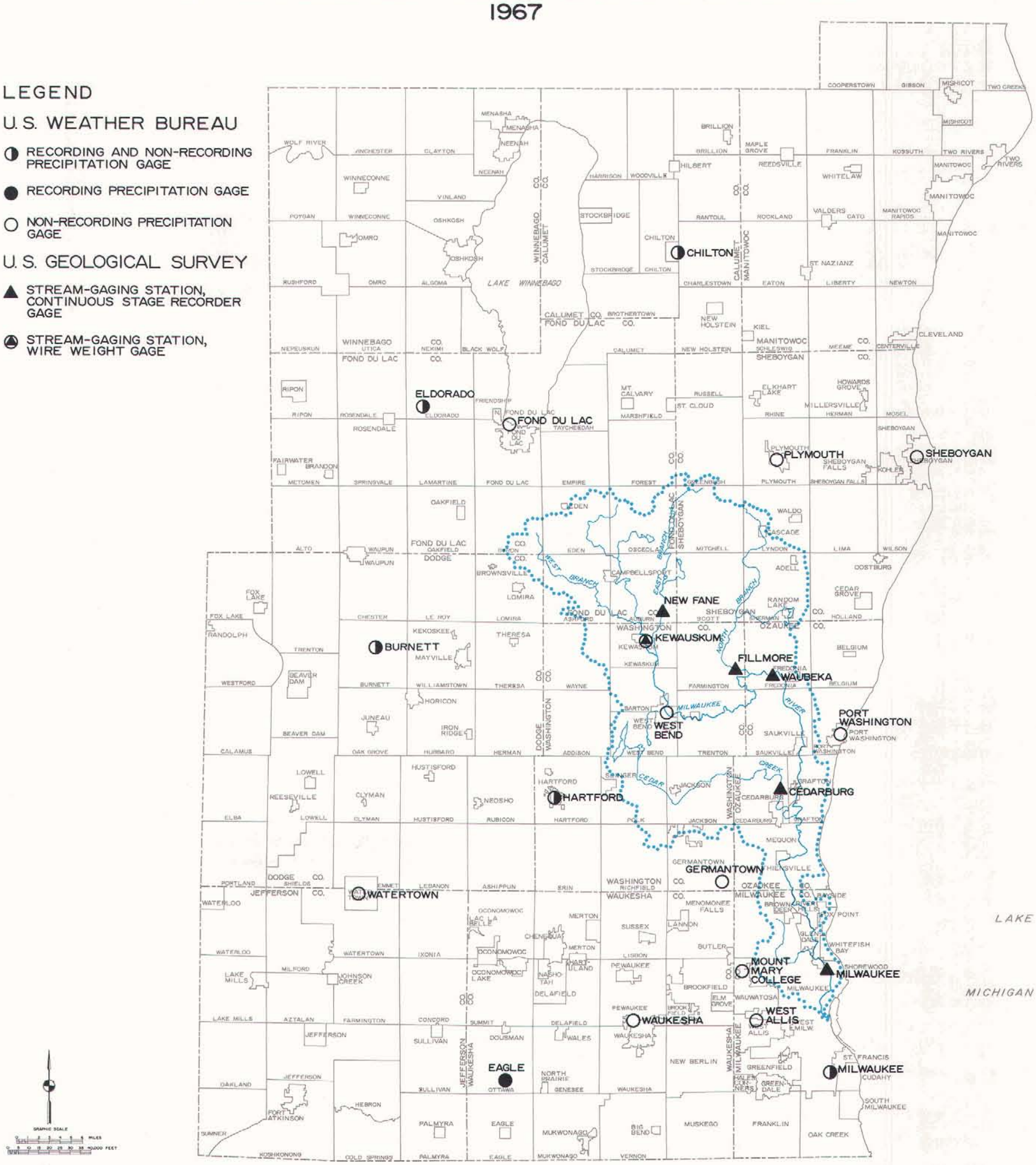
[7] *E. J. Gumbel, "The Return Period of Flood Flows," The Annals of Mathematical Statistics, Vol. XII, June 1941, pp. 163-190.*

Map 28
PRECIPITATION AND STREAM GAGING STATIONS IN THE MILWAUKEE RIVER WATERSHED AND ENVIRONS
1967



Hydrologic information provided from the U. S. Geological Survey stream gaging stations and the U. S. Weather Bureau precipitation stations shown above were used in the watershed study to determine rainfall, runoff, and stream discharges and frequencies. These data were necessary to floodplain delineation and to the design of both alternative flood control and alternative pollution abatement plan elements.

Source: U.S. Geological Survey and Harza Engineering Company.

ration from soils and plants is, depending upon such factors as land use, temperature, available water, and soil conditions, normally less than evaporation from free water surfaces.

SURFACE WATER HYDROLOGY PHASE

Surface water in the Milwaukee River watershed is composed almost entirely of major lake storage and streamflow. Wetlands, flooded gravel pits, and minor lakes and ponds comprise the balance of the surface water but are negligible in terms of the total quantity of surface water in the watershed. Lake storage is the largest of the two major components and exhibits less variation in quantity than does streamflow.

Inventory of Lake Storage

The total quantity of surface water held in the 21 major lakes of the watershed is approximately 58,000 acre-feet; and the combined surface areas of the 21 major lakes total 3,438 acres, or approximately 0.8 percent of the total watershed area. Lake levels fluctuate over time, responding primarily to variations in precipitation surface runoff, temperature, and ground water. No systematic program of monitoring fluctuations in lake levels, however, has been carried out in the watershed.

Inventory of Streamflow

The quantity of streamflow varies widely from day to day, from month to month, and from year to year, responding to variations in precipitation, temperature, land use, soil moisture conditions, the growth cycle of vegetation, and ground water levels. Since the quantity of streamflow is the product of many interrelated hydrologic factors, the most efficient way to determine streamflow characteristics is to measure the streamflow itself.

Prior to initiation of the Milwaukee River watershed study, the U. S. Department of the Interior, Geological Survey, had operated gaging stations in the watershed on the Milwaukee River at Milwaukee and on Cedar Creek near Cedarburg. Continuous streamflow records have been obtained at Milwaukee since May 1914 and at Cedarburg since August 1930. In cooperation with the Regional Planning Commission and the Wisconsin Department of Natural Resources, four additional gaging stations were established within the watershed in 1967 by the U. S. Geological Survey. These gages record flows of the East Branch of the Milwaukee River near New Fane, the North Branch of the Milwaukee River near Fillmore, and the Milwaukee River near Kewaskum and Waubeka. Discharge records were compiled from rating curves based on water stage records observed at gaging points, and discharge measurements made by current meter. The gage at Milwaukee is an automatic, continuous water stage recorder, as are the gages at three of the four new stations, one of the new stations—that at Kewaskum, being a staff gage. The gage on Cedar Creek, which must be operated manually, is a wire weight device and is observed twice daily. Locations of these stations are shown on Map 28. Ideally, a long, continuous streamflow record is required before a representative picture of streamflow can be obtained. Of the stations operated in the Milwaukee River watershed, only the stations at Milwaukee and Cedarburg have records of sufficient length to represent long-term conditions.

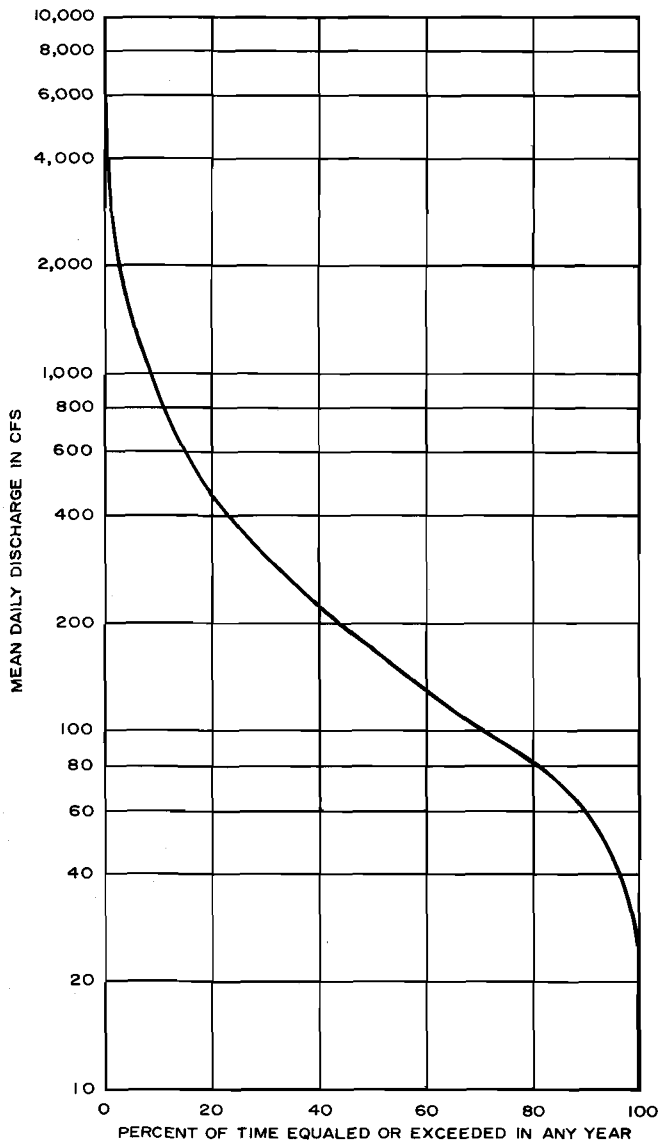
The range of daily variations of streamflow quantity is shown in the flow duration curves in Figures 11 and 12.[8] A flow duration curve is defined as a cumulative frequency curve that indicates the percentage of time that specified discharges may be expected to be equaled or exceeded. For example, the curve developed for the Milwaukee River at Milwaukee indicates that 10 percent of the time the mean daily discharge has been, and may be expected to be, greater than 890 cfs (cubic feet per second). Flow duration curves are most frequently used as an aid in forecasting the availability of specified rates of streamflow. Therefore, they are most valuable when they have been derived from records of sufficient length to include periods of both high and low flow. Curves developed from short periods of record should be used with caution.

The duration curve for the gaging station at Milwaukee was developed using a 46-year period of continuous streamflow record and should be indicative of long-term streamflow characteristics. Recorded mean daily discharges ranged from a maximum of 14,800 cfs to a minimum of 0 cfs. The curve for the station on Cedar Creek near Cedarburg was developed using a 30-year period of record. Recorded mean daily discharges ranged from a maximum of 3,600 cfs to a minimum of 0.2 cfs.

[8] *K. B. Young, Flow Characteristics of Wisconsin Streams, U. S. Department of the Interior, Geological Survey, November 1963.*

Figure 11

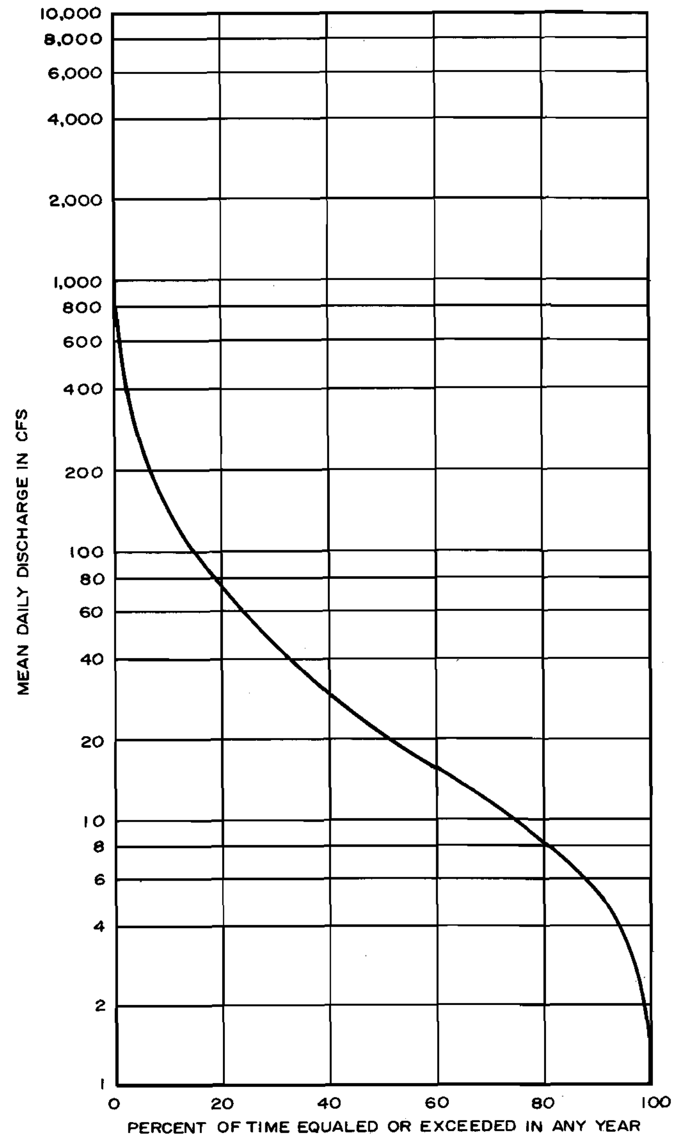
FLOW DURATION CURVES FOR THE MILWAUKEE RIVER AT MILWAUKEE FOR WATER YEARS 1915-1960



Source: Harza Engineering Company.

Figure 12

FLOW DURATION CURVES FOR CEDAR CREEK NEAR CEDARBURG FOR WATER YEARS 1931-1960



Source: Harza Engineering Company.

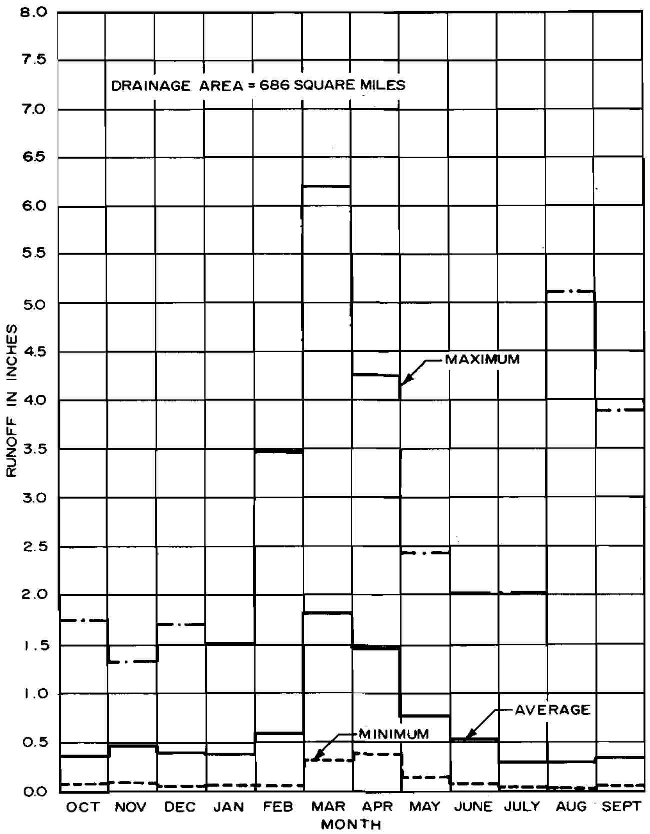
Prolonged periods of high streamflow occur principally in March and April, and minimum monthly runoff generally occurs in July or August. The average, maximum, and minimum monthly runoff amounts for the Milwaukee gage are shown on Figure 13. The average annual runoff at the Milwaukee (Estabrook Park) streamflow gaging station is approximately 381 cfs, or 246 million gallons per day.[9] A similar analysis was conducted for the gage on Cedar Creek near Cedarburg. The average, maximum, and minimum monthly runoff amounts are shown on Figure 14.

[9] *The average annual runoff for the 51-year period, 1915 through 1965, was estimated to be 7.75 inches per year, as compared with 6.9 inches per year for the standard normal period, 1931 through 1960.*

Floods

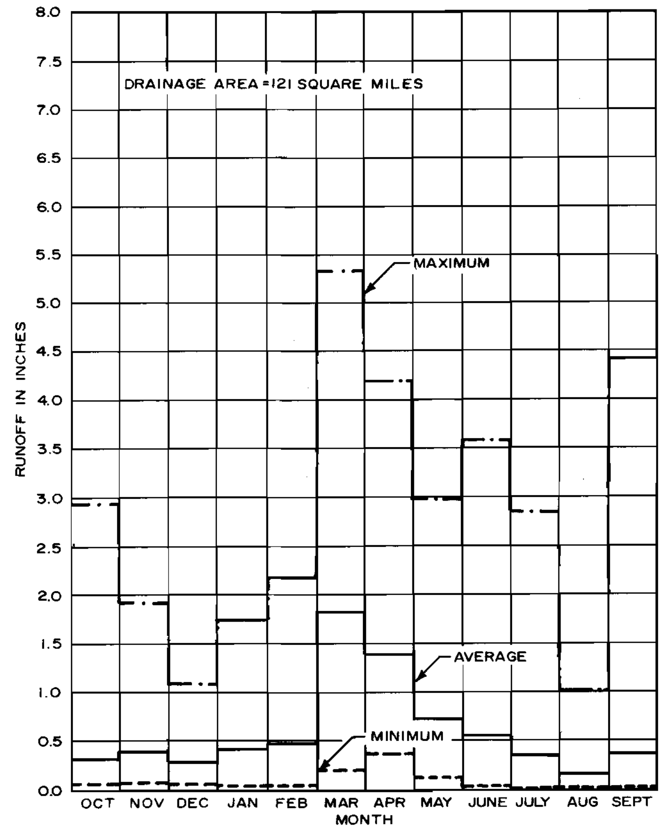
The most important hydrologic characteristics of floods are the probabilities or frequencies of occurrence, the peak rate of discharge, the volume of runoff, and the duration and timing of an event. "Probability" or "frequency" is defined for this purpose as the chance of occurrence, in any year, of a flood equaling or exceeding

Figure 13
MONTHLY RUNOFF FOR THE MILWAUKEE RIVER AT MILWAUKEE FOR WATER YEARS 1915–1965



Source: Harza Engineering Company.

Figure 14
MONTHLY RUNOFF FOR CEDAR CREEK NEAR CEDARBURG FOR WATER YEARS 1931–1965



Source: Harza Engineering Company.

a specified magnitude. Probability may be expressed as a decimal, a fraction, or a percentage. "Recurrence interval" is defined as the average time interval between floods of a given magnitude and is equal to the reciprocal of probability. For example, a flood that would occur on the average of once in 100 years would have a recurrence interval of 100 years and a 1 percent probability or chance of happening in any year.

Frequency Analyses: A long and continuous record of river discharge is the best basis for determination of flood frequency. Discharge records for the gaging stations located on the Milwaukee River at Milwaukee and on Cedar Creek near Cedarburg are of sufficient length to justify probability analyses. Recorded instantaneous maximum discharges for each year were assigned frequencies using the log Pearson Type III statistical procedure.[10] Graphical representation of these relationships is shown in Figures 15 and 16. Discharge values for specific recurrence intervals are listed in Table 26.

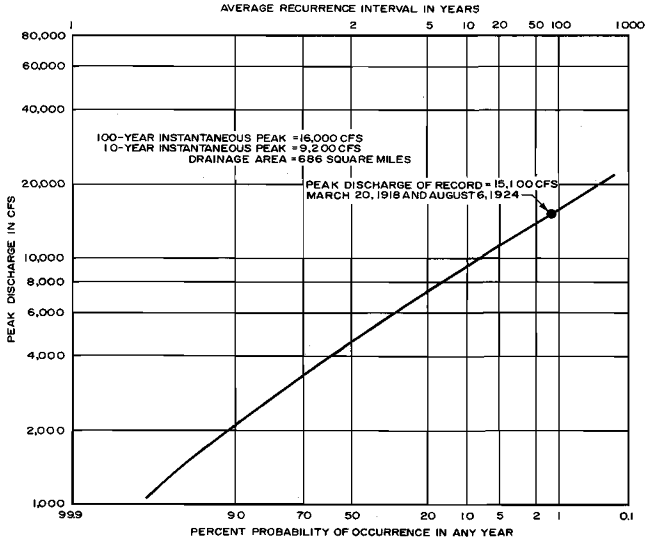
In addition to the peak discharge frequency analyses, volume frequency analyses were made for the Milwaukee River at Milwaukee and for Cedar Creek near Cedarburg. From inspection of actual flood hydrographs, the flood volumes were determined as the amount of water passing the Milwaukee gage in a 12-day period and the Cedarburg gage in a 7-day period. An estimate of base flow was made for each event and was subtracted from the total flood volume. Results of the statistical analyses of these flood volumes are shown graphically in Figures 17 and 18.

Instantaneous maximum flood peaks for 15 major floods for the Milwaukee River at Milwaukee and the corresponding volumes of runoff are tabulated in Table 27. Comparison of the peak discharge and flood volume data listed in Table 27 shows that the five largest annual peak discharge events

[10] *This procedure has been adopted by the Water Resources Council of the U. S. Government as the standard method for preparing frequency analyses of streamflow records.*

Figure 15

PEAK DISCHARGE FREQUENCY FOR THE MILWAUKEE RIVER AT MILWAUKEE FOR WATER YEARS 1915–1965°

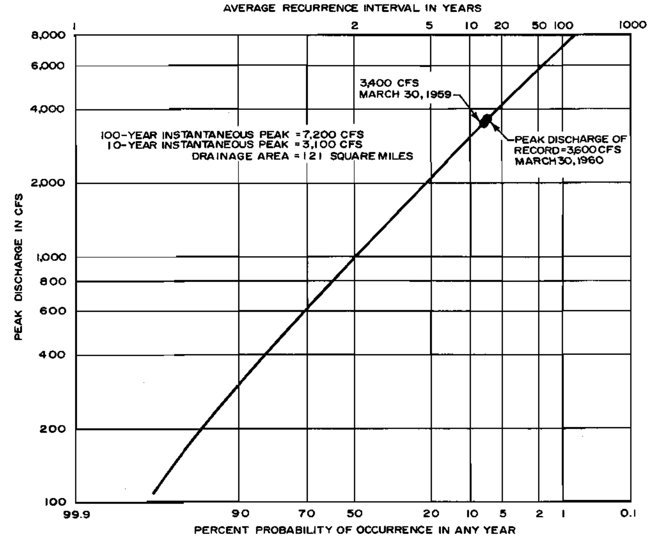


° THE PEAK DISCHARGE FREQUENCY VALUES SHOWN ON THIS FIGURE WERE DETERMINED BY THE LOG-PEARSON TYPE III METHOD.

Source: Harza Engineering Company.

Figure 16

PEAK DISCHARGE FREQUENCY FOR CEDAR CREEK NEAR CEDARBURG FOR WATER YEARS 1931–1965°



° THE PEAK DISCHARGE FREQUENCY VALUES SHOWN ON THIS FIGURE WERE DETERMINED BY THE LOG-PEARSON TYPE III METHOD.

Source: Harza Engineering Company.

which occurred during the 51 years of record were also the five highest annual flood volume events, although not in the same order. As calculated by the frequency analyses described above, the peak discharges for the five events range from 77-year to 8-year flood recurrence intervals. Although spring floods dominate the list of major floods, the summer flood of August 1924 almost exactly equaled the discharge and volume of the largest spring flood of record, which occurred during March 1918. The June 1920 and June 1953 flood volumes may be considered to be conservatively high, as computed by a peak-to-volume relationship based on higher floods; but it is considered that the evidence justifies the use of the peak-to-volume relationship, and that no undue conservatism will result from synthesizing floods on this basis for the 10- and 100-year events. If the technique of using the two frequency analyses jointly were extended to synthesize the 15 major flood events listed in Table 27, only three floods (June 1920, February 1937, and June 1953) would depart significantly either in peak or in volume from the event which actually occurred. The conservatism which would be introduced in synthesizing flood events with such short return periods (one to five years) is relatively unimportant. Inspection of Table 27 shows that these particular events are bracketed by other events with the same frequencies of occurrence that conform very closely with the assumption of joint use of the two separate frequency analyses.

TABLE 26

PEAK DISCHARGE FREQUENCY FOR THE MILWAUKEE RIVER AND CEDAR CREEK FOR SELECTED RECURRENCE INTERVALS

PERCENT PROBABILITY OF BEING EQUALED OR EXCEEDED IN ANY YEAR	INSTANTANEOUS PEAK DISCHARGE	
	MILWAUKEE RIVER AT MILWAUKEE (CFS)	CEDAR CREEK NEAR CEDARBURG (CFS)
1	16,000	7,200
2	13,900	5,800
5	11,100	4,200
10	9,200	3,100
20	7,300	2,200
50	4,600	1,000
90	2,100	300

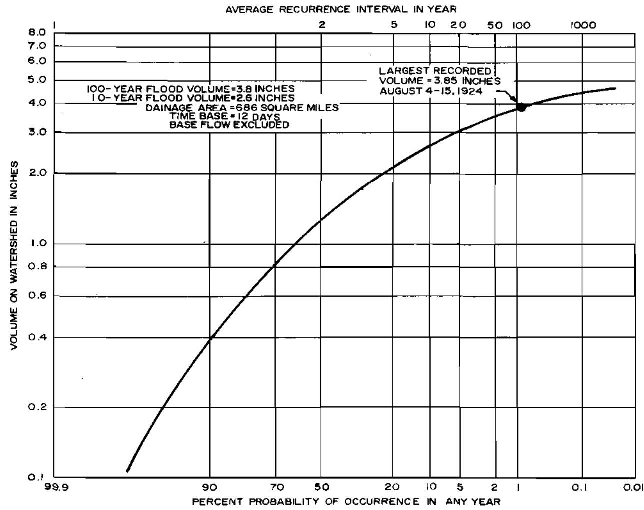
SOURCE- HARZA ENGINEERING COMPANY.

Similar results were found for the 10 major floods for Cedar Creek near Cedarburg, as listed in Table 28. Comparison of the instantaneous peak discharges and flood volume data shows that all but one of the 10 largest annual discharge events which occurred during the 35-year period of record from 1931 to 1965 were accompanied by the annual events of the greatest volumes of runoff, although not in the same order.

The peak discharges for the 10 largest events range from the 14-year to the 3-year recurrence intervals. Since the gage was established in August 1930, the Cedar Creek record does not include the three largest floods of record for the Milwaukee River gage. It is probable that, had the events of 1918, 1924, and 1929 been observed

Figure 17

RUNOFF VOLUME FREQUENCY FOR THE MILWAUKEE RIVER AT MILWAUKEE ANNUAL SERIES FOR WATER YEARS 1915-1965[a]

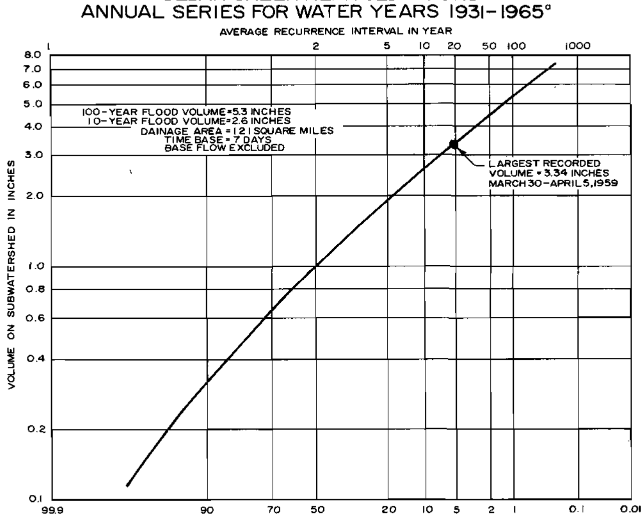


[a] THE RUNOFF VOLUME FREQUENCY VALUES SHOWN ON THIS FIGURE WERE DETERMINED BY THE LOG-PEARSON TYPE III METHOD.

Source: Harza Engineering Company.

Figure 18

RUNOFF VOLUME FREQUENCY FOR CEDAR CREEK NEAR CEDARBURG ANNUAL SERIES FOR WATER YEARS 1931-1965[a]



[a] THE RUNOFF VOLUME FREQUENCY VALUES SHOWN ON THIS FIGURE WERE DETERMINED BY THE LOG-PEARSON TYPE III METHOD.

Source: Harza Engineering Company.

TABLE 27

SELECTED DATA FOR MAJOR FLOODS OF RECORD ON THE MILWAUKEE RIVER AT MILWAUKEE

FLOOD YEAR AND MONTH	MAXIMUM DISCHARGE (CFS)	DISCHARGE RANK[a]	RUNOFF VOLUME[b] (INCHES)	RUNOFF RANK[a]
1924 AUGUST	15,100	1	3.85	1
1918 MARCH	15,100	1	3.67	3
1929 MARCH	11,000	3	3.82	2
1960 MARCH	9,300	4	2.39	5
1959 APRIL	8,780	5	3.43	4
1948 MARCH	8,080	6	1.98	12
1938 FEBRUARY	7,360	7	1.83	7
1923 APRIL	7,060	8	2.09	8
1920 JUNE	7,050	9	0.87	31
1952 MARCH	7,010	10	2.05	10
1937 FEBRUARY	6,640	11	1.38	23
1953 JUNE	6,580	12	0.63	38
1940 JUNE	6,570	13	1.60	16
1933 APRIL	6,370	14	1.43	19
1946 MARCH	6,330	15	1.75	13

[a] FIFTY-ONE YEAR PERIOD, WATER YEARS 1915-1965.

[b] TWELVE-DAY RUNOFF LESS BASE FLOW.

SOURCE- U.S. GEOLOGICAL SURVEY AND HARZA ENGINEERING COMPANY.

TABLE 28

SELECTED DATA FOR MAJOR FLOODS OF RECORD ON CEDAR CREEK NEAR CEDARBURG

FLOOD YEAR AND MONTH	MAXIMUM DISCHARGE (CFS)	DISCHARGE RANK[a]	RUNOFF VOLUME[b] (INCHES)	RUNOFF RANK[a]
1960 MARCH	3,600	1	2.53	5
1952 MARCH	3,500	2	2.30	6
1959 APRIL	3,400	3	3.34	1
1950 MARCH	3,230	4	2.63	3
1940 JUNE	3,180	5	2.59	4
1946 MARCH	3,140	6	1.91	10
1962 MARCH	2,530	7	2.68	2
1965 APRIL	2,000	8	2.16	7
1955 OCTOBER	1,920	9	2.06	9
1948 MARCH	1,610	10	1.78	11

[a] THIRTY-FIVE YEAR PERIOD, WATER YEARS 1931-1965.

[b] SEVEN-DAY RUNOFF LESS BASE FLOW.

SOURCE- U.S. GEOLOGICAL SURVEY AND HARZA ENGINEERING COMPANY.

and included in the analysis, the recurrence interval of the maximum event would have been equal to, or greater than, the period of record.

Historic Floods: Characteristics of the four largest historic floods were analyzed. Two reports, one issued by the State Planning Board of Wisconsin in 1940[11] and a second by the U. S. Army Corps of Engineers in 1964,[12] were drawn upon for source material.

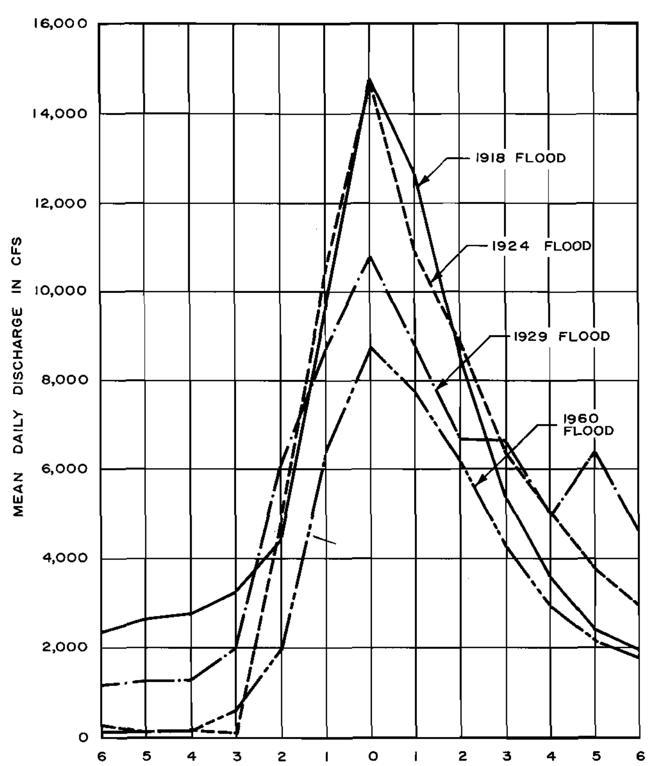
1. Flood of March 1918: The flood of March 1918, when the river reached its highest stage of record, was caused by a combination of snowmelt and rainfall. In January and February 1918, precipitation with a

[11] *Wisconsin State Planning Board Bulletin No. 10, The Milwaukee River Basin, June 1940.*

[12] *U. S. Army Corps of Engineers, Survey Report for Flood Control on Milwaukee River and Tributaries, Wisconsin, November 1964.*

water equivalent of 5.43 inches fell on the basin, mostly in the form of snow. Monthly average temperatures of $10^{o}F$ in January and $22^{o}F$ in February prevented a large portion of this snowfall from melting until March 13 and 14. On these days a total of 0.83 inch of rain fell; and this, combined with the melting of accumulated snowfall due to a temperature rise on March 16, contributed to a rapid increase in runoff. On March 16 the river discharge at Milwaukee was about 3,000 cfs. Four days later the discharge rose to 15,100 cfs and was followed by a rapid recession lasting for about five days. By the sixth day following the peak, the flow had receded to 2,000 cfs (see Figure 19). As noted in Table 27, 3.67 inches of runoff passed the Milwaukee gage during the 12-day period, which began on March 14. Although part of the 5.43 inches of precipitation may have

Figure 19
HYDROGRAPHS OF SELECTED MAJOR FLOODS ON THE MILWAUKEE RIVER AT MILWAUKEE[a]



[a] THE HYDROGRAPHS SHOWN ON THIS FIGURE REPRESENT MEAN DAILY DISCHARGES. THE FOLLOWING ARE THE CORRESPONDING INSTANTANEOUS PEAK DISCHARGES AND DATES OF OCCURRENCE: 1918 FLOOD -- 15,100 CFS, MARCH 20; 1924 FLOOD -- 15,100 CFS, AUGUST 6; 1929 FLOOD -- 11,000 CFS, MARCH 15; AND 1960 FLOOD -- 9,300 CFS, MARCH 31.

Source: Harza Engineering Company.

run off before or after this period, the runoff represents nearly 60 percent of the total of the rain- and snow-water depths.

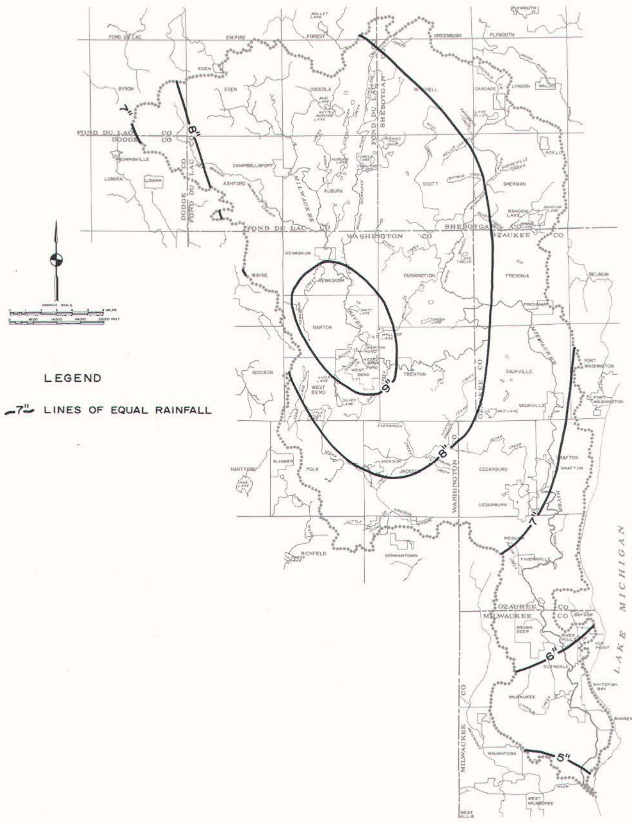
2. Flood of August 1924: The flood of August 1924 was caused by a severe rainstorm. This storm was centered over West Bend, where a total rainfall of 9.31 inches was recorded in a four-day period, of which 7.58 inches fell in a 24-hour period. The rainfall at West Bend occurred as follows:

Date	Inches of Rainfall	Total Accumulated
August 3	0.32	0.32
August 4	7.58	7.90
August 5	1.07	8.97
August 6	0.34	9.31

This flood occurred at a time of year when the capacity of the ground to absorb water is ordinarily at a maximum and when vegetation is normally at its full development. This is indicated by the fact that only 3.85 inches of runoff were recorded at the Milwaukee gage for the 12-day period beginning on August 4. This runoff is about 45 percent of the precipitation depth over the watershed. Map 29 shows the rainfall pattern over the watershed and indicates that the average rainfall for the storm was about eight inches. The Milwaukee River did not begin to rise rapidly until the second day of the storm, August 4, on which day the heaviest rainfall occurred. On August 3 the discharge of the river was relatively low, being only 105 cfs at Milwaukee. On August 4 it had increased to 4,880 cfs. On August 5, the third day of the flood, the discharge rose to 10,700 cfs, passing the flood stage of 5,400 cfs; and on the fourth day, the discharge rose to the peak of 15,100 cfs. Three additional days were required for the flood to subside to a moderate flood stage discharge of 6,400 cfs and about three more days to recede to a moderate discharge of about 3,000 cfs.

3. Flood of March 1929: The flood of March 1929, like the flood of March 1918, was caused by a combination of snowmelt and

Map 29
STORM OF AUGUST 3-6, 1924
OVER THE MILWAUKEE RIVER WATERSHED



The severe flood of 1924 was caused by a four-day rainfall over the watershed of about eight inches, with a high of more than nine inches centered over West Bend, Wisconsin. This unusual rainfall, which occurred in August, resulted in a runoff of 3.85 inches over the watershed and a peak flood flow on the Milwaukee River of 15,100 cfs, as measured at the Estabrook Park gage in Milwaukee, the highest summer flood flow in recorded history. The 1924 flood is estimated to have a recurrence interval of about 77 years. If this flood were to recur under present land use development conditions in the watershed, it could be expected to cause damages totaling about $1.4 million.

Source: U.S. Geological Survey and Harza Engineering Company.

rainfall. During the months of January and February 1929, the cumulative precipitation, mostly in the form of snow, amounted to the equivalent of 4.79 inches of water. The unusually cold monthly average temperatures of 12°F and 19°F, respectively, for these two months support the conclusion that most of this precipitation was held on the watershed until the spring thaw. During the period from March 11 to 16, the mean temperatures rose and remained continuously above freezing. On March 12 and 13, rainfall totaling slightly less than one inch fell on the watershed. Beginning with a discharge of 2,000 cfs on March 12, the river rose to a maximum of 11,000 cfs on March 15; two days later the river dropped to 6,600 cfs and maintained an average discharge of about 5,500 cfs for five more days.

This flood took three days to rise from 2,000 cfs on March 12 to its maximum discharge of 11,000 cfs on March 15, about the same time as the 1918 and 1924 floods previously described. Although the maximum rate of discharge was less than in either of the two previously described floods, the total amount of water discharged during the flood period was approximately equal to that discharged during the August 1924 flood.

4. Flood of March 1960: As described in a 1964 report of the U. S. Army Corps of Engineers:[13]

> ...In the early part of 1960 the snowfall in southeastern Wisconsin was one of the highest of record. During the month of March, there were several snowfalls varying in amounts from one to nine inches. On the 29th the first thunderstorm of the season crossed over the southern and eastern sections of the state. Rainfall at Milwaukee was 0.94 inches and 1.63 inches for the 29th and 30th, respectively. Rainfall at West Bend was 1.50 inches on March 30th. The storm rainfall was not unusually severe but, its occurrence in combination with a sudden thaw over the basin resulted in the fourth highest flood of record on the Milwaukee River.

An isohyetal map of this storm is shown on Map 30.

On March 28 the river discharge at Milwaukee was about 600 cfs. Discharge rose rapidly on March 29 and 30 and peaked at 9,300 cfs on March 31. The discharge receded uniformly, decreasing to 2,100 cfs after five days. Ten days after occurrence of the flood peak, the discharge had subsided to 900 cfs.

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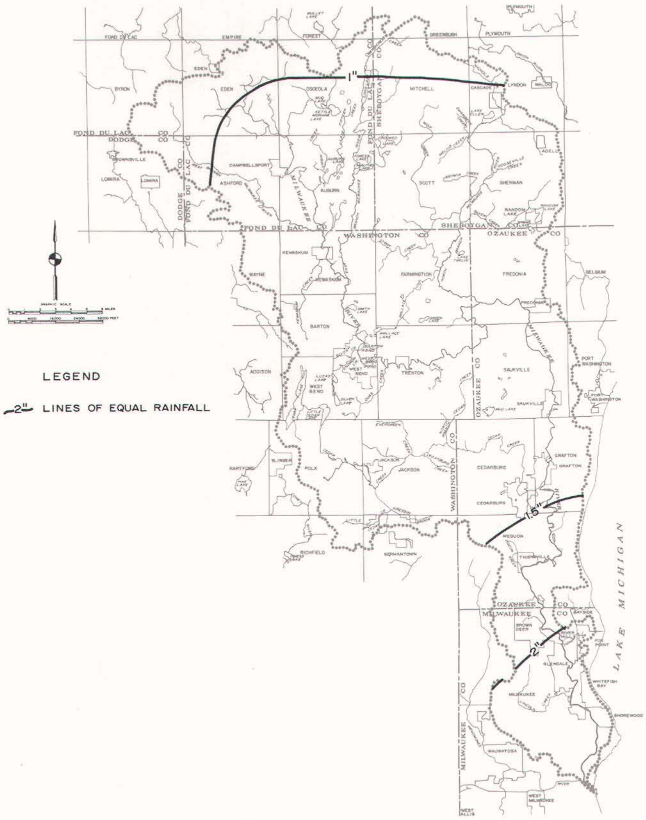
[13] *Ibid, footnote 12.*

Map 30
STORM OF MARCH 29-30, 1960
OVER THE MILWAUKEE RIVER WATERSHED



Although the spring rainfall-snowmelt flood of 1960 was only about a 10-year recurrence interval flood with a discharge of about 9,300 cfs at the Estabrook Park gage in Milwaukee, it caused considerable property damage and created a demand on the part of a segment of the public for flood control facilities to protect the reach from the Village of Saukville to the City of Milwaukee. The March 1960 flood on the Milwaukee River was caused by two days of moderate rainfall occurring simultaneously with a sudden thaw of existing snow cover, producing a runoff equivalent of about 2.6 inches of water.

Source: U.S. Geological Survey and Harza Engineering Company.

Characteristic Duration and Timing of Floods: Analyses of the historic flood events on the Milwaukee River at Milwaukee indicate that the river rises to a maximum discharge two to four days after significant runoff occurs; nearly all the volume of runoff from a storm passes the Milwaukee gage within 12 days; and the ratio of time to peak to time of recession is approximately 1 to 4.[14]

SEDIMENT

The planning of river control structures and the development of measures to control the effects of soil erosion and stream sedimentation on such structures require information on the sources and quantities of sediment being transported.

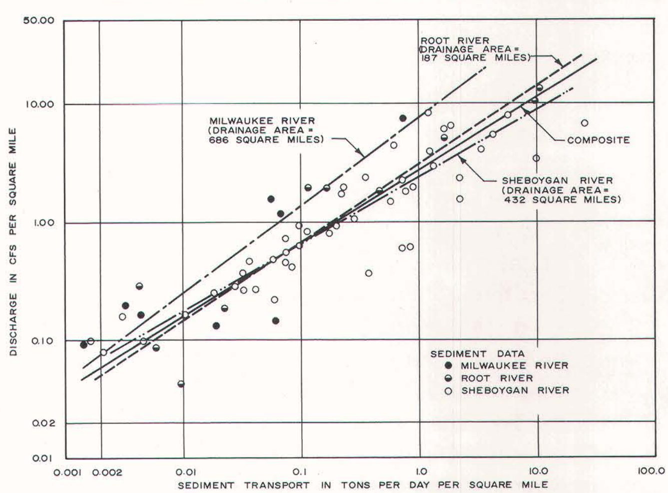
Estimation of Sediment Loading in the Milwaukee River

Eight measurements of suspended sediment transport rates and corresponding river discharges have been made by the U. S. Geological Survey at the Milwaukee River gaging station at Milwaukee. These eight measurements, together with measurements made on the adjacent Sheboygan and Root Rivers, were used as a basis for the estimation of sediment loading in the Milwaukee River basin.

In the analyses, 10 percent was added to each of the measured values of suspended sediment to account for bedload.[15] The adjusted data were reduced to sediment contribution per square mile of drainage area, and the curves shown in Figure 20 were developed. Curves representing the sediment transport capacities of the streams for a range of discharges were fitted graphically to plotted points for each of the three rivers, and a composite curve was drawn based on the plotted data for all three rivers.

The flow duration data for the Milwaukee River at Milwaukee (see Figure 11) was used to derive the yearly sediment transport rate for the Milwaukee

Figure 20
RELATIONSHIP BETWEEN SEDIMENT TRANSPORT AND DISCHARGE FOR THE MILWAUKEE, ROOT, AND SHEBOYGAN RIVERS



Source: Harza Engineering Company.

[14] *See Chapter XII of this volume, "River Performance Simulation," for a definition of terms and discussion of the time distribution of runoff.*

[15] *The term bedload is defined as the coarser sediments which are transported in contact with the stream bottom, as opposed to the finer sediments which are transported in suspension in the streamflow.*

River. Daily discharge rates that occurred during the period 1915-1960 were divided into classes, and the probability of each flow class being equaled or exceeded was determined.[16] The yearly sediment load was calculated by summing the product of days per year that each flow class occurred and the corresponding sediment rate as determined from Figure 20. Table 29 lists the results of these calculations based on the composite sediment transport curve and the flow duration curve for the Milwaukee River at Milwaukee.

As shown in Table 29, the sediment load per square mile is estimated as 16 tons per year using the Milwaukee data only and 61 tons per year using the composite data. Although these results differ substantially, it is considered desirable to use the higher value until more observations of actual sediment loadings on the Milwaukee River have been made.

[16] *Op. cit., footnote 8.*

TABLE 29

ESTIMATED YEARLY SEDIMENT LOAD IN THE MILWAUKEE RIVER WATERSHED

FLOW CLASS	AVERAGE FLOW (CFS)	DAYS PER YEAR	FLOW RATE PER UNIT AREA (CFS / SQUARE MILE)	MILWAUKEE RIVER SEDIMENT LOAD RATE[a] (TONS PER YEAR / SQUARE MILE)	COMPOSITE SEDIMENT LOAD RATE[b] (TONS PER YEAR / SQUARE MILE)
1-10[c]	--	5.91	--	--	--
11	35	7.86	0.051	0.008	0.013
12	45	11.40	0.066	0.018	0.027
13	55	13.48	0.080	0.028	0.044
14	70	30.50	0.102	0.088	0.150
15	90	35.70	0.131	0.146	0.260
16	125	61.20	0.182	0.391	0.765
17	175	35.85	0.255	0.366	0.770
18	225	27.20	0.328	0.395	0.870
19	275	20.90	0.401	0.398	0.961
20	350	28.20	0.510	0.741	1.860
21	450	18.50	0.656	0.685	1.810
22	550	11.93	0.802	0.585	1.610
23	700	15.70	1.020	1.052	3.114
24	900	9.86	1.310	0.917	3.050
25	1,250	13.30	1.820	1.940	6.820
26	1,750	6.36	2.550	1.460	5.810
27	2,250	3.67	3.280	1.190	4.950
28	2,750	2.70	4.010	1.160	5.130
29	3,500	2.24	5.100	1.320	6.050
30	4,500	1.11	6.560	0.920	4.660
31	5,500	0.65	8.020	0.702	3.770
32	7,000	0.48	10.200	0.740	4.120
33	9,000	0.17	13.100	0.370	2.140
34	11,000[d]	0.13	16.050	0.373	2.350
YEARLY TOTAL	--	365.00	--	15.993	61.104

[a]USING SEDIMENT DATA FROM THE MILWAUKEE RIVER ONLY.

[b]USING SEDIMENT DATA FROM THE MILWAUKEE, ROOT, AND SHEBOYGAN RIVERS.

[c]BEYOND THE RANGE OF FIGURE 20.

[d]ASSUMED.

SOURCE- HARZA ENGINEERING COMPANY.

Sediment Loadings in Other Streams

Data have been collected and published for many other streams throughout the United States. Two interagency reports[17] have been published on sediment in streams and sedimentation in reservoirs in the United States. Data in these reports show that the sediment-carrying capacity of streams is extremely variable and that interpretation of the results of observations requires a knowledge of the climate, soils and land use, topography, and geologic and drainage development that prevail in an area.

The annual sediment yield for 35 stations on Wisconsin rivers included in the studies ranges from two to 667 tons per square mile per year, with an average value of less than 100 tons per square mile per year. These data are for streams in all areas of the state except those watersheds drained by rivers flowing to Lake Superior and Lake Michigan. Data are available for several stations located on rivers lying adjacent to the Milwaukee River watershed, which rivers drain areas with similar topographic and land use characteristics. Sediment yield from the 179 square miles of the East Branch of the Rock River near Mayfield, Wisconsin, is 19 tons per square mile per year. This area is very similar to the extreme upper part of the Milwaukee River watershed. The Crawfish River at Milford, Wisconsin drains 732 square miles and yields sediment at the rate of 45 tons per square mile per year; and the Baraboo River near Baraboo, Wisconsin, drains 600 square miles and yields 43 tons of sediment per square mile per year. These two rivers are similar to the Milwaukee River watershed upstream from the Milwaukee gaging station.

Factors Affecting Sediment Yield in the Milwaukee River Watershed

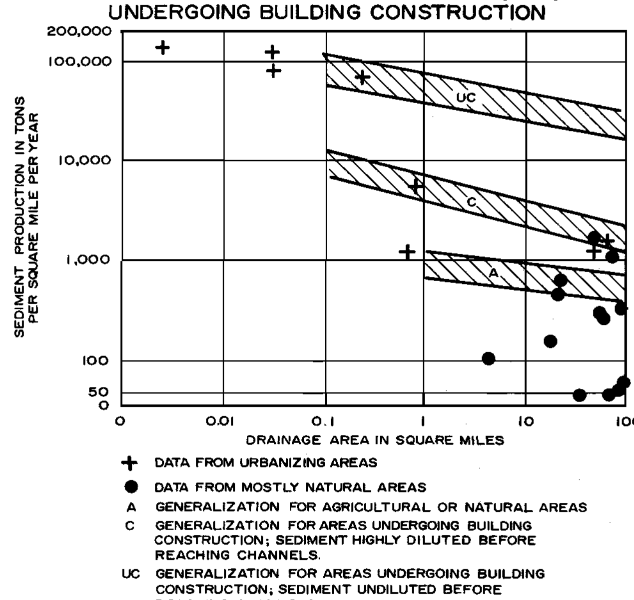
The results of the analyses and comparisons described above indicate that the probable average quantity of sediment transported annually by the Milwaukee River, 16 to 61 tons per square mile per year, is relatively small for such a large stream system in a humid area. The conclusion is reasonable, however, considering the drainage pattern which has developed in this glaciated watershed, the prevailing land use, and the large number of impoundments.

Although some of the lands in agricultural use within the watershed are covered by soils subject to severe erosion, much of the sediment from such lands is trapped and does not reach the main stream system, due to the poorly developed drainage system of the watershed and the presence of numerous wetlands and depressions. The lands covered by permanent vegetation, such as pasture, park lands, woodlands, and wetlands, contribute relatively little sediment to streams.

After land is converted from rural to urban use and fully developed, with established lawns, shrubs, and trees, little erosion occurs. Depending, however, upon soil characteristics and slopes, upon previous land use, and upon construction methods, 500 to 1,000 times as much sediment may be washed away from a single acre of land during construction as from the same land in a stable rural use. Figure 21 summarizes field observations and shows that drainage areas ranging in size from about one to 100 square miles may, on the whole, exhibit a 100-fold increase in sediment production per unit area of land surface during construction activity associated with the transition from agricultural to urban land use. Increases in the steepness and length of land slope, both of which may occur during the urbanization process, increase

Figure 21

SEDIMENT PRODUCTION FROM NATURAL OR AGRICULTURAL AREAS AND FROM AREAS UNDERGOING BUILDING CONSTRUCTION



Source: "Hydrologic Data for Urban Land-Planning," Luna B. Leopold, January 1967.

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[17] *See* *Summary of Reservoir Sediment Deposition Surveys Made in the United States through 1960, Miscellaneous Publication No. 964, Agricultural Research Service, U. S. Department of Agriculture, in cooperation with the Subcommittee on Sedimentation, Inter-Agency Committee on Water Resources, and Draft No. 2 of Appendix G, "Fluvial Sediment in the Upper Mississippi River Basin," U. S. Department of the Army, Corps of Engineers, prepared by an Interagency Task Force on Sedimentation, March 1, 1967.*

the velocity of surface water runoff and thus its erosion potential. By studying field data obtained from a variety of areas, Musgrave[18] quantified the influence of slope steepness and length, concluding that sediment production per unit area of land surface is proportional to slope steepness to the 1.35 power and to slope length to the 0.35 power. Therefore, while both slope steepness and length are important factors, the erosion rate is more highly sensitive to the former. A twofold increase in slope steepness resulting from construction, for example, increases the sediment production per unit area about 2.5 times. From a practical standpoint, land use changes involving construction on slopes over 12 percent are particularly harmful insofar as sediment production is concerned.

In addition to carefully adjusting the kind of urban land use to the ability of the land to accommodate specific urban land uses, especially on steep slopes, several additional measures can be used to minimize the erosion and transport of sediment to stream channels when land is changed from rural to urban use. The amounts of cut and fill in an area can be minimized, tree cutting can be restricted within the construction area, mulching or seeding of exposed surfaces can be required, and a maximum limit can be set for a proportion of a given area which can be exposed, that is, stripped of ground cover at any one time. Even with application of such measures, however, some sediment still will be carried away from development sites. To prevent it from reaching the streams in the watershed, buffer zones adjacent to the areas under urban development should be kept in woods or meadows to catch sediment as spring snowmelt and severe storm water runoff carry it over land.

Sediment Effects in the Watershed

The potential for the Milwaukee River system to decrease storage through deposition of silt in potential large impoundments is very small. The probable loss of storage in three potential reservoirs at the Horns Corners, Newburg Diversion, and Waubeka sites is discussed in Chapter III, Volume 2, of this report. Even the small existing impoundments located on the major streams in the watershed have not been subject to any severe siltation, even though most of the dams were constructed many years ago. This subject is further discussed in Chapter V of Volume 1 of this report.

[18] *G. W. Musgrave, "The Quantitative Evaluation of Factors in Water Erosion - A First Approximation," Journal of Soil and Water Conservation, Vol. 2, No. 3, 1947, pp. 133-138.*

Even though sediment transport in the main river is small, the potential exists for the development of local siltation problems. Particularly on smaller tributary streams, siltation may be caused by temporary poor soil conservation practices during urban development and highway construction operations. Silt bars also can develop in the main stream system due to poor farming and construction practices and due to the erosion of unstable stream banks and reworking of streambed sediments. Such problems are usually transitional and cannot be quantified on the same basis, as can the effects of the long-term sediment-carrying capacity of the streams.

GROUND WATER HYDROLOGY

Principles of Occurrence

That part of precipitation that seeps into the ground and escapes, becoming evapotranspiration or part of the soil moisture, percolates downward until it reaches the water table and becomes part of the ground water system. Ground water occupies the openings in the rock materials below the water table. In loose, unconsolidated materials, it fills the pore spaces between the individual grains. In consolidated rock the openings filled may also include those along bedding planes, fractures, faults, joints, and solution cavities. Solution cavities are important in the dolomite formations of the Milwaukee River watershed. Intergranular pore openings in consolidated rocks may be fewer and smaller than those in unconsolidated rocks because they are often constricted by cementing materials, such as calcite and silica. Crystalline rocks, such as granite and quartzite, contain little or no intergranular pore space; and ground water occupies only the fractures and crevices that cut them.

Movement of ground water can take place only if the openings in the enclosing formations are interconnected. The rate of movement is controlled largely by the size of the openings; movement is slow in fine-grained materials and relatively rapid in coarse-grained materials. The capacity of a particular rock material to transmit water is known as its permeability, or hydraulic conductivity; and a formation capable of transmitting significant quantities of water to wells or springs is called an aquifer.

Movement of ground water between two interconnected points occurs if there is a hydraulic head (elevation head plus pressure head) difference between the points. Flow is always down the hydraulic gradient, from an area of high hydraulic head to one of low hydraulic head. Ground water may occur either under water table or artesian[19] conditions. Under water table conditions, the top of the zone of saturated subsurface earth materials is open directly to atmospheric pressure; and flow is from an area of high elevation toward an area of low elevation of the water table.

Ground water occurs under artesian conditions wherever a permeable formation is overlain by relatively impermeable formations within the zone of saturation. The impermeable formation confines water in the permeable unit under hydraulic pressure. Flow of ground water in an artesian aquifer is similar to gravity flow from a high elevation reservoir through a pipe distribution system. The static water level in wells tapping artesian aquifers always rises above the top of the artesian aquifer. Discharge from artesian aquifers is controlled by the confining stratum, and recharge[20] of the artesian aquifer generally occurs where the confining stratum is missing.

Flowing wells result if the artesian pressure surface at the well is higher than the land surface. Flow continues until the artesian pressure head is lowered below the land surface. Ground water is released from storage in water table and artesian aquifers as the result of different physical processes. In a water table aquifer, ground water is released to wells by gravity drainage of the aquifer pore spaces. In an artesian aquifer, water is released to the well as the result of compression of the aquifer and expansion of ground water caused by the reduction of artesian pressure. Uncased wells provide conduits for easy movement of ground water between aquifers in a multi-aquifer system, such as is present in the Milwaukee River watershed, both upward under artesian pressure and downward under gravity flow conditions.

An aquifer consisting of tightly packed, well-sorted spherical particles of sand may contain up to 45 percent water by volume (about three gallons per cubic foot storage capacity). About one-half of this volume may be drained from a water table aquifer given sufficient time, whereas the quantity of ground water released from a cubic foot of similar materials under artesian conditions is extremely small by comparison. The practical consequence of the difference is that pumping from an artesian aquifer affects an immense area compared to the area affected by pumping at an equivalent rate from a water table aquifer.

[19] *The term artesian refers to ground water under sufficient hydrostatic head to rise above the aquifer containing it if free to do so.*

[20] *The term recharge is defined as the flow to an aquifer from infiltration, from precipitation, from surface streams, and other sources. The term may refer to the process of replenishment or to the quantity of water added to the aquifer.*

The water table and artesian pressure surface are called potentiometric, or piezometric,[21] surfaces; and maps that show the elevation of the water table and artesian pressure surface are known as potentiometric, or piezometric, surface maps.

Principles of Aquifer Hydraulics

To evaluate the water supply potential or the effects of proposed development on an aquifer, the hydraulic properties of the aquifer materials must be known or estimated. Two hydraulic coefficients are used by the U. S. Geological Survey for this purpose. The hydraulic conductivity, K, of an aquifer (former terminology—coefficient of permeability, P) is defined as the rate of flow of water in gallons per day (gpd) through a cross-sectional area of one square foot of geologic material under a hydraulic gradient of one foot drop in head in one of flow distance at a temperature of $60^{\circ}F$. The transmissivity, T, of an aquifer is defined as the rate of flow of water in gpd through a vertical strip of aquifer one foot wide, extending the full saturated thickness of an aquifer under a hydraulic gradient of 100 percent (one foot drop in head in one foot of flow distance). A statement of transmissivity is given by:

$$T = K \times m$$

where:

K = the hydraulic conductivity, as defined above; and

m = the saturated thickness of the aquifer in feet.

The storage coefficient, S, of an aquifer is the volume of water it releases from, or takes into, storage per unit surface area of the aquifer per unit change in the component of head normal to that surface. The storage coefficient is dimensionless; in water table aquifers, the normal range is between 0.05 and 0.30 and in artesian aquifers, between 0.00001 and 0.001.

[21] *The term potentiometric, or piezometric, surface is defined as an imaginary surface that everywhere coincides with the static level of water in an artesian aquifer. It is the surface to which water in such an aquifer would rise under its full head if free to do so.*

The specific capacity of a well is defined as the yield of the well, expressed in gallons per minute, per foot of "drawdown." In Wisconsin water-well drillers perform a specific capacity test on each production well drilled. The test is accomplished by measuring the depth to the static, or nonpumping, water level in the well and then the depth to the pumping water level after a period of several hours of discharge at a constant rate. The difference in depth between the two measurements is the drawdown. Drawdown measured in a discharging well is a function of the hydraulic properties and local boundary conditions in the aquifer, the length and rate of discharge, and the well-construction characteristics. Specific capacity data may be used to estimate the potential yield of a well and the hydraulic properties of the aquifer. Specific capacities of wells in a uniformly permeable aquifer will increase as the thickness of the aquifer open to the well increases.

As already noted, the replenishment of ground water in an aquifer is known as recharge. Infiltration of precipitation and surface water are the chief forms of recharge. Knowledge of the recharge rate to an aquifer is important because it can be used to estimate the practical rate of sustained withdrawal for the aquifer. Wherever ground water withdrawal exceeds the recharge rate, overdraft (mining) of the aquifer occurs; and a continuous decline of the potentiometric surface and depletion of aquifer storage results.

A well discharging from an aquifer forms a cone of depression in the potentiometric surface around the well as ground water flows toward the well. The cone of depression expands and deepens at a decreasing rate if there is no recharge to the aquifer. If recharge is available, the cone of depression stabilizes when the withdrawal rate becomes equivalent to the rate of recharge.

Barrier boundaries are impermeable zones in an aquifer that are barriers to ground water flow. When intersected by a cone of depression, a barrier boundary causes increased drawdown of the cone. Intersecting cones of depression of two or more pumping wells interfere with each other and produce effects similar to those caused by barrier boundaries. The increased drawdown caused by barrier boundaries and interfering wells is minimized by allowing sufficient distance between pumping wells and known barrier boundaries.

A recharge boundary is a recharge source, such as a stream, that fully penetrates and is hydraulically interconnected to a shallow aquifer. The effect of a recharge boundary upon the cone of depression is to reduce the drawdown in the cone of depression.

The effects of barrier and recharge boundaries upon the cone of depression are shown diagrammatically in Figure 22. Barrier and recharge boundaries affecting ground water flow in aquifers are seldom as abrupt as indicated in the figure. Gradual changes in the aquifer materials, aquifer thinning, shallow surface streams, and vertical leakage are common conditions; and each simulates diffused boundary effects during aquifer development.

Hydrology of Aquifers

There are three principal aquifers underlying the Milwaukee River watershed: the sandstone aquifer, the dolomite aquifer, and the sand and gravel aquifer. The two most important of these are the sandstone and the dolomite aquifers, which underlie the entire watershed and are generally available for use at any locality. The sand and gravel aquifer is of less importance because it is present mainly in the more rural western and northern areas of the watershed, where the requirement for intensive ground water development is not foreseen. Table 30 summarizes the hydrology of the watershed aquifers. The details of the hydrology of each aquifer are discussed separately below.

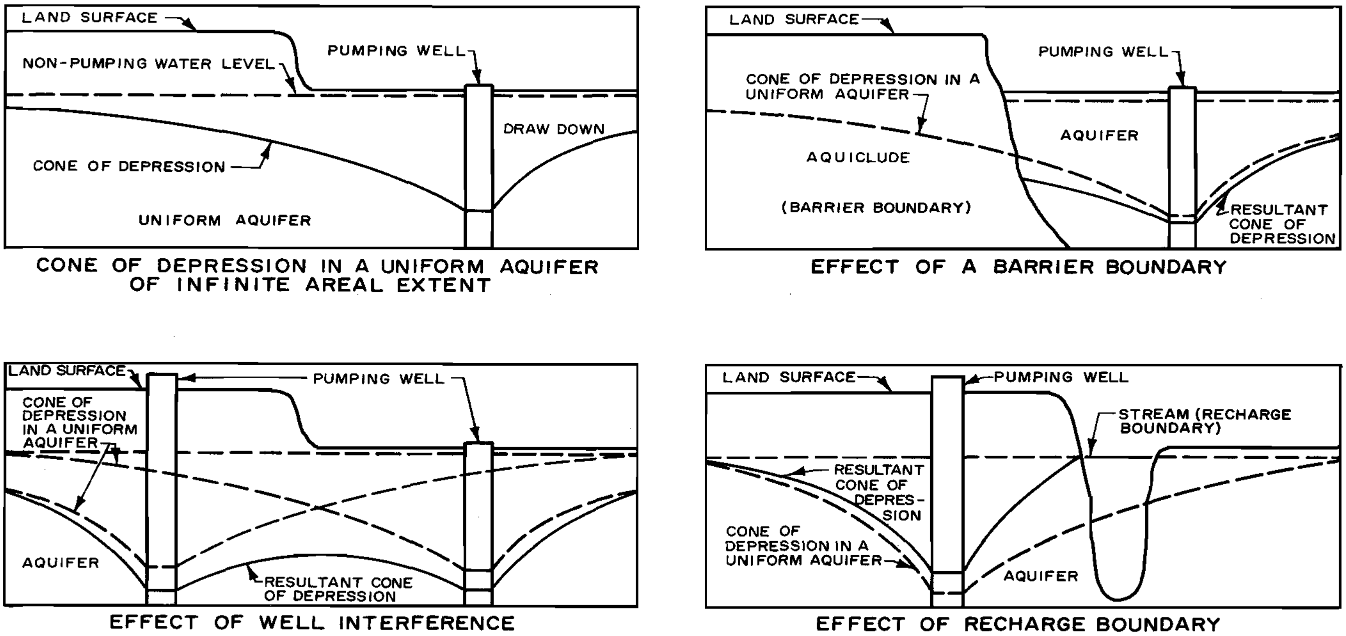
The Sandstone Aquifer: In the Milwaukee River watershed, the sandstone aquifer includes all the geologic units between the Maquoketa shale and the Pre-Cambrian rocks, some of which are not sandstones. Some wells in the sandstone aquifer in the Milwaukee area are reported to yield over 1,800 gpm (about 2.6 mgd). The Maquoketa shale confines water in the sandstone aquifer under artesian pressure and is normally cased off in wells to prevent destruction of the well by caving of the formation.

The average transmissivity and coefficient of storage[22] of the sandstone aquifer in the Milwaukee area have been determined to be 23,000 gpd

[22]*The term coefficient of storage is defined as a dimensionless factor representing the volume of water released from a vertical prism of an aquifer having a base of unit area and a height equal to the thickness of the aquifer when the piezometric surface falls one unit of height.*

Figure 22

EFFECTS OF BARRIER BOUNDARY WELL INTERFERENCE AND RECHARGE BOUDARY ON A CONE OF DEPRESSION



Source: U.S. Geological Survey.

TABLE 30

STRATIGRAPHIC UNITS AND HYDRAULIC CHARACTERISTICS OF THE MAJOR AQUIFERS OF THE MILWAUKEE RIVER WATERSHED[a]

MAJOR AQUIFER	STRATIGRAPHIC UNIT	WATER-BEARING CHARACTERISTICS	RANGE OF AQUIFER HYDRAULIC CHARACTERISTICS			
			SATURATED THICKNESS (FT.)	AVERAGE TRANSMISSIVITY (GPD/FT.)	STORAGE COEFFICIENT	AVERAGE RECHARGE RATE (GPD/SQ. MI.)
SAND AND GRAVEL	ALLUVIUM	SATURATED SAND AND GRAVEL UNITS VERY PERMEABLE BUT THIN. NOT IMPORTANT AS AN AQUIFER.	10-200+	10,000-200,000	0.0001-0.2	48,000-191,000
	GLACIAL DEPOSITS	SATURATED SAND AND GRAVEL UNITS VERY PERMEABLE.				
DOLOMITE	MILWAUKEE FORMATION THIENSVILLE FORMATION LAKE CHURCH FORMATION	PERMEABILITY LOW.	0-600	2,000-10,000	0.0001-0.005	<10,000-143,000
	DOLOMITE UNDIFFERENTIATED	PERMEABILITY GENERALLY LOW. SOLUTION CAVITIES AND CREVICES PRESENT THROUGH-OUT BUT DENSITY OF OPENINGS IS IRREGULAR. IMPORTANT AQUIFER UNIT.				
SANDSTONE	GALENA DOLOMITE DECORAH FORMATION PLATTEVILLE FORMATION	PERMEABILITY LOW.	300->1,000	3,000-28,300	0.0001-0.00001	<3,000
	ST. PETER SANDSTONE	PERMEABILITY MODERATE TO LOW. IMPORTANT AQUIFER UNIT.				
	PRAIRIE DU CHIEN GROUP	PERMEABILITY LOW.				
	TREMPEALEAU FORMATION	PERMEABILITY LOW.				
	FRANCONIA SANDSTONE	PERMEABILITY LOW.				
	GALESVILLE SANDSTONE	PERMEABILITY MODERATE.				
	EAU CLAIRE SANDSTONE	PERMEABILITY MODERATELY LOW.				
	MT. SIMON SANDSTONE	PERMEABILITY MODERATE. IMPORTANT AQUIFER UNIT.				

[a] FOR ADDITIONAL INFORMATION CONCERNING THESE AQUIFERS AND THEIR GEOLOGIC COMPONENTS, SEE CHAPTER IV OF THIS VOLUME.

SOURCE- U.S. GEOLOGICAL SURVEY.

per foot (gallons per day per foot) and 0.00039, respectively. In the extreme northeastern corner of Dodge County, the average values determined have been 5,800 gpd per foot and 0.00013, respectively. Aquifer tests have not been performed in the intervening areas. The minimum average transmissivity of the sandstone aquifer is estimated to be about 3,000 gpd per foot in an area where it is thinnest, in west central Washington County. East and northeast of this area, transmissivity probably increases to as much as 10,000 gpd per foot as the aquifer thickness increases. West of the watershed, where the aquifer is not overlain by the Maquoketa shale, there is an apparent increase in the aquifer transmissivity.

The Platteville-Galena unit, which is mainly dolomite, is considered part of the sandstone aquifer because it is left uncased in deep wells; and it is, therefore, free to contribute water to them. There are no wells in the watershed that obtain ground water from this unit alone, and little is known about its hydraulic properties. The thickness of the Platteville-Galena unit is generally uniform throughout the watershed, but its hydraulic conductivity probably increases toward the west, where the overlying rocks are thinner. Fracture and bedding plane permeability in all of the geologic formations probably is greatest along the western edge of the watershed.

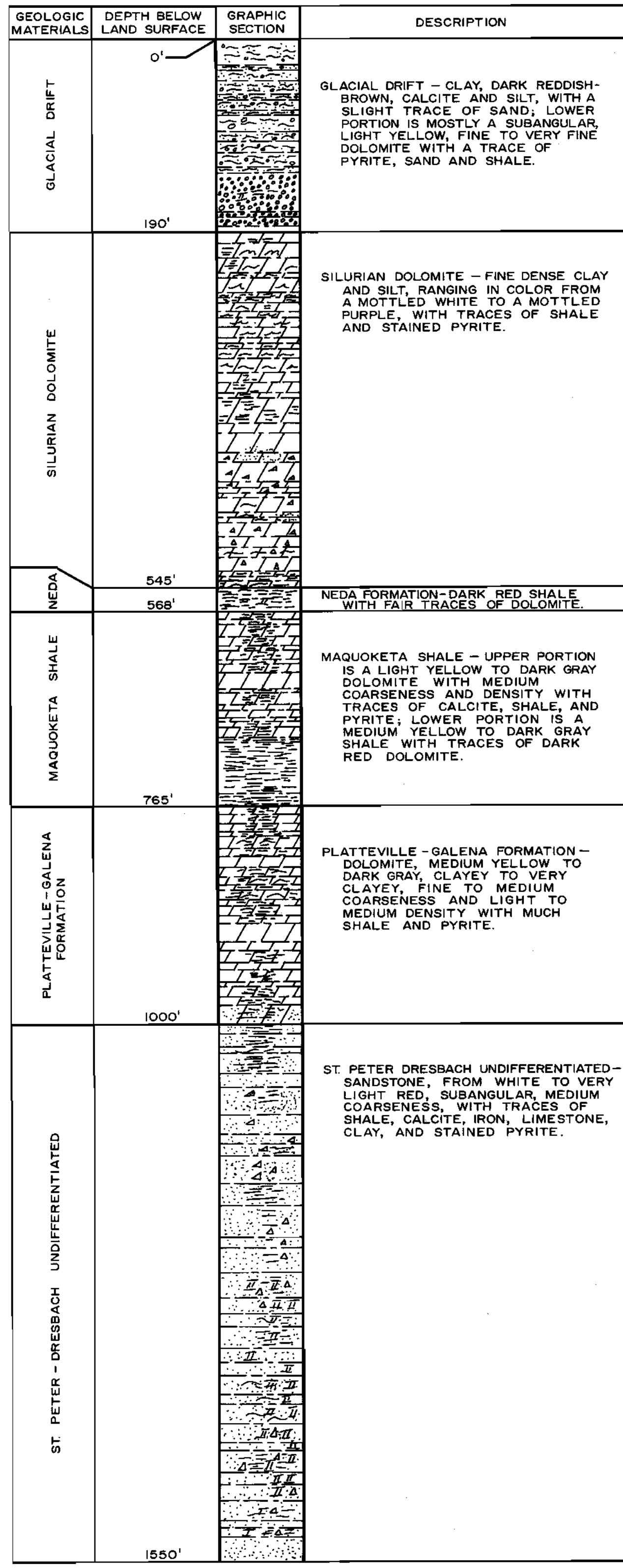
The St. Peter sandstone, the uppermost sandstone unit in the sandstone aquifer, is one of the more permeable water-bearing units in the aquifer. The erosion surface upon which the St. Peter sandstone was deposited cuts across some of the underlying formations and thereby interconnects them hydraulically with the St. Peter sandstone.

In the Milwaukee area, the Mount Simon sandstone is probably the most productive water-bearing unit in the aquifer, whereas in the northwestern part of the watershed, the Galesville sandstone is believed to be the most productive.

Map 31 shows the approximate thickness of the sandstone aquifer below the Platteville-Galena unit. The thinnest part of the aquifer coincides with the position of a hill in the Pre-Cambrian surface. The Platteville-Galena unit adds between 220 and 260 feet to the aquifer thickness throughout the watershed. The thickness of the aquifer beneath the Milwaukee area is unknown but is believed to be as much as 2,000 feet.

Figure 23

WELL LOG OF THE LAC DU COURS SUBDIVISION IN THE CITY OF MEQUON SHOWING LITHOGRAPHIC DETAILS (LAND SURFACE AT WELL – 665 FEET ABOVE M.S.L.)

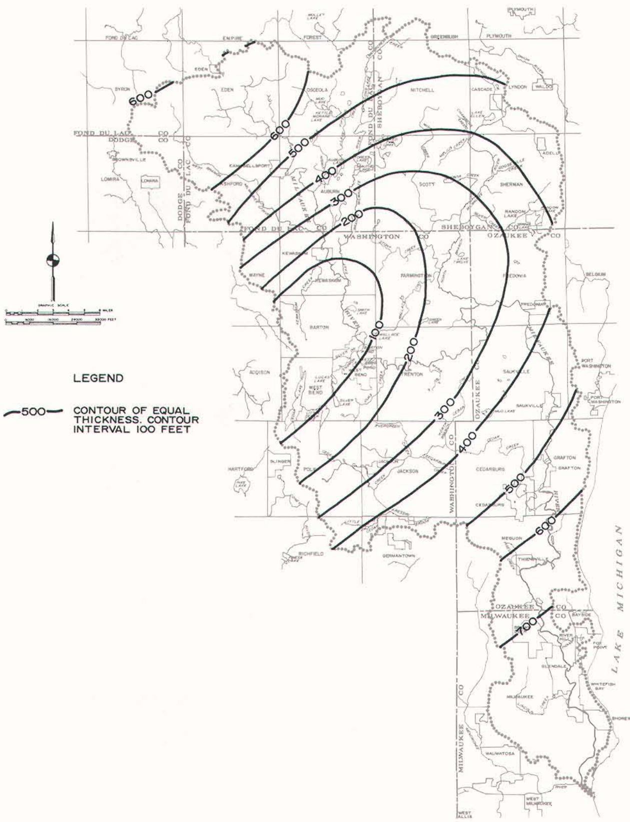


Source: Wisconsin Geological Survey.

The total amount of recharge to the sandstone aquifer is presently less than its discharge and enters the aquifer system in three ways. It occurs as infiltration of precipitation through glacial deposits and the Platteville-Galena unit in a recharge area located west of the watershed, where the Maquoketa shale and younger formations are absent. A small amount of recharge also occurs as vertical leakage through the Maquoketa shale. Leakage occurs because there is a head, or pressure difference, between the sandstone aquifer and the dolomite aquifer, which overlies the Maquoketa shale. The difference in elevation between the potentiometric surfaces of these two aquifers defines the approximate head difference acting across the Maquoketa shale at any locality. If the vertical permeability of the Maquoketa shale is assumed to be uniform, leakage will be greatest where the head differences are largest. Map 32 indicates the potentiometric surface of the sandstone aquifer, and Map 33 indicates the potentiometric surface for the combined dolomite aquifer and the glacial deposits. A comparison of the two maps indicates that the elevation of the potentiometric surface of the combined dolomite aquifer and glacial deposits is greater than the potentiometric surface of the sandstone aquifer throughout the watershed; therefore, some

Map 31

APPROXIMATE THICKNESS OF THE SANDSTONE AQUIFER IN THE MILWAUKEE RIVER WATERSHED

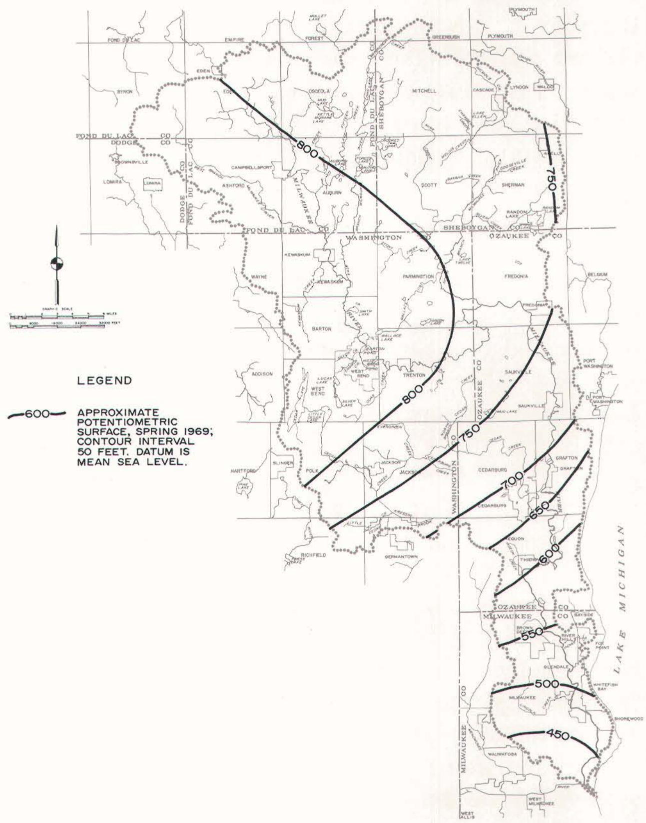


The approximate thickness of the deep sandstone aquifer below the Platteville-Galena unit ranges from less than 100 feet in the West Bend area of the watershed to more than 700 feet at the Milwaukee-Ozaukee County line. The thinnest part of the aquifer coincides with a hill in the Pre-Cambrian rock surface. The Platteville-Galena unit is mainly dolomite but is sometimes considered part of the sandstone aquifer because it is left uncased in deep wells. Inclusion of the Platteville-Galena unit would generally add from 200 to 260 feet to the thickness of the sandstone aquifer. Beneath the Milwaukee area, the thickness of the sandstone aquifer is unknown but is believed to be as much as 2,000 feet.

Source: U.S. Geological Survey.

Map 32

GENERALIZED POTENTIOMETRIC SURFACE OF THE SANDSTONE AQUIFER IN THE MILWAUKEE RIVER WATERSHED 1969

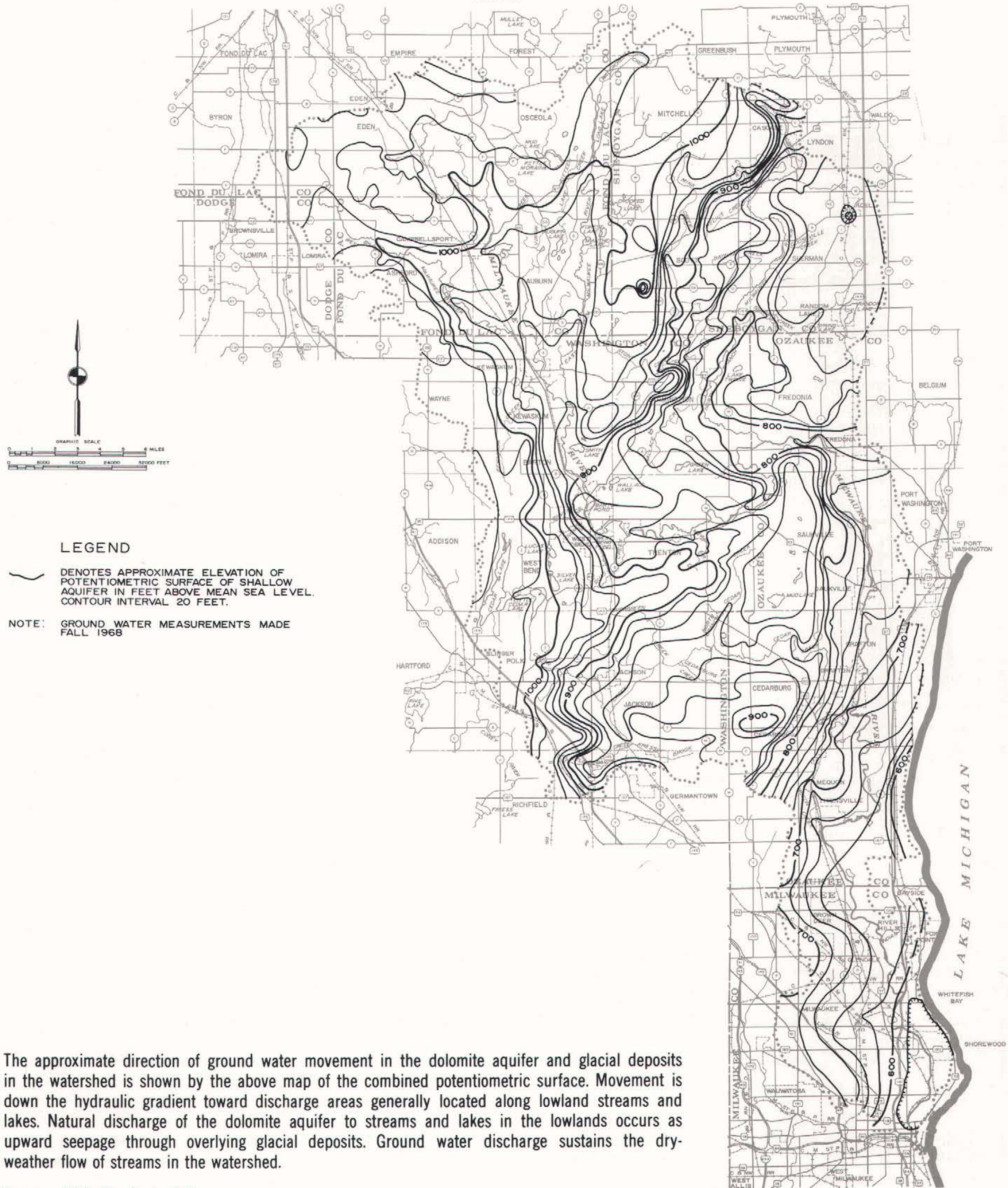


The deep sandstone aquifer has historically been a major source of water supply for Milwaukee industries. Water levels in this aquifer have declined by over 400 feet since this water-bearing strata was first tapped in about 1880, and natural pollution of the aquifer is occurring in northeastern Milwaukee County due to the movement of saline waters into the pumpage area. As a consequence, the use of the aquifer is declining as large water-using industries shift to Lake Michigan as a source of supply.

Source: U.S. Geological Survey.

Map 33

GENERALIZED POTENTIOMETRIC SURFACE OF THE DOLOMITE AQUIFER AND THE GLACIAL DEPOSITS IN THE MILWAUKEE RIVER WATERSHED 1968



The approximate direction of ground water movement in the dolomite aquifer and glacial deposits in the watershed is shown by the above map of the combined potentiometric surface. Movement is down the hydraulic gradient toward discharge areas generally located along lowland streams and lakes. Natural discharge of the dolomite aquifer to streams and lakes in the lowlands occurs as upward seepage through overlying glacial deposits. Ground water discharge sustains the dry-weather flow of streams in the watershed.

Source: U.S. Geological Survey.

downward flow must occur through the Maquoketa shale. The vertical permeability of the Maquoketa shale is estimated to be about 0.00005 gpd per square foot. Less than 3,000 gpd per square mile is an estimate of the maximum leakage that can occur under prevailing hydraulic conditions through the Maquoketa shale in the watershed.

Because of the head difference between these aquifers, deep wells uncased in both the dolomite and the sandstone aquifers allow easy movement of water from the dolomite aquifer into the sandstone aquifer. This leakage or recharge to the sandstone aquifer in the Milwaukee area is significant. In 1950 recharge was estimated to average about 5.5 mgd (million gallons per day) through approximately 100 wells, an average of about 55,000 gpd per well.

The approximate direction of movement of ground water in the aquifer is defined by the potentiometric surface map for the sandstone aquifer (see Map 32). The direction of flow is perpendicular to the contour lines, down the hydraulic gradient. Water in the sandstone aquifer in the southern half of the watershed flows east, then southward toward the Milwaukee area. In the northern half, it flows northeast, then east toward Lake Michigan.

Discharge from the sandstone aquifer in the southern portion of the watershed occurs almost entirely through wells. In 1967 this discharge averaged about 2.74 mgd. Most of the water moving through the aquifer in the northern half of the watershed eventually discharges naturally outside the watershed by upward movement into the overlying formations and Lake Michigan.

The potentiometric surface of the sandstone aquifer sloped gently eastward throughout the watershed in 1880, when the sandstone aquifer was first tapped by wells. Wells in the aquifer in the Milwaukee area generally flowed at the surface as the result of the artesian pressure. Subsequent development of the aquifer in the Milwaukee area has resulted in a decline of the potentiometric surface in excess of 400 feet locally; consequently, wells no longer flow. However, pumpage from the aquifer in the watershed has decreased significantly during the past 20 years. Outside the watershed, pumpage is increasing in some areas but is also decreasing in others; and, as a consequence, the net effect on the aquifer within the watershed cannot as yet be accurately determined. Observation well data indicate that the rate of water level decline in the aquifer in the watershed is at least slowing down.

Circulation of fresh ground water in the aquifer from west to east during recent geologic ages has flushed most of the salt water trapped within the formation during their deposition in ancient seas. However, deep wells along the eastern edge of the watershed obtain water from the sandstone aquifer with a significant concentration of salinity. The position of the western boundary between the fresh water and saline water is poorly defined north of Grafton in Ozaukee County due to the absence of wells in the sandstone aquifer. Salinity will limit the potential use of the water from the sandstone aquifer for many purposes. The problem of salinity is discussed in the section on ground water quality contained in Chapter X of this volume.

<u>The Dolomite Aquifer</u>: The dolomite aquifer underlies the entire Milwaukee River watershed, except for a small area north of the Village of Slinger in Washington County. The dolomite aquifer consists mainly of Silurian dolomite but also includes Devonian dolomite in the southeastern part of the watershed.

Erosion and glacial deposition have complicated the hydrology of the aquifer. Valleys eroded into the dolomite form hydraulic discontinuities in the upper part of the aquifer which may act as barrier or recharge boundaries, depending upon the relative permeability of the contained glacial materials.

Permeability in the dolomite aquifer is due primarily to enlargement by ground water solution of bedding planes, fractures, and other crevices that are irregularly distributed both areally and vertically within the aquifer. The upper part of the aquifer, the part most affected by erosion, probably is more permeable than the lower part. Areas of greater permeability may be present within, and adjacent to, preglacial valleys.

The effective average transmissivity of the aquifer in the watershed is estimated to range between 2,000 and 10,000 gpd per foot; and the storage coefficient is generally within the artesian range, between 0.005 and 0.0001. Water table conditions may occur locally where the saturated glacial deposits overlying the dolomite are either thin, absent, or coarse grained. The storage coefficient resulting from long-term, large-scale aquifer development will probably be semi-artesian—that is, intermediate between water table and artesian—as the result of vertical leakage from the glacial deposits.

Very few unsuccessful wells in the dolomite aquifer are reported in the watershed; high-capacity wells—that is, wells capable of a discharge greater than 70 gpm—have been completed in the aquifer in most of the area. During 1967 a well in the dolomite aquifer in the City of West Bend was pumped at an average rate of 794 gpm, or about 1.14 mgd.

The median specific capacity value for 99 high-capacity wells in the watershed in the dolomite aquifer was 2.4 gpm per foot of drawdown. Specific capacity in 10 percent of these wells exceeded 15 gpm per foot of drawdown, and the maximum specific capacity was 47.1 gpm per foot of drawdown. The wide range in values indicates the variable permeability within the aquifer, due largely to the irregular distribution and density of fracture and solution openings.

Recharge to the dolomite aquifer is primarily from infiltration of precipitation and leakage from glacial deposits. Although the rate of recharge under nonpumping conditions probably is very small, pumping the aquifer induces recharge as vertical leakage from the overlying glacial deposits. The rate of leakage varies according to the vertical permeability of the glacial materials and the dolomite and the head differences acting between the two units. Maximum recharge in any area is reached when the water level in the dolomite aquifer is lowered to the base of the overlying glacial deposits. No additional recharge is induced when drawdown exceeds this depth. Based upon the studies of similar deposits in Illinois, the vertical permeabilities of the glacial deposits in the watershed probably range between 1 and 0.008 gpd per square foot. Recharge will be greatest wherever sand and gravel deposits overlie the dolomite aquifer, and it will be least where the dolomite is overlain by clay or till. An estimate of the recharge from leakage that is available for well development in the dolomite aquifer is between one and three inches annually. This is approximately equivalent to between 48,000 and 143,000 gpd per square mile.

Small quantities of recharge through induced infiltration[23] of streamflow may also take place where streams and abandoned water-filled quarries are cut into the dolomite. The Milwaukee River flows on dolomite bedrock in several places in Milwaukee and Ozaukee Counties.

[23] *The term induced infiltration is defined as the movement of water from a stream or lake into an aquifer due to a decline in the water table caused by the pumping of nearby wells.*

The potentiometric surface map for the combined dolomite aquifer and glacial deposits (see Map 33) in the following section defines approximately the direction of ground water movement in these units in the watershed. Movement is down the hydraulic gradient toward discharge areas along lowland streams and lakes.

Natural discharge of the dolomite aquifer to streams and lakes in the lowlands occurs as upward seepage through overlying glacial deposits. The annual rate of contribution to streamflow from the dolomite aquifer probably is very small. Ground water in the dolomite aquifer and the glacial deposits from the watershed discharges to streams outside the watershed in places along the east edge and northwest corner. Ground water gained from, or lost to, areas outside the watershed is known as underflow.

A small amount of discharge takes place downward to the sandstone aquifer as a result of head differences produced by pumping in the deeper aquifer. Discharge of the dolomite aquifer also occurs through wells. During 1967 pumpage from the aquifer in the watershed was estimated to average about 7.4 mgd (million gallons per day). Rural domestic and farm supplies are generally obtained from the dolomite aquifer through 6- to 10-inch diameter drilled wells. These wells are generally adequate and are constructed to yield less than 20 gpm each.

Pumpage from the dolomite aquifer and leakage from the aquifer through uncased wells into the sandstone aquifer in the Milwaukee area has produced a cone of depression in the potentiometric surface of the dolomite aquifer. As far as can be determined, however, pumping effects in other parts of the watershed are not significant.

Sand and Gravel Aquifer: The sand and gravel aquifer consists of stratified, unconsolidated glacial and alluvial sand and gravel deposits. This aquifer can be developed by large-capacity wells only where the grain size of the materials is larger than very fine sand because construction of high-capacity wells in finer-grained deposits is impractical. The most significant aquifer units are those that underlie areas more than one-half square mile in extent.

A few high-capacity wells in the sand and gravel aquifer have been developed in the watershed.

The maximum yield reported is 1,200 gpm. Most high-capacity wells are within the City of West Bend in Washington County. Specific capacity tests on some of these wells indicate that the transmissivity in the sand and gravel aquifer locally is at least 200,000 gpd per foot, and the storage coefficient is in the water table range. Artesian and semi-artesian storage coefficients probably prevail where the sand and gravel aquifers are overlain by extensive, saturated, fine-grained glacial deposits.

Map 34 shows the approximate saturated thickness of the glacial deposits but includes poor water-bearing materials, such as clay, silt, and till. Important deposits of saturated sand and gravel are present in the area underlain by glacial outwash and along the trend of the interlobate moraine (see Map 15) in the western and northern sections of the watershed. Interlayering of the sand and gravel with less permeable materials is characteristic of the glacial deposits beneath these areas. Lowlands throughout the watershed may also contain sand and gravel of small thickness and extent because many valleys formerly were drainageways for melt waters from receding glacial ice. Because of these circumstances existing within the watershed, the probability of locating significant sand and gravel aquifer units outside the areas previously mentioned is small.

Direct infiltration of precipitation is the major source of recharge to the sand and gravel aquifer. The average annual rate of recharge is variable and probably ranges between one and four inches (approximately 48,000-191,000 gpd per square mile). Recharge is the greatest where the sand and gravel deposits and their associated permeable soils occur at the surface; and it is the smallest where fine-grained soils, clay, silt, or till form the surficial deposits. Locally unsaturated sand and gravel deposits with poorly developed surface drainage and numerous kettle holes probably have a high rate of ground water recharge.

In the Milwaukee River watershed, recharge to the glacial deposits occurs primarily during the spring months after frost has left the ground and before evapotranspiration rates become high. In the Milwaukee River watershed, the principal recharge period usually occurs during April and May. Recharge takes place during other seasons, but the amount is comparatively small.

Ground water recharge also occurs from surface water sources in areas where the water table is lower in elevation than a nearby surface water body. Wherever this condition exists, discharge from the surface water source to the ground water can take place. Stream reaches where this condition occurs are known as losing stream reaches. None of the principal streams in the watershed are known to have major losing reaches under natural conditions except for short periods during peak stream stages. Ground water pumpage has lowered ground water levels in Milwaukee County sufficiently to induce small amounts of recharge from surface water sources.

Water in the subsurface moves downward through the soils to the water table and then laterally toward streams and lakes, where it discharges as seepage. The potentiometric surface map (see Map 33) for the combined dolomite aquifer and glacial deposits defines approximately the direction of movement of the ground water in these units and also the approximate elevation of the static water levels in wells tapping these units. Natural discharge of ground water in the glacial deposits occurs as seepage into the surface water system by direct evaporation to the atmosphere where the water table is shallow, by plant transpiration during growing seasons, and by infiltration to the dolomite aquifer.

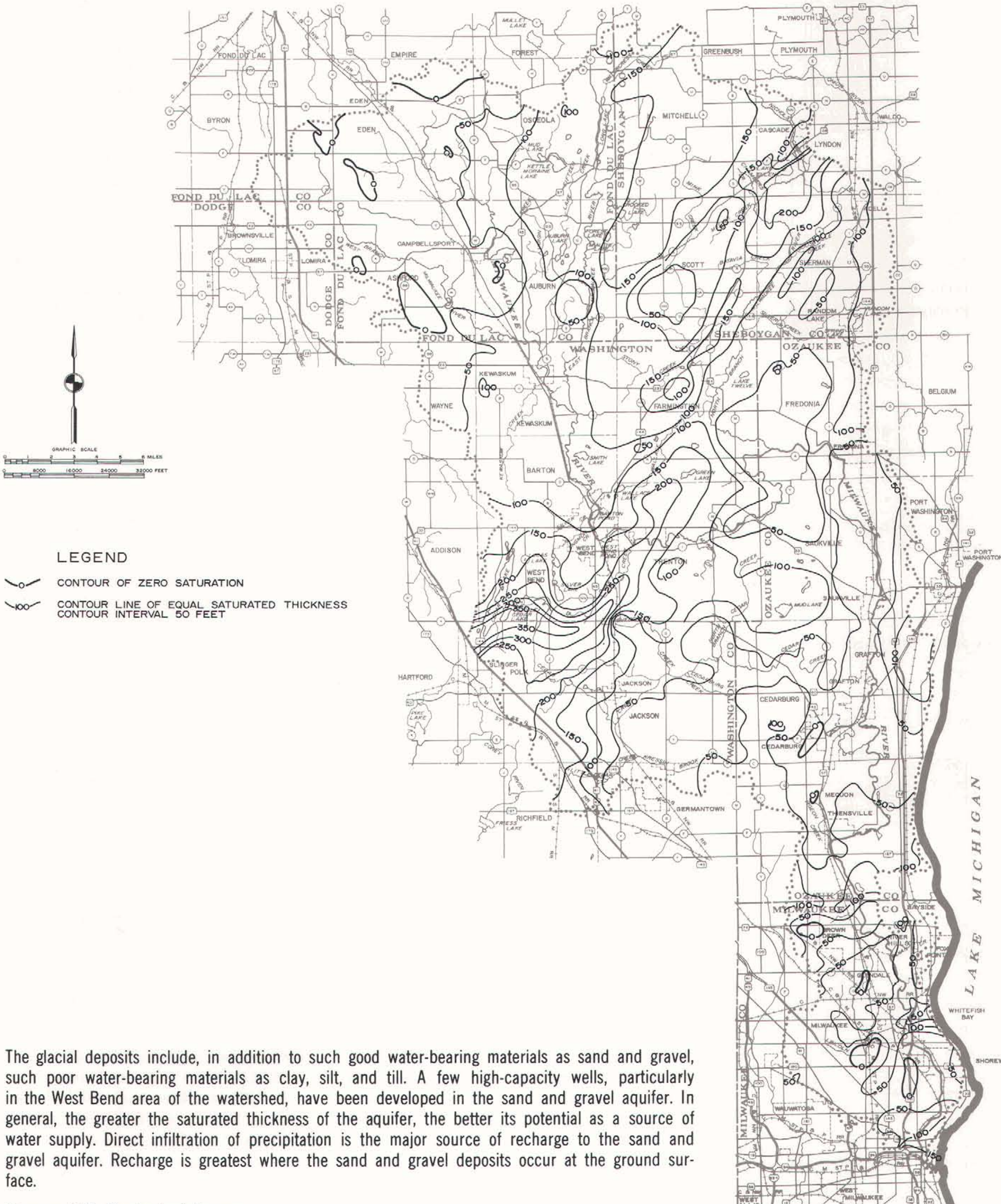
Ground water discharge, primarily from glacial deposits, sustains the dry-weather flow of streams. The average ground water discharge to streams in the watershed is estimated to range between one and four inches annually (48,000-191,000 gpd per square mile). Areas underlain by water table sand and gravel aquifers have comparatively high sustained flow during periods of low flow, which reflects the high storage capacity of the sand and gravel. Ground water discharge is the greatest along the interlobate moraine and in the areas underlain by glacial outwash. It is the smallest in the till-covered areas of the watershed.

Ground water from the sand and gravel aquifer is also discharged through wells. Pumpage from this source in the watershed during 1967 was 1.1 mgd. Ground water withdrawals are expected to increase in the western and northern parts of the watershed as population and economic growth continue.

Ground Water-Surface Water Relationships

Ground water, surface water, and the physical environment in which they occur form a com-

Map 34
APPROXIMATE SATURATED THICKNESS OF THE GLACIAL DEPOSITS IN THE MILWAUKEE RIVER WATERSHED



The glacial deposits include, in addition to such good water-bearing materials as sand and gravel, such poor water-bearing materials as clay, silt, and till. A few high-capacity wells, particularly in the West Bend area of the watershed, have been developed in the sand and gravel aquifer. In general, the greater the saturated thickness of the aquifer, the better its potential as a source of water supply. Direct infiltration of precipitation is the major source of recharge to the sand and gravel aquifer. Recharge is greatest where the sand and gravel deposits occur at the ground surface.

Source: U.S. Geological Survey.

plex, but interrelated, hydrologic system. The degree of relation between the ground and surface water components of the system is dependent upon the hydraulic properties of the geologic formations in contact with surface water streams and lakes and the differences in hydraulic head acting between them.

Glacial deposits are the principal ground water units interconnected with the surface water units in the watershed; but, where the glacial deposits are absent, surface water is hydraulically connected with the dolomite aquifer. A very poor interconnection exists between surface water and the sandstone aquifer because of the great thickness and variability of the geologic formations separating them.

The types of soils and surficial geologic materials underlying a watershed are major factors governing the characteristics of stream runoff, ground water recharge, and ground water discharge. Infiltration of precipitation into fine-grained materials is slow; and streams discharging from watersheds underlain by these materials are generally characterized by high-intensity, short-duration peak runoff and very small low flows. Infiltration of precipitation is more rapid in permeable materials; and, as a consequence, stream discharge from watersheds consisting of permeable units usually is more uniformly distributed in time. Peak streamflow is generally of low intensity and long duration, and the low flows are moderate to high.

The process of urbanization brings about changes in the hydrologic conditions of the natural environment by increasing the percentage of impermeable cover on the surface and improving the natural drainage of an area. Roads, parking lots, housing, storm sewers, culverts, and drainage ditches are the types of structures that accomplish this change. The net effect of urban development on the natural hydrologic system generally is to reduce the rate of ground water recharge and decrease natural retention and storage on the ground surface, thereby increasing the intensity of peak runoff from an area.

Under normal conditions ground water in the glacial deposits discharges to the surface water streams and lakes. The rate of discharge is dependent upon the hydraulic properties of the glacial deposits, the bottom materials of the streams or lakes, and the difference in head acting across the stream bottom materials. The hydraulic interconnection between surface water and water table sand and gravel aquifers is generally good. Therefore, pumpage from wells located in the sand and gravel aquifer units within a few hundred feet of a stream or lake can reverse the natural ground water flow and induce surface water into the aquifer. In general, the closer the well is to the stream, the greater will be the rate of induced infiltration of surface water. The maximum rate of infiltration is reached when the cone of depression in the aquifer is at the same elevation as the bottom of the stream or lake. Additional drawdown of the cone below the stream or lake bottom does not increase the rate of infiltration.

At sites where the streamflow is large, relative to the rate of ground water withdrawal, the problem of flow depletion due to induced infiltration should not be significant. When the surface water supply is small compared to withdrawal rates, considerable depletion of streamflow may result. Depletion problems, if any, will be most acute during warm seasons when surface supplies are comparatively small and the demand for water is large.

Flow-depletion problems may be minimized by discharging used ground water—that is, water pumped from the sand and gravel aquifers—back into the streams near the sites where it is withdrawn and by using the dolomite aquifer or the sandstone aquifer as the source of supply. Because of the poor hydraulic connection existing between these aquifers and surface waters, pumping them should not measurably affect the surface water system, although it does temporarily remove ground water from storage. If sufficient hydrologic data are available for the sand and gravel aquifer at a site where serious flow depletion is anticipated, the depletion problems may be controlled or reduced through management of the ground water-surface water systems.

Surface water may be used to recharge aquifers where the conditions are favorable. The method generally involves diverting excess surface water into specially designed ponds, lagoons, or basins for infiltration into aquifers through bottoms that have a relatively high permeability. Artificial recharge permits ground water withdrawals far in excess of the rate of the natural recharge and is a useful ground water management technique. Unfortunately, conditions favorable for artificial recharge in water table sand and gravel aquifers in the Milwaukee River watershed are most prevalent in the western and northern parts of the watershed, where future large ground water demands are not anticipated. Unforeseen growth or industrial development in that part of the watershed could, however, make the use of artificial recharge feasible.

PHYSICAL CHARACTERISTICS OF THE WATERSHED

A comprehensive evaluation of the surface water hydrology of a watershed must consider the existing physical characteristics of the watershed as an interrelated whole, while identifying the individual effects of each of the component physical characteristics on the unique surface water hydrology of the watershed. The physical characteristics of a watershed which influence surface water runoff include all such natural characteristics as the size and shape of the watershed, climate, soils, drainage pattern, and topography and such man-made features as water control and other hydraulic structures, artificial drainage and channel improvements, and the pattern and intensity of the various land uses. The following discussion of each of these natural and artificial characteristics includes a general introductory description of the entire watershed and then a more detailed discussion of the pertinent characteristics of each of the 11 hydrologic subwatershed units of the Milwaukee River watershed.

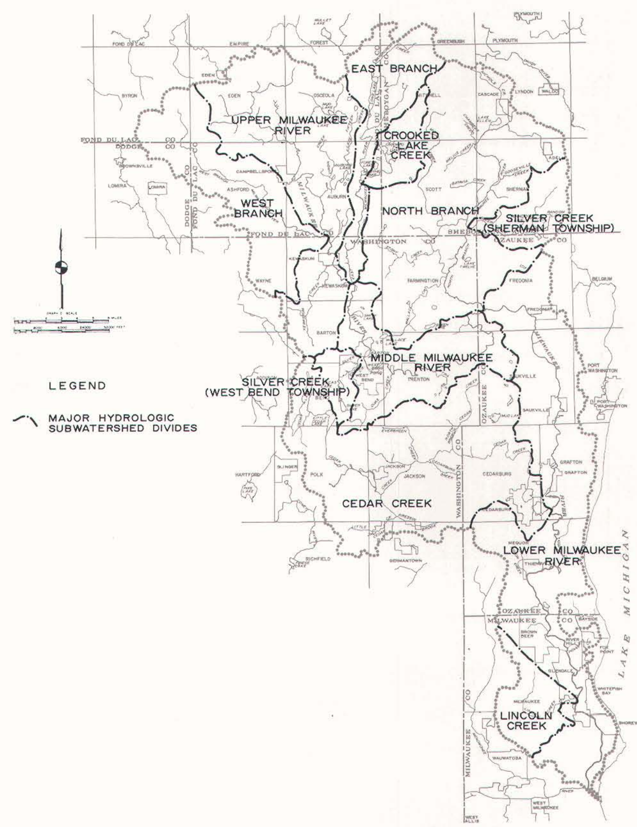
Size and Shape of the Watershed

The Milwaukee River watershed is a composite hydrologic unit of 11 subwatersheds, which flows in a general southeasterly direction and discharges to Lake Michigan at Milwaukee, Wisconsin. The watershed is approximately 46 miles long and 19 miles wide, with the major axis running approximately north and south. The total drainage area of the Milwaukee River watershed, excluding the Menomonee and Kinnickinnic River drainage areas, is 693.8 square miles at Jones Island. The hydrologic subwatersheds of the Milwaukee River watershed and the main stem of the Milwaukee River and its major tributaries are shown on Map 35.

Relationships of Climatic Factors to Runoff

As noted in Chapter IV of this report, the watershed has a continental climate with four distinct seasons which results in two distinct surface water runoff distributions. Hydrologically, the six-month period extending from November 1 through April 30 is characterized by snowmelt and long-duration, low-intensity, frontal-type precipitation, which, in turn, results in runoff hydrographs with a long-time base. The six-month period extending from May 1 through October 31 is characterized by convective thunderstorm-type precipitation occurring in association with moisture-laden frontal systems which generally move from west to east across the watershed. The summer rainstorms produce runoff hydrographs with a shorter-time base. Flood volumes, however, appear to be nearly equal for the larger spring and summer events on the Milwaukee River watershed. Typical hydrographs representing the two distinct surface water runoff distributions as

Map 35
HYDROLOGIC SUBWATERSHEDS OF THE MILWAUKEE RIVER WATERSHED



Eleven hydrologic subwatersheds may be delineated within the Milwaukee River watershed, ranging in size from the lower Milwaukee River subwatershed, of about 132 square miles in area, to the Silver Creek subwatershed near West Bend, of about 10 square miles in area. In addition to providing rational units for hydrologic analysis, the subwatersheds serve as geographic units that enable a watershed resident to readily identify the relationship of his local drainage area to the larger Milwaukee River watershed.
Source: Harza Engineering Company.

gaged at Milwaukee and reduced to a unit graph basis are shown in Figure 24. The unit graph represents the variation of daily discharge with time for the runoff resulting from one inch of excess precipitation over the entire tributary watershed.

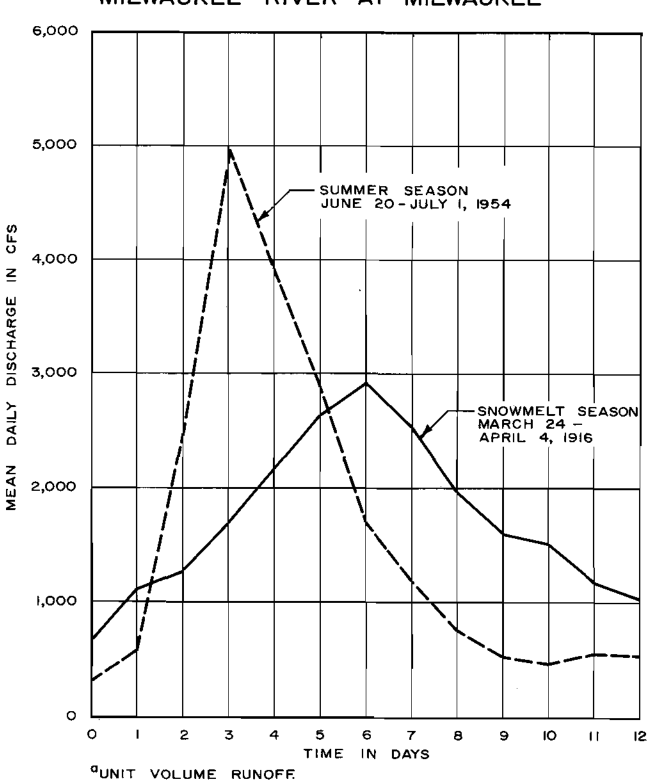
The distributional pattern of precipitation in the watershed results in the lowest values occurring during mid-winter and the highest values during mid-summer. Average annual runoff, however, does not follow this precipitation pattern. Although runoff is directly proportional to precipitation, all other factors being equal, it is inversely proportional to evapotranspiration, which increases during the growing season. This results in 65 percent of the average annual runoff occurring in the six-month period between November 1 and April 30. In contrast, only 38 percent of the average annual precipitation occurs during this same period (see Figure 10).

Relationship of Soils to Runoff

As noted in Chapter IV of this report, an especially complex pattern of soil types has developed in the Milwaukee River watershed. Soil characteristics which affect surface water runoff include infiltration and transmission rates, depth to water table, and, to some degree, moisture retention. A detailed operational soil survey was completed in 1966 by the U. S. Soil Conservation Service, under a cooperative agreement with the Regional Planning Commission, for the entire seven-county Southeastern Wisconsin Region. This survey was extended in 1968 to include all that part of the Milwaukee River watershed which lies in Dodge, Fond du Lac, and Sheboygan Counties. As an integral part of these soil surveys, the soils of southeastern Wisconsin have been classified according to their surface runoff potential into four hydrologic soil groups, designated A, B, C, and D. Group A has the lowest runoff potential, which increases to a maximum value for Group D.[24] For the watershed as a whole, approximately 15 percent of the soils covering the watershed belong to Hydrologic Soils Group A; 43 percent of the soils covering the watershed, to Group B; 32 percent of the soils covering the watershed, to Group C; and 10 percent of the soils covering the watershed, to Group D. Thus, for the watershed as a whole, the soils have moderate infiltration and transmission rates when wet, resulting in a moderate surface runoff potential. A more detailed description of the soil types by subwatershed is provided in Table 31.

Figure 24

HYDROGRAPHS OF TYPICAL SPRING AND SUMMER FLOODS ON THE MILWAUKEE RIVER AT MILWAUKEE[a]



[a]UNIT VOLUME RUNOFF

Source: Harza Engineering Company.

Relationship of Drainage Pattern to Runoff

The drainage pattern of the Milwaukee River watershed is basically dendritic, but much of the pattern of channel system has been modified by the erratic surficial topography created by glaciation. Geologically, the drainage system is a youthful one; and many areas of the watershed are imperfectly drained by circuitous, inefficient, and underdeveloped channel systems. The streams are actively cutting and filling their waterways in an attempt to create channel profiles which will be in equilibrium. The natural geomorphic processes of weathering, mass wasting, and erosion have not yet had time to develop an efficient surface water drainage system within the watershed. This inefficiency is reflected in the numerous lakes and wetland areas within the watershed which tend to retard and prolong surface runoff hydrographs and peak flows. Inefficiency of the drainage pattern is the dominant non-climatic factor determining surface water runoff characteristics in the Milwaukee River basin.

[24]*See SEWRPC Planning Report No. 8, Soils of Southeastern Wisconsin, June 1966, p. 243.*

TABLE 31

HYDROLOGIC SOIL GROUPS IN THE MILWAUKEE RIVER WATERSHED BY SUBWATERSHED

SUBWATERSHED	DRAINAGE AREA (SQUARE MILES)	FREQUENCY OF OCCURRENCE HYDROLOGIC SOIL GROUP IN PERCENTILE RANGES			
		A	B	C	D
CEDAR CREEK..............	126.8	10- 25	10- 25	25- 50	0- 10
CROOKED LAKE CREEK.......	14.2	25- 50	50-100	--	--
EAST BRANCH..............	36.1	0- 10	50-100	10- 25	10- 25
LINCOLN CREEK............	19.8	10- 25	--	50-100	--
LOWER MILWAUKEE RIVER[a]...	132.3	0- 10	25- 50	50-100	0- 10
MIDDLE MILWAUKEE RIVER...	50.5	25- 50	25- 50	25- 50	10- 25
NORTH BRANCH.............	127.9	25- 50	50-100	10- 25	0- 10
SILVER CREEK............. (SHERMAN TOWNSHIP)	19.6	10- 25	50-100	10- 25	0- 10
SILVER CREEK............. (WEST BEND TOWNSHIP)	9.9	10- 25	0- 10	25- 50	50-100
UPPER MILWAUKEE RIVER....	93.2	0- 10	50-100	10- 25	10- 25
WEST BRANCH..............	60.4	--	50-100	--	10- 25
TOTAL	690.7	10- 25	25- 50	10- 25	25- 50

[a] EXCLUDES 3.8 SQUARE MILES OF INTENSELY URBANIZED AREA DOWNSTREAM FROM NORTH AVENUE DAM.

SOURCE- HARZA ENGINEERING COMPANY.

Relationship of Surface Water Storage Areas to Runoff

Surface water storage areas within a watershed modify runoff hydrographs by decreasing peak discharges and increasing the duration of runoff. Under natural conditions, surface water storage areas can be divided into three groups on the basis of the relative influence on the flow regimen in the watershed. In decreasing order of magnitude of storage effect, these groups are: 1) lakes, 2) permanent wetlands, and 3) temporary overflow areas.

There are a total of 71 lakes within the Milwaukee River watershed having a combined surface area of 6.5 square miles, or 0.93 percent of the total watershed area. Most of these lakes occupy basins formed in natural depressions at the time the ice sheets receded. Geologically, most of these lakes are temporary and eventually will be naturally drained when the surface drainage network of the watershed is fully developed. There are 21 natural lakes of 50 acres or more in surface area which have a total combined surface area of 5.4 square miles, or 82.6 percent of the total lake surface area within the watershed. Table 32 summarizes selected hydrologic data for these 21 lakes. None of these lakes are individually large enough to modify significantly the discharge hydrographs of the Milwaukee River. The

TABLE 32

SELECTED HYDROLOGIC DATA FOR MAJOR LAKES IN THE MILWAUKEE RIVER WATERSHED

LAKE	COUNTY	SURFACE AREA (ACRES)	MAXIMUM DEPTH (FEET)	STORAGE VOLUME (ACRE-FEET)
BIG CEDAR..........	WASHINGTON	932	105	31,983
LONG...............	FOND DU LAC	427	47	7,209
LITTLE CEDAR.......	WASHINGTON	246	56	3,153
MUD................	OZAUKEE	245	4	645
KETTLE MORAINE.....	FOND DU LAC	227	30	1,340
RANDOM.............	SHEBOYGAN	209	21	1,280
ELLEN..............	SHEBOYGAN	121	42	1,890
SILVER.............	WASHINGTON	118	47	2,306
AUBURN (FIFTEEN)...	FOND DU LAC	107	29	1,474
CROOKED............	SHEBOYGAN	91	32	1,100
SMITH..............	WASHINGTON	86	5	252
MAUTHE.............	FOND DU LAC	78	23	961
LUCAS..............	WASHINGTON	78	15	461
GREEN..............	WASHINGTON	71	37	1,195
BARTON POND........	WASHINGTON	67	5	189
WEST BEND POND.....	WASHINGTON	67	14	427
SPRING.............	OZAUKEE	57	22	415
MUD................	FOND DU LAC	55	17	452
TWELVE.............	WASHINGTON	53	20	341
WALLACE............	WASHINGTON	52	35	558
FOREST.............	FOND DU LAC	51	32	552
--	--	3,438	--	58,183

SOURCE- HARZA ENGINEERING COMPANY.

combined effects of the lakes on the discharge hydrographs, however, are significant on the East Branch of the Milwaukee River and on three minor tributaries: Silver Creek, located in the Town of West Bend, Washington County; Silver Creek, located in the Town of Sherman, Sheboygan County; and the outlet channel from Crooked Lake, located in the Town of Scott, Sheboygan County, and the Town of Auburn, Fond du Lac County.

A significant natural reduction of flood peaks on the Milwaukee River system is provided by the substantial areas of permanent wetlands within the watershed. The term "permanent wetlands," as used herein, is equivalent to the significant wetland units plus the minor wetland units, as discussed in Chapter IV of this volume, and refers to all marshes, swamps, and other poorly drained areas of the watershed which remain saturated throughout most of the year and are unsuitable for agricultural use or for urban use without artificial drainage. Map 21 shows the wetland areas within the watershed. About 16 percent of the Milwaukee River watershed is covered by permanent wetlands, and a significant part of the total watershed area contributing to surface water runoff must eventually flow through these wetland areas. The amount and distribution of permanent wetlands by subwatershed are shown in Table 33.

Wetland areas, like lakes, tend to increase the base time of surface water hydrographs and reduce peak discharges through decreased flow velocity and temporary storage. The largest wetland areas in the watershed are located on the East Branch of the Milwaukee River and on the central reaches of Cedar Creek. These wetlands have a significant effect upon the flow regimen of the East Branch and upon Cedar Creek, but only a relatively small effect upon the lower reaches of the Milwaukee River. Major wetland areas which, due to their size and locations, have an important effect upon the surface water hydrology of the watershed include the Jackson Marsh and Cedarburg Bog areas above Cedarburg on Cedar Creek; all of the wetland areas along the East Branch of the Milwaukee River; and large wetland areas of the Upper Milwaukee River subwatershed. The large wetland areas through which the East Branch flows have perhaps the most important effect on streamflow of any wetland area within the watershed.

The third type of surface water storage area which is generally closely associated with rivers, lakes, and permanent wetland areas, both in occurrence and effect, is the temporary overflow area. These areas include active floodplains which are located adjacent to the channel system,

TABLE 33

PERMANENT WETLANDS IN THE MILWAUKEE RIVER WATERSHED BY SUBWATERSHED

SUBWATERSHED	TOTAL ACRES	ACRES OF WETLAND	PERCENT OF SUBWATERSHED	PERCENT OF WATERSHED
CEDAR CREEK...............	80,776	12,092	15.97	2.72
CROOKED CREEK.............	8,655	2,269	26.22	0.51
EAST BRANCH...............	24,503	6,388	26.07	1.43
LINCOLN CREEK.............	12,452	6	0.05	--[a]
LOWER MILWAUKEE...........	86,374	6,607	7.65	1.48
MIDDLE MILWAUKEE..........	32,932	4,795	14.25	1.08
NORTH BRANCH..............	82,783	13,131	15.86	2.95
SILVER CREEK.............. (SHEBOYGAN COUNTY)	11,757	2,389	20.32	0.54
SILVER CREEK.............. (WASHINGTON COUNTY)	6,130	761	12.41	0.17
UPPER MILWAUKEE...........	60,070	14,639	24.37	3.29
WEST BRANCH...............	38,519	5.991	15.55	1.35

[a]LESS THAN .001 PERCENT.

SOURCE- WISCONSIN DEPARTMENT OF NATURAL RESOURCES AND SEWRPC.

as well as other topographically low, flat areas subject to inundation during periods of overbank flow. The latter areas may be comprised of marginal areas located around lakes and permanent wetlands, with no marked boundary existing between the lake or wetland area and the temporary overflow area or, because of the glacial origin and the geologic youth of the stream system, may exist as irregular and random "wide spots" in the active floodplain. The temporary surface water storage areas have a significant flood retardation effect during times of high stage. During the snowmelt season in the spring of the year, when storage in the soil profile is least effective, the surface storage areas become most important in attenuating flood flows.

Relationship of Topography to Runoff

Average land slopes within the basin vary from subwatershed to subwatershed but are generally less than 5 percent. Under natural conditions long times of concentration prevail, due to the flat slopes, long overland flow distances, and generally full vegetation cover. Long times of concentration result in low peak flows and long duration runoff contributions to the river channel system. Slopes in the headwater portions of the watershed are steeper than the average within the watershed and contribute to relatively higher peak discharges in these areas.

Bed slopes of the channel system are irregular with steep slopes near the channel heads and often alternating flat and steep slopes in the middle and lower reaches. The generally flat slopes of the Milwaukee River channels result in low streamflow velocities and long flood peak travel times. The bed slope profiles of the main channel system are shown in Figure 25. A summary of mean channel slopes and drainage areas is presented in Table 34.

Channel and floodplain hydraulic roughness is still another feature which effects hydrograph shape and stage-discharge relationships within a watershed. Roughness of the flow cross sections is represented by the "n" value in the Manning formula. It is a function of many factors, including degree of surface irregularity, variation of cross-section size and shape, obstructions, vegetation, and meandering. An "n" value can be calculated for selected channel reaches if data on channel cross sections, discharges, and water surface slopes are known for specific flood events. All of the required information is not ordinarily available, so estimates of the "n" value must usually be made by experienced hydraulic engineers on the basis of a field inspection. Stream channels and floodplains providing considerable obstruction to flow have high "n" values and reduced flood flow velocities. This combination results in attenuated hydrographs and higher stages.

Average channel and floodplain "n" values are summarized by subwatershed in Table 34. The "n" values may change seasonally with the growing cycle of vegetation and accompanying obstructions in the flow area. Values of "n" used in this study are based on summer or foliage season conditions. Although severe floods are more likely to occur during the dormant season, it is probable that these spring floods will be accompanied by unpredictable obstructions consisting of ice, snow, and debris. The use of higher summer "n" values compensates, to some degree, for these random obstructions and, in general, gives higher, more conservative, floodwater heights for equivalent discharges.

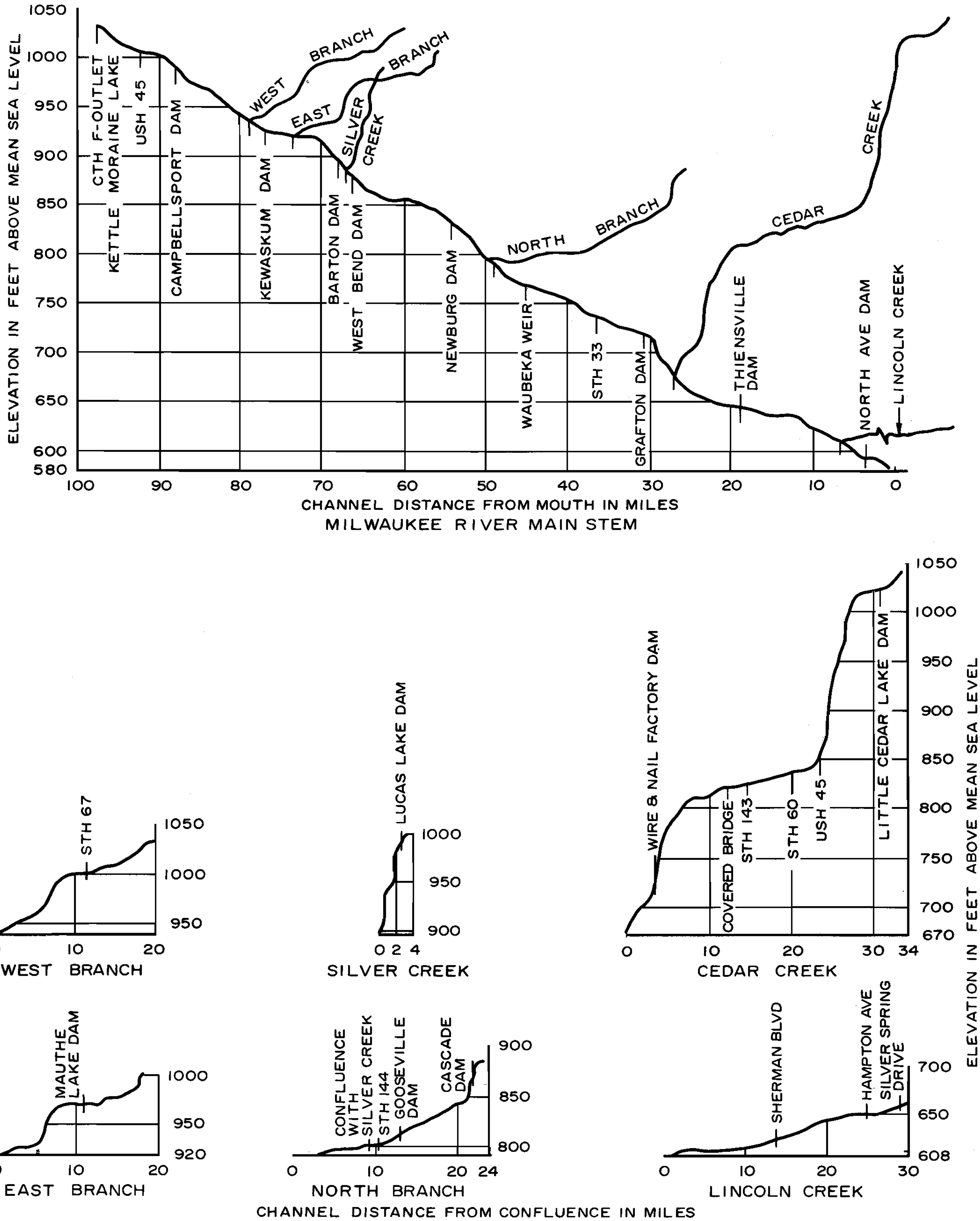
ARTIFICIAL CHARACTERISTICS OF THE BASIN

The preceding discussion was confined to the natural characteristics of the Milwaukee River watershed which would determine the surface water runoff characteristics of the basin in the absence of any external factors. In fact, however, the natural hydrologic regimen of the Milwaukee River watershed has been changed significantly by the activities of man. Consequently, a complex of artificial or "unnatural" characteristics has been superimposed on the natural characteristics previously discussed, and these artificial factors have important effects on the streamflow regimen of the basin.

The fact that man can significantly modify the hydrologic and hydraulic characteristics of a watershed provides at once a powerful tool for abating water-related problems if wisely used and a danger that further severe environmental problems will be created through thoughtless actions. Even intentional acts designed to affect directly the flow regimen of a watershed, such as the construction of dams, improvement of channel capacity and alignment, and drainage activities, may result in locally improved conditions at the expense of increased problems elsewhere in the watershed. Moreover, activities, such as the construction of roads and bridges and changes in

Figure 25

STREAM CHANNEL PROFILES FOR THE MILWAUKEE RIVER AND SELECTED MAJOR TRIBUTARIES 1967



Source: SEWRPC.

TABLE 34

SELECTED HYDROLOGIC AND HYDRAULIC INFORMATION OF THE MILWAUKEE RIVER WATERSHED BY SUBWATERSHED- 1967

SUBWATERSHED	DRAINAGE AREA (SQUARE MILES)	CHANNEL LENGTH[a] (MILES)	MEAN CHANNEL SLOPE[a] (FEET/MILE)	FRICTION COEFFICIENTS				CULVERTS		BRIDGES	TOTAL CROSSINGS	AVERAGE MILES PER CROSSING
				CHANNEL		FLOODPLAIN						
				NUMBER OF OBSERVATIONS[b]	AVERAGE 'N'	NUMBER OF OBSERVATIONS[b]	AVERAGE 'N'	BOX	CMP[c]			
CEDAR CREEK..............	126.8	32.72	10.90	18	0.039	36	0.067	5	3	27	35	0.94
CROOKED LAKE CREEK.......	14.2	5.13	6.65	--[d]	0.034	--[d]	0.050	3	2	1	6	0.86
EAST BRANCH..............	36.1	17.97	4.67	6	0.051	12	0.054	0	0	9	9	2.00
LINCOLN CREEK............	19.8	5.75	9.04	--[d]	0.021	--[d]	0.042	3	0	19	22	0.26
LOWER MILWAUKEE RIVER[e]....	132.3	44.80	4.46	32	0.036	64	0.054	0	0	32	32	1.40
MIDDLE MILWAUKEE RIVER...	50.5	26.37	5.02	21	0.041	42	0.070	0	0	15	15	1.76
NORTH BRANCH.............	127.9	22.66	4.51	9	0.037	18	0.050	1	1	19	21	1.08
SILVER CREEK............. (SHERMAN TOWNSHIP)	19.6	9.60	7.60	--[d]	0.037	--[d]	0.048	3	3	6	12	0.80
SILVER CREEK............. (WEST BEND TOWNSHIP)	9.2	4.62	23.87	--[d]	0.044	--[d]	0.067	1	6	4	11	0.42
UPPER MILWAUKEE RIVER....	93.2	22.61	4.59	6	0.042	12	0.056	0	2	9	11	2.06
WEST BRANCH..............	60.4	20.87	4.50	10	0.040	20	0.042	1	2	12	15	1.39
TOTAL....................	690.0	213.10	--	--	--	--	--	17	19	153	189	1.13

[a]FOR THE PERENNIAL CHANNELS FOR WHICH WATER SURFACE PROFILES HAVE BEEN DETERMINED.

[b]BY FIELD INSPECTION.

[c]CORRUGATED METAL PIPE.

[d]ESTIMATE BASED ON PHOTOGRAPHS FROM SURVEY BY ALSTER & ASSOCIATES, INC.

[e]EXCLUDES 3.10 MILES OF CHANNEL, 16 BRIDGES, AND DRAINAGE AREA OF 3.8 SQUARE MILES DOWNSTREAM FROM NORTH AVENUE DAM.

SOURCE- HARZA ENGINEERING COMPANY.

land use which are not designed to change the hydrologic regimen, do so in an incidental or often drastic manner. It is, therefore, vitally important that the effects of man's activities on the hydrologic regimen, whether intentional or incidental, be understood to the fullest extent possible.

The effect of man's activities on the hydrologic regimen of the watershed can best be investigated by grouping these activities according to their basic effect and first considering each of these groups separately before analyzing the combined effect upon the watershed. Accordingly, man's activities in the Milwaukee River basin have been grouped into five categories: 1) water control structures; 2) channel improvement; 3) artificial drainage; 4) constrictions, such as roads, bridges, and culverts; and 5) land use. The influence of each of these activities on the Milwaukee River basin as a whole is treated briefly in the following discussion.

Water Control Structures

There are 48 man-made water control structures located on the total stream system of the Milwaukee River watershed, of which 38 are located on the 216 miles of channel within the Milwaukee River watershed for which hydraulic studies were made. These structures include all devices designed and built especially to regulate or modify the natural flow regimen of surface runoff but do not include structures, such as bridges and culverts, which are treated separately.

Eleven of the water control structures have been constructed at natural lake outlets to regulate and control lake levels for recreational purposes but do provide a degree of incidental benefits in the form of flood control. The amount of storage provided by these structures per increment of depth above normal lake level is proportional to the lake surface area and, in the case of the larger lakes, is a significant factor in attenuating flood peaks resulting from smaller storms.

Certain man-made water control structures, of which there are 14 in the basin, were originally built to impound water for recreational and aesthetic purposes. Even the two most significant of these, the Estabrook Park Dam and the Kletzsch Park Dam on the main stem of the Milwaukee River, do not have enough storage to affect materially the peaks or durations of surface water runoff hydrographs during the spring runoff period.

A number of water control structures were originally built for water power or water supply. These include 24 low-head millpond dams and one industrial hydroelectric dam. With the availability of inexpensive, areawide electrical power service, these low-head water power developments were abandoned; and the millponds and dams are now maintained for aesthetic and recreational purposes. In their present condition, these artificial impoundments are too small to provide any significant storage effect during major runoff events. Urban and topographic restrictions, furthermore, impose serious limitations on these sites as future flood control developments.

All water control structures in the Milwaukee River watershed have the same effect on the surface water hydrology as do natural impoundments of comparable size. That is, they tend to retard flow velocity and increase hydrograph base time and decrease peak discharge rates. Also, like natural surface water storage areas, they act as channel obstructions and produce backwater which may have detrimental upstream effects in return for somewhat lower flood peaks downstream. There are no impounding structures presently existing within the watershed which have been constructed solely for flood control purposes. The existing dams generally provide only a small overall hydrograph modification, due to the temporary storage above spillway elevation. A few local areas, especially below the water level control structures on the major lakes, do enjoy a fairly significant reduction in flood peak; but even under natural outflow conditions, flooding would probably not be a serious problem at these locations.

Map 26 shows the locations and distribution of these man-made water control structures within the Milwaukee River watershed. A summary of the inspection results of these structures and a brief description of each are given in Chapter V of this volume.

Channel Improvement

Several miles of the perennial stream system of the Milwaukee River watershed have been intentionally modified by man in an attempt to improve their hydraulic characteristics. Channel improvement may consist of straightening, deepening, increasing the cross-sectional area, improving the alignment, or diking, and generally involves all five phases, all of which result in increased velocity of flow and decreased time of concentration. Some portions of the Milwaukee River basin were so poorly drained under natural conditions that it was necessary to improve the hydraulic characteristics of the main stream channels in order to provide adequate outlets for agricultural drainage systems and prevent long periods of inundation which would interfere with efficient agricultural operations. Because of the individual manner and long period of time over which such channel improvements have been made, it is not possible to determine precisely the history of such operations; but it appears that channel straightening and deepening have been carried out through legally organized farm drainage districts, through informally organized citizen action groups, and through individual action since before the end of the last century.

Although small channel improvements have been made in nearly every subwatershed of the Milwaukee River basin, the most intense activity has occurred in the central and southern parts of the watershed, particularly in the Lincoln Creek subwatershed. The spatial distribution of known channel improvements within the Milwaukee River watershed is shown on Map 27 and is summarized in Table 35.

The effects of channel improvement projects are exactly the reverse of those of the structural measures previously discussed. Whereas water control structures retard flow, decrease velocity, and cause backwater effects, upstream channel improvements accelerate flow, increase velocity, and reduce backwater effects upstream. Control structures tend to prolong the base time of surface runoff and decrease peak discharges in the downstream direction, while channel improvement has the effect of decreasing base time and increasing stage and the peak flow rate downstream from the improvement. It is apparent, therefore, that haphazard and uncoordinated channel modification may cause compensating effects with little or no overall benefits or with a negative overall effect on the surface water problems of a watershed and, as such, points to the need for proper water management practices based upon a comprehensive watershed plan.

Because of the lack of adequate historic data, it is extremely difficult to make a meaningful quantitative evaluation of the overall effect which existing channel improvement projects have had on the surface water characteristics of the Milwaukee River watershed as a whole. Because of

TABLE 35

SURFACE AND SUBSURFACE DRAINAGE IN THE MILWAUKEE RIVER WATERSHED BY SUBWATERSHED

SUBWATERSHED	DRAINAGE AREA SQUARE MILES	CHANNEL IMPROVEMENT		ARTIFICIAL AGRICULTURAL DRAINAGE[a]		ARTIFICIAL URBAN DRAINAGE[b]	
		MILES	MILES PER SQUARE MILE	SQUARE MILES	PERCENT OF TOTAL	SQUARE MILES	PERCENT OF TOTAL
CEDAR CREEK..............	126.8	15.6	0.12	17.5	14.0	0.98	0.8
CROOKED LAKE CREEK.......	14.2	2.0	0.14	0.0	0.0	0.00	0.0
EAST BRANCH..............	36.1	1.0	0.02	0.0	0.0	0.09	--
LINCOLN CREEK............	19.8	6.4	0.32	0.0	0.0	9.89	50.0
LOWER MILWAUKEE..........	136.1	6.8	0.05	10.7	8.0	20.73	15.2
MIDDLE MILWAUKEE.........	50.5	0.5	0.01	0.0	0.0	1.79	3.5
NORTH BRANCH.............	127.9	2.4	0.02	1.0	0.8	0.08	--
SILVER CREEK (SHEBOYGAN).	19.6	1.0	0.05	0.0	0.0	0.09	0.5
SILVER CREEK (WASHINGTON)	9.2	0.5	0.05	0.0	0.0	0.30	3.2
UPPER MILWAUKEE..........	93.2	11.0	0.11	4.1	4.0	0.40	0.4
WEST BRANCH..............	60.4	1.6	0.02	0.0	0.0	0.12	0.2
TOTAL....................	693.8	48.8	0.08	33.3	4.8	34.47	4.9

[a] INCLUDES ALL AREAS FOUND TO BE IN HISTORIC OR EXISTING FARM DRAINAGE DISTRICTS.

[b] SUMMARY OF ALL QUARTER SECTIONS WITH THE URBAN LAND USES RESIDENTIAL, COMMERCIAL, INDUSTRIAL, GOVERNMENTAL, AND INSTITUTIONAL TOTALING 50 ACRES OR MORE.

SOURCE- SEWRPC.

the large amount of natural storage which still exists within the main channel system of the watershed, it is reasonable to assume that the net effect on the flow regimen at Milwaukee is hardly measurable. Nevertheless, the basic trends indicated previously are very real. In the Cedar Creek subwatershed, for example, such activity has made possible the drainage of valuable farm land, with the probability that downstream flood peaks are somewhat higher. It is possible, however, that a channel improvement which shortens the time of concentration of a tributary peak could sufficiently cause staggering of tributary peaks to actually decrease the combined discharge rate. The opposite result could also be true, in which case the changed time of concentration would tend to increase the combined discharge rate.

Artificial Subsurface Drainage

Artificial subsurface drainage is another factor affecting the flow regimen of a watershed and is often closely associated with channel improvement. Large portions of the Milwaukee River watershed have such poor surface drainage under natural conditions that it is necessary to install tile underdrains to permit efficient agricultural operations. Because of the individual manner and long period of time over which such drainage improvements were installed, it is not possible to determine precisely the total tile-drained area. Estimates based upon historical records and legally established farm drainage district boundaries indicate that, about 33 square miles, or 5 percent of the entire watershed area, has been tiled, with nearly 53 percent of this total lying within the Cedar Creek subwatershed. Map 3 shows the spatial distribution of known tile-drained areas within the Milwaukee River watershed basin. These areas are also summarized in tabular form for the entire watershed and for the 11 hydrologic subwatershed units in Table 35. The location map indicates that tile-drained areas are often, though not always, associated with channel improvement. This is because straightening and deepening of natural channels is often required to provide adequate outlets for the agricultural drain tiles.

The effect of artificial drainage on the flow regimen of a watershed is difficult to analyze, since the effect of the drainage is not to reduce the surface water storage but to increase the capacity for temporary soil water storage during the growing season. The net result would generally be expected to increase the volume of streamflow due to a reduction of evapotranspiration losses. In the spring, when ice and snow conditions cause blocking of the drainage courses, there is probably little overall effect on natural flow conditions. During the frost-free months, when tile underdrains are fully operable, it is probable that areas that have been tiled to eliminate poor surface drainage or to lower a high ground water table would show a decrease in peak surface runoff due to the increased storage made available in the dewatered soil profile but would result in the ultimate release of a greater volume of flow. For the more infrequent high-intensity short-duration rainfall events, however, where soil infiltration capacity is a limiting factor, it is doubtful that tiling in the Milwaukee River watershed has any perceptible influence on peak rates of runoff.

Roads, Bridges, and Culverts

A total of 231 highway and railroad crossings over the stream system of the Milwaukee River watershed were inventoried in the watershed study. Of this total, 209 structures were located on the 216 miles of perennial stream network for which the flood-flow simulation model was constructed. Of these 209 structures, four did not significantly affect the hydraulic capacity of the stream system and were thus eliminated from the model, leaving a total of 205 structures used in the model. The location of all 231 structures inventoried is shown on Map 36, along with the 48 dams and lake outlet control structures existing in the watershed. All of the 48 dams and lake outlet control structures were inventoried and 38 were used in the flood-flow simulation model.

The number and type of crossing structures are summarized in tabular form for the entire watershed and for the 11 hydrologic subwatershed areas in Table 34. This tabulation shows that the greatest number of crossings per river mile is 3.26, which occurs in the Lincoln Creek subwatershed, and the least number is 0.49 per river mile, which occurs in the Upper Milwaukee River subwatershed. The average distance between crossings for the entire Milwaukee River watershed is approximately one mile.

Roadway and railway bridges and culverts are cultural features imposed upon the watershed by man. Unlike water control structures, they are not built for the purpose of regulating or modifying the natural flow regimen of surface runoff but do so only incidentally. Bridges and culverts, along with their approaches, function as obstructions during times of high surface water discharge, causing upstream water levels to be raised above downstream water levels by an amount equal to the head loss (loss of hydraulic energy) through the structure. This causes the water surface profiles to be raised above natural levels for some distance upstream from the bridges. This backwater effect reduces the effective slope and the amount of energy available for flow, resulting in lower velocities and decreased flow capacity. This, in turn, causes temporary surface water storage, which tends to decrease peak discharges and increase the duration of surface runoff downstream at the expense of higher stages and increased inundation upstream.

The amount of head loss through a bridge is a function of its waterway opening and hydraulic characteristics, as well as the amount of flow in the channel and, for a well-designed bridge, can be quite small. For a given discharge, therefore, the amount of backwater effect depends more on the hydraulic characteristics of the individual structures than on the total number of crossings. Backwater caused by bridges and culverts within the watershed is generally very small and, for a 100-year recurrence interval flood, ranges from only a few tenths of a foot to slightly over 2.0 feet.

Head loss attributed to bridges and culverts varies from subwatershed to subwatershed within the Milwaukee River basin. For the watershed as a whole, however, the significance of the stream crossing effect is overshadowed by the much more significant influence of head losses which occur at dams and head losses associated with natural watershed characteristics, such as channel and overbank frictional resistance and channel meandering. In the Lower Milwaukee River, for example, hydraulic computations indicate that bridges and culverts cause less than one percent of the total head loss during a 100-year recurrence interval flood.

Land Use

The type, intensity, and spatial distribution of land use, along with soil type, determine, to a large extent, the surface water runoff characteristics of a watershed. Soil type, which has been discussed previously, is a natural property; but land use is a result of human activity and must be considered as an artificial characteristic.

The type of land use and treatment have two major effects on hydrologic relationships. The rainfall-runoff ratio is a function of the degree of perviousness of the surface and the type of cover. The rainfall-runoff relationship may be expressed as a hydrologic soil-cover complex number[25], with the volume of runoff being proportional to its magnitude. Time of concentration varies with the hydraulic smoothness associated with the land use. Smoother surfaces, such as bare soil or paved areas, decrease the time of concentration and cause the incremental surface runoff hydrograph to have a high peak and short base, whereas the converse is true to hydraulically rough surfaces.

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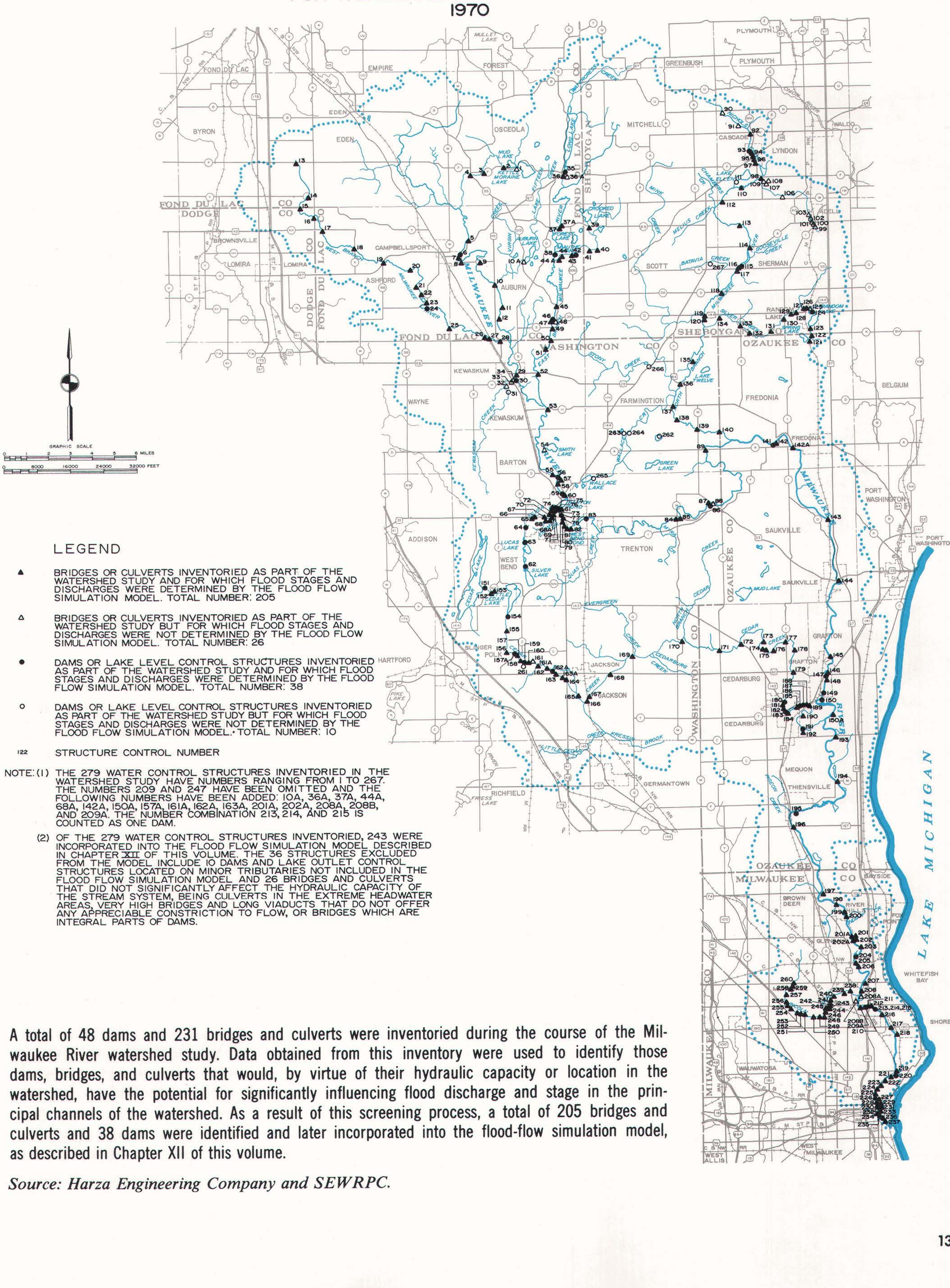
[25] *A hydrologic soil-cover complex is represented numerically by a Runoff Curve Number (RCN), which is based on the combination of hydrologic soil group and land use and treatment class. For further discussion, See Chapter XII of this volume, entitled "River Performance Simulation."*

Map 36

HYDRAULIC STRUCTURE INDEX FOR THE MILWAUKEE RIVER WATERSHED 1970



LEGEND

- ▲ BRIDGES OR CULVERTS INVENTORIED AS PART OF THE WATERSHED STUDY AND FOR WHICH FLOOD STAGES AND DISCHARGES WERE DETERMINED BY THE FLOOD FLOW SIMULATION MODEL. TOTAL NUMBER: 205
- △ BRIDGES OR CULVERTS INVENTORIED AS PART OF THE WATERSHED STUDY BUT FOR WHICH FLOOD STAGES AND DISCHARGES WERE NOT DETERMINED BY THE FLOOD FLOW SIMULATION MODEL. TOTAL NUMBER: 26
- ● DAMS OR LAKE LEVEL CONTROL STRUCTURES INVENTORIED AS PART OF THE WATERSHED STUDY AND FOR WHICH FLOOD STAGES AND DISCHARGES WERE DETERMINED BY THE FLOOD FLOW SIMULATION MODEL. TOTAL NUMBER: 38
- ○ DAMS OR LAKE LEVEL CONTROL STRUCTURES INVENTORIED AS PART OF THE WATERSHED STUDY BUT FOR WHICH FLOOD STAGES AND DISCHARGES WERE NOT DETERMINED BY THE FLOOD FLOW SIMULATION MODEL. TOTAL NUMBER: 10
- 122 STRUCTURE CONTROL NUMBER

NOTE: (1) THE 279 WATER CONTROL STRUCTURES INVENTORIED IN THE WATERSHED STUDY HAVE NUMBERS RANGING FROM 1 TO 267. THE NUMBERS 209 AND 247 HAVE BEEN OMITTED AND THE FOLLOWING NUMBERS HAVE BEEN ADDED: 10A, 36A, 37A, 44A, 68A, 142A, 150A, 157A, 161A, 162A, 163A, 201A, 202A, 208A, 208B, AND 209A. THE NUMBER COMBINATION 213, 214, AND 215 IS COUNTED AS ONE DAM.

(2) OF THE 279 WATER CONTROL STRUCTURES INVENTORIED, 243 WERE INCORPORATED INTO THE FLOOD FLOW SIMULATION MODEL DESCRIBED IN CHAPTER XII OF THIS VOLUME. THE 36 STRUCTURES EXCLUDED FROM THE MODEL INCLUDE 10 DAMS AND LAKE OUTLET CONTROL STRUCTURES LOCATED ON MINOR TRIBUTARIES NOT INCLUDED IN THE FLOOD FLOW SIMULATION MODEL AND 26 BRIDGES AND CULVERTS THAT DID NOT SIGNIFICANTLY AFFECT THE HYDRAULIC CAPACITY OF THE STREAM SYSTEM, BEING CULVERTS IN THE EXTREME HEADWATER AREAS, VERY HIGH BRIDGES AND LONG VIADUCTS THAT DO NOT OFFER ANY APPRECIABLE CONSTRICTION TO FLOW, OR BRIDGES WHICH ARE INTEGRAL PARTS OF DAMS.

A total of 48 dams and 231 bridges and culverts were inventoried during the course of the Milwaukee River watershed study. Data obtained from this inventory were used to identify those dams, bridges, and culverts that would, by virtue of their hydraulic capacity or location in the watershed, have the potential for significantly influencing flood discharge and stage in the principal channels of the watershed. As a result of this screening process, a total of 205 bridges and culverts and 38 dams were identified and later incorporated into the flood-flow simulation model, as described in Chapter XII of this volume.

Source: Harza Engineering Company and SEWRPC.

The spatial distribution of the existing land uses within the watershed is summarized on Map 9, and the various existing land uses are quantified in Table 7. It should be noted from the table that, about 15 percent of the total area of the watershed is devoted to intensive urban-type land uses, which have the highest surface runoff potential; about 61 percent is devoted to agricultural uses; and about 14 percent is devoted to woodlands and wetlands, which have the lowest runoff potential. The volume of surface runoff generally increases with increased land use intensity, while the time of concentration tends to decrease with increased land use intensity. For instance, if woodlands are converted to commercial or industrial land use, runoff volume may be increased as much as three or four times. It can be generally stated that man's activities with respect to land use increase both the volume of runoff and peak discharges over natural conditions, the amount of increase varying with the type and intensity of land use and with the rate of change from one use to another. Although change in land use from natural conditions has had a very definite effect upon the flow regimen of the Milwaukee River basin, a precise quantification of this effect would be difficult. The result can be summarized qualitatively, however, with respect to three major phases of historic development in the watershed, as follows:

1. Before the settlement of the area by Europeans, the entire watershed was either in wetland, prairie, or woodland, all "natural" land uses which tended to reduce both the velocity and volume of surface runoff, resulting in hydrographs with low-peak discharges and long-base times. Erosion and sedimentation problems were minimal.

2. The first major change in the flow regimen came with the transition from natural to agricultural land use. This change was fairly gradual but had a major influence upon the hydrology of the basin. Natural cover was reduced through more intensive grazing; the plow laid much of the area bare and made it susceptible to erosion. Both flood peaks and runoff volumes were increased, probably by as much as 15 percent. Sedimentation problems increased, and small millponds silted up more rapidly.

3. The second major change in the flow regimen came with the transition from agricultural to urban use and is still underway at the present time. The effects of urbanization on the flow regimen of a watershed are of such major importance that they warrant more detailed consideration.

<u>Urbanization</u>: Urbanization is actually a combination of intensive land uses, including commercial, industrial, transportation, and residential uses, each of which has a somewhat different effect upon the flow regimen of a watershed. Since every urban area has differing proportions of each land use, it is obvious that runoff modification will vary accordingly. Since the changes in peaks, duration, and frequency of floods vary widely from subwatershed to subwatershed, depending upon such factors as soils and topography, as well as upon the relative proportions of each of the urban land uses, the effects of land use alone are extremely difficult to evaluate on a quantitative basis.

Urbanization generally modifies the hydrologic system of a watershed by decreasing the storm water retention capability over much of the area and by increasing the rate at which storm water is transported over the surface of the land. The ratio of runoff to rainfall is increased as a result of increased impervious area. The time of concentration is decreased as a result of decreased hydraulic friction and increased drainage density. The time of concentration of an area which is fully storm sewered may be reduced to one-third of the time under agricultural use. These reductions in concentration time and increases in runoff have the effect of shortening the time of tributary outflow but increasing the peaks. It should be pointed out, however, that the increase in impervious area may be somewhat compensated for by the increased retention capability of soils under lawn cover as compared to some types of agricultural use; but the net effect is still toward increased runoff except in the case of extremely low-density residential development.

The preceding discussion is valid for summer rainfall events, but major floods in the Milwaukee River watershed are more likely to be associated with snowmelt conditions when the soil is either saturated or frozen and the retention capacity for concurrent rainfall is practically nil. Effectively then, the entire area of the watershed is impervious regardless of the extent of urban development. In fact, it is likely that the volume of snowmelt runoff in a flood situation will be somewhat smaller under urban conditions than it would be for agricultural conditions. Snow deposits disappear more rapidly in an urban situation, allowing comparatively less accumulation prior to sudden thaw, such as occurred in 1960. Snow is removed or melted from the streets, melts from roofs of buildings, and is more effectively melted off by solar radiation because of darkening from soot and dust.

The rate of runoff of snowmelt water from urban areas is increased, however, because of paved drains and sewers and hydraulically improved stream channels. As a result flood peaks may be higher, even though the total volume of flood runoff is less. It can be concluded that flood peaks from urban areas under snowmelt conditions may be expected to be somewhat higher than under agricultural conditions, especially for the more infrequent events. This is due to shorter concentration times and the increased likelihood of unpredictable conditions, such as ice jams, despite the tendency toward decreased surface runoff volume.

A comparison of peak flood discharges from the Silver Creek (Sherman Township) subwatershed and the Lincoln Creek subwatershed illustrates the aforementioned effects of urbanization on surface water runoff characteristics. The Silver Creek subwatershed is almost entirely in rural land use and, as shown in Table 34, has a drainage area of 19.6 square miles and a mean channel slope of 7.60 feet per mile. In contrast, the Lincoln Creek subwatershed is urbanized, being covered almost entirely with high-density residential land use; however, its drainage area of 19.8 square miles and mean channel slope of 5.80 feet per mile are very similar to the Silver Creek subwatershed. Therefore, different responses of these two subwatersheds to the same flood-producing event may be attributed almost exclusively to the rural state of land use in the one subwatershed as opposed to the urbanized state of land use in the other subwatershed.

The flood-flow model described in Chapter XII of this volume indicates that the 100-year recurrence interval subwatershed rainfall flood would produce a peak discharge of 2,430 cfs at the downstream end of the Silver Creek subwatershed, while the same precipitation sequence applied to the Lincoln Creek subwatershed would generate a peak discharge of 3,700 cfs at the subwatershed discharge point. Therefore, as indicated by the model, urbanization is responsible for a 52 percent increase in peak discharge accompanying the 100-year recurrence interval subwatershed flood. Peak discharges for the 10-year recurrence interval subwatershed rainfall flood events are 1,570 cfs for Silver Creek and 2,800 cfs for Lincoln Creek, a 78 percent discharge increase attributed to urbanization. An increase in peak discharge would also be expected to occur for snowmelt or snowmelt-rainfall flood events on these two subwatersheds, although as stated above, the increase would generally not be as large as for rainfall floods.

Besides increasing surface runoff peaks and decreasing base time, urbanization tends to modify surface water hydrology in other ways. Increased velocity may increase scouring and sedimentation downstream. Shorter runoff time base and ground water pumpage may decrease base flow during low-flow periods. This will lead to increased waste assimilation problems and locally change flow-duration characteristics of the subwatershed.

PHYSICAL CHARACTERISTICS BY SUBWATERSHED

In previous sections of this chapter, the major natural and man-made physical characteristics of the watershed were described and the individual influence of these characteristics upon the overall surface water hydrology of the Milwaukee River basin discussed. The general relationships which have been developed for the basin as a whole also apply to the 11 subwatersheds which have been chosen as basic units for hydrologic analysis. There are eight major subwatersheds ranging in size from 19.8 to 132.3 square miles. These subwatersheds were determined on the basis of their hydrologic similarity and generally correspond to the naturally defined watersheds of the major tributaries at their confluence with the main stem of the Milwaukee River. Each subwatershed is homogeneous enough that it can be reasonably considered as having uniform climatic, hydrologic, geologic, and geomorphologic characteristics. The other three minor subwatersheds range in size from 9.9 to 19.6 square miles and were selected for study due to their particular proximity to existing or anticipated structural developments.

Since the surface water runoff characteristics vary profoundly from subwatershed to subwatershed, it is necessary to discuss for each subwatershed those physical characteristics which affect surface water runoff. Such a discussion is essential to the attainment of a proper understanding of the hydrologic model developed for the watershed, including the synthetic hydrographs and the simulation of actual runoff events. The subwatersheds are discussed in order of their contribution to flow to the main stem of the Milwaukee River, beginning with the Upper Milwaukee River subwatershed, which is the most northerly subwatershed, and the headwaters of the basin and ending with the Lincoln Creek subwatershed within the City of Milwaukee.

Upper Milwaukee River Subwatershed

The Upper Milwaukee River subwatershed has an areal extent of 93.2 square miles, or 13.5 percent of the total watershed area, and is divided into 13 sub-basins. This subwatershed comprises the headwater region of the main stem of the Milwaukee River, lying between the watershed divide and the junction with the East Branch of the Milwaukee River. This subwatershed is characterized by numerous permanent wetlands, totaling 14,639 acres, or 24.4 percent of the subwatershed area. Surface water storage areas cover 799 acres, or 1.3 percent of the subwatershed area. Woodlands cover a total of 4,389 acres, or 7.4 percent of the subwatershed area.

Channel improvement to facilitate drainage is among the most intensive for the entire watershed, and about 5 percent of the subwatershed area has been artificially drained. There are 11 stream-crossing structures on 22.61 miles of channel system for which hydraulic characteristics have been determined, giving the Upper Milwaukee River subwatershed the lowest representative structure density in the watershed. Channel slopes average 4.59 feet per mile, with a mean coefficient of roughness of "n" = 0.042. Five percent of the subwatershed is devoted to urban land use, making it the eighth most urbanized of the 11 subwatersheds.

West Branch Subwatershed

The West Branch subwatershed consists of five sub-basins and has a drainage area of 60.4 square miles, or 8.8 percent of the total watershed area. It is tributary to the Upper Milwaukee River approximately 1.5 miles north of Kewaskum. This subwatershed has scattered wetland areas totaling 5,991 acres, or 15.6 percent of the subwatershed area. Of this total, 1,433 acres, or 26 percent of the subwatershed wetlands, are located in the Wayne Marsh in the Town of Wayne. Surface water storage areas total 5,645 acres, or 15 percent of the subwatershed area. Woodlands cover a total of 1,789 acres, or 4.6 percent of the subwatershed area.

There are 15 stream-crossing structures on 16.66 miles of channel system for which hydraulic characteristics have been determined. Channel slopes average 4.50 feet per mile, with a mean coefficient of roughness of "n" = 0.040. Four percent of the subwatershed is devoted to urban land use, making it the least urbanized of the 11 subwatersheds.

East Branch Subwatershed

The East Branch of the Milwaukee River is tributary to the Upper Milwaukee River approximately five miles north of the City of West Bend. The subwatershed consists of five sub-basins totaling 36.1 square miles, or 5.2 percent of the total watershed area. This subwatershed has extensive natural surface storage areas in depressions, swamps, and lakes. Of these storage areas, wetlands total 6,388 acres, or 26.1 percent of the subwatershed area, while lakes and streams comprise 682 acres, or 3.0 percent of the subwatershed area. Much of the riverine area is within the Kettle Moraine State Forest, which is devoted to the preservation and development of woodlands and wetlands. Woodlands in this subwatershed total 4,274 acres, or 18.5 percent of the total for the subwatershed. The potential for surface runoff, both in volume and peak per unit area, is less for this subwatershed than for nine of the 11 subwatersheds.

There are 9 stream-crossing structures, or about 17.97 miles of channel system, for which hydraulic characteristics have been determined. Channel slopes average 4.67 feet per mile, with a mean coefficient of roughness of "n" = 0.051. Urban land use comprises 1,404 acres, or 5.7 percent of the area of this subwatershed.

Crooked Lake Creek Subwatershed

Crooked Lake Creek drains an area of 14.2 square miles into the East Branch of the Milwaukee River at a point approximately one-half mile south of Mauthe Lake. Much of the riverine area is within the Kettle Moraine State Forest. Wetlands and woodlands total 2,269 and 1,486 acres, respectively, or 26.2 and 16.4 percent, respectively, of the subwatershed area. There are six stream-crossing structures on about 5.13 miles of channel system for which hydraulic characteristics have been determined. Channel slopes average 6.65

feet per mile, with a mean coefficient of roughness of "n" = 0.034. Urban land use comprises 400 acres, or 4.6 percent of the area of this subwatershed.

Middle Milwaukee River Subwatershed

The Middle Milwaukee River subwatershed is herein defined as that area lying along the main stem of the Milwaukee River between the junctions with the East and North Branches of the Milwaukee River. The drainage area of 50.5 square miles, or 7.3 percent of the total area of the watershed, is divided into six sub-basins. Surface water storage areas include 4,795 acres of wetlands and 791 acres of lake and stream surfaces, which represent 14.3 and 2.5 percent, respectively, of the subwatershed area. Woodlands, totaling 2,962 acres, or 9.2 percent of the subwatershed area, are scattered throughout the subwatershed.

Channel improvement to facilitate drainage is the least extensive within the entire Milwaukee River watershed, and only about 4 percent of the total area of the subwatershed has been subjected to artificial drainage improvements. There are 15 stream-crossing structures on about 26.37 miles of channel system for which hydraulic characteristics have been determined. Nearly all the land is in agricultural use, but urbanization is spreading to rural lands around the City of West Bend and could significantly change the runoff characteristics of the subwatershed. Channel slope averages 5.02 feet per mile, with a mean coefficient of roughness of "n" = 0.041.

Silver Creek (West Bend Township) Subwatershed

The Silver Creek (West Bend Township) subwatershed has an areal extent of 9.2 square miles, or 1.4 percent of the total area of the watershed, and is the smallest of the 11 subwatersheds. Silver Creek flows in a northeasterly direction and is tributary to the Milwaukee River within the limits of the City of West Bend. There is a relatively large potential for storage of surface runoff in Lucas and Silver Lakes and extensive marshy areas located in the upstream areas of the subwatershed. Of these storage areas, wetlands total 761 acres, or 12.4 percent of the subwatershed area. The lake surfaces of Lucas and Silver Lakes total 196 acres, or 3.2 percent of the subwatershed area. Peak runoff is significantly reduced by this storage. However, downstream from the storage areas, runoff is rapid, as the mean channel slope is 23.87 feet per mile. This slope is more than twice as steep as the mean channel slopes for the other subwatersheds.

There are 11 stream-crossing structures on about 4.62 miles of channel system for which hydraulic characteristics have been determined. The mean coefficient of roughness in the subwatershed is "n" = 0.044. Urban land use totals 1,237 acres, or 20 percent of the subwatershed area.

North Branch Subwatershed

The North Branch of the Milwaukee River is tributary to the Milwaukee River two miles west of Waubeka. The drainage area of 127.9 square miles, or 18.5 percent of the total area of the watershed, is divided into 12 sub-basins. The drainage system of the North Branch subwatershed includes many well-defined second order tributaries which contribute flow at regular distances along the North Branch channel. There are no large lakes or wetlands in this subwatershed. Of the total surface water storage areas, wetlands total 13,131 acres, or 15.9 percent of the subwatershed area, while lake and stream surfaces total 587 acres, or 0.7 percent of the subwatershed area. Because it lacks large surface water storage areas, the runoff from this subwatershed exceeds the average for the Milwaukee River watershed. Woodlands in the subwatershed total 8,352 acres, or 2 percent of the subwatershed area.

About 0.8 percent of the subwatershed area has been artificially drained. There are 21 stream-crossing structures on about 22.66 miles of channel system for which hydraulic characteristics have been determined. Channel slopes average 4.51 feet per mile, with a mean coefficient of roughness of "n" = 0.037. Most of the drainage area is used for agricultural purposes; and because of this, only 4.6 percent of the area of this subwatershed is in urban land use.

Silver Creek (Sherman Township) Subwatershed

Silver Creek (Sherman Township) drains an area of 19.6 square miles, or 2.8 percent of the total area of the Milwaukee River watershed. It flows into the North Branch of the Milwaukee River one-half mile north of the Sheboygan-Washington County line. The headwater region of the Silver Creek drainage area is controlled by Random Lake. Marshy lands lie astride the stream in the middle reach. These wetlands total 2,389 acres, or 20.3 percent of the subwatershed area. Lake and stream surfaces total 254 acres, or 2 percent of the subwatershed area. Also, in this subwatershed woodlands total 576 acres, or 5 percent of the subwatershed area.

Channel improvement to facilitate drainage is the fifth highest for the watershed, and about 0.4 percent of the subwatershed area has been artificially drained. There are 12 stream-crossing structures on about 9.60 miles of channel system for which hydraulic characteristics have been determined. Channel slopes average 7.60 feet per mile, with a coefficient of roughness of "n" = 0.037. Urban land uses comprise 766 acres, or 6.5 percent of the subwatershed area.

Lower Milwaukee River Subwatershed

The Lower Milwaukee River begins at the junction with the North Branch and terminates at the North Avenue Dam in Milwaukee. The drainage area of 132.3 square miles, or 19.2 percent of the total watershed area, is divided into 11 sub-basins. Wetland areas total 6,607 acres, or 7.7 percent of the subwatershed area. Lake and stream surfaces for the subwatershed total 2,292 acres, or 2.7 percent of the subwatershed area. Also, woodlands total 6,701 acres, or 7.9 percent of the subwatershed area. Runoff from this area is more rapid than from areas farther upstream. In addition, the water yield per unit area is probably greater in this area, due both to the effects of urbanization and due to the type of soils.

Channel improvement to facilitate drainage is the fifth highest for the watershed, and about 23 percent of the area has been artificially drained. There are 32 stream-crossing structures on about 45 miles of channel system for which hydraulic characteristics have been determined. Channel slopes average 4.46 feet per mile, with a coefficient of roughness of "n" = 0.036. Land use varies from rural in the upstream areas to high-density urban within the City of Milwaukee. The subwatershed is undergoing rapid urbanization, which is spreading northward from the City of Milwaukee.

Cedar Creek Subwatershed

The Cedar Creek subwatershed is divided into 10 sub-basins totaling 126.8 square miles, or 18.4 percent of the total watershed area. Beginning at Big Cedar Lake, the largest lake in the watershed, Cedar Creek flows in a general easterly direction and is tributary to the Milwaukee River two miles south of the Village of Grafton. The Cedarburg Bog, located five miles north of the City of Cedarburg, is a large, scientifically monitored wildlife refuge maintained by the Wisconsin Department of Natural Resources. It constitutes a sizable area of off-channel natural storage for runoff. Jackson Marsh lies along the main channel of Cedar Creek and provides considerable on-channel storage during floods. These and other wetland areas total 12,092 acres, or 16.0 percent of the subwatershed area. Lake and stream surfaces total 2,052 acres, or 2.53 percent of the subwatershed area. Also, woodlands total 6,527 acres, or 8.05 percent of the subwatershed area.

About 15 percent of the subwatershed area has been artificially drained. There are 35 stream-crossing structures on about 32.72 miles of channel system for which hydraulic characteristics have been determined. Channel slopes average 11.55 feet per mile, with a coefficient of roughness of "n" = 0.039. Land use varies from recreational and low-density residential in the headwaters to agricultural and marshy areas in the central drainage area to urban in the downstream portion of the subwatershed. The urban land uses comprise 6,678 acres, or 8 percent of the subwatershed area. Runoff from this subwatershed equals approximately the average for the entire watershed.

Lincoln Creek Subwatershed

Lincoln Creek drains 19.8 square miles of high-density residential area, or 2.9 percent of the total watershed area, most of which is within the City of Milwaukee. A portion of Lincoln Creek is now a concrete-lined channel surrounded by a grassy parkway that serves as the floodway. Runoff from this subwatershed is rapid and, for intense storms of short duration, results in high, sharp, peak flows at the Milwaukee River gage which precede the main river peaks.

Lincoln Creek has experienced the most intensive channel improvements of all the streams of the Milwaukee River system. Hydraulic data has been obtained for 5.75 miles of channel. Within this distance there are 22 stream-crossing structures for an average spacing of 0.26 mile, the highest crossing density in the total watershed.

SUMMARY

This chapter has described those elements of the complex hydrologic environment of the Milwaukee River watershed, which, because of their profound influence upon water resources, must be considered in any comprehensive land and water use planning effort. These elements are summarized in the following paragraphs and include the quantity and distribution of precipitation, evapotranspiration, the quantity of runoff and the factors that influence runoff, and surface and ground water storage and the factors that influence storage.

Quantitative knowledge of the complex hydrologic cycle as it affects the watershed is necessary to assess the availability of surface and ground water for various uses and to improve the management potential of water during times of flooding or drought. The quantitative relationships between inflow and outflow, termed the "hydrologic budget," were determined for the watershed. Precipitation is the primary source of water to the watershed and averages approximately 29.4 inches annually. Surface water runoff and evapotranspiration losses constitute the primary outflow from the basin. The average annual runoff approximates 6.9 inches, while the annual evapotranspiration loss to the watershed totals about 22.5 inches. Over a long period of time, the outflow from, and inflow to, the watershed have been equal, indicating that there is no apparent long-term trend in the net gain or loss in the quantity of water in the basin.

There are three main ground water aquifers that underlie the watershed, including the deep sandstone, the shallow dolomite, and the unconsolidated sand and gravel aquifers. The sandstone is the deepest of the three aquifer systems; and wells tapping this aquifer are sometimes more than 2,000 feet deep and, therefore, very expensive to drill and operate. This aquifer, except for minor leakage and a connection to the recharge area, is hydraulically separated from the remainder of the hydrologic system by the overlying semipermeable Maquoketa shale formation. This aquifer in the past has been a principal source of water supply to Milwaukee County industry; however, because of severe water quality problems recently incurred, most industrial users are no longer depending on this source of supply.

There are two shallow aquifer systems that are important sources of ground water supply. One is the shallow dolomite aquifer system. This system, in general, overlies the Maquoketa shale formation. Overlying the dolomite strata are the unconsolidated deposits of sand and gravel which comprise the second shallow aquifer system. Both of these aquifers are important sources of water to the Milwaukee River watershed; and, due to their relative nearness to the land surface, wells therein are inexpensive to construct and operate. The shallow aquifers are extensively used for private residential and commercial purposes but less extensively used by the larger municipalities.

The surface water of the watershed is composed almost entirely of streamflow and lake storage. Streamflow varies widely, reflecting changes in climatic conditions, soil moisture, season of the year, ground water levels, and land use. Records of streamflow for the basin are limited. The 55-year streamflow record of the Milwaukee River at Milwaukee, Wisconsin, is the longest streamflow record available within the basin. This record does not, however, adequately represent the streamflow characteristics of the major tributaries; and, therefore, these characteristics were determined by synthetic means.

The greatest quantity of surface water in the basin exists as lake storage. Variations in the lake levels have occurred in the past in response to a number of natural hydrologic factors. In the future, however, changes in land use, brought about by continued urbanization, may adversely affect lake levels.

An inventory and evaluation of the physical characteristics of the watershed which affect surface water runoff, both natural and artificial, were made as a basic step in the development of meaningful plans to abate serious flooding problems. Each natural feature of the basin—climate, soils, drainage pattern, storage areas, and channel and floodplain areas—and each artificial feature—water control structures, channel improvement, subsurface drainage, bridges and culverts, and land use—were included as a part of this inventory.

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Chapter VII

ANTICIPATED GROWTH AND CHANGE IN THE MILWAUKEE RIVER WATERSHED

INTRODUCTION

In any planning effort, forecasts are required of all future events and conditions which are outside the scope of the plan but which affect either the plan design or implementation. Normally, the future demand for land and water resources in a planning area is determined primarily by the size and spatial distribution of future population and economic activity levels. Control of changes in population and economic activity levels, however, lies largely outside the scope of governmental activity at the regional and local level and entirely outside the scope of the watershed planning process. In the preparation of a comprehensive watershed plan, therefore, future population and economic activity levels within the watershed must be forecast. These forecasts can then be converted to future demand for land and water resources within the watershed, and a land and water use plan prepared to meet this demand.

It is important to note that, because of the basic concepts underlying the Milwaukee River watershed planning program, the spatial distribution of future land use within the watershed lies within the scope of the plan to be produced and is, therefore, a design rather than a forecast problem. Thus, while it is necessary to forecast the future gross requirements within the watershed for each of the major land use categories, the spatial allocation of land to meet these requirements within the watershed is an important element of the plan itself. It is also important to note that the geographic location of the Milwaukee River watershed within the rapidly urbanizing Southeastern Wisconsin Region is an important factor affecting forecast requirements and methods. Economic activity affecting development within the Milwaukee River watershed is located largely, although not entirely, outside the watershed boundaries. Thus, the primary determinant of future land and water demand within the watershed is the future level of population within the watershed; and this level must be forecast primarily on the basis of broader regional forecasts of economic activity and employment levels.

The primary natural resource elements affected by population growth within the watershed are land and water, particularly land as open space with its attendant recreational and broad resource conservation values. The riverine areas are particularly important in this respect because it is here that the problems and opportunities arising out of a land use pattern, rapidly changing in response to changes in the size, characteristics, and, most importantly, the spatial location of the watershed population, will most affect the other elements of the natural resource base and the overall quality of the environment within the watershed. A rapidly changing land use pattern in the remainder of the watershed will also affect certain elements of the natural resource base, particularly woodlands and prime agricultural lands; but the effect upon the total environment will be less intensive than the effect of development in the riverine areas.

The water resource will be, in turn, affected by the land use pattern, particularly by the future spatial distribution of water-using and waste-disposing activities within the watershed. These will, to a considerable extent, determine the waste assimilation demands placed upon the lakes and streams of the watershed and the ability of these lakes and streams to meet the established water use objectives and standards.

POPULATION AND ECONOMIC ACTIVITY

Forecasts of future population and economic activity levels within the Milwaukee River watershed must take into consideration the distinct geographic and political features of the watershed, as well as the present pattern of, and historic trends in, the distribution of population and economic activity within the watershed. With respect to the preparation of forecasts of population and economic activity levels, the watershed may be considered to be comprised of two generally distinct areas: one consisting of that portion of the watershed lying within the Southeastern Wisconsin Region and the other, that portion lying outside the Region. These two areas not only differ with respect to the variety and depth of demographic and economic information available for forecasting purposes but also with respect to growth characteristics and potential.

As indicated in Chapter III of this volume, the headwater area of the watershed lying outside the Region in Dodge, Fond du Lac, and Sheboygan Counties contains 38 percent of the land area of the watershed but only 2 percent of the population. Moreover, since 1920 the population of the entire watershed increased by 104 percent, while the population of the headwater area increased by only 22 percent. Development in that portion of the watershed lying within the Southeastern Wisconsin Region is strongly influenced by the greater Milwaukee metropolitan area, and population and economic activity changes in this portion of the watershed are closely related to the population and employment changes in the Region as a whole. The growth potential of the headwater area is influenced in part by the Milwaukee metropolitan area and in part by the Cities of Fond du Lac and Sheboygan, but the area remains predominately rural in character.

In recognition of these factors, population and economic activity forecasts were prepared separately for the two portions of the watershed and summed to obtain forecasts for the entire watershed. For that portion of the watershed lying outside the Region, population and employment forecasts were based upon an extrapolation of historic trends under the assumption that the area will continue to change and progress at about the same rate as it has in the past. For that portion of the watershed lying within the Region, population and employment forecasts were based upon an analysis of population growth and economic activity levels within the watershed as related to the Region as a whole.

Population Forecasts

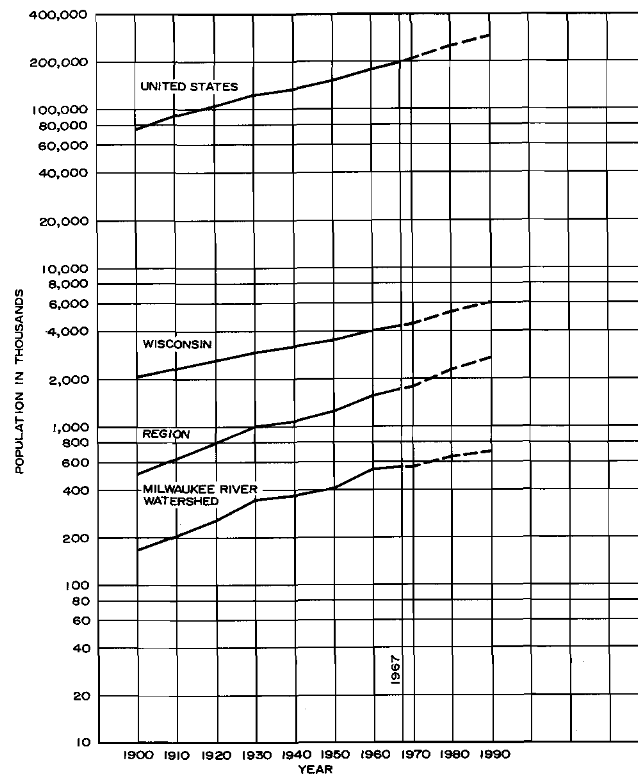
Population forecasts for the Region and for that portion of the Milwaukee River watershed within the Region have been prepared by the Commission to the year 1990. These forecasts are based upon economic, as well as demographic, studies and analyses using several independent methods.[1]

[1] *See Chapter III of SEWRPC Planning Report No. 7, Volume 2, Forecasts and Alternative Plans - 1990, for a discussion of the assumptions and techniques employed in the economic and demographic forecasts. In addition, SEWRPC Planning Report No. 3, The Economy of Southeastern Wisconsin, and SEWRPC Planning Report No. 4, The Population of Southeastern Wisconsin, each contain descriptions of the economic activity and population forecasting techniques employed by the Commission.*

The population of the Region is forecast to reach a 1990 level of approximately 2,700,000 persons, an increase of about 890,000 persons over the 1967 level of 1,809,500 persons (see Figure 26).

Figure 26

POPULATION TRENDS AND FORECASTS FOR THE MILWAUKEE RIVER WATERSHED, THE REGION, WISCONSIN, AND THE UNITED STATES 1900-1990



Source: U.S. Bureau of the Census and SEWRPC.

As indicated in Table 36, the population of the Milwaukee River watershed, considered as a whole, has increased steadily from a level of about 266,000 persons in 1920 to about 544,000 persons in 1967, an increase over the 47-year period of about 104 percent. This level is forecast to increase to about 678,000 persons by 1990, or by an additional 25 percent. The forecast population distribution within the watershed for 1990 is depicted on Map 37 by the overall gross density of each sub-basin area within the watershed. Table 36 also indicates that most of the population growth in the watershed may be expected to occur within that portion of the watershed lying within the Region, with the population of that portion of the Milwaukee River watershed within the Region forecast to reach a 1990 level of approximately 665,000 persons, or 98 percent of the total watershed population. The population of that portion of the watershed lying outside the Region is forecast to reach a 1990 level of approximately

TABLE 36

POPULATION TRENDS AND PROJECTIONS FOR THE UNITED STATES, WISCONSIN, THE REGION, AND THE MILWAUKEE RIVER WATERSHED- 1920-1990

YEAR	UNITED STATES	WISCONSIN	REGION	MILWAUKEE RIVER WATERSHED					WATERSHED POPULATION WITHIN THE REGION AS A PERCENT OF THE REGIONAL POPULATION
				AREA INSIDE REGION		AREA OUTSIDE REGION			
				NUMBER	PERCENT OF TOTAL	NUMBER	PERCENT OF TOTAL	TOTAL	
1920	105,710,620	2,632,067	783,681	256,160	96.2	9,930	3.8	266,090	33
1930	122,775,046	2,939,006	1,006,118	336,560	97.3	9,480	2.7	346,040	34
1940	131,669,270	3,137,587	1,067,699	352,330	97.3	9,750	2.7	362,080	33
1950	151,325,798	3,434,575	1,240,618	388,930	97.5	10,110	2.5	399,040	31
1960	179,323,175	3,952,771	1,573,620	514,392	97.9	10,920	2.1	525,312	33
1967	198,852,000	4,188,000	1,809,500[a]	531,680[a]	98.0	12,110	2.0	543,790	30
1970	203,675,000[b]	4,366,766[c]	1,742,883[c]	514,791[c]	98.0	12,861[c]	2.0	527,652[c]	30
1980	245,313,000	5,176,000	2,223,000	629,700	98.0	12,190	2.0	641,890	28
1990	288,219,000	5,977,000	2,678,000	664,930	98.0	12,720	2.0	677,650	25
1967-1990 PERCENTAGE INCREASE	45	43	98	25	--	5	--	25	--

[a]ESTIMATE BASED ON SYMPTOMATIC INDICATORS OF POPULATION CHANGE BETWEEN 1960 AND 1967.

[b]ESTIMATED BY U. S. BUREAU OF THE CENSUS, CURRENT POPULATION REPORTS, SERIES P-25, NO. 445.

[c]BASED UPON PRELIMINARY REPORTS OF 1970 U. S. CENSUS OF POPULATION.

SOURCE- U. S. DEPARTMENT OF COMMERCE, BUREAU OF THE CENSUS, AND SEWRPC.

13,000 persons, or 2 percent of the total watershed population.

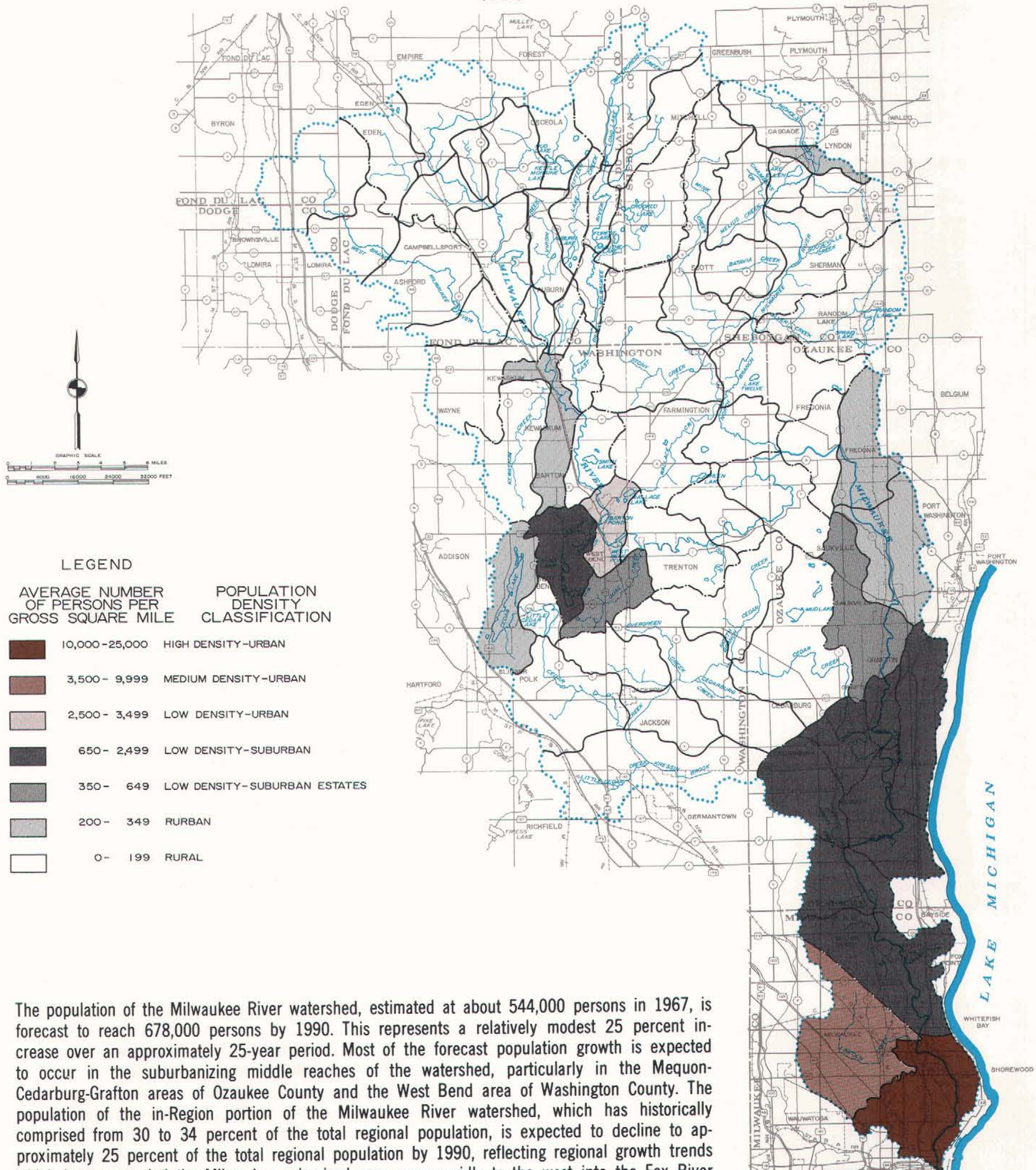
Although the population levels forecast represent a quite moderate rate of population growth for the watershed, a review of the historic relationship between population growth in the watershed and population growth in the Southeastern Wisconsin Region indicates the forecast levels to be reasonable, particularly in light of the location of the watershed within the seven-county Region (see Map 1). That portion of the watershed lying within the Region has, since 1920, consistently comprised from 31 to 34 percent of the total regional population. This portion of the watershed is, however, expected to account for a decreasing proportion of the total regional population, decreasing from 31 percent in 1967 to 25 percent by 1990. This anticipated decline reflects present trends which are tending to concentrate new urban development within the Region in areas to the west and south of the Milwaukee River watershed rather than within the watershed itself. Moreover, although completion of the proposed freeway system within the Region by 1990 may change somewhat the existing trends with respect to the direction and magnitude of urban development within the Region and the watershed, the system will probably not be completed in time to influence in any major way the 1990 forecast population and economic activity levels in the watershed.

As discussed in Chapter III of this volume, the preliminary 1970 U. S. Census of Population figures for the Milwaukee River watershed became available late in the watershed study. These figures revealed that the total watershed population grew by only about 0.2 percent during the 1960-1970 decade, from a 1960 estimated population of 526,823 to a 1970 estimated population of 527,652. Furthermore, the 1970 population level reveals an estimated population loss in the watershed from 1967 to 1970 of about 16,000, since the 1967 population of the watershed was estimated at about 544,000. All of this population loss, however, was concentrated in the lower reaches of the watershed and within the City of Milwaukee, where a number of extraordinary factors have been cited as contributing to a net population loss. These factors include the substantial depletion of the housing stock through extensive urban renewal, freeway, and other essential public works activities, as well as a reduction in the average household size. Combined with this significant population loss in the lower watershed is a pattern of equally significant population growth in the middle or suburban reaches of the watershed.

The impact of these recent population shifts and changes on the forecast 1990 watershed population, as presented above, could not be properly assessed within the context of the watershed study itself. Not only were the detailed census data not to be available until after completion of the study, but also it was recognized that the socioeconomic changes evidenced in the watershed were part of a set of complex factors at work throughout the

Map 37

FORECAST POPULATION DENSITIES
IN THE MILWAUKEE RIVER WATERSHED BY HYDROLOGIC SUB-BASIN
1990



The population of the Milwaukee River watershed, estimated at about 544,000 persons in 1967, is forecast to reach 678,000 persons by 1990. This represents a relatively modest 25 percent increase over an approximately 25-year period. Most of the forecast population growth is expected to occur in the suburbanizing middle reaches of the watershed, particularly in the Mequon-Cedarburg-Grafton areas of Ozaukee County and the West Bend area of Washington County. The population of the in-Region portion of the Milwaukee River watershed, which has historically comprised from 30 to 34 percent of the total regional population, is expected to decline to approximately 25 percent of the total regional population by 1990, reflecting regional growth trends which have expanded the Milwaukee urbanized area more rapidly to the west into the Fox River watershed than to the north into the Milwaukee River watershed.

Source: SEWRPC.

Southeastern Wisconsin Region and, indeed, the state and the nation and, hence, can only be properly studied after more detailed comparative census data became available on a nation and statewide, as well as a regionwide, basis. It is significant to note, however, that sharp reductions in the growth rate of the population of the watershed have also occurred in past decades, particularly in the 1930-1940 and 1940-1950 decades (see Figure 26). Such periods of relatively slow growth have normally been followed by periods of rapid growth. It is also significant to note that, if the urban renewal activities are successfully completed in the lower watershed as proposed and according to planned densities, it is likely that the population decline in the lower watershed will cease and that population levels there will stabilize or actually increase. Finally, it is important to recognize that the overall watershed growth pattern in the 1960's, which, as noted above, reflected a total watershed growth rate of about 0.2 percent, masks a true pattern of substantial population growth in the middle reaches of the watershed, combined with housing stock depletion and consequent population loss in the lower watershed. Heavy demands are and may be expected to continue to be, therefore, placed upon the limited land use, natural resource, and public utility base of the watershed, despite the fact that total watershed population growth has slowed.

Changes in the characteristics of the watershed population are expected to parallel closely those of the regional population, as described in SEWRPC Planning Report No. 7, Volume 2, Chapter III. In 1990 there will be proportionately more older people (ages 65 and over) and more younger people (ages 34 and under) than there were in 1967. The average household size within the watershed is expected to increase from the present level of about 3.16 persons to approximately 3.28 persons by 1990 due, in part, to an increasing rate of household formation and, in part, to the majority of the population increase in the watershed occurring in the outlying areas of the watershed.

Economic Forecasts

Economic activity, considered chiefly in terms of employment and employment opportunities, is not, within southeastern Wisconsin, functionally linked to watershed patterns. Rather, the forces from which economic activity originates and is sustained, as is partly the case of the Milwaukee River watershed, may lie outside the watershed itself. The watershed, and particularly the middle and lower portions, may be expected to continue to serve as a residential "dormitory" or "bedroom" area for many of the workers in the industrial complexes of the Milwaukee urbanized area. The watershed may also expect to continue to provide the location for new and expanding industrial and commercial enterprises seeking location on the periphery of the existing urbanized areas, particularly in the lower portions of the watershed and in the area surrounding the City of West Bend. In addition, the watershed may be expected to continue to provide for a substantial portion of the Region's agricultural production, although the product mix will probably change as more intensive use is made of the remaining agricultural lands. As indicated in Table 37, employment opportunities within the watershed are forecast to increase from the 1967 level of about 290,000 to a 1990 level of about 346,000, an increase of 19 percent.

LAND USE DEMAND

The requirements of approximately 678,000 residents for dwelling space and service facilities will largely determine the amount and variety of each of the various land uses within the Milwaukee River watershed in 1990. If present trends were to continue without guidance and regulation in the public interest, it is probable that the approximately 134,000 new residents which the watershed may be expected to gain between 1967 and 1990 will live primarily in residential areas developed at medium densities. The approximately 30 percent of the new residents, however, who will live in residential areas developed at low densities, will require nearly two-thirds of the newly developed residential land.

An analysis of urban development within the watershed from 1950 to 1967 indicates that about 64 percent of the land developed for residential use during this period consisted of low-density development, nearly 30 percent consisted of medium-density development, and about 6 percent consisted of high-density development.[2] Because

[2] *Low-density residential development is defined as development having an overall average density of 0.2 to 1.7 dwelling units (households) per gross acre (350-3,499 persons per gross square mile); medium-density, as 1.8 to 4.7 dwelling units per gross acre (3,500-9,999 persons per gross square mile); and high-density, as over 4.8 dwelling units per gross acre (10,000-25,000 persons per gross square mile). The midpoints of these ranges would correspond to net lot areas of 35,700, 10,000, and 3,630 square feet per dwelling unit, respectively.*

TABLE 37

EXISTING AND FORECAST EMPLOYMENT WITHIN THE MILWAUKEE RIVER WATERSHED AND THE REGION- 1967 AND 1990

AREA	EXISTING 1967		INCREMENT 1967-1990		TOTAL 1990	
	NUMBER	PERCENT OF REGION	NUMBER	PERCENT CHANGE	NUMBER	PERCENT OF REGION
MILWAUKEE RIVER WATERSHED..........	289,900	--	56,200	19.4	346,100	--
INSIDE REGION.....	285,835	42.3	55,765	19.5	341,600	34.7
OUTSIDE REGION....	4,065	--	435	10.7	4,500	--
SOUTHEASTERN WISCONSIN REGION.............	675,500	100.0	308,500	45.7	984,000	100.0

SOURCE- SEWRPC.

higher-density development by definition contains proportionally more households per acre than lower-density development, it was found that, within the watershed from 1950 to 1967, less than 28 percent of the new households resided in low-density areas, while 46 percent resided in medium-density areas and more than 26 percent resided in high-density areas. The high proportion of new medium- and high-density households in the watershed as compared to the Region as a whole reflects, in part, the greater predominance of Milwaukee County's urban growth pattern within the watershed than within the Region. It also reflects, to some extent, the recent historic trend in the Milwaukee area of the expansion of urban sprawl westward to a greater degree than northward. The analysis further indicates that, for the Region as a whole, 98 percent of the population reside in households and that the average household size in 1960 was 3.30 persons. The remaining 2 percent of the population reside in group quarters, such as dormitories and boarding houses, or are inmates of institutions.

For land use demand forecast purposes, therefore, it was assumed that 98 percent of the population increase in the watershed from 1967 to 1990 would reside in households with an average household size of 3.28 persons. It was further assumed that, if existing trends (1950-1967) continue, approximately 28 percent of the new households within the watershed would reside in low-density residential areas; that 46 percent would reside in medium-density residential areas; and that 26 percent would reside in high-density residential areas. Commercial, industrial, and governmental and institutional land uses were forecast using the land use-to-population ratios established in the regional forecast of 6.3 commercial acres, 4.9 industrial acres, and 8.8 governmental and institutional acres per 1,000 additional persons. Transportation and utility land uses were forecast to increase in direct proportion to increases in residential, commercial, industrial, and governmental and institutional land uses. This increase in the transportation and utility land use category was forecast as equaling one-third of the increases in other categories. Recreational land use demand was forecast using a land use-to-population ratio of 14 acres per 1,000 additional persons. Future agricultural and water, woodland, and wetland demand was not forecast since these uses within the watershed generally provide the area for expansion of the other land uses.

Based upon the foregoing assumptions and the population forecast for the watershed, the 1990 demand within the watershed for the major land use categories was forecast as shown in Table 38. Comparison with existing land use data indicates that the continuation of present residential land development trends within the watershed may be expected to result in an increase in residential land use from over 42 square miles in 1967 to nearly 60 square miles in 1990, an increase of about 42 percent. All other urban land uses may be expected to increase from a total of nearly 60 square miles in 1967 to over 73 square miles in 1990, or by about 23 percent. This total demand for urban land will have to be satisfied primarily through the conversion to urban use of existing agricultural lands, woodlands, and unused lands, which may be expected to decline collectively by about 31 square miles, or approximately 6 percent.

TABLE 38

FORECAST LAND USE DEMAND IN THE MILWAUKEE RIVER WATERSHED

LAND USE CATEGORY	EXISTING LAND USE 1967		INCREMENTAL LAND USE DEMAND 1967-1990		TOTAL LAND USE 1990	
	ACRES	SQUARE MILES	ACRES	SQUARE MILES	ACRES	SQUARE MILES
URBAN LAND USE						
RESIDENTIAL.......	27,020	42.22	11,338	17.71	38,358	59.93
LOW-DENSITY.....	12,258[a]	19.15	7,294	11.39	19,552	30.54
MEDIUM-DENSITY..	6,014[a]	9.40	3,356	5.24	9,370	14.64
HIGH-DENSITY....	8,748[a]	13.67	688	1.08	9,436	14.75
COMMERCIAL........	1,368	2.14	674	1.05	2,042	3.19
INDUSTRIAL........	1,763	2.76	524	0.82	2,287	3.58
MINING............	1,113	1.74	--[b]	--	1,113	1.74
TRANSPORTATION[c]...	25,511	39.86	4,492	7.02	30,003	46.88
GOVERNMENTAL[d].....	3,452	5.39	941	1.47	4,393	6.86
RECREATIONAL[e].....	5,081	7.94	1,803	2.82	6,884	10.76
TOTAL URBAN LAND USE............	65,308	102.05	19,772	30.89	85,080	132.94
RURAL LAND USE						
AGRICULTURE.......	271,370	424.01	-19,772	-30.89	294,821	460.66
WOODLAND..........	35,032	54.74				
UNUSED LAND.......	8,191	12.80				
WATER & WETLAND...	65,050	101.64	--	--	65,050	101.64
TOTAL RURAL LAND USE............	379,643	593.19	-19,772	-30.89	359,871	562.30
TOTAL LAND USE	444,951	695.24	--	--	444,951	695.24

[a]ESTIMATED FROM 1967 LAND USE INVENTORY INFORMATION.

[b]NO INCREMENT WAS FORECAST FOR THE MINING LAND USE CATEGORY DUE IN PART TO A LACK OF DETAILED INFORMATION ON HISTORIC MINING LAND USE ACTIVITY AND IN PART TO AN ASSUMPTION THAT THE TOTAL AMOUNT OF LAND DEVOTED TO MINING ACTIVITIES WILL SUBSTANTIALLY REMAIN THE SAME OVER TIME, ALTHOUGH THE SPATIAL LOCATION OF SUCH ACTIVITIES WOULD BE ALTERED.

[c]INCLUDES OFF-STREET PARKING AND UTILITY USES.

[d]INCLUDES INSTITUTIONAL USES.

[e]INCLUDES MAJOR AND NEIGHBORHOOD PARKS.

SOURCE- SEWRPC.

SUMMARY

It is estimated that the population of the Milwaukee River watershed may be expected to increase from the 1967 level of about 544,000 persons to about 678,000 persons by 1990, an increase of about 25 percent over the 23-year period. The level of economic activity, measured at about 290,000 jobs in 1967, may be expected to increase to about 346,000 jobs by 1990, an increase of 19 percent. It is also anticipated that the population of the watershed will share in the increased levels of income, educational achievement, and leisure, as will the Region in general.

If present trends in urban development within the watershed are projected to 1990, residential land use may be expected to increase by nearly 42 percent and supporting urban land uses by over 23 percent. In turn, the expansion of urban development within the watershed under forecast conditions would require the conversion of nearly 31 square miles, or over 6 percent of the existing open land resources of the watershed.

Chapter VIII

FLOOD CHARACTERISTICS AND DAMAGE

INTRODUCTION

Flooding of the perennial stream system of the Milwaukee River watershed is a common occurrence, with at least nuisance levels of inundation to be expected almost annually from spring snowmelt and less frequently from summer thunderstorms. Flood damage from these events has been, to a large extent, an unnecessary consequence resulting from failure to recognize and understand the proper relationships which should exist between the use of land and the behavior of the river system. The unnecessary occupancy of the natural floodplains of the watershed by flood vulnerable land uses, together with development-induced changes in the hydrologic regimen of the watershed, has increased flood risks to substantial proportions. Comprehensive watershed planning is the first step in achieving or restoring a balance between the use of land and the hydrologic regimen in the riverine areas of the watershed. To ensure that future flood damage will be held to a minimum, plans for the proper utilization of the riverine areas of the watershed must be developed which, through public acquisition, land use controls, and river engineering, can be used to direct properly new development into a pattern which is compatible with the demands of the river system on its floodplains and to seek a mutual adjustment or balance between development and flood needs.

Flood-damage potential and flood risk have grown from a nuisance level during predominantly agricultural occupation of the watershed to substantial proportions as urban land use has increased. Practically all of the present flood risk can be ascribed to unnecessary residential occupation of the river floodplain—unnecessary since adequate alternative locations are available for residential use. Nevertheless, such residential occupation of the floodplain is continuing to increase as urban development proceeds within the watershed. Most of the floodplain, however, is as yet unoccupied by flood-vulnerable uses; and the opportunity still exists for limiting flood risk by means of sound land use planning and control.

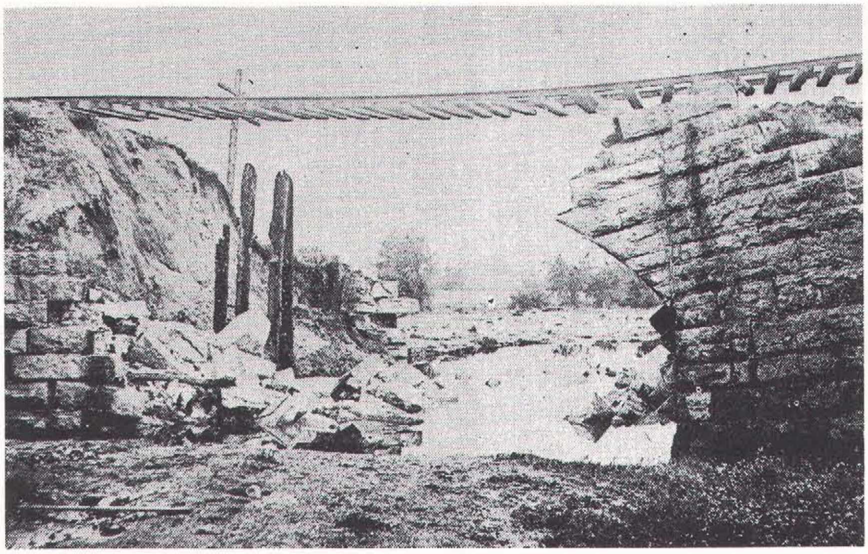
HYDROLOGIC CHARACTERISTICS OF FLOODS

Historic Floods

The Milwaukee River has experienced flood stages[1] at Estabrook Park in Milwaukee County during 25 of the 54-year period of stream gaging records extending from 1915 through 1968. Two floods of moderate severity (10-year recurrence interval) occurred in 1959 and 1960, with the 1960 flood being slightly larger. The major floods of 1918 and 1924 were each nearly as severe as a 100-year recurrence interval event, both having a recurrence interval of about 77 years at the Estabrook Park stream gaging station in the City of Milwaukee.

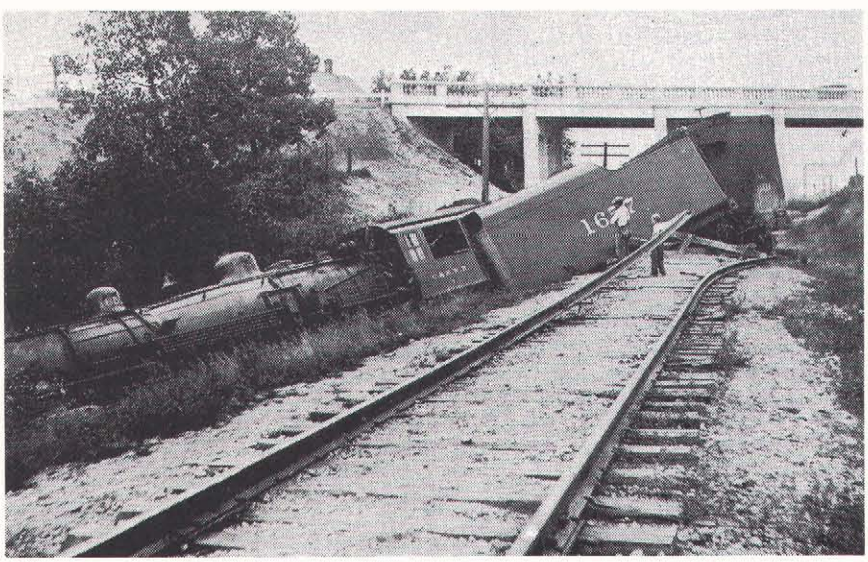
Long-term residents of the watershed interviewed during the historic flood damage inventory conducted as a part of the watershed study recalled that the flood event of 1918, like the events of 1959 and 1960, was a typical spring flood which originated from a combination of snowmelt and rainfall, but that the 1924 flood event was generated entirely by an unusual summer rainfall. The severe rainstorm that produced the 1924 flood centered over the City of West Bend in Washington County, where a total of 9.31 inches of rainfall was recorded in a four-day period, of which 7.58 inches fell in a 24-hour period. Map 29, an isohyetal map of this storm, shows the rainfall pattern which occurred over the watershed and further indicates that the rainfall over the watershed averaged about eight inches. A discharge of 15,100 cfs (cubic feet per second), equivalent to a runoff of 3.85 inches over the tributary watershed area, was recorded by the U. S. Geological Survey at the Milwaukee River gaging station at Milwaukee. Although the flood was not gaged at West Bend, reports indicate a larger unit flood occurred in the upstream tributary areas.

[1] *Flood stage is herein defined as the water surface elevation that accompanies a discharge exceeding 5,000 cubic feet per second at Estabrook Park in Milwaukee County, the stage at which the river overtops its banks and leaves its channel to occupy its floodplain.*



The 1918 and 1924 floods were the most severe and damaging floods on the Milwaukee River in the living memory of the residents of the watershed. Historic newspaper accounts make reference to an even greater flood in 1881, but no definitive data can be assembled for that flood. The accompanying photos illustrate the severity of the damages caused by the 1924 flood to highway and railway bridges and facilities in the West Bend area of the watershed.

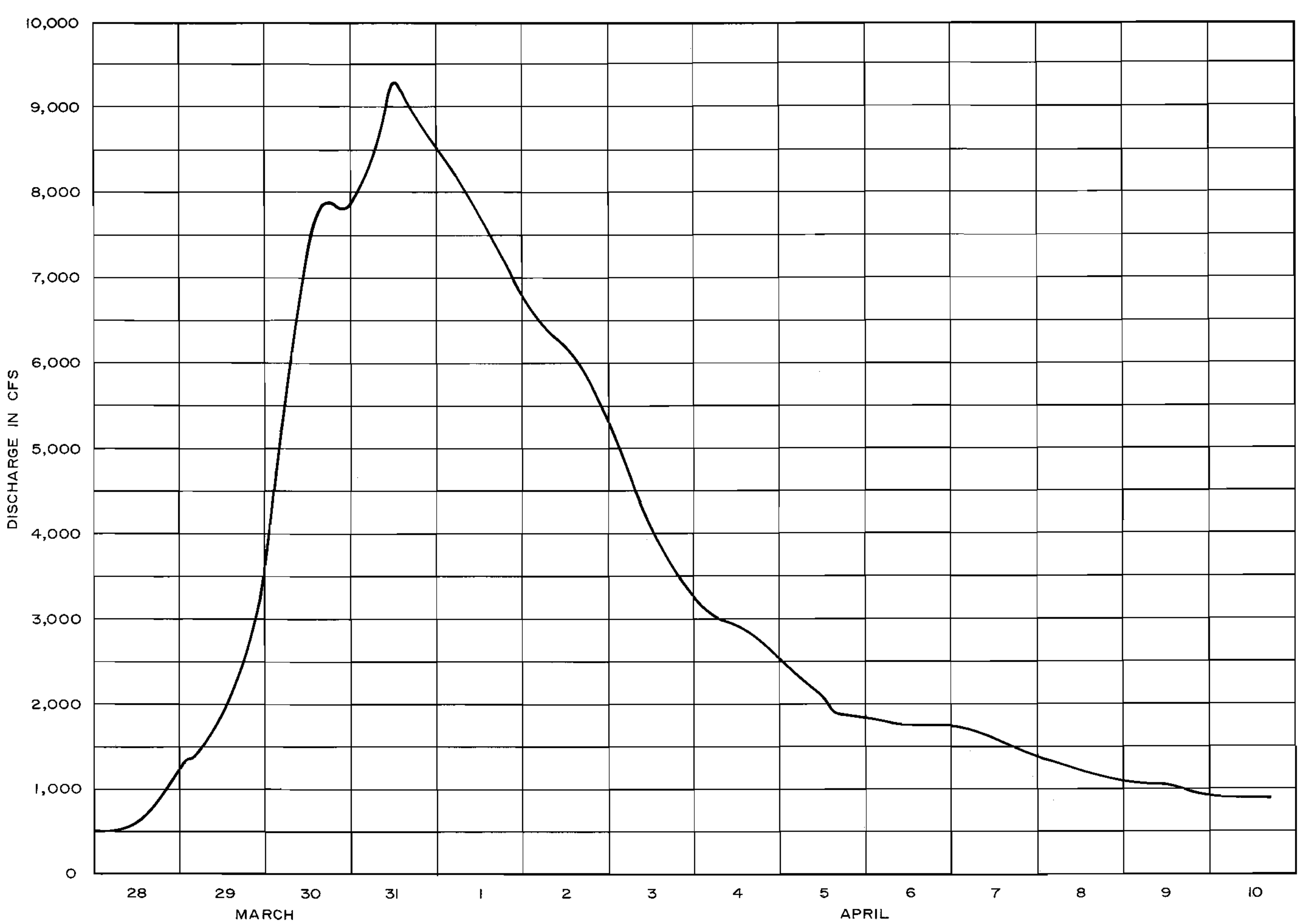
Photos Courtesy of The West Bend News



Although, as already noted, the resulting flood that occurred at Milwaukee was slightly less severe than the estimated 100-year recurrence interval event (77-year recurrence interval), the pattern and amount of rainfall indicate that the flood at upstream points, such as West Bend, may have equaled or exceeded the 100-year recurrence interval event.

The combination of climatological events which caused the 1960 flood was also unusual. Measurements of the snow cover at the U. S. Weather Bureau Station in Milwaukee indicate that the depth of snow on the ground immediately prior to the flood was 24 inches, equivalent to 2.8 inches of water. Temperatures, after having been below normal for most of the month, began to rise on March 27 and reached a high of 62°F on March 29. Starting in the evening of the 29th, rain fell intermittently for a period of about 24 hours. An isohyetal map of this storm is shown on Map 30 and indicates that the average depth of rainfall over the watershed during this 24-hour period was 1.2 inches. These two events combined to produce a peak flood flow of 9,300 cfs at the U. S. Geological Survey gaging station at Milwaukee, equivalent to a runoff of 2.39 inches over the tributary watershed area, and a discharge of 3,600 cfs at Cedarburg, equivalent to a runoff of 2.53 inches over the tributary watershed area. Figures 27 and 28 show the hydrographs of the 1960 flood at Milwaukee and Cedarburg.

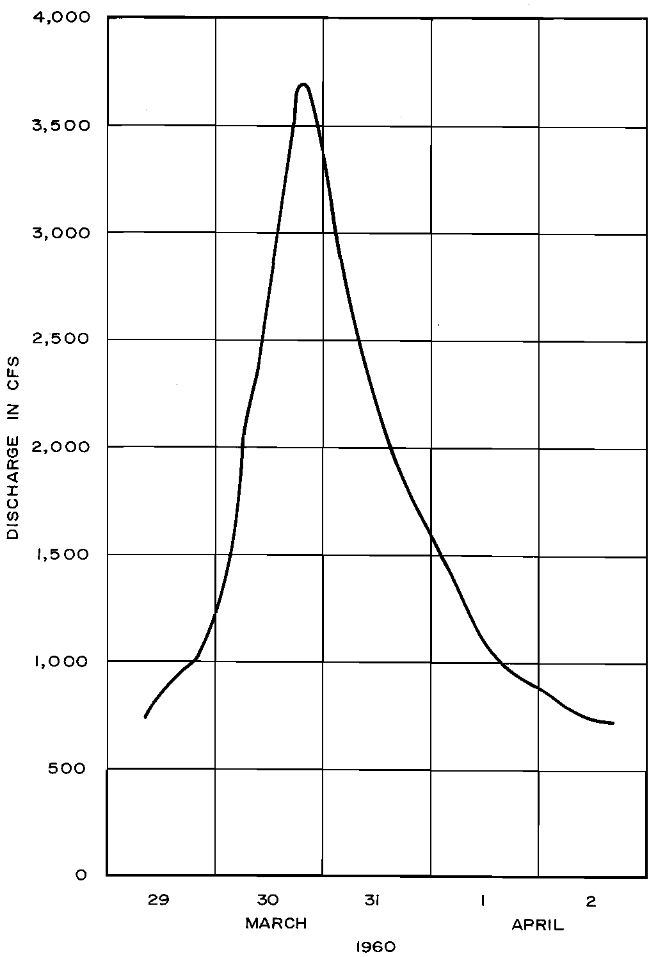
Figure 27
HYDROGRAPH OF THE MARCH-APRIL 1960 FLOOD
MILWAUKEE RIVER AT MILWAUKEE



Source: Harza Engineering Company.

Figure 28

HYDROGRAPH OF THE MARCH-APRIL 1960 FLOOD CEDAR CREEK NEAR CEDARBURG



Source: Harza Engineering Company.

Seasonal Nature of Floods

The record of river discharge obtained since 1915 at Milwaukee by the U. S. Geological Survey shows that most floods on the Milwaukee River in the last 54 years have occurred during the late winter or early spring. The date of occurrence of 54 annual flood peaks between 1915 and 1968 is shown in Figure 29. During the 54 years, 32 of the yearly peaks, including five of the six highest recorded, have occurred in March or April. In 1938 the highest discharge during the year occurred on February 15. Although severe floods are unusual in February, it is not uncommon for sudden thaws to occur at this time of the year and produce minor floods.

The record of discharge obtained since 1931 at Cedarburg by the U. S. Geological Survey shows that most floods on Cedar Creek in the last 38 years have also occurred during the late winter or early spring. The date of occurrence of 38 annual flood peaks between 1931 and 1968 is shown in Figure 30. During the 38 years, 27 of the yearly peaks, including seven of the eight highest recorded, have occurred in March or April.

The probability of heavy rainfall within the watershed is much greater in the summer months than at any other time of the year. In spite of this greater rainfall potential, summer floods within the watershed have been much less frequent than spring floods, with the August 1924 flood being the only major summer flood event in the 54 years of record. Several factors contribute to this distribution of major flood events during the 54-year period of streamflow recorded at Milwaukee. Summer floods generally result from the rapid rate of runoff that accompanies high-intensity rainstorms. The hydraulic characteristics of the watershed above Milwaukee, however, are such that intensive rainfall will not usually produce peak flood flows on the Milwaukee River. This is due to the large amount of natural floodwater storage existing above Milwaukee which is normally available to suppress the effect of intensive rainfall and rapid runoff to the extent that high peak flows are not generated. Such suppression requires that the natural storage in lakes and wetlands be available due to normal seasonally low water levels in these natural reservoirs. The August 1924 rainfall was so heavy and intense that the natural storage was filled, and a large component of rainfall excess ran off. The probability of severe summer floods, therefore, does exist on the Milwaukee River, although spring floods are far more frequent.

HISTORIC FLOOD DAMAGE SURVEYS

Although the streams within the Milwaukee River watershed have since time immemorial periodically occupied their floodplains, no flood problem existed within the watershed until flood-vulnerable development was allowed to intrude into the natural floodplains. This unwise land use development has generated a demand from the flood-vulnerable property owners for relief from periodic damages through the construction of flood control works. In order to determine what type of relief is required, where this relief should be applied, and whether or not the provision of this relief is economically sound, the conduct of a historic flood damage survey is necessitated. Such a survey serves to determine the exact nature of the flood problem

Figure 29

SEASONAL DISTRIBUTION OF ANNUAL PEAK DISCHARGE OCCURRENCES
MILWAUKEE RIVER AT MILWAUKEE
1915-1968

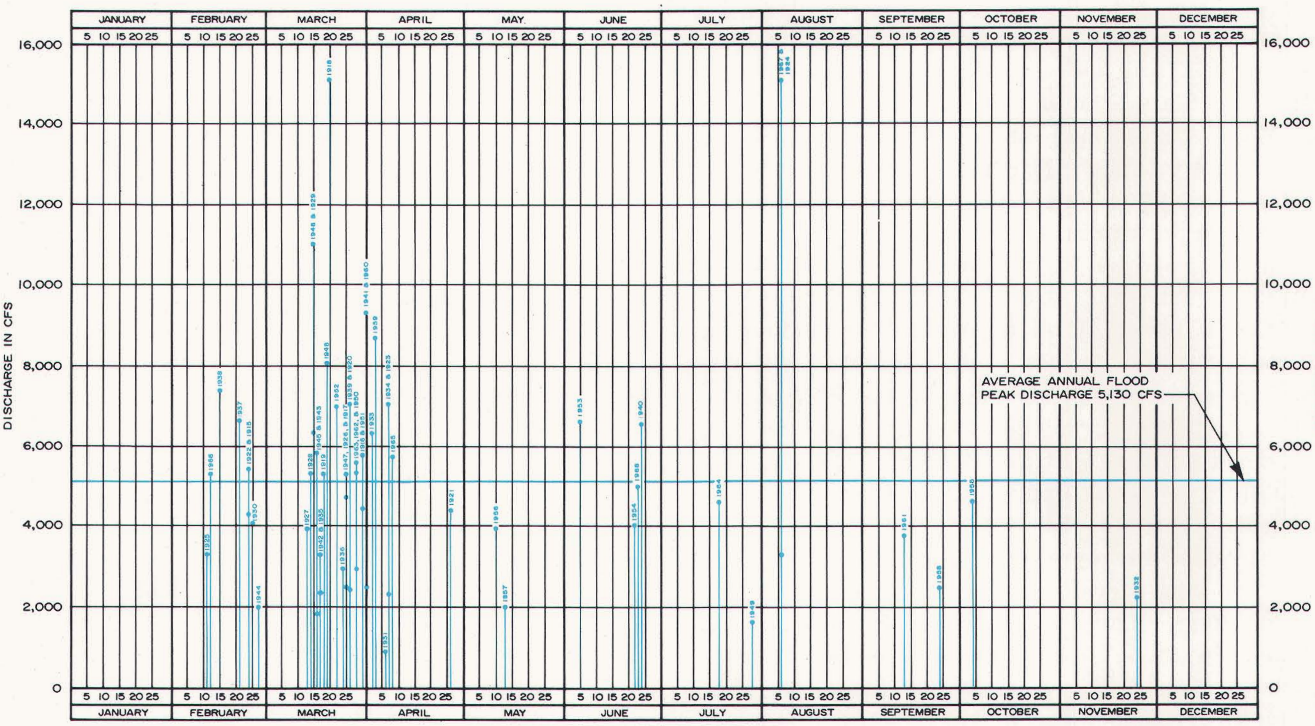
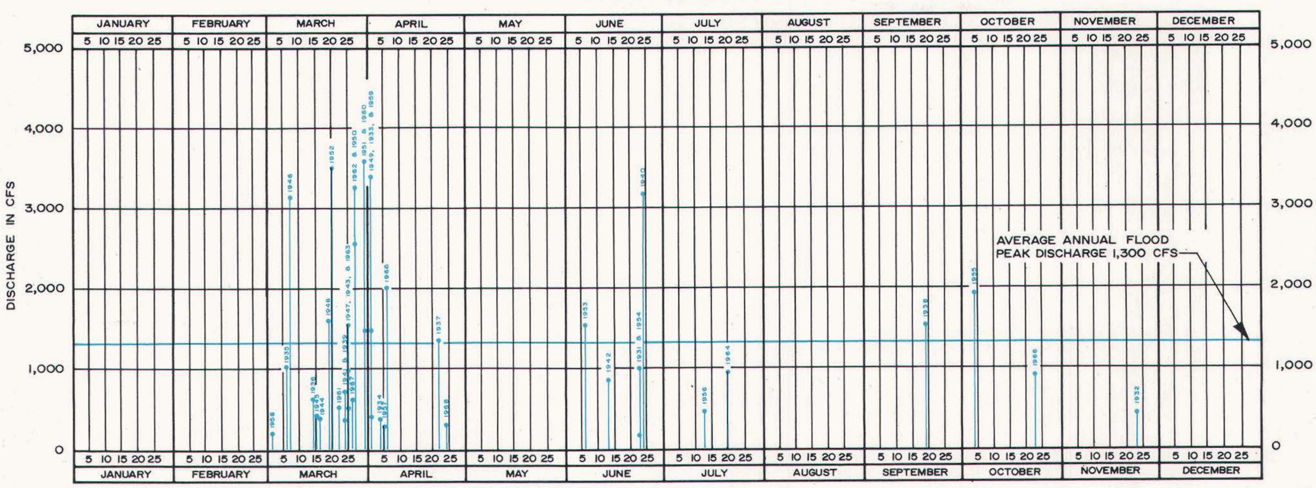


Figure 30

SEASONAL DISTRIBUTION OF ANNUAL PEAK DISCHARGE OCCURRENCES
CEDAR CREEK NEAR CEDARBURG
1931-1968



Source: Harza Engineering Company.

and to assess the annual monetary risk of flood damage under present land use, hydrologic, and hydraulic conditions and provides the basis for forecasting such risks under alternative future land use and water control facility development conditions within the watershed.

Wisconsin State Planning Board

Several historic flood damage surveys have been carried out within the Milwaukee River watershed. The first major flood damage survey was carried out in 1938 as a part of the U. S. Department of Commerce, Works Project Administration (WPA) project, sponsored by the Wisconsin Public Service Commission. It incorporated the findings of several preceding minor studies carried out pursuant to the state Flood Control Enabling Act of 1931. The WPA survey covered the flood damages which had occurred in the flood of 1924 along the main stem of the Milwaukee River from the City of Milwaukee through the Village of Saukville. The results of the survey were documented in a report[2] published in 1940 which, while describing the areas and buildings along the Milwaukee River inundated by the 1924 flood, does not present any information on the actual monetary damages incurred. The purposes of the project included determination of the principal facts concerning flood conditions on the Milwaukee River; collection of data on historic flood stages and building inundation and on the probability of future floods; exploration of alternative means of flood control and abatement; and estimation of the cost of flood control works. The two major alternative means of flood control explored were the construction of a single-purpose floodwater detention reservoir at a site at the junction of the North Branch and the main stem of the Milwaukee River near Waubeka and the construction of a flood-flow diversion facility. The latter consisted of two subalternatives: the first, a 6,000-foot long flood-flow diversion tunnel to Lake Michigan from a point on the Milwaukee River near the center of Section 18, Town 9 North, Range 22 East, in the City of Mequon, and the second, a 10,500-foot long open floodwater diversion channel to Lake Michigan from Duck Lake, a point on the Milwaukee River in the City of Mequon about three-fourths of a mile south of the proposed tunnel location.

[2]*The Milwaukee River Basin, Wisconsin State Planning Board Bulletin No. 10, June 1940.*

Although the WPA project report does not present a reach-by-reach discussion of historic flood damages for the river system, it does generally identify the problem reaches of the river by describing the location of the most serious flood problems as they existed at that time:

> Probably the most insistent present demand for the control or diminution of floods on the Milwaukee River comes from people who are interested in occupying lands within the flood plain of the river within areas located as follows: (1) that portion of the flood plain in Milwaukee County lying north of Lincoln Park and along Lincoln Creek, (2) in Ozaukee County, in the low-lying lands along the river in the first six tiers of sections north of the Milwaukee County line, (3) in the village of Thiensville, (4) in the village of Saukville and low-lying lands in the vicinity extending along the river to a point about 2 1/2 miles north of Saukville, and (5) the village of Waubeka. This is the territory which suffers most from floods. Considerable portions of the lands described, outside the three villages named, are platted for residential purposes. There are summer cottages along the river which would be occupied the year around were it not for the probability of flooding during the spring. As it is, the occupants move out during the winter, taking such precautions as are necessary to protect the furnishings from high water when it comes, and return after the spring floods subside. The farmers along that portion of the river below Waubeka are not greatly harmed by floods, unless they come during the season when there are crops to be damaged. A large portion of these lands is in "wild pasture" which is benefited by the sediment deposited by floods. Floods damage crops only during the growing season; most of the Milwaukee River floods have occurred in the early part of the year, before spring planting.[3]

[3]*See The Milwaukee River Basin, Wisconsin State Planning Board Bulletin No. 10, Chapter II, "Present Demand for Flood Control-Statement of Extent of Flooding," p. 6, June 1940.*

The report describes in very general terms the flood problems in that reach of the Milwaukee River extending from the Waubeka reservoir site downstream to Lincoln Park in the City of Milwaukee, describes in some detail the channel improvements made by the City of Milwaukee in the Lincoln Park area of the Milwaukee River in 1935, and describes the manner in which the Estabrook Park Dam regulates flood flows. The project collected enough high water mark data to permit delineation of the historic floodplain of the Milwaukee River, as defined by the outer limits of the area subject to inundation by the 1924 flood in the Lincoln Creek area of the Milwaukee River, the Kletzsch Park area of the Milwaukee River (see Map 38), and a reach of the Milwaukee River in Ozaukee County (see Map 39). The 1940 report indicates that a total of 296 buildings located in the floodplain could be expected to experience first-floor inundation along that reach of the Milwaukee River extending from Lincoln Park to Kletzsch Park if a flood of the magnitude of the 1924 flood were to reoccur under 1940 development conditions. The stage of the 1924 flood was approximately the same as the stage of a 100-year recurrence interval flood, with the stage differential between the 1924 flood, which had a 77-year recurrence interval, and a 100-year recurrence interval flood at the Ozaukee County line on the main stem of the Milwaukee River, being less than 0.5 foot. The report also identifies channel sections subject to ice jams and concomitant floodwater backup in the reach of the Milwaukee River extending from Silver Spring Drive to Good Hope Road.

The fact that no flood inundation of any buildings was found to occur in that reach of the Milwaukee River extending from the Kletzsch Park Dam to the Ozaukee County line was due to the fact that all of the buildings then existing along this reach were located on high ground, well above the stage of the 100-year recurrence interval flood. Very little flood inundation of buildings was found to occur along the rest of the main stem of the Milwaukee River surveyed, from the Ozaukee County line up to Waubeka, due to the fact that very little development existed on the floodplain at that time, with the exception of the Thiensville area (see Map 39). The report presents a table, reproduced herein as Table 39, listing 417 platted lots located in Ozaukee County outside the Villages of Saukville, Thiensville, and Waubeka as subject to flooding. No specific costs for flood damages were, however, reported for these lots, although the information regarding high water marks in the area was gained by personal interview of residents within the locality at the time of the flood. Even though the report does not indicate any monetary flood damages of these 417 platted lots, it does indicate 169 of the lots were occupied by buildings of some kind. The report also presents a table of historic maximum flood discharges, reproduced herein as Table 40. This table indicates that the discharge of a flood on the Milwaukee River at Estabrook Park likely to be equaled or exceeded once in 100 years was 16,000 cfs.

The report attempted to make public officials and citizen leaders aware that the flood problem of the river could be expected to intensify if development of the floodplains of the Milwaukee River was allowed to continue. That this warning was ignored is indicated by the fact that, in those reaches of the river covered by the 1938 survey, the number of buildings subject to inundation increased from about 380 in 1938 to over 1,200 in 1968. The report is an invaluable historic record in that it maps the areas along lower reaches of the Milwaukee River which were actually inundated by the 1924 flood and provides evidence that development of the floodplain was allowed to continue even after this particular report was published.

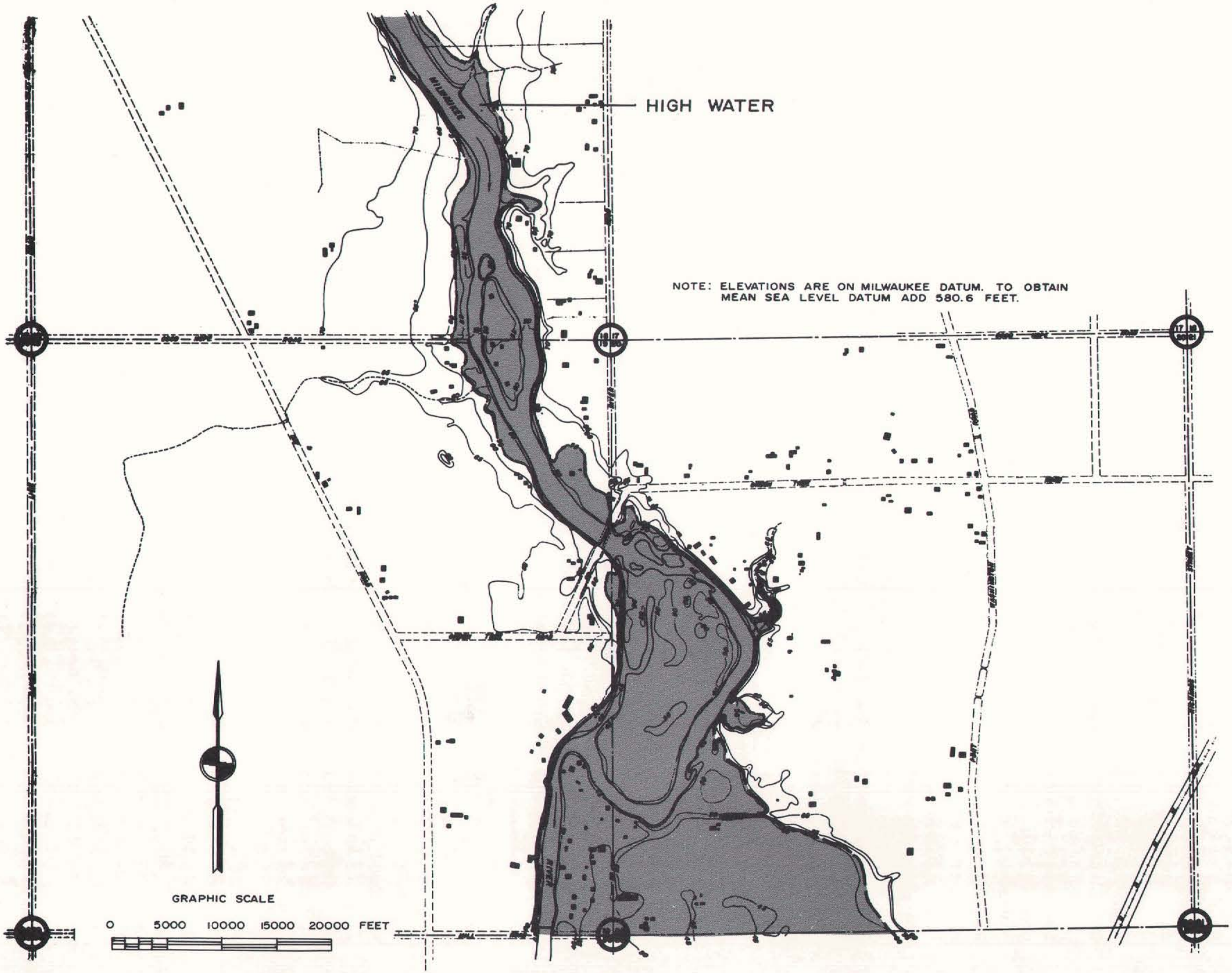
To aid the reader in visualizing the extent of flooding, historic flood inundation maps, where available, have been included as part of this chapter. Maps 38 and 39 were obtained from The Milwaukee River Basin, Wisconsin State Planning Board Bulletin No. 10, which was published in June 1940. These maps indicate the extent of the area flooded in 1924 and also the extent of development in the floodplain in 1936. As noted above, substantial development has continued to occur within the floodlands of the Milwaukee River since publication of this report in 1940. The principal characteristics of the potential flood damages are described in this chapter by river reach, as shown on Map 40.

First U. S. Army Corps of Engineers Survey Report—1942

In 1942 the U. S. Army Corps of Engineers submitted a preliminary examination report for flood control of the Milwaukee River. This report was authorized pursuant to the provisions of Section 4 of the Flood Control Act of 1941, under Public Law 228 passed during the first session of the 77th Congress. The report, utilizing available

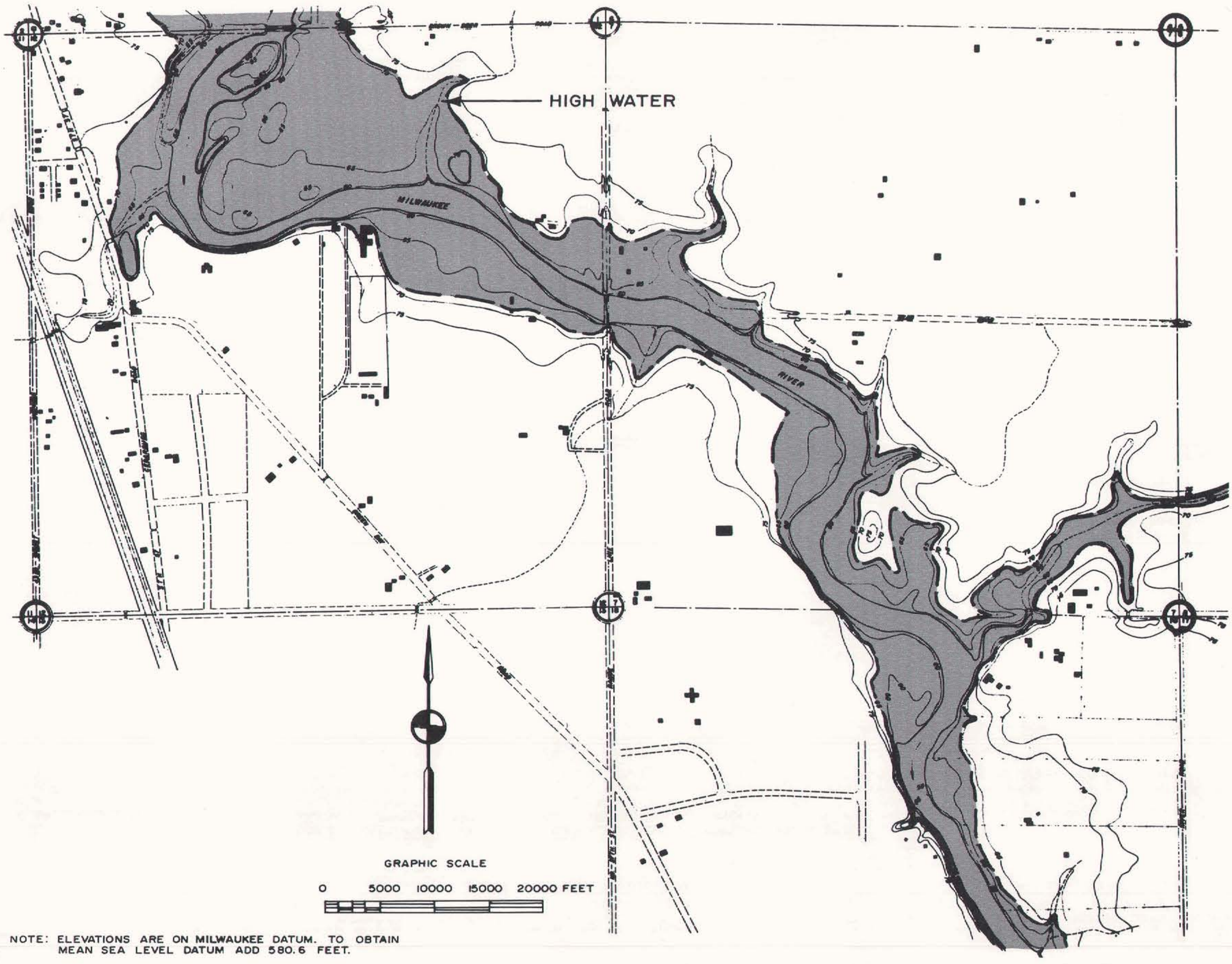
Map 38

FLOOD INUNDATION MAP KLETZSCH PARK DAM TO THE OZAUKEE COUNTY LINE
1924 FLOOD (SOUTHERN SECTION)



Map 38 (Continued)

FLOOD INUNDATION MAP KLETZSCH PARK DAM TO THE OZAUKEE COUNTY LINE
1924 FLOOD (INTERMEDIATE SECTION)



NOTE: ELEVATIONS ARE ON MILWAUKEE DATUM. TO OBTAIN MEAN SEA LEVEL DATUM ADD 580.6 FEET.

Map 38 (Continued)

FLOOD INUNDATION MAP KLETZSCH PARK DAM TO THE OZAUKEE COUNTY LINE 1924 FLOOD (NORTHERN SECTION)

NOTE: ELEVATIONS ARE ON MILWAUKEE DATUM. TO OBTAIN MEAN SEA LEVEL ADD 580.6 FEET.

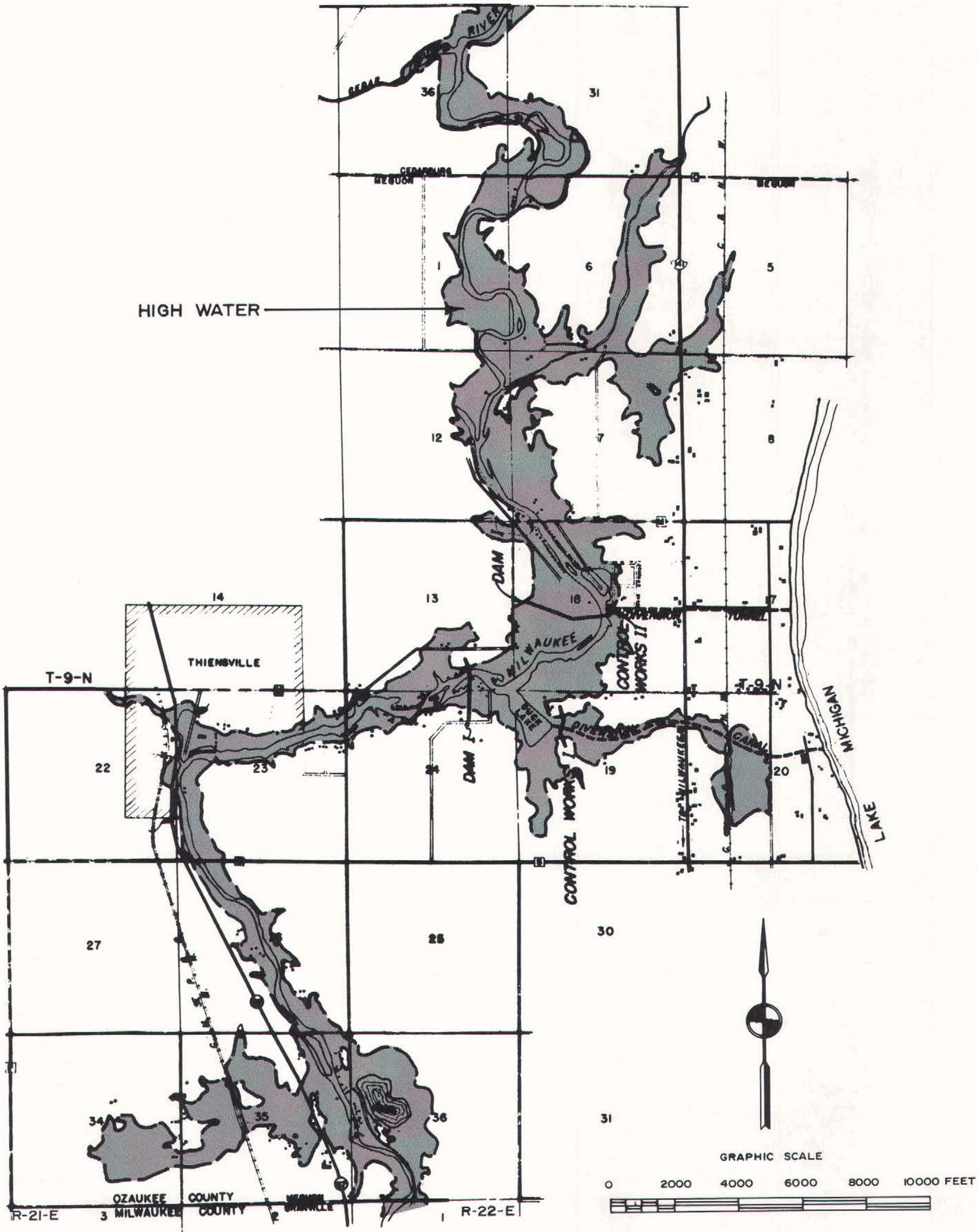
Very little urban development existed in the natural floodplains of the Milwaukee River from the Kletzsch Park Dam north to the Ozaukee County line in 1936. Therefore, it can be reasonably assumed that even less such development existed at the time of the 1924 flood. The historic map reproduced above shows the extent of the areas inundated by the 1924 flood superimposed upon 1936 land use conditions. The 1924 flood was one of the major floods within the watershed and had a recurrence interval of about 77 years, only slightly less than the 100-year recurrence interval flood recommended for use today in floodplain regulation.

Source: Wisconsin State Planning Board, Bulletin No. 10, June 1940.

Map 39

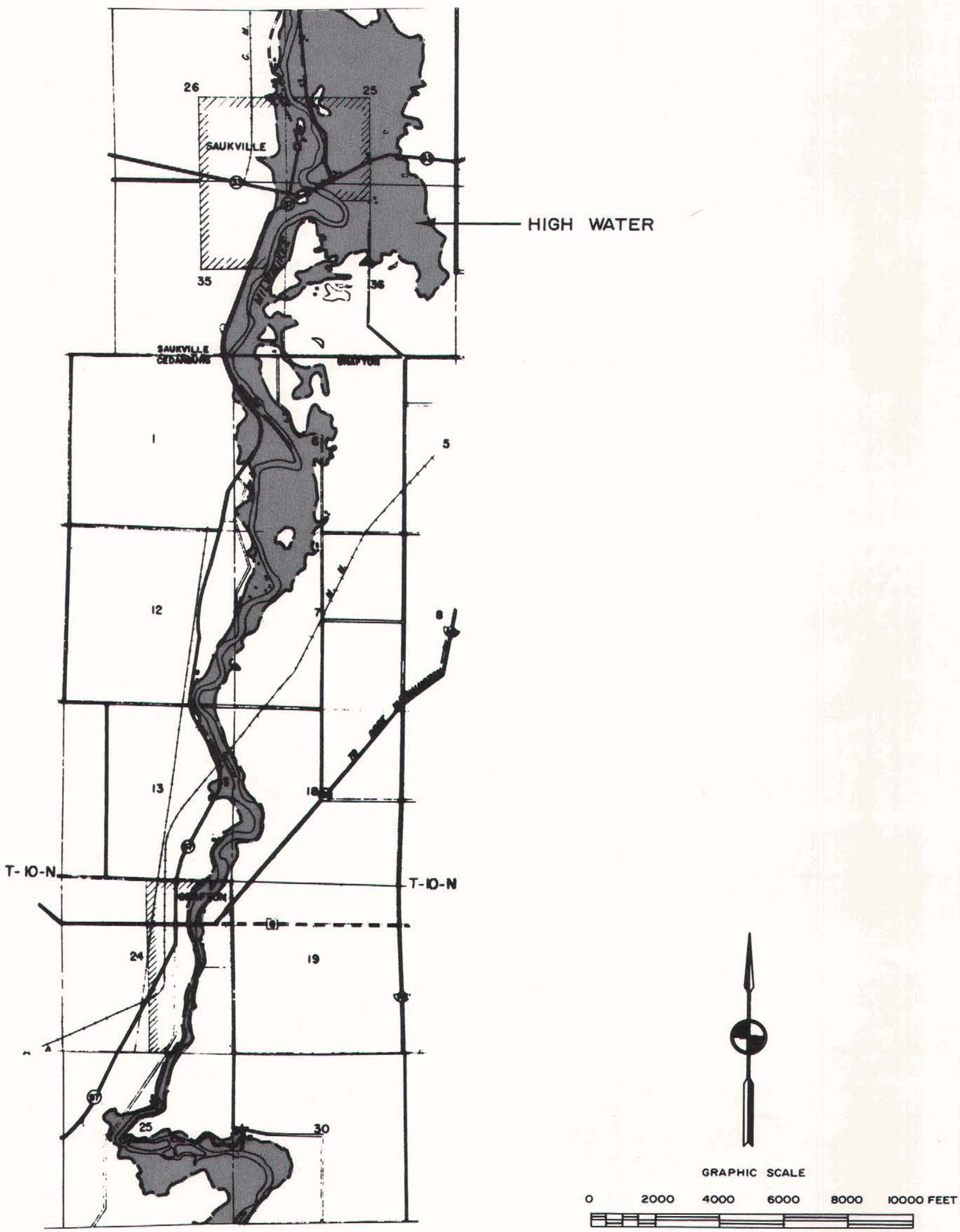
FLOOD INUNDATION MAP OZAUKEE COUNTY LINE TO WAUBEKA

1924 FLOOD



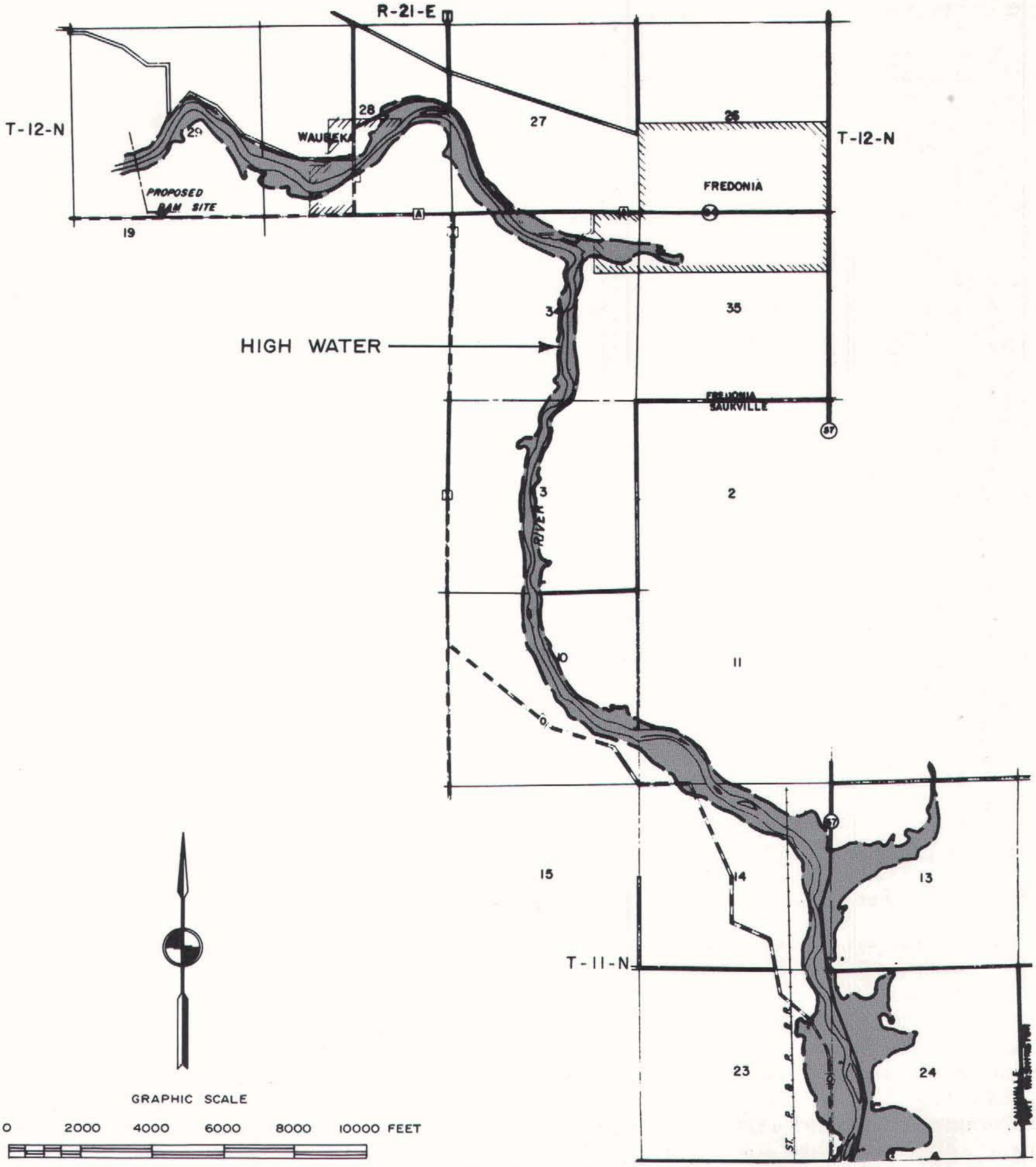
Map 39 (Continued)

FLOOD INUNDATION MAP OZAUKEE COUNTY LINE TO WAUBEKA
1924 FLOOD



Map 39 (Continued)

FLOOD INUNDATION MAP OZAUKEE COUNTY LINE TO WAUBEKA 1924 FLOOD



The extent of the area flooded in 1924 along the Milwaukee River from the Ozaukee County line north to the unincorporated Village of Waubeka is shown on this historic map, along with land use development conditions in 1936. With the exception of the Village of Thiensville, very little urban development existed on the natural floodplains of the River in this reach. There were, however, well over 400 platted lots located along the River in 1936, many of which contained summer cottages. Despite repeated flooding, these natural floodplains have since been intensely developed with permanent urban land uses, particularly in the Mequon and Saukville areas of this reach.

Source: Wisconsin State Planning Board, Bulletin No. 10, June 1940.

TABLE 39

LOTS AND BUILDINGS IN OZAUKEE COUNTY BELOW MILWAUKEE RIVER HIGH WATER MARK AS SHOWN ON MAP 39[a]

TIER[b]	SECTION	TOWN NORTH	RANGE EAST	ELEVATION		LOTS & BLDGS. BELOW H.W.M.			
				HIGH WATER MARK		EAST BANK		WEST BANK	
				S. LINE	N. LINE	LOTS	BLDGS.	LOTS	BLDGS.
I	34, 35, 24	9	21	653	655	30	22	1	1
II	26	9	21	655	658	--	--	--	6
III	22, 23, 24	9	21	658	663	--	15	--	32
IV	13	9	21	--	--	23	--	--	--
IV	18	9	22	663	663	60	19	45	24
V	12	9	21	--	--	--	--	--	--
V	7	9	22	663	665	--	5	48	9
VI	1	9	21	--	--	--	--	--	--
VI	6	9	22	665	668	--	3	11	5
VII	36	10	21	--	--	--	--	--	--
VII	31, 32	10	22	668	681	--	1	--	2
VIII	25	10	21	--	--	--	--	--	--
VIII	30	10	22	681	710	--	--	--	--
IX	24	10	21	710	740	--	--	--	--
X	13	10	21	--	--	--	--	--	--
X	18	10	22	740	747	--	--	--	2
XI	12	10	21	--	--	--	--	--	--
XI	7	10	22	747	752	--	--	--	11
XII	1	10	21	--	--	--	--	--	--
XII	6	10	22	--	--	--	2	--	1
XIII	35, 36	11	21	753	755	--	--	--	2
XIV	25, 26	11	21	755	759	--	--	--	5
XV	23, 24	11	21	759	763	--	--	--	2
XVI	13, 14	11	21	763	766	--	--	--	--
XVII	10, 11	11	21	766	772	30	--	--	--
XVIII	3	11	21	772	777	--	--	--	--
XIX	34	12	21	777	784	--	--	--	--
XX	27, 28, 29	12	21	784	793	--	--	--	--
TOTAL						143	67	105	102

[a]MAP 39 DOES NOT INCLUDE VILLAGES OF THIENSVILLE, SAUKVILLE, OR WAUBEKA.

[b]TIER III-THIENSVILLE. TIER XIII-SAUKVILLE. TIER XX-WAUBEKA.

SOURCE- THE MILWAUKEE RIVER BASIN, WISCONSIN STATE PLANNING BOARD BULLETIN NO. 10, JUNE 1940, PAGE 12.

secondary information on historic flood damages, concluded that flood control improvements were not economically justified under the development conditions existing at the time. No new flood damage survey was carried out for the report. The report was not distributed to the public, but was prepared for internal use by the U. S. Army Corps of Engineers only. A copy of the report is on file in the Chicago District Office of the U. S. Army Corps of Engineers.

Lieberman-Unger Survey

After the March-April 1960 flood on the Milwaukee River, two families living along the river in the Village of Brown Deer—the Jerome S. Lieberman and the Irvin W. Unger families—undertook, as a private effort, a flood damage survey along that reach of the Milwaukee River extending from the Village of Saukville through the City of Glendale, inclusive of both municipalities. The purpose of the survey was to identify the monetary flood

TABLE 40

ARRAY OF ANNUAL SPRING AND SUMMER FLOOD EVENTS
THE MILWAUKEE RIVER AT MILWAUKEE
MAXIMUM OBSERVED RATE OF DISCHARGE DURING EACH YEAR[a]
(IN THE DESCENDING ORDER OF MAXIMUM DISCHARGE)

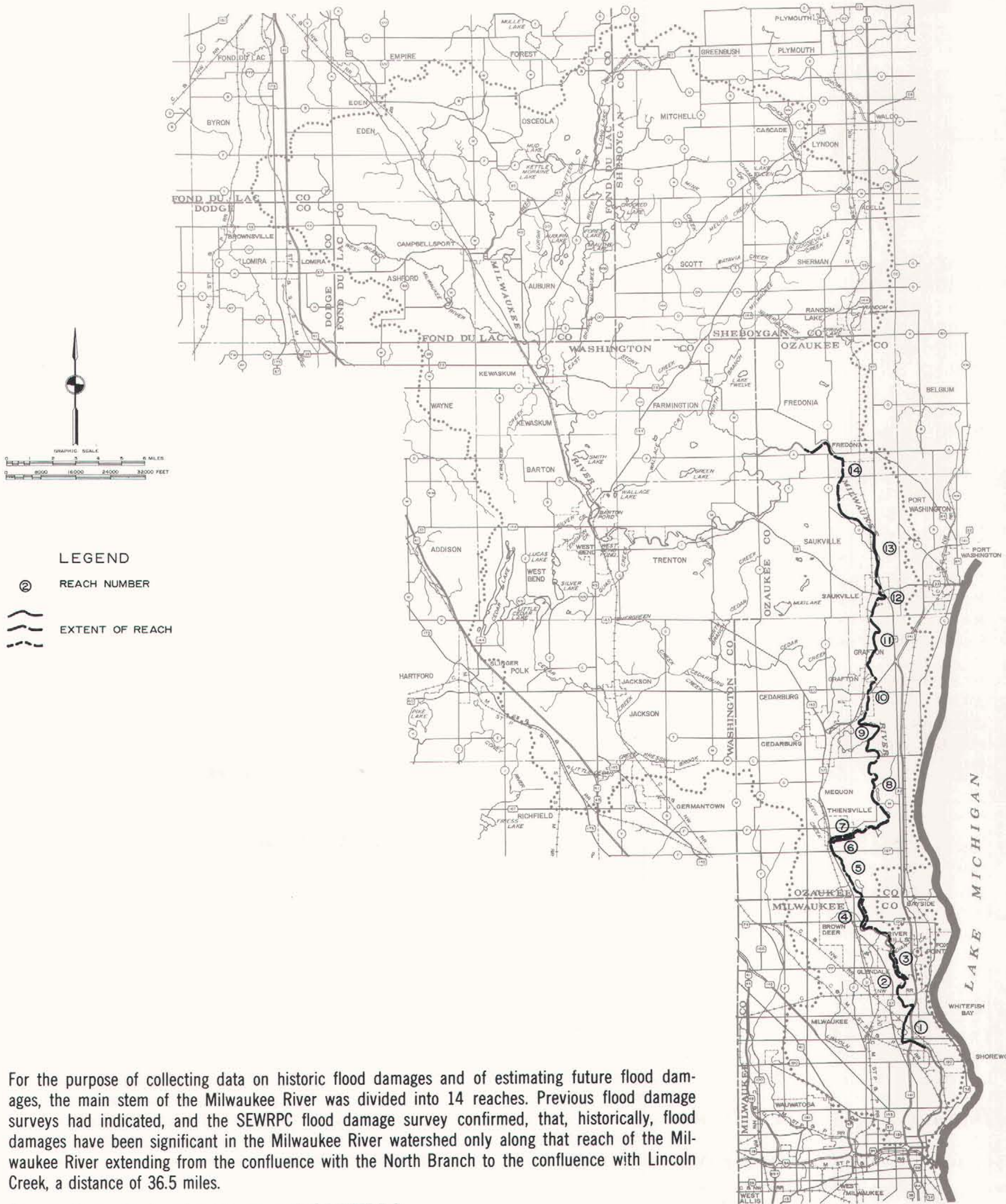
SPRING FLOODS		NO. FLOODS AS GREAT OR GREATER	SUMMER FLOODS	
DATE	MEAN HIGH DAILY DISCHARGE (CFS.)		DATE	MEAN HIGH DAILY DISCHARGE (CFS.)
MARCH 20, 1918	15,100[b]	1	AUGUST 6, 1924	14,700[b]
MARCH 15, 1929	10,800[b]	2	SEPTEMBER 18, 1938	6,220
APRIL 7, 1923	7,950[b]	3	JUNE 17, 1920	5,630
FEBRUARY 15, 1938	7,360[b]	4	APRIL 23, 26, 27, 1921	4,150
FEBRUARY 21, 1937	6,360	5	APRIL 22, 1937	3,580
APRIL 2, 1933	6,060	6	MAY 29, 1915	3,570
FEBRUARY 24, 1915	5,310	7	MAY 20, 1933	3,550
MARCH 26, 1920	5,160	8	APRIL 12, 1922	2,960
MARCH 17-18, 1919	5,160	9	APRIL 24, 1925	2,790
MARCH 25, 1917	5,160	10	APRIL 20 & JUNE 9-10, 1916	2,500
MARCH 14-15, 1928	4,940	11	MAY 3, 1930	2,380
MARCH 29, 1924	4,600	12	APRIL 28, 1929	2,290
MARCH 25, 1926	4,540	13	APRIL 21, 1927	2,160
FEBRUARY 24, 1922	4,150	14	MAY 1, 1917	2,140
MARCH 29, 1916	4,130	15	NOVEMBER 24, 1931	2,020
FEBRUARY 26, 1930	3,970	16	MAY 27, 1926	1,910
MARCH 13, 1927	3,740	17	MAY 4, 1919	1,800
MARCH 17, 1935	3,300	18	APRIL 14, 1935	1,710
FEBRUARY 11, 1925	3,160	19	NOV. 30 & DEC. 1, 1934	1,570
MARCH 24, 1936	2,880	20	JUNE 22, 1914	1,560
MARCH 26, 1939	2,180	21	APRIL 19-20, 1939	1,540
APRIL 4-5, 1934	2,070	22	APRIL 19-MAY 19, 1928	1,430
JANUARY 14, 1932	1,210	23	MAY 22, 1918	1,220
MARCH 17&20, 1921	1,000	24	JUNE 19, 1923	1,160
MARCH 2, 1931	598	25	MAY 7, 1936	931
			MAY 23, 1932	695

[a]THE FOSTER METHOD OF DETERMINING PROBABLE FLOOD FREQUENCIES AND INTENSITIES APPLIED TO THE REVISED MILWAUKEE RIVER DATA IN TABLE 40 (PEARSON CURVE, TYPE III, COEFFICIENT OF VARIATION 0.645, COEFFICIENT OF SKEW, 1.8.) INDICATES THAT THE ESTIMATED MAGNITUDE OF ANNUAL SPRING FLOOD LIKELY TO BE EQUALLED OR EXCEEDED ONCE IN 100 YEARS IS 16,000 CFS., ONCE IN 50 YEARS, 14,000 CFS., ONCE IN 25 YEARS, 11,700 CFS., AND ONCE IN 10 YEARS, 9,000 CFS. THESE RESULTS SEEM A LITTLE LOW, BUT THEY ARE A USEFUL GUIDE, BASED ON SOMETHING BETTER THAN GUESSWORK, AS TO WHAT FREQUENCIES AND INTENSITIES MAY BE EXPECTED IN THE FUTURE. IT MAY BE THAT THE 15,100 CFS. MAXIMUM DISCHARGE OBSERVED IN MARCH 1918 WILL NOT OCCUR AGAIN ON THIS WATERSHED FOR A PERIOD MUCH GREATER THAN 25 YEARS. ON THE OTHER HAND, THERE IS NO GUARANTEE THAT DISCHARGES EVEN GREATER THAN THE OBSERVED MAXIMUM OF 15,100 CFS. WILL NOT OCCUR MUCH SOONER.

[b]INSTANTANEOUS PEAK DISCHARGE.

SOURCE- THE MILWAUKEE RIVER BASIN, WISCONSIN STATE PLANNING BOARD BULLETIN NO. 10, JUNE 1940, PAGE 21.

Map 40
MAJOR FLOOD DAMAGE REACHES IN THE MILWAUKEE RIVER WATERSHED



For the purpose of collecting data on historic flood damages and of estimating future flood damages, the main stem of the Milwaukee River was divided into 14 reaches. Previous flood damage surveys had indicated, and the SEWRPC flood damage survey confirmed, that, historically, flood damages have been significant in the Milwaukee River watershed only along that reach of the Milwaukee River extending from the confluence with the North Branch to the confluence with Lincoln Creek, a distance of 36.5 miles.

Source: Harza Engineering Company and SEWRPC.

The extended width of the normal floodplain of the Milwaukee River in certain reaches is illustrated by this photo taken of the 1960 flood just south of Highland Road in the City of Mequon. The channel of the Milwaukee River is in the foreground, clogged with ice. The homes along the River are completely surrounded by floodwaters, with several homes in this reach experiencing first-floor inundation. Unwise, improper floodland development such as this inevitably results in pleas for public officials to "do something about it."

Photo courtesy of The Milwaukee Journal

damages incurred by residents of this reach of the river during the spring floods of 1959 and 1960. Through personal interviews, the survey determined that 154 residences, commercial establishments, and public properties were damaged either by the 1959 or the 1960 flood, or by both; and the total monetary damages incurred in the two floods were estimated at $345,300, expressed in 1960 dollars. Of the six communities surveyed the City of Glendale was reported to have experienced approximately $40,200 worth of damages to 40 privately owned properties; the Village of Thiensville, approximately $33,400 worth of damages to 15 privately owned properties; the Village of Grafton, approximately $13,100 worth of damages to 15 privately owned properties; the Village of Brown Deer, approximately $73,500 worth of damages to six privately owned properties; the Village of Saukville and the Town of Saukville, together approximately $63,100 worth of damages to privately and publicly owned properties; and the City of Mequon, over $122,000 to 78 privately owned properties.

The survey apparently was undertaken to make public officials and interested citizens generally aware of the existing flood problem; to identify flood-vulnerable areas; and to illustrate, by means of the estimated monetary flood damages incurred, just how severe the flood problem actually was in the area surveyed. The Lieberman–Unger survey is documented in an unpublished memorandum entitled, "Flood on the Milwaukee River" and dated March-April 1960, a copy of which is on file in the Commission offices. The report provides an important and invaluable source of historic flood damage data for the reaches of the Milwaukee River covered. The survey was made at a time (fall of 1960) when the extent and cost of the flood damages resulting from the 1959 and 1960 spring floods were still fresh in the minds of those residents of the riverine areas unfortunate enough to be damaged by these two floods. It is also apparent from the report that the residents of the floodplain were very willing to discuss the nature and estimate the cost of the flood damages incurred at that time, an attitude which, as indicated later in this report, has changed so that the residents of the floodplain are now very reluctant to discuss the historic flood damages, probably in fear that such information will lower the value of their properties.

Soil Conservation Service Report

The U. S. Department of Agriculture, Soil Conservation Service (SCS), in February of 1961, issued a flood control report for the Milwaukee River watershed.[4] The purpose of the report was to review and dispose of an application for planning assistance to the State Soil Conservation Committee filed under Public Law 566 by the Honorable Gaylord A. Nelson, then Governor of Wisconsin. The report concluded that small floodwater retarding structures would not provide a satisfactory level of protection in the main flood damage areas; that diversion channels could be designed to provide such protection; that careful land use planning implemented through zoning would be necessary to prevent further unwise

[4] *U. S. Department of Agriculture, Soil Conservation Service, Report for Flood Control in the Milwaukee River Watershed, February 1961.*

development in the floodplains; and that, inasmuch as the principal damages were of an urban nature, any further study of the flood problems should be made by the U. S. Army Corps of Engineers, with due consideration being given to possible contributions to flood control by Public Law 566 small flood control works. No new flood damage surveys were made by the Soil Conservation Service for this report, all analyses and conclusions being based upon available secondary data.

Second U. S. Army Corps of Engineers Survey Report—1964

As a direct result of the findings of the Lieberman-Unger Survey, the U. S. Army Corps of Engineers in 1964 undertook a new flood damage investigation of the Milwaukee River watershed. This investigation was undertaken as a part of a flood control study of the Milwaukee River watershed authorized in 1958 pursuant to the provisions of Section 205 of the Flood Control Act of 1950, Title II Public Law 516—81st Congress. The resulting report[5] is the most complete report issued to date on the flood problems of the Milwaukee River watershed and potential solutions to those problems. The field investigations carried out under the study included a reconnaisance of the area by the District Engineer; subsurface explorations to determine soil and bedrock characteristics along the route of a possible diversion channel; engineering surveys to establish horizontal and vertical survey control in the watershed and to obtain cross sections of the existing riverbed and a profile along the route of a possible diversion channel; and a historic flood damage survey to determine the extent and magnitude of the flood damages.

The historic flood damage survey included the Menomonee and Kinnickinnic River watersheds, as well as the Milwaukee River watershed, as defined in this report. The Corps report indicates that the most persistent demand for the control of floods on the Milwaukee River comes from property owners occupying or interested in occupying floodplain lands located along the river downstream from the Village of Saukville. Above Saukville flood damages are generally confined to agricultural uses, although a number of summer cottages along the Milwaukee River might be converted to permanent residences if the flood hazard were reduced.

The flood damage survey and the flood control measures considered were limited to that area along the Milwaukee River below Saukville, indicating that the flood problem above Saukville was not considered of sufficient importance to warrant investigation. The survey attempted to collect flood damage data not only for the spring floods of 1959 and 1960, but also for the summer flood of 1924. The data collected indicated that a recurrence of the 1924 flood in 1964 would have damaged 621 homes and 81 commercial structures, while a recurrence of the 1959 flood would damage 173 homes and 19 commercial structures and a recurrence of the 1960 flood, 267 homes and 18 commercial structures. Monetary damages were determined for public buildings and grounds and for utilities and streets and bridges, as well as for private residential and commercial structures. Agricultural damages were not surveyed. The total flood damages that would be incurred in a recurrence of the 1924 flood were estimated at \$851,400;[6] for a recurrence of the 1959 flood, \$306,500; and for a recurrence of the 1960 flood, \$375,000, all measured in 1964 dollars.

The report recommends the construction of a floodwater diversion channel extending from the Milwaukee River at the Village of Saukville a distance of about three miles to a point on the Lake Michigan shore about one and one-half miles south of the City of Port Washington. Control structures at Saukville would divert flood flows into the diversion channel. The outlet at Lake Michigan would include a chute and stilling basin. Construction of the single-purpose diversion channel could be expected to reduce average annual flood damages by an amount estimated at \$217,000 (see Table 41). The flood control benefits would be achieved by lowering the hydraulic gradeline (high water surface elevation) of the flood flows on the Milwaukee River below the Village of Saukville. The total installation cost of the diversion channel was estimated by the Corps of Engineers at \$4,410,000 in 1964 dollars, including construction, engineering, and administrative services, but not including the cost of obtaining land easements and land rights-of-way. Amortized at 3 1/8 percent interest over a 100-year period, the average annual capital cost would be \$185,000. Average annual operation and maintenance costs were estimated at \$14,100. Average annual costs would be \$200,000. The benefit-cost ratio of the single-

[5] *Survey Report for Flood Control on the Milwaukee River and Tributaries, Wisconsin, November 1964, U. S. Army Engineer District Chicago, Corps of Engineers.*

[6] *Developed from synthetic unit damages, 1924 floodplain data, and 1964 structure count.*

TABLE 41

PROJECT FORMULATION STUDIES-DETERMINATION OF OPTIMUM PROJECT (FLOODWATER DIVERSION CHANNEL)

DEGREE OF PROTECTION (YEARS)	AVERAGE ANNUAL BENEFITS[a]	AVERAGE ANNUAL CHARGES	BENEFIT-COST RATIO	INCREMENTAL AVERAGE ANNUAL BENEFITS	INCREMENTAL AVERAGE ANNUAL CHARGES	INCREMENTAL BENEFIT - COST RATIO
100	$217,000	$200,000	1.09	$3,000	$12,000	0.25
200	220,000	212,000	1.04			

[a] INCLUDES BENEFITS ATTRIBUTABLE TO LAND ENHANCEMENT.

SOURCE- U. S. ARMY CORPS OF ENGINEERS SURVEY REPORT, MILWAUKEE RIVER AND TRIBUTARIES, WISCONSIN, 1964.

purpose diversion channel, calculated at 3 1/8 percent interest, would be 1.09 to 1.0, including both flood damage reduction and land enhancement benefits. The diversion channel was one of six alternative flood control measures considered. The other alternatives include the construction of channel improvements, the construction of levees, the construction of flood control reservoirs, the construction of multi-purpose reservoirs, and floodplain evacuation.

The U. S. Army Corps of Engineers flood control report provides invaluable historic flood damage data along that reach of the Milwaukee River extending from the City of Milwaukee through the Village of Saukville, data constituting an important input to the flood damage survey conducted by the Commission. The report also provides important engineering data about the river below Saukville and proposes a possible solution to the flood problems of the lower river.

SEWRPC MILWAUKEE RIVER WATERSHED FLOOD DAMAGE SURVEY

All of the past historic flood damage surveys previously described were considered to be incomplete because the geographic scope of the surveys was limited to the lower reaches of the main stem of the Milwaukee River, extending from the City of Milwaukee through the Village of Saukville, and because the economic scope of the survey was limited to urban flood damages. Therefore, a new flood damage survey was conducted by the Commission in the summer of 1968 as an integral part of the Milwaukee River watershed study. This study was comprehensive, including all of the watershed and all forms of flood damages, including agricultural, as well as urban, damages, and public, as well as private, losses. The primary objectives of the survey were to obtain comprehensive, as well as accurate, information on historic and potential flood losses and to solicit

Historic high water marks are essential to the determination of high water surface profiles for actual major floods and attendant flood hazards and are an invaluable aid in calibrating the flood-flow simulation models used to synthesize high water surface profiles for floods of specified recurrence intervals. This photo shows documented historic high water marks as recorded by a resident of the City of Mequon for the 1959 and 1960 floods on the Milwaukee River. Many such high water marks were collected in the SEWRPC flood damage survey.

SEWRPC Photo

information useful in the necessary hydrologic and hydraulic investigations, such as the maximum height of the floodwaters (see Table 107), time of flood crest, and duration of flooding. Before undertaking the new survey, all available previous flood damage survey information was carefully reviewed in order to identify the measures necessary to both update the information and to expand its geographic and economic scope.

The procedures developed by the Commission for the conduct of the historic flood damage surveys carried out under the Root and Fox River watershed planning programs were utilized in this survey. These procedures are in accordance with, and patterned after, historic flood damage survey practices established by the U. S. Army Corps of Engineers and the U. S. Soil Conservation Service.

Field Survey Operations

SEWRPC field survey operations consisted primarily of on-site personal interviews with homeowners, farmers, and businessmen located in the historic floodplains of the watershed who either suffered direct or indirect damages from floods which occurred in the recent past or, in the case of structures erected since the last major flood, could potentially incur flood damages. The field interviews were conducted by a team of Commission flood damage surveyors who were instructed to collect sufficient information on historic flood damages to enable accurate reconstruction of monetary losses in terms of current dollar values. The team of surveyors was kept small in number to assure consistency in damage interpretation and reporting throughout the watershed and was supplied with standard flood damage questionnaire forms to be utilized during interviews with owners, lessees, or managers of the damaged property and with appropriate public officials. Eight separate questionnaire forms were utilized, relating to the flood damage categories of public buildings and grounds; railroads; streets and highways; bridges; utilities and communications; relief and health expenditures; agricultural damages; and nonpublic buildings and grounds. The questionnaire forms used are reproduced in Appendix D of this volume. The flood damage data thus collected were divided into three sectors: public property and utilities, private agriculture, and private residential and commercial.

Because of the relatively large size of the Milwaukee River watershed, it was impractical to arrange personal interviews with officials of all the federal, state, and local public agencies within the watershed that might have incurred flood damage costs. Instead, letters of inquiry were sent to officials of these agencies. The letters explained the purpose of the SEWRPC flood damage survey and requested information concerning public expenditures incurred because of flooding in recent years. Such letters of inquiry were sent to all village presidents and town board chairmen within the watershed; to all county sheriffs and civil defense directors of Fond du Lac, Milwaukee, Ozaukee, Sheboygan, and Washington Counties; to all chiefs of the police departments of the Cities of Cedarburg, Glendale, Mequon, and West Bend; to officials of the State Highway Commission of Wisconsin and the county highway departments; to all city and village engineering departments; and to all public utilities within the watershed, both because these agencies were more likely to have incurred significant flood damage costs and because the officials of these agencies were more likely to be able to supply definitive hydrologic and hydraulic data to the study.

Personal interviews were conducted with 262 homeowners in, and residents of, the riverine areas of the watershed. The interviews included questions concerning the direct flood damages incurred to structures, furnishings, and other contents, as well as the indirect damages incurred, such as the cost of flood fighting and evacuation. The height of floors above, and the depth of floors below, ground level was also obtained for each structure. In the conduct of the survey, three basic categories of residential flood damage were recognized; and sampling rate objectives for these were established as follows:

1. Inundation from direct overflow of the first (ground level) floor of buildings: 100 percent sample rate within the assumed historic floodplain.

2. Inundation from direct overflow but limited to basements, lawns, and grounds: 20 percent sample rate within the assumed historic floodplain.

3. Sewer backup or seepage through walls and floors, resulting in basement flooding: 20 percent sample rate within the assumed historic floodplain.

In isolated areas containing relatively few damaged properties, a 100 percent sampling rate within the assumed historic floodplain was set as the objective for all residential damage categories.

Personal interviews were conducted with the owners or managers of 11 commercial properties located in the floodplain. Because of the extreme variability of flood damage susceptibility of individual commercial properties, a 100 percent sampling rate within the assumed historic floodplain was set as the objective for this sector.

Personal interviews were conducted with 48 farmowners or operators. A 100 percent sampling rate within the assumed historic floodplain was set as the objective for this sector. The farmers were questioned as to direct damage to crops, livestock, equipment, buildings, and other property; as to damage resulting from erosion and sedimentation; and as to other water resource-related problems, such as poor drainage or deteriorating surface water quality. Wherever the farmowners or operators were able to reconstruct them, inundation lines were delineated on prints of 1" = 400' scale aerial photographs.

Evaluation of Flood Damage Survey Results

The field data were entered on the personal interview forms and aerial photographs used for this purpose and, together with the data collected through the letters of inquiry, were reviewed immediately after completion of the interviews or receipt of the replies and converted into a consistent form suitable for analysis. Such conversion was necessary, since most of the interviews resulted in information on the extent and type of physical damage incurred by the damagees rather than in dollar amounts of damage. Moreover, in the case of structures erected on the known historic floodplain since the last major flood, damages had to be imputed in order to enable the total flood damages which would be incurred in a future major flood to be estimated. All such new structures were identified in order to permit a reconstruction of the actual 1960 flood damages and to permit the preparation of an estimate of the potential flood damage under existing land use development. Some of the interviews, however, resulted in information on the actual costs of the damages, while in a few instances, the interviews resulted only in information on the flooding characteristics of the river.

The individual flood damage forms completed by the U. S. Army Corps of Engineers in the 1964 flood damage survey and supplied to the Commission upon the submittal of a release from individuals originally interviewed by the Corps were analyzed in the same manner as the SEWRPC interview forms.[7] Every effort was made by the SEWRPC surveyors to obtain the necessary releases and thereby permit full use to be made in the current SEWRPC survey of the data collected in the previous Corps flood damage survey. In several instances a flood damagee who had been included in the Corps survey was reinterviewed by the SEWRPC surveyors as a basis for comparison of survey results and to ensure consistence in the evaluation of individual flood damage forms. The results of such comparisons were excellent and indicated a very high degree of consistency in the results.

Public, as well as private-sector, cost quotations, where provided, were carefully reviewed and adjusted as necessary. Where data on the extent and type of physical damage were available, these were converted to monetary values with the aid of a cost schedule based on average regional prices. If neither cost quotations nor the exact nature of the physical damage were available, empirically derived cost tables obtained from the U. S. Soil Conservation Service were used to compute probable monetary loss from the depth of inundation. The probable depth of flooding was determined from careful analyses of the outer limits of the areas of inundation, as defined by historic high water marks and the high water surface profiles determined through application of the mathematical flood-flow simulation model developed under the study. The tables used are reproduced in Appendix E of this volume. All monetary flood damages were expressed in 1969 dollars. This required the adjustment of reported flood damages to reflect the changes in the actual purchasing power of the dollar between 1960 and 1969 in some cases, and in other cases between 1964 and 1969. In a few instances in which both flood inundation data and individual cost quotations were provided, the tables were found to compare quite satisfactorily with the quoted damage costs, adjusted to 1969 dollars, for the various depths of flooding which occurred.

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[7] *All flood damage survey forms are on file in the SEWRPC offices.*

Many possible sources of error exist in any flood damage survey and must be guarded against during the conduct of the interviews and in the interpretation and application of resulting data. The principal factors which may adversely affect the accuracy of the flood damage survey are:

1. A high rate of change in ownership between the time of the last major flood (1960) and the time of the flood damage survey (1968), especially in high damage reaches. Present owners of damaged units were often found to be unaware of past flood damage, while former owners were difficult to find or were uncooperative because they retained little interest in the affected property.

2. The large number of the residences located in certain floodplain areas were vacation homes owned by persons residing outside the watershed. Because many of these homes were occupied only at unpredictable times during the summer, it was not always practical to achieve full interview coverage in these areas.

3. A relatively long period of time had elapsed since the last major flood (spring of 1960) and the flood damage survey (summer of 1968). With the passage of eight years, many private damagees had either forgotten entirely or inaccurately recalled past flood damages.

4. Under-reporting of damages was likely in some areas because of fear that the survey results might depreciate property values. This fear was particularly apparent among owners who were subdividing farmland for urban development or trying to sell urban dwellings.

5. Some damaged properties were not restored to preflood condition, so that repair costs were not representative of actual damages.

6. It was apparent that some owners failed to recognize all damages sustained, particularly certain indirect costs.

It is important to note that all of the above factors will tend to result in an under-reporting of actual flood damages and, therefore, in conservatively low flood damage estimates.

Results of the flood damage surveys indicated that residential flood damages are significant only along that reach of the Milwaukee River extending from the confluence with the North Branch of the Milwaukee River in Ozaukee County to the confluence with Lincoln Creek in Milwaukee County, a distance of about 36.5 miles.

It should be emphasized that the procedures followed in the SEWRPC flood damage survey resulted in both a reconstruction of the actual monetary damages incurred in the 1960 flood on the Milwaukee River and an estimate of the potential damages from 10- and 100-year recurrence interval floods under existing (1967) land use development in the floodplains. In addition, the survey permitted estimates to be made of flood damages under future (1990) land use conditions. All damages were expressed in 1969 dollars. In order to be conservative, the damages actually incurred in the 1960 flood were reconstructed by simply totaling only those damages actually reported by interviewed damagees, even though these represented only a sample of the total universe. The flood damages attendant to the 10-year and 100-year recurrence interval floods under present (1967) land use conditions, however, are based upon computations of potential damage to all existing land uses in the floodplains of the watershed, as those land uses were identified in the flood damage survey. As already noted, the damages were computed using empirical cost tables and actual flood stage heights. It should be noted that a 10-year recurrence interval flood would be of approximately the same magnitude as the 1960 flood; a 100-year recurrence interval flood would be of a slightly greater magnitude than the 1918 and 1924 floods. The latter floods both had an estimated recurrence interval of 77 years and, therefore, a stage somewhat lower than the 100-year recurrence interval flood.

COST AND CHARACTERISTICS OF FLOOD DAMAGE

Definitions

Flood damage may be defined as the physical deterioration or destruction caused by floodwaters. The term flood loss refers to the net effect of the flood damage on the regional economy and is usually expressed in monetary units. All losses resulting from a flood or the risk of a flood can be broadly classified as direct, indirect, depreciation, and intangible. To assure full compatibility with the policies and practices of those federal agencies which may be asked to assist in the implementation of the recommended watershed plan, these four categories of flood losses were defined for the purpose of the study so as to be consistent with the definitions used by the U. S. Army Corps of Engineers and the U. S. Soil Conservation Service, as follows:

1. Direct losses were defined as monetary expenditures required, or which would be required, to restore flood-damaged property to its preflood condition. Included in this category within the agricultural sector is the net potential value of farm crops destroyed by flooding.

2. Indirect losses were defined as the net monetary cost of flood-fighting, floodproofing, and flood-caused loss of wages, sales, and production. Cost of evacuation and relocation, increased cost of carrying on operations during periods of flood disruption, and increased cost of transportation because of flood-caused detours were also defined as indirect losses. Indirect losses, although often difficult to determine with accuracy, nevertheless constitute real monetary losses to the economy of the Region.

3. Depreciation losses were defined as the reduction on the value of real property when the risk of flooding becomes known. Property values after a flood are reduced by the probable amount of money which will have to be expended for future flood repairs. This being the case, depreciation losses should be equal to the probable direct losses from future floods. Depreciation losses are difficult to define in monetary terms, however, because the economic value of depreciation depends not only on actual direct flood losses but on public attitudes, time elapsed since the last damaging flood, the vagaries of human memory, and the information available to prospective buyers. When damaging floods are infrequent, many residents or buyers of residential property in a potential damage area are unaware of flood risks; and, consequently, flood risk may not actually enter into the establishment of property values. Because of the difficulty and uncertainty in assigning a monetary value to depreciation losses, these losses were not included in the economic analyses. The direct losses, which are another means of determining the depreciation, were instead evaluated and included in the economic analyses of the alternative watershed plans.

4. Intangible losses were defined as losses which cannot be measured in monetary terms. Intangible losses caused by floods range from loss of life to minor inconvenience and include health hazards, interruption of schooling, loss of fire protection, and severe mental aggravation. It is significant to note, however, that, in the course of the flood damage survey, many damagees declared that the intangible damages, such as mental aggravation, were the most severe flood damage they experienced, monetary costs notwithstanding.

Automobiles often become useless vehicles to residents of natural floodplains during flood periods, as shown in this photo of the 1960 flood near the unincorporated Village of Kohler in Ozaukee County. Canoes and rowboats are often the only way floodplain residents can reach their homes. Floodwaters such as these often require several days to recede, thus causing rather extended periods of disruption of normal daily lives.

Photo Courtesy of The Milwaukee Journal

Flood damage may also be classified on the basis of ownership into public-sector and private-sector losses. Private-sector can be further subclassified into residential-commercial losses, road-user detour costs, and agricultural losses. A summary of these estimated losses within the Milwaukee River watershed expressed in present day prices (1969) is set forth for the 10-year and 100-year recurrence interval floods under present (1967) land use conditions in Tables 42 and 43.

Public-Sector Losses

The costs of flood damages to public property, utilities, and relief agencies were accepted as reported in the 1964 flood damage survey conducted by the U. S. Army Corps of Engineers but were adjusted to account for the increases in prices between 1964 and 1969. This was done on the assumption that no new flood-vulnerable public facilities were constructed in the historic floodplains between 1960 and 1967. Direct losses included road and bridge repairs, basement pumping, and flood cleanup operations. Indirect losses included blasting of ice jams, relief and health services, and highway and railway traffic rerouting. In evaluating flood costs resulting from public labor charges, only the cost of overtime pay was included.

Public-sector damage incurred in the 1960 flood, a flood having a recurrence interval of approximately 10 years, as reported in the U. S. Army Corps of Engineers flood damage survey and adjusted for the increase in the Milwaukee area consumer price index from 1964 to 1969,[8] totaled about $75,000 and may be assumed to be the same under present (1967) land use conditions. Public-sector damages for a 100-year recurrence interval flood under present land use conditions may be expected to total about $169,000. The average annual public-sector losses may be estimated at about $17,000.

Private-Sector Losses

Residential and Commercial Losses: Damages to the private residential sector, as measured in terms of monetary loss, number of people affected, and intangible damages, were by far the most significant damages resulting from the 1960 flood; and it is estimated that about 75 percent of the total flood damages incurred in all major floods along the Milwaukee River are sustained by private residences, as was the case in the 1960 flood. At least 267 families in 8 communities were directly affected by the 1960 flood event, with damages ranging from basement seepage to first-floor inundation, and monetary damages in the private residential sector totaled about $200,000. The residential losses that would be incurred as a result of a 10-year recurrence interval flood, using a 1967 structure count and 1969 dollar values, are indicated in Table 42. As noted in the table, total residential flood damages may be expected to total about $227,900. The comparable dollar losses which could be expected with the occurrence of a 100-year recurrence interval flood on the Milwaukee River under present (1967) land use conditions exceed $1.5 million for residential damages alone (see Table 43).

The cost of flood damage to commercial-industrial property was accepted as reported in the 1964 U. S. Army Corps of Engineers Survey Report, the total cost being adjusted only to reflect the change in the Milwaukee area consumer price index from 1964 to 1969. This was done on the assumption that no new flood-vulnerable commercial-industrial uses were constructed on the historic floodplains between 1960 and 1967. Eighteen commercial establishments reported damage from the 1960 flood; and estimated damage to the commercial sector totaled $23,000, expressed in 1969 dollars, and may be assumed to be the same under present (1967) land use conditions. It is estimated that over 80 commercial establishments would experience about $75,500 in damages if the 100-year recurrence interval flood occurred under present (1967) land use conditions. Average annual commercial losses are estimated to approximate $6,000. Observation of recent commercial development in the floodplains indicates that commercial developers are becoming more aware of flood risks and may be expected in the future to take precautions to insure against flood damage. Therefore, the probable future annual commercial flood damage was not increased beyond the estimated 1969 levels.

Road-User Detour Costs: Detour costs to road users are often an important indirect loss accompanying flood closure of streets. This cost was calculated for affected arterial streets and highways on the basis of traffic volume, incremental detour length, hours of flooding, and an esti-

[8] *The Milwaukee consumer price index increased from 105.2 in 1964 to 122.8 in 1969, an increase of 16.8 percent.*

TABLE 42

ESTIMATED FLOOD DAMAGES IN THE MILWAUKEE RIVER WATERSHED BY MAJOR DAMAGE REACH -- 10-YEAR RECURRENCE INTERVAL FLOOD UNDER 1967 LAND USE CONDITIONS[a] (1969 DOLLARS)

MAJOR DAMAGE REACH[b]			PRIVATE SECTOR DAMAGES			
NUMBER	RIVER MILES	NAME -- GEOGRAPHIC DESCRIPTION	RESIDENTIAL	COMMERCIAL[c]	ROAD USERS	TOTAL
1	6.2-8.5	MILWAUKEE -- SILVER SPRING DR TO ESTABROOK PARK	$ --	$ --	$ --	$ --
2	8.1-12.0	GLENDALE -- SILVER SPRING DR TO 1/4 MILE SOUTH OF BRADLEY RD	54,600	7,600	--	62,200
3	11.3-16.0	RIVER HILLS-- GREENTREE RD TO COUNTY LINE RD	2,500	--	--	2,500
4	14.8-16.0	BROWN DEER -- 1/4 MILE SOUTH OF BRADLEY RD TO COUNTY LINE RD	2,500	6,300	--	8,800
5	16.0-18.8	MEQUON -- COUNTY LINE RD TO STH-167	35,000	1,200	--	36,200
6	18.8-20.6	THIENSVILLE (VILLAGE)	8,000	5,300	--	13,300
7	18.8-22.0	MEQUON -- STH-167 TO SW CORNER OF SECTION 18, T9N, R22E	70,000	--	--	70,000
8	22.0-26.3	MEQUON -- SW CORNER OF SECTION 18, T9N, R18E TO CTH-C	40,000	--	--	40,000
9	26.3-30.0	GRAFTON -- CTH-C TO 3/4 MILE SOUTH OF STH-60	2,800	--	--	2,800
10	30.0-31.8	GRAFTON -- 3/4 MILE SOUTH OF STH-60 TO 3/4 MILE NORTH OF STH-60	6,500	--	--	6,500
11	31.8-35.0	GRAFTON -- 3/4 MILE NORTH OF STH-60 TO SAUKVILLE-GRAFTON TOWN LINE	1,000	--	--	1,000
12	35.0-37.5	SAUKVILLE (VILLAGE)	3,800	3,000	7,700	14,500
13	37.5-42.0	SAUKVILLE -- VILLAGE LINE NORTH 4 MILES	1,200	--	--	1,200
14	42.0-46.0	WAUBEKA -- 4 MILES NORTH OF SAUKVILLE VILLAGE LINE THROUGH WAUBEKA	--	--	--	--
--	46.0+	UPSTREAM OF WAUBEKA	--	--	--	--
--	--	CEDAR CREEK	--	--	1,000	1,000
SUBTOTAL................................			$227,900	$23,400	$8,700	$260,000
PUBLIC SECTOR DAMAGES[c,d]						74,800
TOTAL DAMAGES................................						$334,800

[a]A 10-YEAR RECURRENCE INTERVAL FLOOD IS A FLOOD OF ABOUT THE SAME MAGNITUDE AS THE 1960 FLOOD ON THE MILWAUKEE RIVER.

[b]SEE MAP 40.

[c]DAMAGES FROM U. S. ARMY CORPS OF ENGINEERS, SURVEY REPORT FOR FLOOD CONTROL ON THE MILWAUKEE RIVER AND TRIBUTARIES WISCONSIN, NOVEMBER 1964.

[d]BREAKDOWN OF DAMAGE BY REACH NOT AVAILABLE.

SOURCE- HARZA ENGINEERING COMPANY AND SEWRPC.

TABLE 43

ESTIMATED FLOOD DAMAGES IN THE MILWAUKEE RIVER WATERSHED BY MAJOR FLOOD DAMAGE REACH -- 100-YEAR RECURRENCE INTERVAL FLOOD UNDER 1967 LAND USE CONDITIONS[a] (1969 DOLLARS)

MAJOR DAMAGE REACH[b]			PRIVATE SECTOR DAMAGES			
NUMBER	RIVER MILES	NAME -- GEOGRAPHIC DESCRIPTION	RESIDENTIAL	COMMERCIAL[c]	ROAD USERS	TOTAL
1	6.2-8.5	MILWAUKEE -- SILVER SPRING DR TO ESTABROOK PARK	$ --	$ 4,100	$ --	$ 4,100
2	8.1-12.0	GLENDALE -- SILVER SPRING DR TO 1/4 MILE SOUTH OF BRADLEY ROAD	570,000	14,700	--	584,700
3	11.3-16.0	RIVER HILLS--GREENTREE RD TO COUNTY LINE RD	38,800	--	--	38,800
4	14.8-16.0	BROWN DEER -- 1/4 MILE SOUTH OF BRADLEY RD TO COUNTY LINE RD	19,100	10,700	--	29,800
5	16.0-18.8	MEQUON -- COUNTY LINE RD TO STH-167	196,500	1,900	6,000	204,400
6	18.8-20.6	THIENSVILLE (VILLAGE)	93,300	24,800	--	118,100
7	18.8-22.0	MEQUON -- STH-167 TO SW CORNER OF SECTION 18, T9N, R22E	218,600	--	--	218,600
8	22.0-26.3	MEQUON -- SW CORNER OF SECTION 18, T9N, R22E TO CTH-C	179,740	--	2,110	181,850
9	26.3-30.0	GRAFTON -- CTH-C TO 3/4 MILE SOUTH OF STH-60	16,600	2,700	--	19,300
10	30.0-31.8	GRAFTON -- 3/4 MILE SOUTH OF STH-60 TO 3/4 MILE NORTH OF STH-60	26,600	--	--	26,600
11	31.8-35.0	GRAFTON -- 3/4 MILE NORTH OF STH-60 TO SAUKVILLE-GRAFTON TOWN LINE	53,500	--	--	53,500
12	35.0-37.5	SAUKVILLE (VILLAGE)	48,150	16,600	21,100	85,850
13	37.5-42.0	SAUKVILLE -- VILLAGE LINE NORTH 4 MILES	20,300	--	--	20,300
14	42.0-46.0	WAUBEKA -- 4 MILES NORTH OF SAUKVILLE VILLAGE LINE THROUGH WAUBEKA	74,500	--	--	74,500
--	46.0+	UPSTREAM OF WAUBEKA	--	--	5,100	5,100
--	--	CEDAR CREEK	--	--	2,490	2,490
SUBTOTAL..............................			$1,555,690	$75,500	$36,800	$1,667,990
PUBLIC SECTOR DAMAGES[c,d]...						169,000
TOTAL DAMAGES...						$1,836,990

[a] A 100-YEAR RECURRENCE INTERVAL FLOOD IS A FLOOD OF SLIGHTLY GREATER MAGNITUDE THAN THE 1924 FLOOD ON THE MILWAUKEE RIVER. THE 1924 FLOOD HAD AN ESTIMATED RECURRENCE INTERVAL OF 77 YEARS.

[b] SEE MAP 40.

[c] DAMAGES FROM U.S. ARMY CORPS OF ENGINEERS, SURVEY REPORT FOR FLOOD CONTROL ON THE MILWAUKEE RIVER AND TRIBUTARIES, WISCONSIN, NOVEMBER 1964.

[d] BREAKDOWN OF DAMAGE BY REACH NOT AVAILABLE.

SOURCE- HARZA ENGINEERING COMPANY AND SEWRPC.

mated 12 cents per mile vehicle operation cost.[9] The synthesized 10-year and 100-year flood profiles were used to determine which roads could be expected to be closed by major flood events, and the synthesized flood hydrographs were used to determine the probable duration of flooding. Curves were then prepared which related the duration of closure to frequency, the area under these curves representing the average annual hours of closure for each arterial street or highway affected.

The detour cost attributable to the March-April 1960 flood, a flood having a recurrence interval of approximately 10 years, using 1963 average daily traffic volumes (ADT), was thus estimated at about $9,000. With present (1969) average daily traffic volumes, the detour costs attendant to a 10-year recurrence interval flood would total about $8,700,[10] and for a 100-year recurrence interval flood, about $37,000, all expressed in 1969 dollars. Table 44 lists the arterial streets and highways that were flooded during the 1960 (10-year recurrence interval) flood event and those that could be expected to be flooded by a 100-year recurrence interval flood.

[9] *Traffic volume and vehicle operating cost data were derived from data developed under the SEWRPC land use-transportation study.*

[10] *The decrease in the estimated detour cost from 1963 to 1969 accompanying a 10-year recurrence interval flood was not due to any decrease in traffic volumes but to a shift in traffic from older flood-prone surface arterials to freeway facilities and new high-type surface arterials not subject to flood closure.*

Average daily traffic volumes were obtained from the SEWRPC Regional Land-Use Transportation Study. Annual detour costs were estimated for each detour route by the following formula:

$$\text{Annual cost in dollars} = \frac{t}{24} \cdot ADT \cdot L \cdot C$$

where: t = estimated average annual flood closure in hours.

ADT = average weekday traffic volume in vehicles per day.

L = incremental detour length in miles.

C = vehicle operation costs ($0.12 per mile).

The average annual detour cost is estimated at $2,600 in 1969 dollars under 1969 traffic volume conditions.

Agricultural Losses: Historic floods have caused a wide range of, but only minor, agricultural damage within the watershed, including damage to crops and orchards; loss of livestock; damage to farm buildings, machinery, and equipment; damage to stored feed and supplies; damage to farm bridges, roads, and fences; damage to drainage and irrigation works; and soil erosion and siltation. The monetary loss from flooding of a crop varies with the date of flood occurrence, the duration of flooding, the velocity of floodwaters, the depth of flooding, and the type of crop. An early flood may allow time for replanting of a crop, the

Detour costs to road users are often an important indirect loss accompanying flood closure of streets and highways. This photo of thick cakes of ice littering STH 57 north of the Village of Saukville was taken in March 1962 and illustrates the closure of a major transportation facility due to floods on the Milwaukee River. In this case an ice jam had to be dynamited to clear the nearby channel and permit the floodwaters to recede, after which the roadway had to be cleared.

Photo courtesy of The Milwaukee Journal

TABLE 44

DURATION OF ROAD CLOSURE FOR THE 10- AND 100- YEAR RECURRENCE INTERVAL FLOODS ON THE MILWAUKEE RIVER WATERSHED

ROAD	LOCATION (RIVER MILE)	10-YEAR RECURRENCE INTERVAL		100-YEAR RECURRENCE INTERVAL	
		DEPTH (FEET)	FLOOD DURATION (HOURS)	DEPTH (FEET)	FLOOD DURATION (HOURS)
MILWAUKEE RIVER					
STH 167	18.83	1.0	33	--	--
CTH M	23.15	1.2	53	--	--
STH 33	36.79	1.3	54	--	--
STH 57	36.90	4.0	98	1.5	74
CTH O	37.60	2.0	80	--	--
STH 33	57.52	2.6	38	--	--
CTH M	57.70	2.3	35	--	--
CTH H	74.10	1.9	48	--	--
STH 28	77.10	2.1	17	--	--
STH 67	87.68	1.4	15	--	--
CEDAR CREEK					
CEDAR CREEK ROAD	35.47	4.0	64	1.0	31
CEDAR CREEK ROAD	37.00	1.3	36	--	--
CTH N	37.61	1.8	38	--	--
HORNS CORNER ROAD	38.19	6.2	82	3.9	54
CTH M	43.75	3.5	48	--	--
CTH G	46.88	6.5	54	2.0	28
STH 60	48.31	1.0	10	--	--

SOURCE- HARZA ENGINEERING COMPANY.

Agricultural flood damages have, on the whole, been relatively minor in the Milwaukee River watershed. Many of the rural lands subject to flooding are used for pasture and are not, therefore, subject to heavy flood damage. In addition, most major flood events on the Milwaukee River have been early spring flood events occurring before any crops were planted. If a 10-year recurrence interval flood were to occur in early summer, however, it is estimated that agricultural damages within the watershed could exceed $200,000. Also, as shown in this photo, many inconveniences result from the placement of farm homes in floodplains.

Photo Courtesy of The Milwaukee Journal

yield of which may be equal to that of the crop destroyed, with only the cost of replanting representing the flood loss. A mid-season flood may allow the production of a lesser value crop, such as hay. Late season floods shortly before harvest may cause a complete loss with no opportunity for recovery but "save" the expense of harvesting. Floods occurring prior to planting or after harvest cause no crop damage but may result in some of the other kinds of agricultural damage listed above.

Truck crops, such as cabbage and potatoes, can be severely damaged by only a few inches of water, especially if air temperatures are high during and immediately after flooding. Oats and soybeans can survive flood inundations which would destroy truck crops but are less flood tolerant than corn. Certain types of hay and pasture are very flood tolerant; and, indeed, their crop yields might be substantially increased from the irrigation benefits of flooding during early stages of their growth.

In poorly drained areas of the watershed, farmers were often unable to distinguish between crop damage resulting from direct flooding by the river and from localized ponding of storm water due to inadequate agricultural drainage facilities. In those instances where analysis of the historic high water marks and the floodwater surface profiles determined through application of the flood-flow simulation model developed under the study so indicated, the reported damage was adjusted to exclude any costs relating to poor drainage. A substantial number of farmowners within the watershed have placed floodplain farmlands under soil reserve programs administered by the U. S. Department of Agriculture, Agricultural Stabilization and Conservation Service (ASCS).[11] Because this land has been temporarily diverted from agricultural use, no flood losses can presently be assigned to it. For the purpose of evaluating future flood damage risks, however, it was assumed that, under the pressure of increasing population levels, this land would eventually revert to agricultural use.

Although the monetary value of crop losses was estimated during the interviews, all crop damage costs ultimately used in the economic analyses were adjusted utilizing the following formula:

Adjusted Monetary Loss = full probable cash value of original crop -

costs not incurred in cultivation, harvest, and storage +

cost of all operations in harvesting, and storing substitute crop -

market value of the substitute crop.

Of the total reported damages incurred in the 1960 flood event of $220,000, only $7,100, or about 3 percent, were reported as agricultural damages.[12] This low monetary loss may be ascribed to two factors: 1) most of the rural lands subject to flooding were being used for pasture and were, therefore, not subject to heavy damages, and 2) the 1960 flood event was an early spring event occurring before any crops were planted. The occurrence of a 10-year recurrence interval flood event in the early summer, after crops are planted, could cause agricultural damages in excess of $200,000, based on an estimated 2,000 acres of agricultural cropland located within the floodplain.

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[11] *The three major federal soil reserve programs affecting agricultural land use in the watershed are:*

1. *Conservation Reserve Program–This program was established under the Federal Soil Bank Act of 1956 for the purpose of removing cropland from production and instituting conservation measures on land so removed. Farmowners who participated or are participating in this program agreed to harvest no crops, to permit no livestock grazing on the reserve land, and to prevent the reserve land from creating nuisances from noxious weeds, insects, and rodents. Under this program contracts were entered into for periods ranging from three to ten years. No contracts were, however, executed later than December 31, 1960; and all such contracts will terminate on or before January 1, 1970.*
2. *Cropland Adjustment Program–This program was established under the Federal Food and Agricultural Act of 1965 for the purpose of removing cropland from production and instituting conservation measures on land so removed. Farmowners who are participating in this program have agreed to harvest no crops, to permit no livestock grazing on the reserve land, and to prevent the reserve land from creating nuisances from noxious weeds, insects, and rodents. Under this on-going program, contracts can be entered into for periods of either five or ten years. Also under this program, the Federal Government will financially participate in the conversion of the reserve land to conservation, recreation, and wildlife uses.*
3. *Feed Grain Program–This program was initially established under the Federal Feed Grain Act of 1961 for the purpose of reducing surplus crop production of barley, corn, and grain sorghums. This program is presently authorized under the Agricultural Act of 1965, as amended. Farmowners who are participating in this program have agreed to harvest no crops, to permit no livestock grazing from April 1 to September 30 on the reserve land, and to prevent the reserve land from creating nuisances from noxious weeds, insects, and rodents. This is an on-going program to which participating farmers must commit themselves annually.*

[12] *Of the reported $7,100 agricultural damages in the 1960 flood, $6,575 was incurred by two farms in combined damage Reach Numbers 9-10-11. In that combined reach, a total of $6,500 was reported by one farm for dredging and diking and for asphalt driveway repair. Other reported agricultural damages include: Reach No. 14–one farm, $200 damage, and Reach No. 15–one farm, $325 damage.*

Flood Damage Characteristics by River Reaches

Milwaukee, Mouth of the Milwaukee River to the North Avenue Dam: For the reasons stated in Chapter II of this report, the geographic scope of the Milwaukee River watershed study, as a fully comprehensive study, extended from the headwater reaches of the watershed to the North Avenue Dam in the City of Milwaukee. Because of the highly urbanized nature of the area traversed by the reach of the River below the North Avenue Dam—an area which includes the central business district of the City of Milwaukee—this reach was, however, included in the flood-related work elements of the comprehensive watershed study. The historic flood damage survey indicated that flood damages have been very minor in the 3.1-mile reach of the Milwaukee River below the North Avenue Dam, being limited to minor damage due to basement seepage in structures along the river and to the backup of sewers within the downtown area of the City of Milwaukee. Some shallow inundation of low-lying street intersections located relatively close to the Milwaukee River has also occurred.

Floodwater surface profiles for this reach of the river were determined under the Milwaukee River watershed study for both the 10-year and 100-year recurrence interval floods by backwater computations. The magnitude of the flood flow for this reach of the river was assumed to be the same as the flow at the North Avenue Dam, as that flow was derived from the flood-flow simulation model. The drainage area downstream from the North Avenue Dam, totaling about 3.8 square miles in area, all of which is highly urbanized, has a very short time of concentration; and it was, therefore, assumed that this area would not contribute any significant flow to the peak rate of discharge of the Milwaukee River at and below the North Avenue Dam.

A discharge for the Menomonee River was determined by a comparative analysis of the Cedar Creek watershed and the Menomonee River watershed, both of which have a drainage area of approximately 128 square miles and stream channel lengths of approximately 32 miles. The Menomonee River watershed, as a result of urbanization, is a more efficient hydraulic system than the Cedar Creek watershed; and, therefore, the peak discharges for the Menomonee River would normally be considerably higher than those for Cedar Creek. It is, however, highly unlikely that the peak discharge on the Menomonee River will correspond in time to the peak discharge on the Milwaukee River. Because these two factors tend to offset each other, it was estimated that the peak rate of discharge of the Menomonee River, coinciding with a 100-year recurrence interval flood crest on the Milwaukee River, would be about 3,800 cubic feet per second and that coinciding with a 10-year recurrence interval flood crest on the Milwaukee River about 2,800 cubic feet per second. A sensitivity analysis was performed in order to determine the effect of varying peak discharge rates for the Menomonee River on the floodwater surface elevations of the Milwaukee River up to the North Avenue Dam. Varying the peak rate of discharge of the Menomonee River from 3,600 cfs to 10,000 cfs[13] was found to have no appreciable effect upon the high water surface profile of the Milwaukee River. The analysis indicated that the structures which have the greatest relative effect on floodwater surface elevations are the Michigan Street Bridge, the Wisconsin Avenue Bridge, and the Wells Street Bridge. These bridges all have small cross-sectional areas due to large piers and abutments and a corresponding constricted channel. The sensitivity analysis indicated further that the primary determinant of the floodwater surface elevations up to North Avenue was the elevation of Lake Michigan.

Low, average, and probable high lake levels of 576, 580, and 583 feet above mean sea level, respectively, were then used to compute high water surface profiles to the North Avenue Dam for various flow rates. The lake elevations and flow rates used and the corresponding high water elevations are set forth in Table 45. The corresponding high water surface profiles are reproduced in an appendix to Volume 2 of this report. The analyses indicate that no overbank flooding should occur during the 100-year recurrence flood when Lake Michigan is at or below elevation (583 feet) if the channel is maintained in its present cross section and configuration. Some minor

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[13] *An engineering report prepared by the Klug and Smith Company, Milwaukee, Wisconsin, for The Falk Corporation in 1960, estimated the peak rate of discharge of the 1960 flood on the Menomonee River at 10,000 cfs. The 1960 flood was a 10-year recurrence interval flood on the Milwaukee River, a 37-year recurrence interval flood on the Fox River, and a 100-year recurrence interval flood on the Root River.*

local overbank flooding may be expected during the 100-year flood event when Lake Michigan is at its highest elevation. Any damages attendant to the overbank flooding should be slight, since the lands which would be inundated are presently utilized for parking lots, street intersections, and other types of open-space uses. No overbank flooding should occur during a 10-year recurrence interval flood even when Lake Michigan is at the highest elevation and extreme flows occur on the Menomonee River.

Some basement damages may occur due to seepage along the dock lines through older dock walls. Floodwaters may also be backed through existing storm sewers and drains, damaging streets and buildings during extremely high Lake Michigan stages. Measures should be taken to avoid such storm sewer, as well as sanitary sewer backups, in order to protect those portions of buildings which are below the extreme high water surface elevations of the 100-year recurrence interval flood in the downtown Milwaukee area (see discussion of basement flooding and sewer backup in Chapter IX of this volume). The City and Metropolitan Sewerage Commissions have notified the public of high water problems along the lower river by issuing the notice reproduced in Figure 31 to all property owners within the area delineated in Figure 31. An elevation of +4 referred to City of Milwaukee datum is equal to an elevation of 584.60 referred to mean sea level datum.

Milwaukee County, North Avenue Dam to Estabrook Park: No historic flood damages are known to have occurred in that reach of the Milwaukee River, extending from the North Avenue Dam to Estabrook Park, a distance of about three miles. The river banks along this reach are generally high, and a considerable proportion of the stream banks are devoted to park or other open-space uses. No reach number was, therefore, assigned to this section for purposes of flood damage analysis.

Milwaukee County, Estabrook Park to Silver Spring Drive (Reach Number 1): Historic flood damages have been relatively low in this 2.1-mile reach of the Milwaukee River, extending from Estabrook Park to Silver Spring Drive in the City of Glendale. Lincoln Creek, which is about 7.1 miles in length, extending from its confluence with the Milwaukee River in Lincoln Park to approximately N. 51st Street and W. Good Hope Road in the City of Milwaukee, flows into this reach of the Milwaukee River. There are no reported flood damages along Lincoln Creek; and only one home reported lawn damage in this reach as a result of the 1960 spring flood, but no actual monetary damages were reported.

Significant lengths of the floodlands of this reach of the Milwaukee River and the shoreline of Lincoln Creek are not subject to severe flood damages, since three miles, or 71.4 percent of the Milwaukee River shoreline, is in park or parkway use, and eight miles, or 56.3 percent of the Lincoln Creek shoreline, is in park or parkway use.

During the 1924 flood (77-year recurrence interval flood), portions of this reach of the Milwaukee

TABLE 45

INFLUENCE OF LAKE MICHIGAN ELEVATION ON THE MILWAUKEE RIVER ESTUARY FLOOD STAGE

FLOOD EVENT	PEAK DISCHARGE RATE (CFS)		LAKE MICHIGAN ELEVATION (FT-MSL)[a] (RIVER MILE 0.00)	REPRESENTATIVE MILWAUKEE RIVER WATER SURFACE ELEVATIONS (FT-MSL)[a]		
	MILWAUKEE RIVER	MENOMONEE RIVER		CONFLUENCE WITH MENOMONEE RIVER (RIVER MILE 0.90)	DOWNSTREAM OF STATE STREET BRIDGE (RIVER MILE 1.57)	DOWNSTREAM OF NORTH AVENUE DAM (RIVER MILE 3.09)
100-YEAR	16,700	3,600	576.0	576.3	578.7	581.1
100-YEAR	16,700	3,600	580.0	580.1	581.5	583.0
100-YEAR	16,700	3,600	583.0	583.1	584.1	585.2
100-YEAR	16,700	5,600	583.0	583.1	584.1	585.2
100-YEAR	16,700	10,000	583.0	583.2	584.2	585.3
10-YEAR	10,300	2,800	583.0	583.0	583.4	583.9

[a]MEAN SEA LEVEL (1929 ADJUSTMENT)-580.60= CITY OF MILWAUKEE DATUM.

SOURCE- HARZA ENGINEERING COMPANY.

Figure 31

NOTICE ISSUED BY MILWAUKEE-METROPOLITAN SEWERAGE COMMISSIONS RELATIVE TO BASEMENT FLOODING CAUSED BY SEWER BACKUP MARCH 1952

<u>GENERAL NOTICE</u>

TO: Building Owner and/or Occupant

Record high lake levels predicted for this year may seriously interfere with the operation of both the City and Metropolitan Sewerage Commission sewer systems by raising the levels of the rivers. This will result in direct interference with the outlets of the combined storm and sanitary sewers in the downtown area, as well as the separate sanitary sewers in other districts.

Under conditions of high lake levels, rapidly melting snow or heavy rains may result in surcharging the sewer system to a point where flooding of basements may occur.

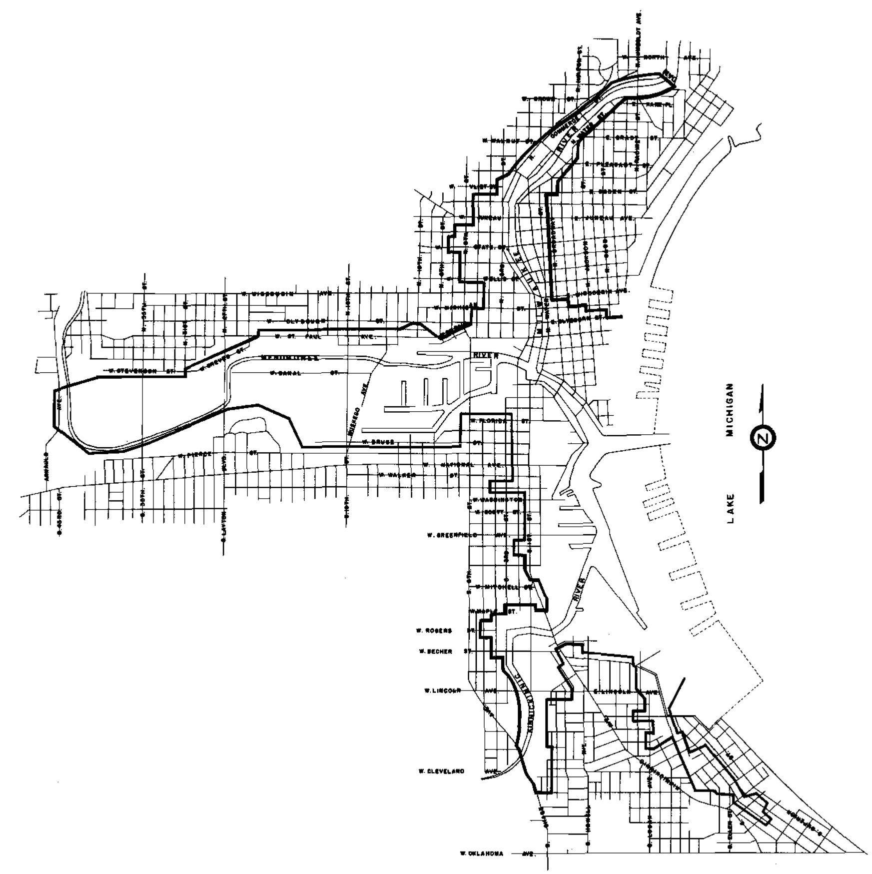
It therefore becomes necessary for all residences, stores, commercial establishments or other buildings to protect themselves to an elevation of plus four.

This means that materials, facilities and equipment located in basements should be protected or so placed that water rising to an elevation of four (4) feet above City of Milwaukee datum will cause no damage.

The accompanying map shows the outline of the area most likely to be affected.

CITY and METROPOLITAN SEWERAGE COMMISSIONS

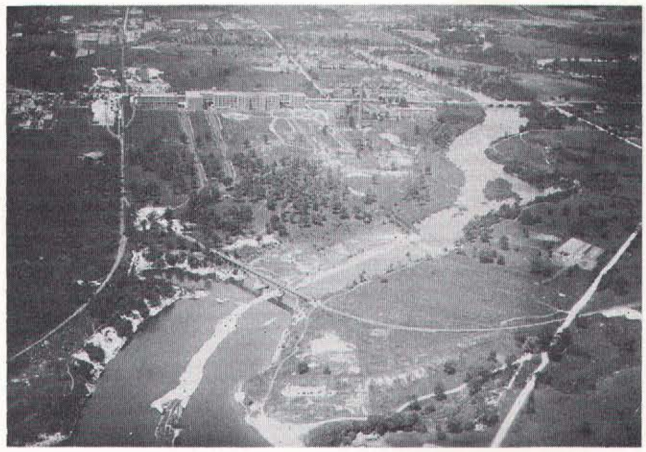
March 26, 1952



Source: Milwaukee-Metropolitan Sewerage Commissions.

The Estabrook Park reach of the Milwaukee River is shown in this photo prior to the construction of the Estabrook Park Dam in 1940. A swimming beach is evident at the bottom of the photo, and as in the case of the swimming beach at Lincoln Park shown in another photo reproduced in this chapter, is indicative of a water use no longer safe in this reach of the Milwaukee River. The development of park lands in the floodplains of the river in this reach represents sound land use development, in direct contrast to the residential floodplain development evidenced in other photos reproduced in this chapter.

Photo Courtesy of the Milwaukee County Park Commission



River were subjected to very high water levels, as evidenced by reported high water marks. At the peak flood stage at the W. Silver Spring Drive crossing, the water level in the river reached a height of 627.9 feet above mean sea level, or approximately 11 feet above normal stage, and only about 2.4 feet below the crown of the road over the bridge.[14] In their 1964 report, the U. S. Army Corps of Engineers estimated that, had 1964 land use conditions prevailed in 1924, about 78 homes would have been flooded within this reach. Much of the damage potential in this reach has been eliminated, however, by channel improvements carried out between Lincoln Park and N. Port Washington Road in 1937. These improvements consisted of cutting a new channel through the oxbow bends in the park, thereby improving the alignment of the channel and increasing its capacity (see Figure 32). If the 1924 flood occurred under present improved river channel and land use development conditions, the flood stage at W. Silver Spring Drive would be expected to be about five feet lower than the stage experienced in 1924; and none of the 78 residences located in the original floodplain in this reach would be flooded.

Basement flooding has also been experienced in the past along this reach of the Milwaukee River due, however, to storm water drainage problems not directly related to the flood stages of the Milwaukee River. Remedial measures have been taken by the Department of Public Works of the City of Milwaukee to alleviate the surface drainage problems causing this basement flooding.

Glendale, Silver Spring Drive to One-Quarter Mile South of W. Bradley Road (Reach Number 2): Historic flood damage has been frequent and extensive in this 3.7-mile reach of the Milwaukee River, extending from W. Silver Spring Drive in the City of Glendale to one-quarter mile south of W. Bradley Road in the Village of River Hills. Estimated total flood damages in this reach for the 10-year recurrence interval flood under present (1967) land use conditions are approximately $62,200, or 19 percent of the total 10-year flood damages in the watershed, with approximately $17,000 worth of flood damages being incurred by residences in the "Sunny Point Lane peninsula" area, where, in the 1960 flood, two homes each received about $3,000 in flood damages.

Certain portions of this reach, however, are not subject to serious flood damages, since two miles, or 27 percent of the river shoreline in this reach, are in park or parkway use. The 1960 spring flood in this reach, however, caused damages to parking areas, roads, and large sections of lawn area in Kletzsch Park totaling $8,000. This total could have been much larger, however, had there been urban development located on the site of Kletzsch Park. North of Kletzsch Park several homes damaged in the 1960 flood have been removed as a result of the construction of W. Good Hope Road (CTH PP), including a new bridge across the Milwaukee River.

Flood damages in this river reach increase rapidly with relatively small increases in river stage. The portions of the reach which are sensitive to river stage fluctuation are along the west side of

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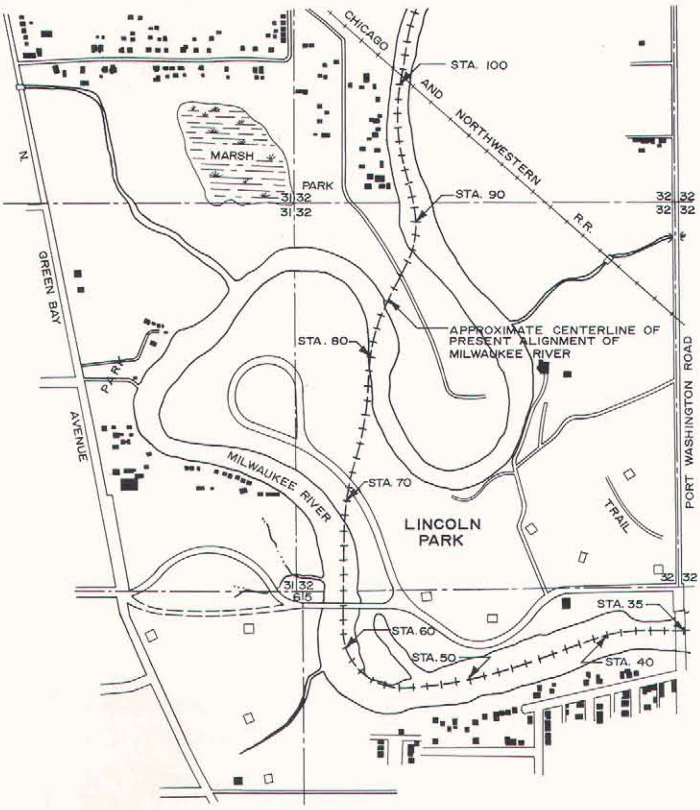
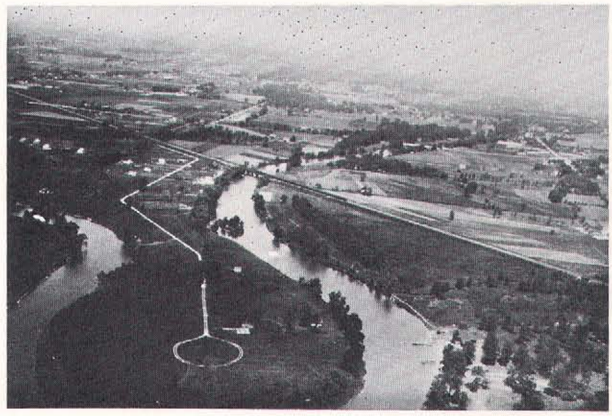
[14] *The roadway elevation of the present bridge carrying Silver Spring Drive over the river is at elevation 631.1 mean sea level datum, or only 0.8 foot above the roadway elevation of the old bridge which crossed the river at this same location in 1924.*

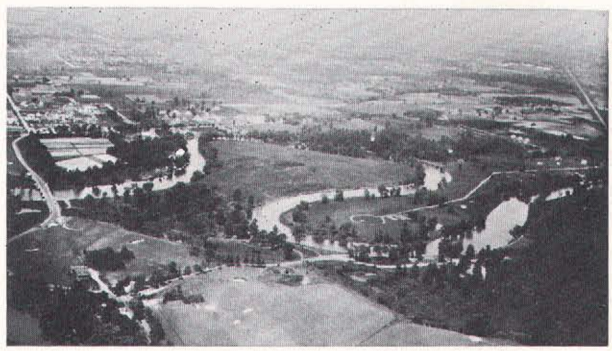
The "Sunny Point Lane peninsula" area in the City of Glendale has received frequent and extensive historic flood damage. In the 1960 flood shown in this photo, two homes in this area each reported damages of about $3,000. The hardship, inconvenience, and mental anguish suffered by residents of areas along the Milwaukee River, such as this, to say nothing of economic loss, could have been avoided had sound land use controls prohibiting residential development on natural floodplains been instituted prior to development.

Photo Courtesy of The Milwaukee Sentinel

Figure 32
HISTORIC CHANNEL ALIGNMENT IN LINCOLN PARK







Much of the flood damage potential in that reach of the Milwaukee River extending from Estabrook Park to Silver Spring Drive has been eliminated by channel improvements carried out between Lincoln Park and N. Port Washington Road in 1937. The historic oxbow bends in the River, as shown in the above map and photos, caused numerous ice jams during flood events, thus creating very high water levels. The top photo, probably taken in the early 1930's, shows the easterly oxbow looking northerly from Lincoln Park. A bathing beach, piers, bathhouse facilities, and swimmers are evident in the lower right hand corner of the photo, evidencing a use of the Milwaukee River no longer considered safe. The bottom photo, taken in 1925, shows the two oxbows looking westerly from Lincoln Park. The approximate centerline of the present alignment of the Milwaukee River, which eliminated the oxbows and created islands, is shown on the map at left. Such channel improvements can relieve flooding in very limited reaches of a river but have limited applicability for a watershed as a whole since such improvements increase downstream flood flows and stages.

Source: Map adapted from The Milwaukee River Basin, Wisconsin State Planning Board Bulletin No. 10, June 1940. Photos courtesy of the Milwaukee County Park Commission.

the river from W. Silver Spring Drive north to W. Good Hope Road and along the east side of the river from Bender Road to about one mile upstream. It is estimated that 342 homes would be inundated if the 1924 flood occurred under present land use conditions in this reach. The 1960 flood damaged only 22 homes in this reach. Because of several very sharp bends in this reach of the river, ice jams may cause flood stages higher than those indicated by stage-discharge relationships for this reach.

Urban development has continued on the floodlands in this reach, despite the 1924 and even the 1960 floods. Map 41 shows a portion of this reach as development existed in the late 1930's. The 1924 flood has been superimposed on this map to show the extent of inundation. Map 42 shows the same area as development presently (1969) exists and shows also the extent of inundation of the 10-year and 100-year recurrence interval floods.

River Hills and Brown Deer, One-Quarter Mile South of W. Bradley Road to the Ozaukee County Line (Reach Numbers 3 and 4): Historic flood damage has been frequent but moderate in this 3.3-mile reach of the Milwaukee River, extending from one-quarter mile south of W. Bradley Road, through the Villages of Brown Deer and River Hills, to the Ozaukee County line. Indian Creek, which is about 1.9 miles in length from its confluence with the Milwaukee River in the Village of River Hills to approximately the 8000 block of N. Port Washington Road in the Village of Fox Point, flows into this reach of the Milwaukee River. There is no reported flood damages along Indian Creek. Private-sector damages have been the largest single flood loss in the reach. Only one home experienced damage as a result of the 1960 spring flood, and the monetary cost was not reported. The 1959 flood, however, which was of a slightly smaller magnitude than the 1960 flood, caused damages totaling $4,500 in this reach, with one house receiving $3,700 worth of damages. Since this reach is susceptible to ice jams due to the presence of river bends and islands, this difference in the flood damages between 1959 and 1960 floods was probably caused by ice jams rather than the discharge-related stage. Portions of this reach of the Milwaukee River are protected somewhat from extensive flood damages, since one mile, or 15.1 percent of the river shoreline in this reach, is in park or parkway use.

The majority of residences along this river reach are located well above any major flood stage; and it is, therefore, estimated that only 10 homes would be flooded under present conditions by the 100-year recurrence interval flood. The 100-year recurrence interval flood would also flood W. Brown Deer Road and N. Range Line Road, but the depth of flooding would not close these roads to traffic.

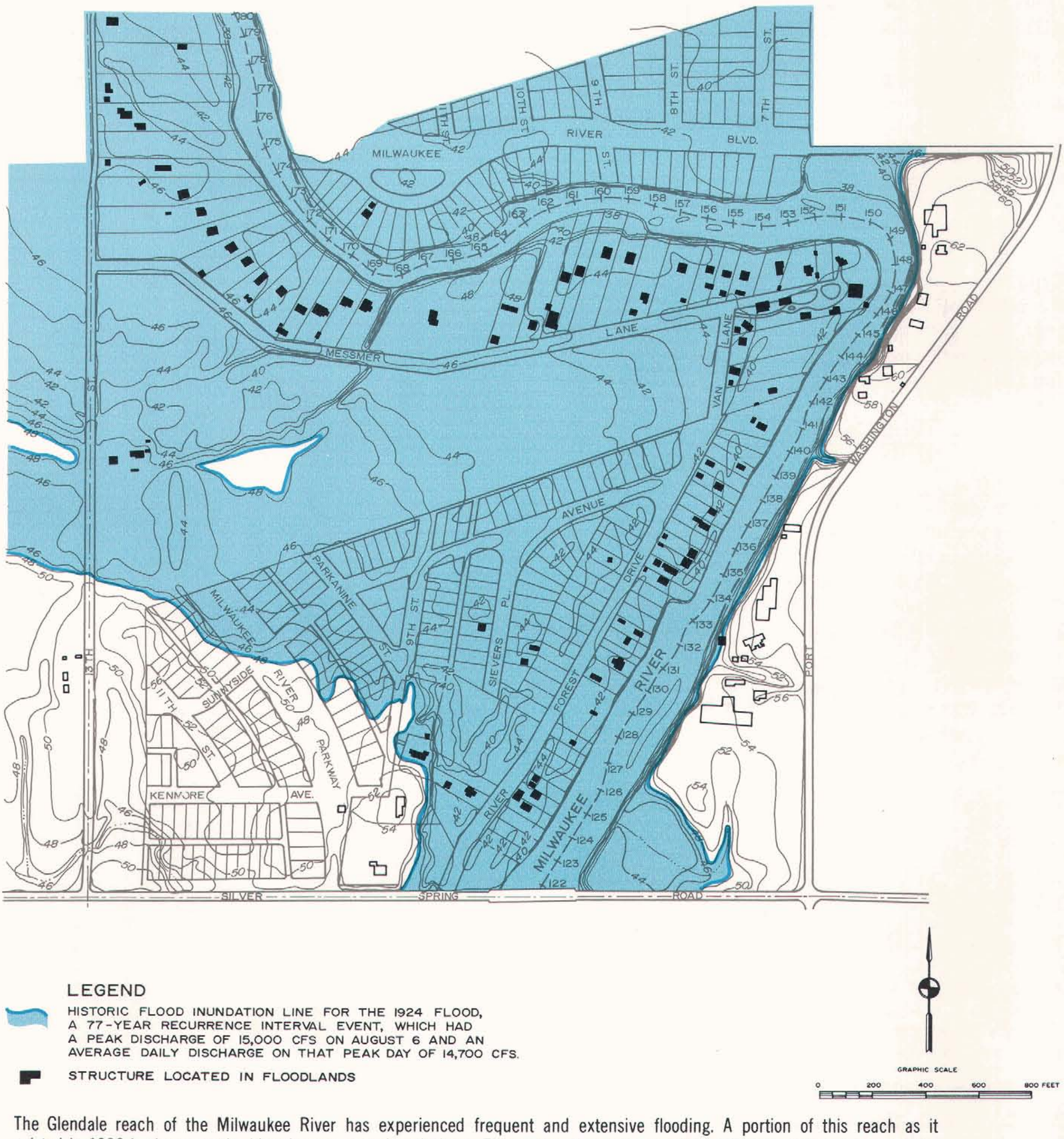
Mequon, Ozaukee County Line to CTH C (Reach Numbers 5, 7, and 8): Historic flood damage has been quite extensive in this 10-mile reach of the Milwaukee River, extending from the Ozaukee County line to CTH C, all within the City of Mequon and excluding the Village of Thiensville. Private-sector damages have been the largest single flood loss in this reach. Total flood

Street intersections and walkways located in natural floodplains are subject to frequent, sometimes yearly, inundation. This photo of an urbanizing area in the City of Mequon along the Milwaukee River was taken in March 1963, a year in which flooding was not particularly severe. Such flooding not only constitutes a hazard to public safety but also a hazard to public health.

Photo Courtesy of The Milwaukee Journal

Map 41

FLOOD INUNDATION MAP
PORTION OF THE CITY OF GLENDALE
1924 FLOOD

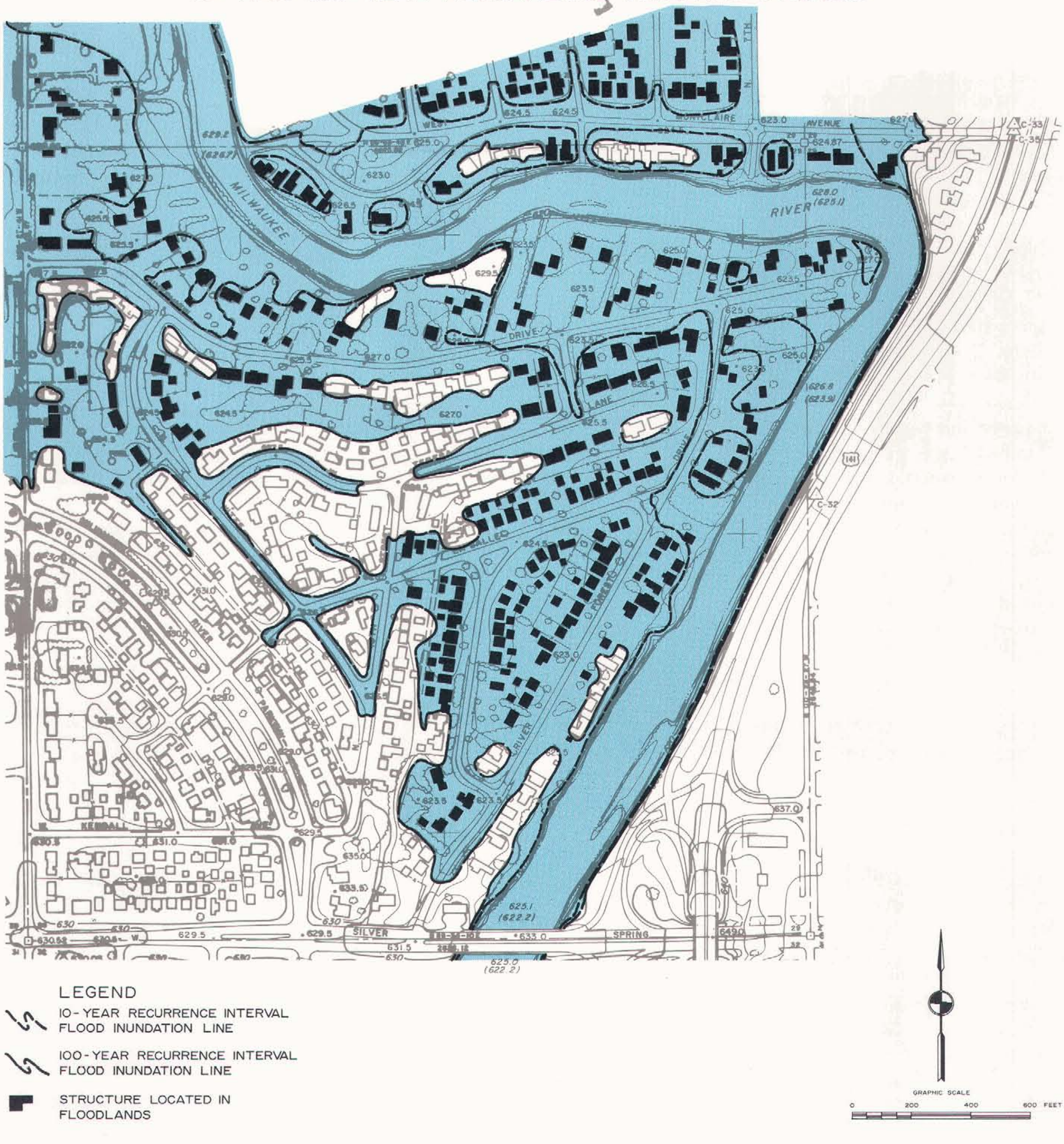


The Glendale reach of the Milwaukee River has experienced frequent and extensive flooding. A portion of this reach as it existed in 1936 is shown on the historic map reproduced above. The extent of inundation of the 1924 flood has been superimposed on the 1936 land use conditions shown on the map. This same area as it exists today is shown on Map 42. It is evident that the known flood hazard provided no deterrent to continued urban development in the floodplains of the River.

Source: Adapted from The Milwaukee River Basin, *Wisconsin State Planning Board Bulletin No. 10, June 1940.*

Map 42

FLOOD INUNDATION MAP
PORTION OF THE CITY OF GLENDALE
10- AND 100-YEAR RECURRENCE INTERVAL FLOODS



Despite major historic floods in 1918, 1924, 1939, 1959, and 1960, urban development has continued to occur on the natural floodplains of the Milwaukee River in the City of Glendale. Many of the homes shown on this 1969 map prepared by the Regional Planning Commission were constructed since 1960, the year in which the last major flood on the river occurred. If the 10- and 100-year recurrence interval floods were to occur today, it is estimated that 32 and 200 homes, respectively, in the area shown, would be subject to inundation. Because of rapid turnover in home ownership, many of the homeowners in this area contacted during the SEWRPC flood damage survey were unaware of the flood hazards to which their homes were subject.

Source: SEWRPC.

damages in this reach for the 10-year recurrence interval flood under present (1967) land use conditions are approximately $146,000, or 44 percent of total 10-year flood damages in the watershed. This 10-mile reach also sustains approximately 64 percent of all residential flood damages along the Milwaukee River.

Only 0.6 mile, or 3.2 percent of the river shoreline in this reach, is in park or parkway use. Residential structures are the primary type of urban land use development occurring on the floodplain, while agricultural uses and wetlands are the primary type of rural land use.

Approximately 192 homes would be flooded in this reach if the 1924 flood occurred under present conditions, while about 123 homes would sustain damage during an event similar to the 1960 flood. A large number of homes which are susceptible to flood damage are located on W. Shoreland Drive, E. Shoreland Drive, Circle Drive, and Island Drive immediately south of CTH M. Depths of flooding in these homes would be as much as five feet over the first-floor level during a 100-year recurrence interval flood. It is estimated that STH 167 would be closed for 33 hours and, CTH M would be closed for 53 hours during a 100-year recurrence interval flood; however, these two roads would not be closed during a flood similar to the 1960 flood event.

Village of Thiensville (Reach Number 6): Historic flood damage has been extensive in this 1.6-mile reach of the Milwaukee River in the Village of Thiensville and in that portion of Pigeon Creek affected by the backwater of the Milwaukee River. Pigeon Creek is 2.4 miles in length and flows into the Milwaukee River at Thiensville, with its headwater area located in the northwestern part of the City of Mequon. The public-sector flood cost has been high in Thiensville compared to other river reaches due to the recognition by the Village that repair of the Thiensville Dam is sometimes required following a major flood. Repairs costing $5,800 were made to the Dam following the 1959 flood.

Portions of this reach are protected from extensive flood damage, since 0.4 mile, or 25 percent of the river shoreline in this reach, is in park or parkway use. The remaining 1.2 miles, or 75 percent of the river shoreline, arein some form or urban land use, with some scattered empty lots remaining.

Both residential and commercial structures are located on the floodplain in Thiensville. It is estimated that about 40 homes and 40 commercial establishments experienced flooding during the 1924 flood. During the 1960 flood, however, only eight homes and nine commercial establishments experienced flooding. No major new development on the floodplain is expected in Thiensville,[15] but increasing property values and improvements to existing properties could contribute to a small, steady increase in flood damage potential. It is interesting to note that many of the older commercial establishments built shortly after the 1918 and 1924 floods have first-floor elevations about two feet above ground level (ground level being about 660 feet above mean sea level), while many of the newer commercial establishments have first floors built at ground level.

Grafton, CTH C to the Saukville Town Line (Reach Numbers 9, 10, and 11): Historic flood damage has been occasionally extensive in this 8.4-mile reach of the Milwaukee River from CTH C on the City of Mequon-Town of Cedarburg line to the Saukville Town line. Cedar Creek, 31.5 miles in length from its confluence with the Milwaukee River in the Town of Cedarburg to its source in Big Cedar Lake in the Towns of Polk and West Bend in Washington County, flows into this reach of the Milwaukee River. Private-sector damages in this reach for the 10-year recurrence interval flood under present (1967) land use conditions are $10,300, or 3 percent of the total 10-year flood damages in the watershed. Only 0.4 mile, or 2.3 percent of the river shoreline in this reach, is in park or parkway use.

Cedar Creek enters the Milwaukee River in the downstream portion of this reach and, therefore, has little effect on the overall flow of the river within this reach. The Village of Grafton, with two dams located inside the village limits and one dam located just south of the village limits, is located in the middle of this reach. Even though these dams each have a head loss of 10 feet or

[15] *In 1970 a proposal was made to construct a new U. S. Post Office in the floodway and floodplain of the Milwaukee River in the Village of Thiensville. The site was located along the river on the east side of STH 57 and adjacent to the south corporate limits of the Village. This proposal was objected to by the Regional Planning Commission in a letter dated February 6, 1970, and addressed to Mr. Kenneth Backstrom, Chief, Engineering Branch, U. S. Post Office Department, Minneapolis Regional Office.*

more, they have very little, if any, effect on flood flows, since the dams cannot be regulated for flood control purposes.

North of the Village of Grafton, in the upper part of this reach, most residential development along the river is located on the west side, with primarily farmland occupying the east side. Along the west side of the river is located Edgewater Park Subdivision, portions of which have experienced historic flood damage. The subdivision is located on a peninsula which is formed by a sharp bend in the river where ice jams form and cause the river to flow directly across this peninsula. Several of residences have been flood-proofed by being raised onto additional tiers of concrete block, while a two-foot high concrete block floodwall has been constructed completely around another house in this subdivision.

This reach of the river does experience damage during moderate-sized floods, such as those which occurred in 1959 and 1960. Two homes would be flooded during a 1960 flood event, and it is estimated that 19 homes would be flooded during an equivalent 1924 flood event under existing land use conditions.

Saukville, Saukville Town Line to Approximately Four Miles North of the Village of Saukville (Reach Numbers 12 and 13): Historic flood damage has been extensive in this 6.6-mile reach of the Milwaukee River from the Saukville Town line to approximately four miles north of the Village of

Historic flood damage has been extensive in the Saukville reach of the Milwaukee River, including large public-sector damages to repair transportation facilities. This photo shows the extent of flooding in the spring of 1960 in the Village of Saukville itself.

Photo courtesy of Wisconsin Department of Natural Resources

Saukville in the Town of Saukville. Public-sector damages have been the largest single flood loss in this reach. The intersection of STH 57 and STH 33 in the Village of Saukville and the roadbed of STH 57 north of the Village were flooded during both the 1959 and 1960 flood. As a result of the 1960 flood event, $30,000 was spent to repair these roads following the flood. Private-sector losses for a 10-year recurrence interval flood under existing (1967) land use conditions would total about $15,700, or 5 percent of the total flood damages for the watershed.

Only 0.8 mile, or 6.0 percent of the river shoreline, is in either park or parkway use. The remaining 12.4 miles, 94.0 percent of the river shoreline, are in either urban or agricultural use.

At the Village of Saukville, the Milwaukee River makes a sharp bend, forming a peninsula where ice jams form and cause the water to back up and flow over the peninsula. This peninsula consists primarily of wetlands and is not, therefore, subject to flood damages. Adjacent residences have experienced lawn damage in past floods; however, no monetary losses were reported. About 99 homes could be expected to be flooded, if the 1924 flood recurred under present land use conditions, while only seven homes would be flooded during a 10-year recurrence interval flood.

Within one mile of the village's northern limits lie two large islands in the river which also cause ice jams to form, resulting in water backing up and flowing over the banks and causing lawn damage to several residences located along CTH O. On several occasions the residents of this area have cleared the brush from these islands to facilitate the flow of the river during periods of high water.

Waubeka, Approximately Four Miles North of the Village of Saukville Through the Unincorporated Village of Waubeka (Reach Number 14): Historic flood damage in recent years has been relatively small in this 4.0-mile reach of the Milwaukee River from approximately four miles north of the Village of Saukville through the unincorporated Village of Waubeka in the Town of Fredonia. Private-sector damage has been the largest single flood loss in this reach. The only portion of this reach which has historically received flood damage is the unincorporated Village of Waubeka. However, there was no report of damage as a result of the 1959 or 1960 flood event. Private-sector losses for a 100-year recurrence interval flood under present (1967) land use conditions would total approximately $74,500. Portions of this reach are protected somewhat from extensive flood damage, since 1.6 miles, or 20.0 percent of the river shoreline in this reach, are in park or parkway use.

From the Village of Waubeka to the Headwaters and All Tributaries of the Milwaukee River: No significant recent flood damage has been known to occur to residences along the remaining portion of the main stem of the Milwaukee River or along any of the major tributaries. Minor flood damage to industrial plants, bridges, livestock, and crops was reported, however, during the 1924 flood. It was reported that the old "Plating Mill" of the West Bend Company in the City of West Bend was flooded to a depth of three feet in 1924; however, no monetary cost estimates were available for the 1924 flood in this area. The West Bend City Engineer's office reported that a small culvert and roadway on Silver Creek were washed out in 1924 but not replaced.

ANNUAL RISK OF FLOOD DAMAGE

Annual flood-damage risk is defined as the sum of the damage costs of floods of all probabilities, each weighted by its probability of occurrence. Thus, the 10-year flood damage is weighted 10 percent; the 50-year, 2 percent; and the 100-year, 1 percent. Determination of annual flood-damage risk, associated with existing conditions and with each alternative watershed development plan, is an essential basis for the comparison of the flood protection benefits of each alternative plan and for sound economic analyses of flood protection measures. A summary of the estimated average annual flood-damage risk for present day land use development conditions and for 1990 conditions of uncontrolled land use development is presented in Table 46.

Stage-Damage Curves for Residences

The relationship between flood-damage costs and stage is defined by a stage-damage curve. As already noted, tables of flood damage costs that might be sustained by residences with a range of market values and with different depths of flooding have been developed by the U. S. Soil Conservation Service (SCS). These tables were used to prepare stage-damage curves for residential properties located in each reach of the main stem of the Milwaukee River.

TABLE 46

AVERAGE ANNUAL RESIDENTIAL FLOOD DAMAGE RISK IN THE MILWAUKEE RIVER WATERSHED BY MAJOR FLOOD DAMAGE REACH- 1967 AND 1990

MAJOR DAMAGE REACH[a]			ANNUAL FLOOD DAMAGE RISK	
NUMBER	RIVER MILES	NAME -- GEOGRAPHIC DESCRIPTION	1967	1990[b]
1	6.2-8.5	MILWAUKEE -- SILVER SPRING DR TO ESTABROOK PARK	$ --	$ --
2	8.1-12.0	GLENDALE -- SILVER SPRING DR TO 1/4 MILE SOUTH OF BRADLEY ROAD	33,000	36,900
3	11.3-16.0	RIVER HILLS--GREENTREE RD TO COUNTY LINE RD	1,610	2,100
4	14.8-16.0	BROWN DEER -- 1/4 MILE SOUTH OF BRADLEY RD TO COUNTY LINE RD	900	1,800
5	16.0-18.8	MEQUON -- COUNTY LINE RD TO STH-167	11,220	16,800
6	18.8-20.6	THIENSVILLE (VILLAGE)	3,310	3,310
7	18.8-22.0	MEQUON -- STH-167 TO SW CORNER OF SECTION 18, T9N, R22E	21,500	38,700
8	22.0-26.3	MEQUON -- SW CORNER OF SECTION 18, T9N, R22E TO CTH-C	12,300	15,700
9	26.3-30.0	GRAFTON -- CTH-C TO 3/4 MILE SOUTH OF STH-60	950	950
10	30.0-31.8	GRAFTON -- 3/4 MILE SOUTH OF STH-60 TO 3/4 MILE NORTH OF STH-60	1,830	2,000
11	31.8-35.0	GRAFTON -- 3/4 MILE NORTH OF STH-60 TO SAUKVILLE-GRAFTON TOWN LINE	1,740	1,740
12	35.0-37.5	SAUKVILLE (VILLAGE)	2,430	2,600
13	37.5-42.0	SAUKVILLE--VILLAGE LINE NORTH 4 MILES	740	890
14	42.0-46.0	WAUBEKA -- 4 MILES NORTH OF SAUKVILLE VILLAGE LINE THROUGH WAUBEKA	2,590	2,800
TOTAL...............................			$94,120	$126,290

[a] SEE MAP 40.

[b] ASSUMES A CONTINUATION OF SUBSTANTIALLY UNCONTROLLED URBAN DEVELOPMENT IN THE FLOODLANDS.

SOURCE- HARZA ENGINEERING COMPANY AND SEWRPC.

The 100-year flood profile was used as the base level for estimating damages, and additional damage values were estimated for flood levels differing from the 100-year levels in one-foot increments. To permit identification of structures subject to flooding, inundation lines for the synthesized 100-year flood event were drawn on 1" = 2000' scale, 10-foot contour interval and, where available, 1" = 100' scale, 2-foot contour interval topographic maps. Aerial photographs flown in 1967 by the Commission were used to confirm the locations and numbers of structures on the floodplain. The depth of flooding and the market value of every flooded home were estimated, and damages were determined for the households using the SCS damage tables.

To aid in estimating the market value of a home, assessed market values were obtained for several areas from tax assessors; and these values were adjusted to current market values. Information concerning the percent of homes with basements and the distribution of the levels of the first floors above ground level were obtained from the SEWRPC flood damage survey reports.

The stage-damage curves prepared under the watershed study are shown in Appendix F of this volume and represent 1967 land use conditions for each of 14 river reaches along the main stem of the Milwaukee River, as shown on Map 40. The criteria governing the selection of the river reaches included: a relatively uniform character of land use, relatively uniform hydraulic characteristics, and a relationship to the location of possible flood control structures.

The curves indicate whether or not the damages in some reaches are particularly sensitive to small changes in stage within the range of the 100-year flood levels. Damages in Reach Number 2, for example, increase by 270 percent between stages one-half-foot below the 100-year stage and one-half-foot above the 100-year stage. Overall flood-damage estimates are not as sensitive, however, since the damages in this reach constitute only about 30 percent of the residential damages estimated for the watershed. About 35 percent of the estimated residential damages occur in Reach Numbers 7 and 8. In these reaches the curves are relatively insensitive to stage changes, with increases of only 47 and 53 percent, respectively, with the one-foot change in stage described above.

Damage-Frequency Curves

The frequency of a specific flood-damage total can be derived by combining stage-damage curves and stage-frequency curves. Depths of flooding along the entire river system for floods with 10-, 25-, 50-, and 100-year recurrence intervals were determined by use of the flood simulation model, as described in Chapter XII of this volume, "River Performance Simulation." These stage and discharge values were used to convert previously established stage-discharge curves to stage-frequency curves for each of the 14 damage reaches.

The damage frequency curves prepared under the watershed study for all of the 14 reaches of the Milwaukee River are shown in Appendix G of this volume.

As a test of the validity of the synthesized damage-frequency curves, flood damages were determined for historic flood events, with present day conditions, and then compared with damage values determined during the flood-damage surveys. The simulated damages were generally found to differ somewhat from the reported historic damages. When the probable effects of ice jams, changes in property values, and increased numbers of structures located on the floodplain were evaluated, however, the differences all appeared to be reasonable. In some reaches minor adjustments of local water surface profiles and stage-damage curves were made to eliminate differences judged to be reasonable in light of changes in river flow regimen or development.

The area under the damage-frequency curve for each river reach is equal to the annual flood-damage risk in that reach. Total annual residential flood-damage risk along the main stem of the Milwaukee River is $94,120 for 1967 conditions and $126,290 for 1990 conditions under projected uncontrolled development trends. Estimated values for the individual reaches are shown in Table 46. The total annual flood-damage risk along the Milwaukee River main stem is $119,020 for 1967 conditions and $159,890 for 1990 conditions under projected uncontrolled development trends.

The annual flood-damage risk for 1990 uncontrolled land use development conditions was obtained by adjusting the 1967 annual damages. Each reach was examined separately, and estimates were made of present and probable future development by quarter section. The percent of floodplain presently being used was estimated by examining 1967 aerial photos and topographic maps. Future development was estimated by use of SEWRPC population forecasts for conditions of uncontrolled sprawl. If the forecasts indicated an increase in population, it was assumed that there would be a corresponding increase in development. It was also assumed that the annual flood damage would increase at the same rate as the development of the floodplain. Therefore, if the floodplain development was expected to increase by 30 percent, the 1967 average annual damage was expected to increase by 30 percent by 1990.

[16] *Includes $94,120 residential damages, $2,600 road-user damages, $5,700 commercial damages, and $16,600 public-sector damages.*

[17] *Includes $ 126,290 residential damages, $3,800 road-user damages, $5,700 commercial damages, and $24,100 public-sector damages.*

SUMMARY

An understanding of the interrelationships that exist between the flood characteristics of the major stream system of a watershed and the urban and rural land uses to which the riverine areas of the watershed are put is fundamental to any comprehensive study of a watershed. This chapter, therefore, has described the hydrologic factors that have contributed to historic flooding in the Milwaukee River watershed and the monetary losses that have accrued to the watershed from this flooding as a direct consequence of unnecessary occupation of the floodplain by flood-vulnerable land uses.

The watershed, while having a history of relatively frequent minor flooding, has experienced five major floods in recent times. The most recent of these floods occurred in March-April of 1960, due to a combination of heavy rainfall and rapid snowmelt, and was a flood having an approximately 10-year recurrence interval. Other major significant flood events which have occurred over the watershed occurred in March 1959, March 1929, August 1924, and March 1918. The August 1924 flood was the result of a high-intensity thunder shower storm centered approximately over the City of West Bend and was a flood having a 77-year recurrence interval.

The Commission conducted a comprehensive survey of historic flood damages in the watershed in the summer of 1968. In order to assess the historic damage to private property, the survey included actual on-site personal interviews with 262 homeowners and occupants, 11 owners or managers of commercial properties, and 48 farm-owners or operators. The survey also included an assessment of historic damage to public property through mail questionnaires addressed to appropriate officials of all of the local units of government in the watershed, of certain federal and state agencies of government, and of public utility and railroad companies operating within the watershed. The flood-damage survey revealed that, if the March-April 1960 flood on the Milwaukee River and its major tributaries were to recur under present (1967) land use conditions, it would cause monetary damages totaling about $334,800, expressed in 1969 dollars, about 78 percent of which would be incurred by private owners and 22 percent, by public or quasi-public agencies. If a 100-year recurrence interval flood were to occur which, as noted above, would be a flood of slightly greater magnitude than the 1924 flood (77-year recurrence interval), it would cause monetary damages totaling about $1.8 million. In the absence of sound regulations for floodland development in the watershed by the local units of government responsible for such regulations, these damages could be expected to increase to $485,000 and $2,200,000, respectively, by the year 1990.

The reaches of heaviest potential residential flood damages along the Milwaukee River for the 10-year recurrence interval flood are in the City of Glendale, from W. Silver Spring Drive to one-quarter mile south of W. Bradley Road, where residential damages from a 10-year recurrence interval flood could be expected to exceed $54,000, or 16 percent of the total flood damages throughout the watershed; in the City of Mequon, from County Line Road to STH 167, where such residential damages could be expected to exceed $35,000, or 10 percent of the total flood damages; in the reach from STH 167 to the south line of Section 18, Town 9 North, Range 21 East, where such residential damages could be expected to exceed $70,000, or 21 percent of the total watershed damages; and from the south line of Section 18 to CTH C, where residential damages would be expected to exceed $40,000, or 12 percent of the total damages throughout the watershed. These four river reaches, having a total length of about 13.7 miles, would total $199,600, or 88 percent of the total residential damages, and $208,400, or 62 percent of all of the anticipated total damages caused by a 10-year recurrence interval flood within the watershed under existing land use conditions.

The same four reaches could be expected to experience a total of $585,000, $204,000, $219,000, and $182,000 in flood damages, respectively, if a 100-year recurrence interval flood were to occur within the watershed under present land use conditions, and would thus represent more than one-half of the estimated $1,837,000 in damages which would result from such a flood.

No flood damages should be incurred from either the 10- or the 100-year recurrence interval floods in that reach of the river below the North Avenue Dam in the City of Milwaukee. The channel section in this reach is able to pass the 100-year recurrence interval flood with only minor local overbank flooding.

As a basis for the comparison of flood protection benefits of alternative plan elements and for the economic evaluation of flood protection measures, the annual risk of flood damage within the watershed was calculated. The annual risk of flood damage under 1967 land use conditions was estimated to be $119,000. Significantly, the annual risk of flood damage was estimated to increase to $160,000 by 1990, or by 35 percent, should the uncontrolled use of the floodplain areas be allowed to continue.

Urban land use development within the floodplains of the watershed has greatly increased during the past 25 years. Most of this urban land use developed has occurred in the reaches of the river near the Milwaukee-Ozaukee County line and through the City of Mequon. A relatively large new subdivision has been constructed in the floodplain within the City of Mequon since the 1960 flood occurred. If such unwise and unnecessary development is to be avoided, a greater public awareness of the concomitant flood damage risks is needed.

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Chapter IX

SURFACE WATER QUALITY AND POLLUTION

INTRODUCTION

The term "water quality" refers to the physical, chemical, and bacteriological characteristics of water. Water quality is determined both by the natural environment and by the activities of man. The uses which can be made of a particular water are significantly affected by its quality, and each potential use requires a certain level of water quality. Since the activities of man in a particular area affect, and are affected by, water quality in that area, any comprehensive watershed planning effort must include an evaluation of present and anticipated future conditions of water quality and of the relationship of water quality to existing and probable future land and water uses.

The term "pollution" is often defined as the presence of any substance or the existence of any condition in water that tends to degrade its quality to such an extent as to constitute a hazard or to impair its usefulness. Such a definition, however, does not consider the source of the polluting substance, which may significantly affect the meaning and use of the term. For the purpose of this report, the causes of pollution are considered to be exclusively related to human activity. Thus, any substance present in such quantities as to adversely affect certain beneficial water uses but derived from natural sources would not be herein defined as pollution but would constitute a natural condition that impairs the usefulness of the water.

Before the intensive settlement of the watershed, water quality in the Milwaukee River basin presented no significant problem for any water uses. Drainage from a few large marsh areas undoubtedly caused some periodic natural degradation of stream water quality; but, in general, the quantity of this drainage was relatively small in comparison to the total quantity of surface water available for dilution. As population increased and portions of the watershed became urbanized, the quality of the surface water was steadily degraded; and, at present, serious water quality problems exist within the watershed. Some of the lakes within the watershed are also presently experiencing water quality problems and related problems of prolific algae and other aquatic plant growth. As population levels and urban land uses increase within the watershed, water quality will continue to be degraded; and future levels of water quality, in the absence of a water quality management plan and its implementation, may be expected to impose serious restrictions upon most beneficial uses of the surface waters in major portions of the Milwaukee River watershed.

WATER QUALITY PARAMETERS

There are literally hundreds of water quality indicators, or "parameters," available for measuring and describing water quality. A list of these parameters would include all of the physical and chemical substances in solution or suspension in water, all the macroscopic and microscopic biological organisms in water, and the physical characteristics of the water itself. Only a few of these hundreds of parameters, however, are normally useful in the evaluation of natural surface water quality or as indicators of pollution. Eight parameters were selected for use in the evaluation of the water quality of the lakes and streams of the Milwaukee River watershed: dissolved oxygen, biochemical oxygen demand, coliform bacteria, chlorides, nitrogen, phosphorus, temperature, and aquatic organisms.

Dissolved Oxygen

The dissolved oxygen (DO) concentration is often considered to be the single most important indicator of surface water quality. Low dissolved oxygen concentrations in surface waters contribute to an unsuitable environment for fish and other desirable forms of aquatic life; and the absence of dissolved oxygen leads to a septic condition, with its associated foul odors and unpleasant appearance. The maximum possible dissolved oxygen concentration varies inversely with the water temperature. The highest saturation level is 14.6 milligrams per liter (mg/l), which occurs at 32°F (0°C) and decreases to 8.4 mg/l at 77°F (25°C) and to lower levels at still higher temperatures. Major sources of dissolved oxygen in surface waters are the atmosphere and aquatic plant life. Large reductions in dissolved oxygen content are caused by microorganisms utilizing oxygen in the process of decomposing organic wastes. In addition, algae and other aquatic plants may cause both large increases and decreases in the dissolved oxygen concentration of surface waters, as these plants produce oxygen through photosynthetic processes during the daylight hours and consume oxygen at night. This diurnal variation of dissolved oxygen often produces unfavorable effects on desirable forms of aquatic animal life.

The minimum dissolved oxygen concentration that should be maintained in a stream is dependent upon the desired uses of the stream. In order to prevent the development of anaerobic conditions in a stream, a dissolved oxygen concentration of at least 1.0 mg/l should be maintained. For a stream to support a varied and healthy fishery, the dissolved oxygen concentration under average conditions should remain at or above 5.0 mg/l. Concentrations of 3.0 mg/l or less are regarded as hazardous or lethal to fish life.

Biochemical Oxygen Demand

The biochemical oxygen demand (BOD) is a measure of the amount of oxygen consumed during a given period of time and at a given temperature by aerobic bacteria in the process of decomposing organic material. The time and temperature normally used as a standard of measurement are five days and 20°C (68°F). BOD is expressed as the concentration of oxygen-consuming organic material present in milligrams per liter (mg/l) or as the total amount present, in pounds, in a given body of water. BOD is a measure of the potential decrease in dissolved oxygen concentration and thus indirectly affects the usefulness of a water. The actual decrease in dissolved oxygen below an organic waste discharge is dependent upon the amount of BOD in the stream, the rate at which the BOD is exerted, and the dissolved oxygen content and reaeration characteristics of the stream. A knowledge of these factors is important in water quality studies in order to determine whether a waste discharge will deplete oxygen levels to such an extent that the suitability of the water for certain uses will be impaired.

Coliform Bacteria

The number of coliform bacteria in a particular water is the most widely used indicator of possible fecal contamination. Coliform bacteria are easily detected and apparently harmless microorganisms which occur in extremely large concentrations in the intestinal tracts of man and warm-blooded animals, along with pathogenic (disease-producing) bacteria. Therefore, the presence of large numbers of coliform bacteria in a water is used as an indicator of the possible presence of enteric pathogens in that water, while the absence of coliform bacteria is used as an indicator of the probable absence of pathogenic bacteria. Coliform bacteria are also present in the soil, however, and, therefore, may originate from sources other than the human intestinal tract, so that a high coliform count is not necessarily indicative of fecal pollution. A high degree of correlation has been established between high coliform counts in drinking water and epidemics of water-borne diseases, such as typhoid; but, in waters used for recreational purposes, the correlation between high coliform counts and disease is not as well established.

The Drinking Water Standards of 1962 of the U. S. Public Health Service limit the average monthly coliform concentration in treated drinking water to one organism per 100 ml or a membrane filter coliform count (MFCC) of one per 100 ml. In water used for recreational purposes, total coliform limits are generally established on the order of 1,000 MFCC or less per 100 ml for whole-body-contact recreation, such as swimming, and 5,000 MFCC or less per 100 ml for partial-body-contact recreation, such as boating.

Although the use of fecal coliform counts is a newer technique to determine water quality, no official standards for water uses have as yet been adopted based upon fecal coliform counts; moreover, no historic data would be available as a bench mark against which to monitor and evaluate changes now and in the future. The Wisconsin Department of Natural Resources has indicated that a geometric mean fecal coliform count for full-body-contact recreation of not more than 200 MFFCC per 100 ml and a maximum count not exceeding 400 MFFCC per 100 ml more than 10 percent of the time might be considered as a future standard.

Chlorides

Chlorides are present in practically all surface and ground water, since the chlorides of calcium, magnesium, potassium, and sodium are readily soluble in water. The source can be the natural environment, specifically the leaching of minerals by ground water movement and surface runoff, or induced through human activities, including domestic and industrial waste discharges, agricultural drainage, and application of salts to roads for winter maintenance. During the period of time that the flow of a stream is sustained exclusively by ground water seepage, the prevailing chloride concentration is usually referred to as the background concentration. This background concentration is on the order of 5 to 10 mg/l in streams of the Milwaukee River watershed, although a measurement of 0 mg/l was recorded by the Commission for a sample taken in August 1964 near Kewaskum. Concentrations higher than the background amount chloride concentration indicate the influence of human activities on water quality. Chlorides in surface waters are generally not harmful to humans unless concentrations in excess of 1,000 mg/l are reached. Concentrations on the order of 250 to 400 mg/l, however, impart a salty taste to water, render it unsuitable for many industrial uses, and inhibit the growth of certain aquatic plants. Certain industrial uses may be affected by chloride concentrations as low as 30 mg/l.

Nutrients

Fertilization of a body of water is brought about by an inflow of nutrients to the water. While a limited amount of fertilization is desirable to produce a balanced aquatic flora and fauna, excessive fertilization produces large growths of aquatic weeds and organisms which choke out desirable forms of aquatic life, limit recreational activities, and create an aesthetic nuisance. The nutrients most often cited as causing problems of overfertilization are nitrogen and phosphorus compounds. A comprehensive study of southern Wisconsin lakes has indicated that the approximate threshold concentrations for algal blooms in these lakes are 0.3 mg/l inorganic nitrogen and 0.015 mg/l soluble phosphorus.[1] These values are not necessarily applicable to other lakes, however, since the occurrence of nuisance growths of algae and other aquatic plants depends on the physical characteristics and general environment of a lake, as well as on the concentrations of nutrients present in the lake. A recent report on water quality criteria[2] contained guideline values of a maximum of 0.10 mg/l total phosphorus in flowing streams and 0.05 mg/l in streams entering lakes or reservoirs to prevent nuisance growths of aquatic plants. Similar criteria for nitrogen levels in streams are not available.

Temperature

The temperature of water is important for many uses. It affects the taste of water, the value of water for certain industrial processes, the efficiency of treatment processes, and the suitability of the water as a habitat for aquatic life. Temperature changes in surface waters result from the natural environment and from waste discharges. In southern Wisconsin natural climatic temperature conditions do not raise water temperatures sufficiently high to affect significantly most uses of the water. Waste discharges, such as spent cooling water, however, can raise the temperature of surface waters sufficiently high to preclude other water uses.

Other Aquatic Organisms

A biological assay of a stream, lake, or impoundment provides a good indication of the prevailing level of water quality. Unpolluted waters usually support a large number of species of organisms but relatively few individuals of any particular species because of predation and competition for food and living space. Polluted waters are characterized by relatively large numbers of organisms of a few pollution-tolerant species. Typical organisms found in polluted or dirty water are flatworms (Turbellaria), threadworms (Nematodes), midges and wheel animalcules (Rotifera), and sometimes earthworms, if dead organic matter is available to them for food. The clean-water organisms, or less tolerant organisms, are the Copepods, Crustacea, and moss animalcules (Bryozoa) and are usually found in the cleaner recovery zones of a stream or lake. Thus, a biological survey and analyses will indicate those reaches of a stream which are relatively unpolluted, those which are polluted, and those which serve as intermediate recovery zones.

Pesticides

In nature the problem of pesticide contamination is greater than it is relative to man. The extent to which fish and wildlife populations have been affected by pesticides is largely unknown except for numerous obvious examples of mortality. However, the addition to water of any persistant chlorinated-hydrocarbon pesticide is likely to result in damage to aquatic life. Progressive

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[1] *Sawyer, "Fertilization of Lakes by Agricultural and Urban Drainage," Journal New England Water Works Association, Vol. 61, 1947.*

[2] *Water Quality Criteria, Report of the National Technical Advisory Committee to the Secretary of the Interior, April 1968.*

damage often results in concentrations as these chemicals increase in the environment. The use of other kinds of chemical pesticides in or around water may produce a variety of acute and chronic effects on fish and the rest of the biota. Many pesticides are resistant to degradation and inhibit productivity of phytoplankton and growth of mollusks. This makes them among the most harmful of all chemical wastes affecting marine organism.

WATER QUALITY STANDARDS

The uses to which a water can be put are significantly affected by its quality. Standards of water quality are statements of the physical, chemical, and biological characteristics of the water that must be maintained if it is to be suitable for the specified uses. Pursuant to Section 144. 025(2)(6) of the Wisconsin Statutes, the Wisconsin Department of Natural Resources, on June 14, 1968, acted to adopt intrastate water quality standards for Wisconsin waters. These standards were formulated for the following major water uses: preservation and enhancement of fish life, recreation, public water supply, and industrial and cooling water. In addition, certain minimum standards for all waters were specified. The adopted state standards are set forth in Table 47. Interim standards[3] were formulated by the Commission on an advisory basis in 1964, four years prior to the adoption of the state standards. These interim standards were used in preparation of the Root River Watershed Plan. The two sets of standards are very similar; however, only the officially adopted state standards have been used in the Milwaukee River watershed planning program, and any succeeding references to such standards in this report will refer to the adopted state

[3]*See SEWRPC Technical Report No. 4, Water Quality and Flow of Streams in Southeastern Wisconsin, November 1966.*

TABLE 47

ADOPTED WATER QUALITY STANDARDS[a] FOR MAJOR WATER USES[b] FOR WISCONSIN

PARAMETER	PRESERVATION AND ENHANCEMENT OF FISH LIFE		MUNICIPAL (PUBLIC) WATER SUPPLY	RECREATION		INDUSTRIAL AND COOLING WATER	MINIMUM STANDARDS FOR ALL WATERS
	FISH REPRODUCTION OF PRIMARY IMPORTANCE	WARM-WATER FISHERY		WHOLE BODY CONTACT[c]	PARTIAL BODY CONTACT[d]		
DISSOLVED OXYGEN (MG/L)	5.0M[e]	4.0M[f]	--[g]	--[h]	--[h]	1.0M[i]	SUBSTANCES IN CONCENTRATIONS OR COMBINATIONS WHICH ARE TOXIC OR HARMFUL TO HUMAN BEINGS SHALL NOT BE PRESENT IN AMOUNTS FOUND TO BE OF PUBLIC HEALTH SIGNIFICANCE, NOR SHALL SUBSTANCES BE PRESENT IN AMOUNTS WHICH, BY APPROPRIATE TEST, INDICATE ACUTE OR CHRONIC LEVELS TO ANIMALS, PLANTS, OR AQUATIC LIFE. SUBSTANCES THAT WILL CAUSE OBJECTIONABLE DEPOSITS ON THE SHORE OR IN THE BED OF A WATER BODY, FLOATING OR SUBMERGED DEBRIS, OIL, OR OTHER MATERIAL, AND MATERIAL PRODUCING COLOR, ODOR, TASTE, OR UNSIGHTLINESS SHALL NOT BE PRESENT IN SUCH AMOUNTS AS TO CAUSE A NUISANCE.
COLIFORM COUNT (MFCC/100ML)	--[g]	--[g]	5,000[j]	1,000[k]	5,000[l]	--[g]	
TEMPERATURE (°F)	84[m]	89[m]	--[g]	--[g]	--[g]	89	
PH (UNITS)	--[g]	--[g]	6.0-9.0[n]	--[g]	--[g]	6.0-9.0[n]	
DISSOLVED SOLIDS (MG/L)	--[g]	--[g]	500[o]	--[g]	--[g]	750.0[p]	
OTHER PARAMETERS	--[q]	--[r]	--[s]	--[h]	--[h]	--[g]	

[a]LIMITS ARE MAXIMUM PERMISSIBLE VALUES, EXCEPT MIMIMUM LIMITS, WHICH ARE DENOTED BY THE SUFFIX M. STANDARDS FOR PH HAVE A RANGE OF LIMITING VALUES.

[b]STANDARDS ADOPTED BY THE WISCONSIN RESOURCE DEVELOPMENT BOARD ON JUNE 14, 1968 FOR WATERS OF WISCONSIN. THE WISCONSIN RESOURCE DEVELOPMENT BOARD HAS SINCE BEEN SUCCEEDED BY THE WISCONSIN NATURAL RESOURCES BOARD.

[c]WHOLE-BODY-CONTACT RECREATION REFERS TO SWIMMING, WATER SKIING, AND SKIN DIVING.

[d]PARTIAL-BODY-CONTACT RECREATION REFERS TO FISHING, BOATING, AND HUNTING.

[e]ALSO, NOT LESS THAN 80 PERCENT SATURATION AND NO ABRUPT CHANGE IN BACKGROUND BY MORE THAN 1 MG/L AT ANY TIME.

[f]ALSO, NOT LESS THAN 5 MG/L DURING AT LEAST 16 HOURS OF ANY 24-HOUR PERIOD.

[g]NO STANDARD ESTABLISHED.

[h]QUALITATIVE CRITERIA LISTED UNDER MINIMUM STANDARDS AND ESTHETICS APPLY.

[i]ALSO, NOT LESS THAN 2.0 MG/L AS A DAILY AVERAGE VALUE.

[j]COLIFORM NUMBER NOT TO EXCEED 5,000 PER 100 ML AS A MONTHLY ARITHMETIC AVERAGE VALUE, NOR EXCEED THIS VALUE IN MORE THAN 20 PERCENT OF THE SAMPLES EXAMINED DURING ANY MONTH, NOR EXCEED 20,000 PER 100 ML IN MORE THAN 5 PERCENT OF THE SAMPLES.

[k]ARITHMETIC AVERAGE OF 1,000 MFCC/100 ML OR LESS AND A MAXIMUM NOT EXCEEDING 2,500 MFCC/100 ML DURING RECREATION SEASON. A SANITARY SURVEY AND/OR EVALUATION TO ASSURE PROTECTION FROM FECAL POLLUTION IS THE CHIEF CRITERION IN DETERMINING RECREATIONAL SUITABILITY.

[l]ARITHMETIC AVERAGE OF 5,000 MFCC/100 ML OR LESS AND NO MORE THAN 1 OF THE LAST 5 SAMPLES EXCEEDING 20,000 MFCC/100 ML DURING RECREATION SEASON.

[m]ALSO, NO CHANGE FROM BACKGROUND BY MORE THAN 5°F AT ANY TIME NOR AT A RATE IN EXCESS OF 2°F PER HOUR. AUTHORIZATION MUST BE OBTAINED FOR PROPOSED INSTALLATIONS WHERE DISCHARGE OF A THERMAL POLLUTANT MAY INCREASE THE NATURAL MAXIMUM TEMPERATURE OF A STREAM BY MORE THAN 3°F.

[n]EXCEPT IN NATURAL WATERS HAVING A PH OF LESS THAN 6.5 OR GREATER THAN 8.5 WHERE EFFLUENT DISCHARGES MAY NOT REDUCE THE LOW VALUE OR RAISE THE HIGH VALUE MORE THAN 0.5 PH UNITS.

[o]MONTHLY AVERAGE VALUE NOT TO EXCEED 500 MG/L, AND A MAXIMUM NOT TO EXCEED 750 MG/L AT ANY TIME.

[p]THE MONTHLY AVERAGE VALUE NOT TO EXCEED 750 MG/L, AND A MAXIMUM NOT EXCEEDING 1,000 MG/L AT ANY TIME.

[q]STREAMS CLASSIFIED BY LAW AS TROUT WATERS SHALL NOT BE ALTERED FROM A NATURAL BACKGROUND BY EFFLUENTS THAT AFFECT THE STREAM ENVIRONMENT TO SUCH AN EXTENT THAT THE TROUT POPULATION IS ADVERSELY AFFECTED IN ANY MANNER.

[r]UNAUTHORIZED CONCENTRATIONS OF SUBSTANCES ARE NOT PERMITTED THAT ALONE OR IN COMBINATION WITH OTHER MATERIALS PRESENT ARE TOXIC TO FISH OR OTHER AQUATIC LIFE.

[s]CONCENTRATIONS OF OTHER CONSTITUENTS MUST NOT BE HAZARDOUS TO HEALTH. ALSO, THE INTAKE WATER SUPPLY MUST BE SUCH THAT, BY APPROPRIATE TREATMENT AND SAFEGUARDS IT WILL MEET THE PUBLIC HEALTH SERVICE DRINKING WATER STANDARDS, 1962.

SOURCE- WISCONSIN DEPARTMENT OF NATURAL RESOURCES.

standards. The intent of the state standards, as expressed in Section 144.025(2)(6) of the Wisconsin Statutes, is:

> ...standards of quality shall be such as to protect the public interest, which include the protection of the public health and welfare and the present and prospective future use of such waters for public and private water supplies, propagation of fish and aquatic life and wildlife, domestic and recreational purposes and agricultural, commercial, industrial, and other legitimate uses. In all cases where the potential uses of water are in conflict, water quality standards shall be interpreted to protect the general public interest.

Minimum Standards for All Waters

The adopted state minimum standards for all waters listed in Table 47 apply to all surface waters at all locations within the state. Essentially, these minimum standards are designed to maintain all state waters in an aesthetically pleasant condition and to protect the public health. They also serve as the standards for determining suitability for livestock and wildlife watering, irrigation, navigation, and waste assimilation.

Public Water Supply

Quality standards for raw water for public water supply should be such that the water, after appropriate treatment, will be suitable for human consumption. The factors considered in formulating these criteria are that the finished water should be physiologically harmless, palatable, odorless, and aesthetically desirable. Because of the effectiveness of present treatment methods, most standards are now applied to the finished water rather than to the raw water supply. Although the state-designated water uses for the Milwaukee River do not, at present, include public water supply, the water supply standards are presented in Table 47, since water supply may, at some future time, become a necessary or desirable use of the river.

Preservation and Enhancement of Fish Life

Standards for water to be used for the preservation and enhancement of fish and other aquatic life are generally specified in terms of parameters that affect the physiologic condition of the fish, the food chain that sustains the fish, and the aquatic environment. Dissolved oxygen concentration and temperature are the most frequently used parameters, since the reproduction and survival of fish and their susceptibility to toxic substances are highly dependent upon these factors. In addition, there are many substances, particularly insecticides, herbicides, and heavy metals, that are highly toxic to aquatic life in very small amounts. The adopted state standards for the preservation and enhancement of fish life are set forth in Table 47.

Recreation

Waters to be used for recreational purposes should conform to the following general conditions: 1) absence of obnoxious floating or suspended substances, objectionable color, and foul odors; 2) absence of substances that are toxic upon ingestion or irritating to the skin of human beings; and 3) reasonably free from pathogenic organisms. The first two conditions are satisfied if the water meets the minimum standards for all waters previously described. The third condition, however, requires that a standard be set to ensure the safety of a water from the standpoint of health. The concentration of coliform bacteria is the parameter normally used for this purpose. Since the coliform count is only a general, rather than a specific, indicator of fecal contamination, the Wisconsin Standards, as set forth in Table 47, recommend that the primary criterion for determining the suitability of a water for recreational use should be a thorough sanitary survey to assure protection from fecal contamination, with the coliform concentrations serving only as guidelines in evaluating this suitability.

Industrial and Cooling Water

The ideal water quality for industrial and cooling uses varies widely for the many industrial uses to which water is put. The Wisconsin Standards, as set forth in Table 47, are intended to assure that the water would be suitable for most industrial uses after proper treatment. The required treatment will vary, depending on the final water quality necessary for each industrial operation. One requirement common to all industries, however, is that the concentration of various constituents of the water should remain relatively constant. The quality of ground water and of Lake Michigan water is more constant than the quality of surface water of the Milwaukee River watershed. Since most industries depend on ground water and Lake Michigan as sources of water supply, either directly or by way of a municipal distribution system, the standards for industrial and cooling water are meaningful only in those few areas of the watershed where surface water is used as a source of supply.

Guidelines for Application of Standards[4]

It is important to note that the particular standards to be applied to a given stream reach depend upon the existing or potential water uses in that reach; that is, the Wisconsin Standards, as listed in Table 47, cannot be applied without the prior knowledge of existing water uses or designation of water use objectives. Also, the capacity of a stream to receive and assimilate discharges with potential pollutants is determined by the flow and quality of water in the stream which is available for dilution. It is specified in the guidelines that evaluation of compliance with water use objectives and standards is to be based on estimates of water available for dilution, with a streamflow equivalent to the lowest average for any period of seven consecutive days in the most recent 10 years.

[4] *Wis. Adm. Code, Chapter RD 2.*

Water use objectives for streams in the Milwaukee River watershed, as shown in Table 48, have been adopted by the State Resource Development Board, now the State Natural Resources Board. These objectives state that all surface waters within the watershed should meet the standards for whole-body-contact recreational uses and for the preservation of fish and other aquatic life, with the exceptions of the streams noted below, and, additionally, that the Milwaukee River over its entire length and Cedar Creek at Cedarburg should also meet the standards for industrial and cooling water uses. The exceptions to these objectives are Lincoln Creek and the Milwaukee River downstream from the North Avenue Dam, which are not required to meet the standards for fish and other aquatic life or for whole-body-contact-recreation, and Indian Creek, which must meet only minimum standards.

The water use objectives and supporting standards adopted by the State of Wisconsin are subject to revision as either additional data are accumulated that bear on the desirability and feasibility of

TABLE 48

STATE DESIGNATED WATER USES FOR MAJOR STREAMS IN THE MILWAUKEE RIVER WATERSHED

NAME OF STREAM	WATER USE					
	FISH REPRODUCTION OF PRIMARY IMPORTANCE	RECREATION		MUNICIPAL (PUBLIC) WATER SUPPLY	INDUSTRIAL AND COOLING WATER	MINIMUM STANDARDS FOR ALL WATERS
		WHOLE-BODY CONTACT	PARTIAL-BODY CONTACT			
MILWAUKEE RIVER DOWNSTREAM FROM NORTH AVENUE DAM			X		X	X
UPSTREAM FROM NORTH AVENUE DAM	X	X	X		X	X
LINCOLN CREEK			X			X
INDIAN CREEK						X
PIGEON CREEK	X	X	X			X
CEDAR CREEK AT CEDARBURG	X	X	X		X	X
UPSTREAM FROM CEDARBURG	X	X	X			X
NORTH BRANCH MILWAUKEE RIVER	X	X	X			X
SILVER CREEK (SHERMAN TOWNSHIP)	X	X	X			X
ADELL TRIBUTARY	X	X	X			X
SILVER CREEK (WEST BEND TOWNSHIP)	X	X	X			X
EAST BRANCH MILWAUKEE RIVER	X	X	X			X
WEST BRANCH MILWAUKEE RIVER	X	X	X			X

SOURCE- CHAPTER RD 4 OF THE WISCONSIN ADMINISTRATIVE CODE.

revising the water use objectives in the public interest or as new data or techniques are developed that permit the standards to be expressed in more precise, quantitative, and statistically valid terms.

Pesticides

The widespread use of chemical pesticides has created a number of complex environmental problems, including special water pollution problems. More than 60,000 pesticide formulations based on over 500 individual chemical compounds have been registered for sale in the United States. This volume, coupled with an equally large number of use patterns, makes laboratory determination of the potential effects of new products on the environment extremely difficult. In general, the chlorinated hydrocarbon pesticides, DDT and the aldrin toxaphene group, are among the most economically important and most widely used compounds. Typically, these are very persistent in the environment and may have far-reaching ecological effects. Certain pesticides have been identified as constituting a serious hazard to wildlife other than those target pests it is intended to control. Such pesticides include: 1) DDT, 2) DDD (TDE), 3) Endrin, 4) Aldrin, 5) Dieldrin, 6) Heptachlor, 7) Lindane, 8) BHC, and 9) Alkyl Mercury Compounds.

As residues in soil and marine sediments, these may persist unchanged for many years and, consequently, present a continuing threat to animal communities. The organophosphorus pesticides hydrolyze or break down into less toxic products more readily than the organochloride compounds. Members of this group, such as malathion and parathion, exhibit a wide range of toxicity and have become increasingly popular because of their relatively short life. To humans pesticide exposure occurs chiefly from ingestion of foods, direct skin or respiratory contact during use, and inhalation of airborne materials near treated areas. Although there appears to be no immediate danger to human health in general, there is a genuine concern on the part of a large number of scientists and public health officials about the long-term chronic effects of pesticide pollution. Pesticides do injure a variety of non-target fish and wildlife, and changes in these living organisms may give a suttle indication of long-range effects of pesticides on people.

Death and serious illness from pesticide poisoning are rare, but everyone in the United States has a measurable body burden of some of these substances accumulated mainly from small contaminating amounts in food and water. Each individual averages about one-tenth of a gram of DDT residue and measurable amounts of dieldrin and other chlorinated hydrocarbon pesticides accumulated in his body. The adverse effects of these small accumulations have not been fully assessed but are generally considered insignificant. In nature the problem of pesticide contamination is much greater. The extent to which fish and wildlife populations have been affected by pesticides is largely unknown except for numerous obvious examples of mortality. An example of this is the DDT treatments in New York State, resulting in complete elimination of lake trout production in certain lakes and great reduction in others. Endrin is generally considered responsible for the death of a great many fish in the lower Mississippi River. Decreasing bird populations are cited and constitute yet another example of pesticide effects. Increasing pesticide accumulations in the environment have been noted in Wisconsin, especially in lakes and streams. The persistence of insecticidal residues depends on the insecticide itself, the soil type, the soil moisture, and temperature, air movement, cover crops, rate of application, formulation, and microorganisms. Pesticides settling on soil pose still other problems, for such pesticides will move with the soil particles. Thus, erosion by wind or water may move the pesticides into lakes and streams. The addition to water of any persistent chlorinated hydrocarbon pesticide is likely to result in damage to aquatic life. Progressive damage often results as concentrations of these chemicals increase in the environment. The use of other kinds of chemical pesticides in or around water may produce a variety of acute and chronic effects on fish and other desirable biota. The control of pesticide pollution, however, lies beyond the scope of a watershed study and will have to be founded in the development and application of better pest control measures, such as biological control measures.

POLLUTION AND WASTE SOURCES

As defined herein, water pollution is the direct result of human activity in the tributary watershed. Water pollution may occur as one or more of six types: 1) chemical or inorganic pollution, such as toxic compounds and heavy metals; 2) organic pollution, which usually removes oxygen from the water and severely alters flora and fauna; 3) nutrient pollution, which is an oversupply of minerals normally considered fertilizers, such as nitrates and phosphates; 4) aesthetic pollution, which could be any combination of the above, along with floating objects and unsightly trash along the banks and in the water; 5) pathogenic contamination; and 6) thermal pollution.

As man utilizes water for various purposes, many substances, either not originally present in the water or present in only small amounts, are added to the water. These substances tend to degrade the quality of the water, and, if present in sufficient amounts, cause pollution in the streams and lakes when the used water is returned to receiving bodies of surface water. It is the purpose of waste treatment processes to remove those substances in a used water that might cause pollution when discharged to a receiving body of water. Conventional waste treatment, however, cannot economically remove all of the possible pollutants. Therefore, some amount of each potential pollutant usually remains in the treated effluent discharged to the stream. If the quantity of the effluent is relatively large in comparison to the quantity of dilution water available in the receiving stream or lake, then water quality in the stream or lake will be seriously degraded. The two sources most often associated with water pollution are municipal and industrial wastes. Pollution may also be caused, however, by numerous other sources, including drainage and runoff from urban areas and overflow and drainage from septic tanks. Although these latter sources present a more dispersed contribution to surface water pollution than do municipal and industrial wastes, they may, at certain times, exert a significant undesirable influence on surface water quality. They are, moreover, difficult to identify and regulate.

Problems Related to Discharge of Pollutants to Streams and Lakes and Resulting Conditions

Sewer overflows and industrial and other discharges of pollutants result in oxygen-consuming organic and inorganic pollutional matter, plant nutrients, and disease-producing bacteria entering streams or lakes. The necessity of dealing with this problem is widely recognized; and corrective action is being taken on local, regional, and national levels. Although the necessity for dealing with pollution is widely recognized, the degree of seriousness of the problems and the relative impact of each problem element are not easily defined, due to a general lack of basic data for accurately quantifying the problem. Although there still are data deficiencies for the Milwaukee River watershed, as elsewhere, several important data collection programs have been carried out in recent years; and the information provided by these programs has been collated and analyzed in the watershed study to permit identification of the problems and assignment of general orders of magnitude to the various pollution sources in the watershed upstream from the North Avenue Dam.

Water Quality Data: Water quality data are available for streams in the Milwaukee River watershed from stream surveys carried out by the Commission itself, the Wisconsin Department of Natural Resources, the Milwaukee Sewerage Commission, and the City of Milwaukee. The Commission conducted a stream water quality sampling program from January 1964 to February 1965. Samples were obtained once a month from 12 stations in the watershed and were analyzed for DO, BOD, temperature, coliform concentration, and other parameters. A monitoring program, consisting of sample collection and analysis twice a year from the 12 stations, has been maintained since completion of the 1964 program.

The Wisconsin Department of Natural Resources conducted a water quality survey in the Milwaukee River watershed outside Milwaukee County during 1966 and 1967 and within Milwaukee County during 1968. Grab samples were obtained on a monthly basis during the summer at 67 locations within the watershed; and the resulting 364 samples were analyzed for DO, BOD, temperature, pH, and coliform concentration. In addition, samples were obtained for biological analysis at 52 locations throughout the stream system. The Department of Natural Resources also maintains a water quality monitoring station on the Milwaukee River at Brown Deer Road in Milwaukee County. Samples have been collected monthly at this station since May 1961 and are analyzed for 20 parameters, including DO, BOD, temperature, coliform count, nitrogen, and phosphorus.

The Commission, through its consulting engineer, Harza Engineering Company, conducted an intensive program of water quality sampling in the watershed from April 29 to May 3, 1968, and from July 27 to August 7, 1968, as an integral part of the Milwaukee River watershed planning program. DO and temperature measurements were made around the clock at three-hour intervals at 26 locations during the spring survey and from dawn to dusk during the summer survey. Samples were collected and analyzed for BOD at 13 locations during the summer survey and for nitrogen and phosphorus concentrations at 26 locations in the spring and 16 locations in the summer. Light-and-dark bottle studies to measure algae effects on DO were made at nine locations during the summer survey.

Laboratory personnel of the Milwaukee-Metropolitan Sewerage Commissions conducted stream surveys along Lincoln Creek and the Milwaukee River within Milwaukee County during the period from approximately May 1 to November 30 of each year from 1946 to 1968. Samples were collected at seven locations along the Milwaukee River upstream from the North Avenue Dam and at one location on Lincoln Creek and are analyzed for DO, BOD, temperature, pH, total coliform, fecal coliform count, chloride, and turbidity.

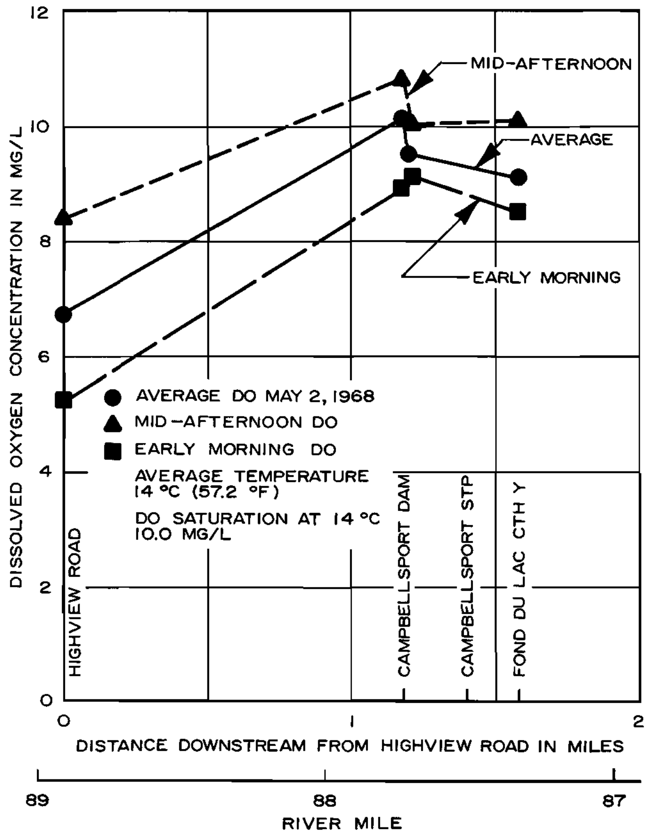
The City of Milwaukee, through its consulting engineer, Consoer, Townsend & Associates, and assisted by personnel of Marquette University, collected water quality data at five locations along the Milwaukee River upstream from the North Avenue Dam during 1967 and 1968 as a part of a Federal Water Pollution Control Administration (FWPCA) demonstration grant program. Samples were analyzed for DO, BOD, temperature, coliform count, nitrogen, phosphorus, and other parameters.

As a part of the study of the feasibility of using storage tanks for controlling combined sewer discharges, a 3,900,000 gallon tank and an in-sewer monitoring system are being constructed on the bank of the Milwaukee River at a combined sewer outfall near N. Humboldt Avenue by the City of Milwaukee as a part of the same FWPCA grant program. This tank will store overflows from a tributary service area of 303 acres, extending from the Milwaukee River on the south and east to E. Locust Street on the north and to N. Third Street on the west. Sewer overflows are to be monitored in a 570-acre area which includes the 303 acres and the area north from E. Locust Street to E. Townsend Street, as shown on Map 45.

Stream Reaction to Organic Wastes: The ability of a stream to purify itself is an important process related to water quality. When organic wastes are discharged into water, a succession of changes in water quality takes place. In a stream these changes occur in different reaches and establish a profile of pollution and natural purification sufficiently well defined that it can be subject to mathematical analysis. The initial effect of pollution on a stream is to degrade the physical and chemical quality of the water and its biological characteristics. The number of microorganisms in the stream rapidly increases both in response to the increased food supply provided by the waste discharge and to the addition of microorganisms in the wastes. These organisms utilize the organic matter as a food source and transform it to such stable end-products as inorganic salts, carbon dioxide, and water. In this transformation process, the organisms utilize large amounts of oxygen. As a result dissolved oxygen concentrations in the stream decrease downstream from a waste outfall until the amount of oxygen consumed in waste assimilation becomes less than that supplied by reaeration from the atmosphere and from the process of plant photosynthesis. At this point the dissolved oxygen begins to increase until the oxygen demand created by the waste load is fully satisfied. This ability of a stream to assimilate organic waste and gradually return to its original condition is referred to as natural stream purification. This natural process is important to water quality management, since it permits the discharge of wastes to a stream without a permanent degradation of water quality, provided that the natural waste assimilation capacity of the stream is not exceeded.

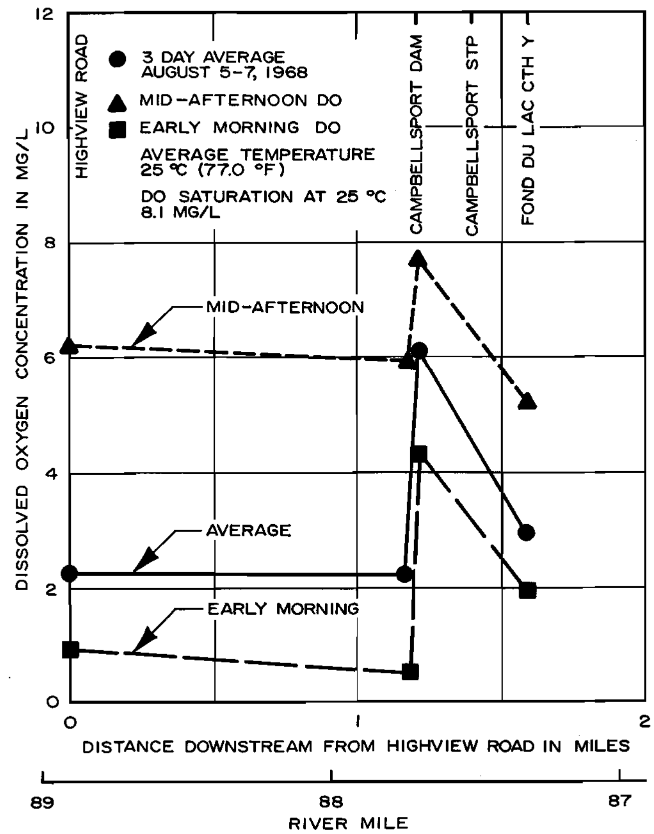
Nutrients, Aquatic Plants, and Dissolved Oxygen in Streams: After stream recovery has occurred, the major factors affecting stream water quality in terms of dissolved oxygen concentrations are reaeration, the process of photosynthesis, and respiration of aquatic plants. These plants produce oxygen during the daylight hours and consume oxygen at night. This results in a diurnal (daily) fluctuation in dissolved oxygen levels, the magnitude of which is dependent upon the numbers of aquatic plants present in the stream. Nutrients derived from upstream waste discharges and rural and urban drainage and runoff stimulate the growth of these aquatic plants. Although the effects of aquatic plants on dissolved oxygen levels in a stream can be analyzed mathematically, general knowledge is inadequate to permit a practical mathematical analysis of the relationship between nutrient levels in a stream and corresponding aquatic plant growths. The magnitude of the influence aquatic plant life exerts on the diurnal variation of dissolved oxygen levels in the Milwaukee River is indicated by Figures 33 and 34 for conditions as measured during May and August 1968.

Figure 33
MEASURED DISSOLVED OXYGEN PROFILE
CAMPBELLSPORT REACH
OF THE MILWAUKEE RIVER
SPRING 1968



Source: Harza Engineering Company.

Figure 34
MEASURED DISSOLVED OXYGEN PROFILE
CAMPBELLSPORT REACH
OF THE MILWAUKEE RIVER
SUMMER 1968



Source: Harza Engineering Company.

Nutrients, Aquatic Plants, and Dissolved Oxygen in Lakes: The major water quality-associated problem in the lakes of the Milwaukee River watershed is excessive fertilization. Many of these lakes already show signs of deteriorating water quality as a result of receiving excessive amounts of nutrients, and the frequency and severity of this deterioration will undoubtedly increase with further urbanization and recreational uses. Problems resulting from excessive fertilization include luxurious growths of aquatic plants and algae, curtailment of recreational activities, periodic destruction of aquatic life, losses in property values, reduction of dissolved oxygen content, and nuisance conditions that impair aesthetic enjoyment.

In order to formulate plans for controlling excessive fertilization in lakes, it is necessary to know the major sources and amounts of nutrients that are entering the lake. Since no definite information of this type was available for any of the lakes in the Milwaukee River watershed, it was decided that estimates should be based on information available from studies of various other lakes. Although such estimates necessarily represent approximations, they do provide indications of the relative nutrient contributions from each source and thus suggest areas in which proper corrective actions can be taken.

Nutrient Sources in Lakes and Streams: The nutrients most often associated with excessive fertilization of lakes and streams are nitrogen and phosphorus. Phosphorus is generally considered to be the principal nutrient controlling the fertility of natural waters and is the nutrient most amenable to control. It is principally derived from domestic sewage, urban and rural runoff, precipitation, ground water, and wetland drainage. Most of the data used in this study concerning these sources were obtained from a study of the nutrient sources of Lake Mendota, Madison, Wisconsin;[5] from a report on water fertilization in the State of Wisconsin;[6] and from studies of phosphorus content in runoff from rural land in the Lake Michigan watershed,[7] from records of measurements made at the Jones Island sewage treatment plant, and from values measured in the Milwaukee River for this study.[8] A summary of the estimated amount contributed by each major nutrient source to lakes within the watershed is presented in Table 49.

Sewage treatment plant effluent is often cited as a major contributor to water fertilization. The average per capita contribution of phosphorus to domestic sewage was taken as 3.5 pounds per year. About one-third of this total is contributed by sanitary wastes and two-thirds by detergents in wash waters. Conventional secondary treatment facilities generally remove only a small portion of the phosphorus contained in raw domestic sewage and, consequently, discharge large amounts to the receiving waters. For purposes of this study, it was assumed that sewage treatment plants located upstream from Milwaukee County in the Milwaukee River watershed remove about 45 percent of the phosphorus contained in the raw sewage. Thus, the annual per capita phosphorus contribution from treated domestic sewage discharged to surface waters within the watershed was estimated to be 1.9 pounds. The annual per capita nitrogen contribution from this same source was similarly estimated at 6.5 pounds. Concentrations of phosphorus in overflows from sanitary sewers in Milwaukee County were assumed to be 7 mg/l, based on the quality of sewage bypasses at the Jones Island sewage treatment plant. Estimates of quantities of phosphorus in overflows from combined sewers were made based on concentrations of 5 mg/l.

[5] *Nutrient Sources Subcommittee of the Technical Committee of the Lake Mendota Problems Committee, Report on the Nutrient Sources of Lake Mendota, Madison, Wisconsin, 1968.*

[6] *Working Group on Control Techniques and Research on Water Fertilization, Excessive Water Fertilization, Report to the Water Subcommittee, Natural Resource Committee of State Agencies, Madison, Wisconsin, 1967.*

[7] *H. A. Hall, Runoff As a Source of Phosphate in the Waters of Streams and Lakes, Great Lakes-Illinois River Basins Project, Federal Water Pollution Control Administration, Chicago, Illinois, April 1968.*

[8] *SEWRPC Planning Memorandum No. 1, Evaluation of Water Quality Field Survey Conducted on the Milwaukee River During 1968.*

Sewage disposal facilities at homes and cottages around most of the major lakes in the watershed and in rural areas of the watershed consist of individual soil absorption systems. While this type of system has the advantage of generally confining the nutrients, a certain amount may still reach the lake by movement through the soil or by direct overflow of improperly functioning systems. The nutrient contributions from this source were estimated by assuming average per capita contributions of 10.0 pounds of nitrogen and 3.5 pounds of phosphorus in the raw sewage and by further assuming that 30 percent of the nitrogen and 5 percent of the phosphorus ultimately reach the lakes.[9]

[9] *Ibid, footnotes 5 and 6.*

TABLE 49

ESTIMATED CONTRIBUTION OF MAJOR SOURCES OF NITROGEN AND PHOSPHORUS

SOURCE	NITROGEN	PHOSPHORUS
TREATED DOMESTIC SEWAGE	6.5 LBS./CAPITA/YR.	1.9 LBS./CAPITA/YR.
SOIL ABSORPTION SEWAGE DISPOSAL SYSTEMS	3.0 LBS./CAPITA/YR.	0.2 LB./CAPITA/YR.
RURAL RUNOFF	3.09 LBS./CAPITA/YR.	0.094 LB./ACRE/YR.
URBAN RUNOFF	8.0 LBS./ACRE/YR.	0.72 LBS./ACRE/YR.
PRECIPITATION	8.0 LBS./ACRE/YR.	0.14 LB./ACRES/YR.
GROUND WATER	1.2 MG/1	NEGLIGIBLE

SOURCE- NATURAL RESOURCES COMMITTEE OF STATE AGENCIES.

The amount of nitrogen and phosphorus contained in surface water runoff from rural areas is dependent upon the land use and soil and water conservation practices in the tributary drainage area. The nutrient contribution from runoff from cropland and pasture was determined by using the concentrations of nitrogen and phosphorus in such runoff, as reported in previous studies, and assuming an average surface runoff of two inches per year. The contribution in runoff from forested land was estimated from the nitrogen and phosphorus contents in streams flowing through wooded areas. The use of manure on frozen land can be a very significant contributor of nutrients in rural runoff, especially during the spring high runoff season. Since rainfall and snowmelt in early spring cannot enter the frozen soil, they drain over the surface of the land to streams and lakes, carrying with them the soluble constituents of the manure. Included in this runoff is much of the nitrogen and phosphorus normally contained in the manure. Estimates of nutrients lost from manured land were based on a normal year-round application of 10 tons of manure per acre and on the assumption that the ground is frozen for four to five months every year. The amounts of nitrogen and phosphorus contributed from each of these sources of rural runoff are listed in Table 49 and averaged 1,980 and 60 pounds per square mile, respectively.

Runoff waters from urban areas generally contain large amounts of nitrogen and phosphorus. The values used in this study for the nutrient contribution of urban runoff were based upon studies of runoff from a residential-light commercial area in Cincinnati, Ohio.[10] The values for the Fox River and the Milwaukee River watersheds were taken as 90 percent of the Cincinnati values, or 5,120 pounds of nitrogen and 1,410 pounds of phosphorus per square mile, to reflect the lower average annual precipitation in the southeastern Wisconsin area.

Precipitation directly on a lake or stream surface contributes nutrients that have been flushed out of the atmosphere. Studies of the nitrogen content of rainwater indicate an approximate annual contribution of 8.0 pounds per acre per year in southeastern Wisconsin. Studies of the phosphorus content of rainwater, however, have yielded extremely variable results, ranging from trace values to 0.1 mg/l. For purposes of this study, a value of 0.02 mg/l of phosphorus was used; and the average annual rainfall was taken as 29.4 inches throughout the watershed. This resulted in an average annual phosphorus contribution of 0.14 pound per acre per year.

The final major nutrient source evaluated was ground water. Nitrogen found in ground water is generally in the form of highly soluble nitrates derived from precipitation percolating through the soil layer. Very little phosphorus is normally present in ground water, since the phosphorus is usually bound in the soil layers through which the water percolates. The values of 1.2 mg/l of nitrogen and 0.01 mg/l of phosphorus in ground water that were used in this study are the average concentrations present in Wisconsin water supplies and should be comparable to the average levels found in ground water.

There are several additional sources that may contribute significant amounts of nutrients to lakes in the watershed, but they have not been evaluated in this study, since no data exist on which an estimate of their relative contributions could be based. These sources include wetland drainage, nitrogen fixation by various species of algae, and leaching of nutrients from bottom sediments in a lake.

Computation Methods: The method used in computing the amounts of nutrients contributed by the major sources to each major lake in the Milwaukee River watershed was based on the methods used in the two previously cited reports on nutrient sources in Wisconsin. This method involved the determination of population and land use around each lake, the size of the lake, and the amount of ground water contribution to the lake. This information was utilized in conjunction with the data listed in Table 49 to estimate total nutrient contributions from each major source.

Estimates of the nitrogen and phosphorus contribution from private sewage disposal facilities were made by determining the total population residing within the tributary drainage areas to each lake and by applying the per capita contributions shown in Table 49. Population estimates were based on U. S. Public Land Survey quarter-section totals included within the delineated tributary drainage areas located around each lake. Areas served by a municipal sanitary sewerage

[10] *R. J. Anderson, S. R. Weibel, and R. L. Woodward, "Urban Land Runoff As a Factor in Stream Pollution," Journal Water Pollution Control Federation, Vol. 36, No. 7, July 1964.*

system were excluded from the estimates, since the nutrient contribution from such areas was considered under the category of treatment plant effluent.

Estimates of the nutrient contribution from surface runoff were based on the present land use in the watersheds tributary to each lake. Approximate acreages devoted to urban use, cropland and pasture, wetland, and forest in each watershed were determined from SEWRPC existing land use data. The nitrogen and phosphorus derived from each of these sources, except wetlands, were then estimated using the values shown in Table 49. The contribution from wetlands was not estimated, since no data exist upon which an estimate could be based.

In addition to the contribution from the above land uses, an estimate was made of the contribution from cropland and pasture upon which manure was spread. Calculation of the amount of nutrients lost from manured land required estimates of the amount of manure applied and the amount of nutrients lost from a given application. The estimated amount lost from a normal 10-ton per acre application rate on frozen ground is reported in Table 49. Information on the number of dairy cows per square mile of agricultural land in Fond du Lac, Ozaukee, Sheboygan, and Washington Counties was obtained from the 1964 U. S. Census of Agriculture and used to estimate the total number of dairy cows in each subwatershed. It was assumed that each cow produces 15 tons of manure per year and that half of the manure is applied while the ground is frozen. This estimate may be considered high if representative of only manure production by dairy cows. Such manure, however, will be augmented by manure produced by steers, hogs, chickens, and young stock within the watershed. The total amount of manure applied on frozen ground was calculated from this information; and, assuming a 10-ton per acre application rate, the total acreage involved was determined. Using this acreage and the nutrient losses shown in Table 49 for manured land, the nitrogen and phosphorus contributions to each lake were estimated.

Direct nitrogen and phosphorus contributions from precipitation on each lake were estimated by applying the per acre contributions shown in Table 49 to the total surface area of each lake. Data on the surface area of the major lakes in the Milwaukee River watershed were obtained from the Wisconsin Department of Natural Resources.

Nutrient contribution from ground water inflow to the lakes was estimated by determining the total amount of ground water entering each lake and by calculating the total nutrient content using the unit nitrogen and phosphorus contributions shown in Table 49. Ground water inflow was determined by assuming a contribution of 3.5 inches per acre of the contributing area, as determined from a piezometric map of ground water levels in the Milwaukee River watershed prepared by the U. S. Geological Survey. The 3.5 inches represent the average combined ground water outflow plus well pumpage for the State of Wisconsin.

Utilization of the Results: The total amounts of nitrogen and phosphorus contributed to the 21 major lakes within the watershed were obtained by summing the contributions from each source. The final results of the computations, expressed in terms of the percent contribution of each source to the total, are presented in this chapter. An analysis of these results identified the most important nutrient sources for each lake and provided a guideline for formulating and evaluating corrective measures for controlling excessive fertilization in the lakes.

Disease-Bearing Wastes: Sewer overflows and most discharges from sewage treatment plants are at present entering the Milwaukee River without being disinfected. These discharges and sewer overflows are potentially disease bearing and constitute a public health hazard. This hazard is most pronounced in several reaches of the middle and upper parts of the stream system which are designated for whole-body-contact recreational use. Although this hazard is minimal on the lower portion of the Milwaukee River since the River is not used for any whole-body-contact recreation or as a source of potable water supply, the polluted water ultimately reaches Lake Michigan, contaminating the lake water from which municipal water supplies are drawn as well as the water along which bathing beaches are located in the Milwaukee metropolitan area.

Division of Watershed for Description of Individual Waste Sources

The following discussion of individual sources of pollution is, for convenience of description, presented in the order of occurrence in the watershed upstream to downstream and not in the order of importance or impact on stream pollution. The sources of pollution from agricultural and septic tank runoff and drainage are discussed first as they originate almost entirely in the upstream rural.

areas. Industrial, municipal, and storm water sources, which occur over the entire watershed, are described separately for the still largely rural upstream area of the watershed and for the highly urbanized lower part of the watershed.

Upstream from the Milwaukee-Ozaukee County line, urbanization has occurred in relatively small, isolated clusters or colonies; and wastes are collected and treated in relatively small sewerage systems located along the river system. Downstream from this line, almost all of the tributary watershed area is urbanized; and wastes are collected and treated in a single, large, centralized sewerage system. The scope and complexity of the problems of the two areas differ considerably, as 14 sewage treatment plants serve a population of only 38,160 in the upper watershed, whereas only two plants serve over 1 million persons, of which 464,400 persons reside within the lower watershed. Therefore, for descriptive and analytical purposes, the Milwaukee River watershed has been divided, for the purpose of describing stream water quality and the factors affecting such quality, into two distinct units: that portion of the watershed lying upstream from the Ozaukee-Milwaukee County line and that lying downstream from that line.

Agricultural Sources

As noted in Chapter III of this volume, 424 square miles, or 61 percent of the total area of the Milwaukee River watershed, are in agricultural use. Of this 424 square miles of crop- and pastureland, all but 419 square miles, or 99 percent, are located outside Milwaukee County. Drainage and runoff from these agricultural lands are potential sources of water pollution. The major pollutants associated with such drainage and runoff are silt, nutrients, pesticides, and oxygen-demanding organic materials. Excessive quantities of silt impair the quality of the receiving waters for most uses and often destroy certain desirable forms of aquatic life. Nutrients, particularly nitrogen and phosphorus derived from artificial fertilizers and manure, are commonly present in agricultural drainage and runoff. The practice of spreading manure on frozen soils may result in large amounts of nutrients being carried to streams and lakes during the spring runoff. In excessive amounts, these nutrients promote nuisance growths of algae and other aquatic plants in receiving streams and lakes. Luxuriant growths of these plants often render the water unsuitable for many uses. Pesticides in runoff from agricultural, forest, and urban lands, even in minute amounts, can, through cumulative effects, endanger fish and wildlife and may become toxic to humans. Oxygen-demanding materials, particularly the wastes from livestock and poultry production in confined lots, yards, or buildings, may seriously reduce oxygen concentrations in receiving waters. This, in turn, may result in a level of water quality unsuitable for some uses. While excessive amounts of any or all of the above pollutants may be present in agricultural drainage and runoff, good soil and water conservation practices can be adopted and applied through careful farm management to reduce greatly the amount of these potential pollutants in the agricultural drainage and runoff.

Stream water quality data for the Milwaukee River watershed indicate that agricultural drainage and runoff generally constitute a relatively minor source of organic pollution in the watershed in comparison to the organic pollution caused by municipal and industrial waste discharges. In terms of nutrients, however, drainage and runoff from agricultural and rural areas contribute approximately 30 percent of the total amount of phosphorus discharged to stream waters in the Milwaukee River watershed outside Milwaukee County. Such drainage and runoff, therefore, constitute a major contributor to the problems of overfertilization present in the surface waters of the watershed.

Septic Tanks

All of that portion of the Milwaukee River watershed lying within Milwaukee County is served by a centralized sewerage system; and, therefore, no significant problem of pollution of the stream system from septic tanks exists within Milwaukee County. Of the 54.65 miles of area developed for urban use in the Milwaukee River watershed outside Milwaukee County, 12.24 square miles, or 22 percent, are served by public sanitary sewerage facilities. Approximately 38,160 persons, or 48 percent of the total watershed population outside Milwaukee County, reside in areas served by public sanitary sewerage systems. The remaining 42.41 square miles, or 78 percent of developed urban area, and all of the rural areas within that part of the watershed outside Milwaukee County, containing a combined population of approximately 40,390 persons, or less than 8 percent of the total watershed population, are not presently served by public sanitary sewerage facilities but must rely primarily on individual septic tank soil absorption systems for disposal of domestic wastes. These systems will serve a home satisfactorily if properly located, designed, constructed, and maintained. If any of these aspects are neglected, however, liquid wastes may pollute the ground water or overflow to the ground surface and pollute surface waters. Foul odors, unsightly conditions, and health hazards develop if overflows are ponded on the surface or carried away in open ditches.

Final disposal of the septic tank effluent in a suitable subsurface soil absorption system is necessary to the proper functioning of the system. Approximately 365 square miles, or about 57 percent of the Milwaukee River watershed outside Milwaukee County, are covered by soils having severe limitations for small lot residential development with soil absorption sewage disposal systems. Some urban development has already occurred in these areas. Faulty soil absorption systems can have very significant effects on local water quality conditions in terms of nuisances and health hazards.

Municipal Waste Sources—Upstream from Milwaukee County

There are 14 municipal sewage treatment plants located in the Milwaukee River watershed upstream from the Milwaukee-Ozaukee County line. The locations of these plants are shown on Map 43; and information on the population served by each plant, the average daily sewage flow, the type of treatment provided, and the approximate pollution load in terms of BOD discharged to the streams is tabulated in Table 50. All of the municipal sewage treatment plants within the watershed were designed to provide secondary treatment; but only three plants, those at Campbellsport, West Bend, and Newburg, currently (1967), provide effluent disinfection before discharging the treated wastes to the receiving stream. The Wisconsin Department of Natural Resources, on June 12, 1968, issued orders[11] to all municipalities operating sewage treatment plants in the Milwaukee River watershed requiring the submission by the municipalities of a report and schedule for the construction of adequate sewage treatment facilities in keeping with the State Water Quality Standards and the recommendations of the Lake Michigan Enforcement Conference, including continual disinfection of the effluent and removal of 80 percent of the total phosphorus content of the wastes. The adequacy of the sewage treatment plants in the Milwaukee River watershed for achieving acceptable levels of treatment and the efficiency of the operation of these plants are discussed in a report issued in 1968 by the Wisconsin Department of Natural Resources.[12] The probable capabilities of these plants for removing BOD and the identification of probable operational efficiencies at these plants, as described in this report, are summarized in Table 51.

Urban Runoff Pollution Sources—Upstream from Milwaukee County

Storm water runoff from urban areas can constitute a significant source of water pollution. Recent investigations[13] by the Federal Water Pollution Control Administration of the quality of storm water runoff from urban areas in Cincinnati, Ohio, and Ann Arbor, Michigan, indicate relatively high concentrations of BOD, suspended solids, nutrients, and coliform organisms in the runoff. These findings are supported by studies made elsewhere in the United States and in other countries.[14]

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[11] *a. All effluent discharges to the surface waters of the Lake Michigan Basin must have secondary bio-mechanical treatment or equivalent by December 1972.*

b. All municipalities or industries with a population equivalent of more than 2,500 persons (8,750 pounds of total phosphorus per year) shall remove 85 percent of the total phosphorus on an annual basis.

c. Year-round disinfection of all effluents containing pathogens or their indicator organisms must be provided.

d. A program for separation or control of pollution from combined sewers and those receiving excessive amounts of clear water must be developed, and completion of the project control facilities must be attained by July 1977.

While the Department did not order phosphorus removal for communities under 2,500 population, the Department is not precluded from ordering phosphorus removal where such discharges are causing or may cause overfertilization of surface waters.

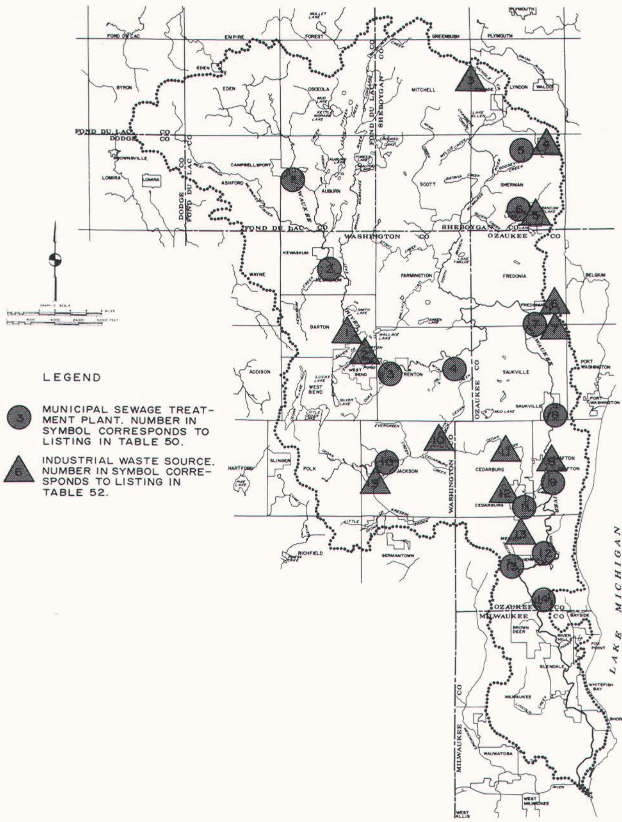
[12] *Wisconsin Department of Natural Resources, Division of Resource Development, Report on an Investigation of the Pollution in the Milwaukee River Basin Made During 1966 and 1967, Madison, Wisconsin, January 23, 1968.*

[13] *See R.J. Anderson, S.R. Weibel, and R.L. Woodward, "Urban Land Runoff As a Factor in Stream Pollution," Journal Water Pollution Control Federation, Vol. 36, No. 7, July 1964; Benzie, Courchaine, "Discharges from Separate Storm Sewers and Combined Sewers," Journal Water Pollution Control Federation, Vol. 38, No. 3, March 1966; and R.J. Burm, G.L. Harlow, and D.F. Krawczyk, "Chemical and Physical Comparison of Combined and Separate Sewer Discharges," Journal Water Pollution Control Federation, Vol. 40, No. 1, January 1968.*

[14] *American Public Works Association, Water Pollution Aspects of Urban Runoff, published by the U. S. Department of the Interior, Federal Water Pollution Control Administration, Research Project No. 120, January 1969.*

Map 43

MUNICIPAL AND INDUSTRIAL WASTE SOURCES IN THE MILWAUKEE RIVER WATERSHED UPSTREAM FROM THE MILWAUKEE COUNTY LINE 1967



Field investigations conducted during the watershed study revealed that a total of 27 major waste sources existed in the watershed above the Milwaukee County line--14 municipal sewage treatment plants and 13 industrial waste discharges. No such waste sources were found in the Milwaukee County portion of the watershed, since all industries and municipalities are connected to a metropolitan sewerage system served by the Milwaukee Jones Island sewage treatment plant located on Lake Michigan. In the upper watershed, the municipal sewage treatment plants constitute collectively the greatest source of stream water pollution in that portion of the watershed.

Source: Harza Engineering Company and Wisconsin Department of Natural Resources.

Although urban storm water runoff may be of poor quality, pollution from this source is usually concentrated in a relatively short period of time and is partially offset by the large amounts of water available for dilution as a result of increased streamflow during storms.

Only 54.65 square miles, or 9 percent of the total watershed area outside Milwaukee County, are occupied by urban land uses; and, therefore, the contribution of urban runoff to pollution of surface waters in the upstream portion of the watershed is relatively minor. Moreover, the SEWRPC public utility inventory indicates that no integrated storm sewerage systems exist outside Milwaukee County and that, increasingly, suburban communities are utilizing rural street sections, ditches, and natural watercourses for urban drainage. Little, if any, definitive data are available about the effect of such drainage systems on the quality of urban runoff; nor do these systems lend themselves as readily as piped storm sewage systems to the application of water quality improvement measures.

Industrial Waste Sources—Upstream from Milwaukee County

Thirteen industries discharged industrial wastes, either continuously or intermittently, to surface waters of the Milwaukee River watershed upstream from the Milwaukee-Ozaukee County line in 1967. The locations of these waste discharges are shown on Map 43, and the source and type of waste and treatment provided are indicated in Table 52. Information on the quantity and quality of these industrial waste discharges is not available.

Nine of the industrial waste discharges listed in Table 52 were identified in 1968 by the Wisconsin Department of Natural Resources as contributing to the pollution of surface waters in the Milwaukee River watershed. Orders were issued to the companies involved to initiate and maintain operating procedures that would result in the control of this pollution as prescribed by the state. These orders require that the Badger Worsted Mills, Inc., Line Material Industries, and the West Bend Company connect to the local municipal sewer systems and that De Soto Chemical Coatings, Inc.; Federal Foods, Inc.; Foremost Foods, Inc.; Kiekhaefer Corporation; Krier Preserving Company; and the River Road Cheese Factory construct adequate waste treatment facilities. As indicated in Table 52, several of these industries have partially or completely complied with the orders issued by the state; and it is anticipated that all of the remaining deficiencies will be corrected by the end of 1970.

Municipal Storm Water, Industrial Waste Sources, and Stream Water Pollution—Milwaukee County

As noted in Chapter I of this volume, the dam at North Avenue provides a sharp break in the hydraulic gradeline of the Milwaukee River, separating the downstream lake estuary from the upstream impoundment and terminating any backwater effects of downstream developments. Unlike for the lake estuary, all water pollution sources, including overflows and discharges from combined sewers, sanitary sewers, storm sewers, and waste water systems of industries, tributary to the stream above the dam, lie entirely within the watershed. The North Avenue Dam, consequently, constitutes a logical cutoff point for all watershed-oriented studies of water quality pollution and control in the Milwaukee River system. No municipal sewage treatment plants discharge effluent to the Milwaukee River below the Milwaukee-Ozaukee County line, all sanitary wastes being collected by a centralized sewerage system connected to the Jones Island and South Shore sewage treatment plants operated by the Sewerage Commission of the City of Milwaukee. Both of these plants discharge effluent directly to Lake Michigan.

Historic Development: Prior to 1840 the Milwaukee area had no sewers. Storm runoff was allowed to flow over the surface of the ground to the nearest watercourse, while domestic wastes were discharged to open gutters running down the center of the streets. These gutters discharged the raw wastes directly to the Milwaukee River or tributaries to the river. Construction of the first sewer in the City of Milwaukee was begun in the late 1840's. It was built of planks under what is now Wisconsin Avenue and extended from the Milwaukee River west to the base of the rise bordering the Milwaukee River Valley near where N. 6th Street is now located. The purpose of this sewer was to rid the area of the sights and smells associated with the open carriage of raw sewage in the center of the street. Since the raw wastes were still to be discharged directly to the river, improvement in the condition of the Milwaukee River was not an objective of this early sewer construction. The river was so dirty in the 1860's that a papermill which had been built at the mouth of the river in 1847 was moved five miles upstream to find cleaner water. In the 1850's and 1860's, numerous small networks of combined sewers were constructed to serve the growing city, each discharging directly to the river.

In 1871 it was decided to build a large sewer to intercept and carry the wastes and storm waters from the combined sewer systems serving the central areas of the City of Milwaukee to Jones

TABLE 50

MUNICIPAL WASTE DISCHARGES IN THE MILWAUKEE RIVER WATERSHED UPSTREAM FROM THE MILWAUKEE COUNTY LINE- 1967

WASTE DISCHARGE (SEWAGE TREATMENT PLANT)	ESTIMATED POPULATION SERVED	AVERAGE DAILY DISCHARGE (MGD)	TREATMENT FACILITIES		ESTIMATED BOD DISCHARGED (LBS./DAY)
			TYPE	EFFLUENT DISINFECTION	
(1) VILLAGE OF CAMPBELLSPORT....	1,590	0.25[a]	ACTIVATED SLUDGE	YES	60[b]
(2) VILLAGE OF KEWASKUM.........	1,800	0.40[a]	ACTIVATED SLUDGE	NO	150[b]
(3) CITY OF WEST BEND...........	15,100	1.60[a]	ACTIVATED SLUDGE	YES	450[b]
(4) NEWBURG SANITARY DISTRICT...	330	0.03[c]	ACTIVATED SLUDGE	YES	10[b]
(5) VILLAGE OF ADELL............	380	0.06[b]	ACTIVATED SLUDGE	NO	15[b]
(6) VILLAGE OF RANDOM LAKE......	950	0.07[b]	TRICKLING FILTER	NO	25[b]
(7) VILLAGE OF FREDONIA.........	900	0.08[b]	ACTIVATED SLUDGE	NO	20[b]
(8) VILLAGE OF SAUKVILLE........	1,200	0.15[b]	TRICKLING FILTER	NO	25[b]
(9) VILLAGE OF GRAFTON..........	5,100	0.42[b]	ACTIVATED SLUDGE	NO	150[b]
(10) VILLAGE OF JACKSON..........	500	0.04[c]	TRICKLING FILTER	NO	16[b]
(11) CITY OF CEDARBURG...........	7,000	1.10[c]	TRICKLING FILTER	NO	165[b]
(12) VILLE DU PARC SUBDIVISION... (MEQUON)	120	-- d	EXTENDED AERATION	--d	1[e]
(13) VILLAGE OF THIENSVILLE......	3,000	0.56[f]	ACTIVATED SLUDGE	NO	150[e]
(14) LAC DU COURS SUBDIVISION.... (MEQUON)	190	-- d	EXTENDED AERATION	--d	1[e]

[a] SEWAGE TREATMENT PLANT OPERATOR'S REPORT, ON FILE WITH THE WISCONSIN DEPARTMENT OF NATURAL RESOURCES, MADISON, WISCONSIN.

[b] REPORT ON AN INVESTIGATION OF THE POLLUTION IN THE MILWAUKEE RIVER BASIN MADE DURING 1966 AND 1967, WISCONSIN DEPARTMENT OF NATURAL RESOURCES, DIVISION OF RESOURCE DEVELOPMENT, MADISON, WISCONSIN JANUARY, 1968.

[c] SEWAGE TREATMENT PLANT OPERATION AND MAINTENANCE PRACTICES QUESTIONNAIRE, FEDERAL WATER POLLUTION CONTROL ADMINISTRATION, CHICAGO, ILLINOIS.

[d] NO DATA AVAILABLE.

[e] THE MILWAUKEE RIVER, AN INVENTORY OF ITS PROBLEMS, AN APPRAISAL OF ITS POTENTIALS, MILWAUKEE RIVER TECHNICAL STUDY COMMITTEE, 1968.

[f] WATER SUPPLY AND WATER QUALITY CONTROL STUDY, WAUBEKA RESERVOIR, MILWAUKEE RIVER BASIN, WISCONSIN, UNITED STATES PUBLIC HEALTH SERVICE, REGION V, CHICAGO, ILLINOIS, OCTOBER, 1965.

SOURCE- HARZA ENGINEERING COMPANY.

TABLE 51

CAPABILITIES AND OPERATIONAL EFFICIENCIES OF MUNICIPAL SEWAGE TREATMENT PLANTS UPSTREAM FROM MILWAUKEE COUNTY IN THE MILWAUKEE RIVER WATERSHED[a] 1964-1967

NAME OF SEWAGE TREATMENT PLANT	PERCENT EFFICIENCY IN BOD REMOVAL FROM RAW WASTE[b]			COMMENTS
	SURVEYED DATE	PERFORMANCE PERCENT	PROBABLE CAPABILITY PERCENT	
ADELL	--	--	--	NEW PLANT BEGAN OPERATION IN 1964. NO FLOW EXISTS IN RECEIVING WATERCOURSE EXCEPT DURING PERIODS OF STORM WATER RUNOFF.
CAMPBELLSPORT	11/30/64 12/01/64	43.0	90	PLANT ENLARGED IN 1963. RECEIVES FILTERED WASTE FROM MILK PROCESSING PLANT.
CEDARBURG	7/20/67 7/21/67	78.5	--	PLANT ENLARGED IN 1962.
FREDONIA	11/22/66 11/23/66	55.0	90	PLANT ENLARGED IN 1962. RECEIVES WASTE FROM CHEMICAL COATINGS INDUSTRY.
GRAFTON	9/21/66 9/22/66	60.0	90	REMOVAL OF SUSPENDED SOLIDS WAS INADEQUATE.
JACKSON	8/23/66 8/24/66	72.0	--	CAPABILITY OF PLANT TO PROVIDE MORE TREATMENT NOT JUDGED OR DETERMINED.
KEWASKUM	9/26/66 9/27/66	69.0	90(+)	RECEIVES WASTES OF SLAUGHTERING, MILK PROCESSING, AND MALT PRODUCTION.
LAC DU COURS	--	--	--	PLANT ABANDONED, AND SEWERS OF SUBDIVISION WERE CONNECTED TO SYSTEM OPERATED BY THE SEWERAGE COMMISSION OF THE CITY OF MILWAUKEE IN 1968.
NEWBURG	--	95.0[c]	--	NEW PLANT BEGAN OPERATION IN 1965.
RANDOM LAKE	9/27/66 9/28/66	90.0	--	NO FLOW EXISTS IN RECEIVING WATERCOURSE EXCEPT DURING PERIODS OF STORM WATER RUNOFF.
SAUKVILLE	11/21/63 11/22/63	86.0	--	PLANT BEGAN OPERATION IN 1959.
THIENSVILLE	7/20/66 7/21/66	87.0	--	IMPROVEMENTS MADE IN 1963.
VILLE DU PARC	--	--	--	PLANT ABANDONED AND SEWERS OF SUBDIVISION WERE CONNECTED TO SYSTEM OPERATED BY THE SEWERAGE COMMISSION OF THE CITY OF MILWAUKEE IN 1968.
WEST BEND	--	--	--	NEW PLANT BEGAN OPERATION IN 1966.

[a] SOURCE OF DATA, UNLESS OTHERWISE NOTED, IS A REPORT ON AN INVESTIGATION OF THE POLLUTION IN THE MILWAUKEE RIVER BASIN MADE DURING 1966 AND 1967, WISCONSIN DEPARTMENT OF NATURAL RESOURCES, DIVISION OF RESOURCE DEVELOPMENT, MADISON, WISCONSIN, JANUARY 23, 1968.

[b] EFFICIENCY OF REMOVAL OF BOD IS A MEASURE OF THE PERCENT OF OXYDIZABLE MATTER THAT IS REMOVED FROM THE RAW SEWAGE WHICH ENTERS THE PLANT DURING THE TREATMENT PROCESS.

[c] FEDERAL WATER POLLUTION CONTROL ADMINISTRATION, SEWAGE TREATMENT PLANT OPERATION AND MAINTENANCE PRACTICES QUESTIONNAIRE, NOVEMBER, 1967.

SOURCE- WISCONSIN DEPARTMENT OF NATURAL RESOURCES AND HARZA ENGINEERING COMPANY.

TABLE 52

INDUSTRIAL WASTE DISCHARGES IN THE MILWAUKEE RIVER WATERSHED UPSTREAM FROM THE MILWAUKEE COUNTY LINE- 1967[a]

INDUSTRIAL WASTE SOURCE	LOCATION	PRODUCT	TYPE OF WASTE	TREATMENT PROVIDED	LOCATION OF DISCHARGE	REMARKS[b]
(1) LINE MATERIAL INDUSTRIES MC GRAW EDISON COMPANY	OLD BARTON AREA WEST BEND	PITCH IMPREGNATED FIBER PIPE	PROCESS WATER WITH PUMP AND OIL WASTES	PRETREATMENT OF INDUSTRIAL PROCESSING WATER	TO WEST BEND MUNICIPAL SEWERS[c]	COOLING WATER IS DISCHARGED TO MILWAUKEE RIVER[c]
(2) THE WEST BEND COMPANY	WEST BEND	COOKING UTENSILS AND SMALL ELECTRICAL APPLIANCES	WASTE WATER FROM UTENSIL WASHING	NONE AT PLANT	TO WEST BEND MUNICIPAL SEWERS[c]	COOLING WATER IS DISCHARGED TO MILWAUKEE RIVER[c]
(3) PASSINI CHEESE COMPANY, INC.	RT 2, PLYMOUTH	CHEESE	PROCESS WATER FROM CHEESE	SEPTIC TANKS, LAGOON	NORTH BRANCH OF MILWAUKEE RIVER	OPERATIONS DISCONTINUED IN 1967
(4) FOREMOST FOODS, INC.	ADELL	DRIED WHEY	WASH WATER AND CONDENSATE	AERATED LAGOON	ADELL TRIBUTARY	COOLING WATER IS DISCHARGED DIRECTLY TO ADELL CREEK[d]
(5) THE KRIER PRESERVING COMPANY	RANDOM LAKE	CANNING--CORN, PEAS, AND JUICE	CANNING	CANNING WASTES SCREENED AND IRRIGATION AND JUICE PRODUCTS TO MUNICIPAL SEWAGE TREATMENT PLANT	SILVER CREEK (SHERMAN TOWNSHIP)	DURING THE 1966-1967 SURVEY THERE WAS A NEED FOR DEVELOPING MORE IRRIGATION AREA.
(6) RIVER ROAD CHEESE FACTORY	RT 1, FREDONIA	CHEESE	PROCESS WASTE FROM CHEESE	SEPTIC TANK, LAGOON	TRIBUTARY TO MILWAUKEE RIVER NEAR FREDONIA	DURING THE 1966-1967 SURVEY, THIS PLANT WAS RATED A BORDERLINE POLLUTION PROBLEM AT THE LEVEL OF OPERATION THEN PRACTICED.
(7) DE SOTO CHEMICAL COATINGS, INC.	FREDONIA	CLEANING COMPOUNDS AND WAXES	WASH WATER FROM TANKS AND EQUIPMENT	HOLDING TANK AND SETTLING LAGOON AT THE PLANT	MUNICIPAL SEWER SYSTEM, FREDONIA	FLOW FROM HOLDING TANK AND LAGOON MUST BE CAREFULLY REGULATED TO PREVENT SHOCK LOADINGS TO MUNICIPAL SYSTEM.
(8) BADGER WORSTED MILLS, INC	GRAFTON	DYED YARN PROCESSED FROM WOOL AND SYNTHETIC FIBER	WASTE WATER FROM DYEING OPERATIONS	NONE	MILWAUKEE RIVER[e]	--
(9) LIBBY, MC NEILL, AND LIBBY	JACKSON	CANNING--SAUERKRAUT AND CARROTS	WASH WATER AND BRINES	SCREENED AND IRRIGATED IN SUMMER AND LAGOONED IN WINTER	SEEPAGE TO GROUND IN SUMMER AND TO CEDAR CREEK IN WINTER	--
(10) LEVEL VALLEY DAIRY	RT 1, WEST BEND	BUTTER AND BUTTERMILK	WASH WATER	AERATION, LAGOON	NORTH BRANCH CEDAR CREEK	TREATMENT FACILITIES WERE NEARLY CONSTRUCTED IN 1967.
(11) JUSTRO FEED CORPORATION	CEDARBURG	ANIMAL FOOD FROM PACKING HOUSE BY PRODUCTS	ANIMAL FOOD	LAGOONS, THREE IN SERIES	SEEPAGE TO GROUND	--
(12) KIEKHAEFER CORPORATION	CEDARBURG	OUTBOARD BOAT MOTORS AND STEM-DRIVES AND DYE CASTING	MOTOR TEST WATER AND COOLING WATER	GRAVITY OIL SEPARATORS	CEDAR CREEK	TWO PLANTS WITH ONE DISCHARGING COOLING WATER FROM DIE CASTING OPERATIONS, VIA STORM SEWER, TO POND OF RUCK DAM AND ONE OCCASIONALLY DISCHARGING MOTOR TEST WASTE WATER VIA STORM SEWER TO CEDAR CREEK DOWNSTREAM FROM RUCK DAM. GASOLINE AND OIL ODORS WERE A PROBLEM AT TIME OF 1966-67 SURVEY
(13) FEDERAL FOODS, INC.	THIENSVILLE, BOX K	FROZEN, CANNED, AND DRY ANIMAL FOODS FROM CEREALS, ANIMAL BY PRODUCTS, FISH, AND POULTRY BY PRODUCTS.	PRODUCT WASTES AND COOLING WATER.	SEPTIC TANKS WHICH DISCHARGE TO A SWAMP.	PIGEON CREEK	ODORS WERE A PROBLEM AT THE TIME OF 1966-67 SURVEY.

[a] INFORMATION BASED ON A SURVEY PUBLISHED AS, REPORT ON AN INVESTIGATION OF THE POLLUTION IN THE MILWAUKEE RIVER BASIN MADE DURING 1966 AND 1967, DEPARTMENT OF NATURAL RESOURCES, DIVISION OF RESOURCE DEVELOPMENT, MADISON, WISCONSIN JANUARY 23, 1968, EXCEPT AS NOTED.

[b] SOME DEFICIENCIES IN WASTE WATER TREATMENT NOTED WILL HAVE BEEN CORRECTED BY THE TIME THIS REPORT IS PUBLISHED.

[c] BASED ON INFORMATION OBTAINED FROM OPERATOR OF SEWAGE TREATMENT PLANT. CONNECTED TO MUNICIPAL SYSTEM IN 1968 AND 1969.

[d] BASED ON ADDITIONAL INFORMATION RECEIVED FROM THE WISCONSIN DEPARTMENT OF NATURAL RESOURCES, DIVISION OF ENVIRONMENTAL PROTECTION.

[e] CONNECTED TO MUNICIPAL SYSTEM IN 1969.

SOURCE- WISCONSIN DEPARTMENT OF NATURAL RESOURCES AND SEWRPC.

Island for discharge directly and without treatment to Lake Michigan. This first intercepting sewer was completed in 1886. The sewage and industrial wastes from the remaining outlying areas of the city and its rapidly developing suburbs were still discharged directly and without treatment through the growing combined sewer system into the three rivers that flow through the city. By the late 1870's, the pollution carried by these rivers through the heart of the city created an almost unbearable nuisance.

In 1879 a report was prepared recommending the construction of a tunnel to bring water from Lake Michigan to the Milwaukee River for the purpose of flushing the river to improve its condition during times of low flow. The tunnel was completed in 1888. This tunnel discharges water drawn from Lake Michigan into the Milwaukee River immediately below the North Avenue Dam. The lake water provided through the tunnel served to dilute the polluted river water, to supply dissolved oxygen to the river to reduce the odor nuisance, and to move the polluted river water through the downtown area into the lake. Although the flushing, which is still practiced today, did alleviate the worst nuisance effects of the polluted river, it provided no health protection.

It soon became apparent that operation of the flushing tunnel created a problem of pollution of the city water supply by conveying severely polluted river water more directly to the lake in large flows. The city slowly recognized this potential danger to the water supply and public health. After a bad outbreak of typhoid fever in the city in 1913, the City of Milwaukee sought and obtained the enactment of State Legislation providing for the creation of the Sewerage Commission of the City of Milwaukee and charging that Commission with the duty of collecting, transmitting, and disposing of the sewage from the city in a safe manner.

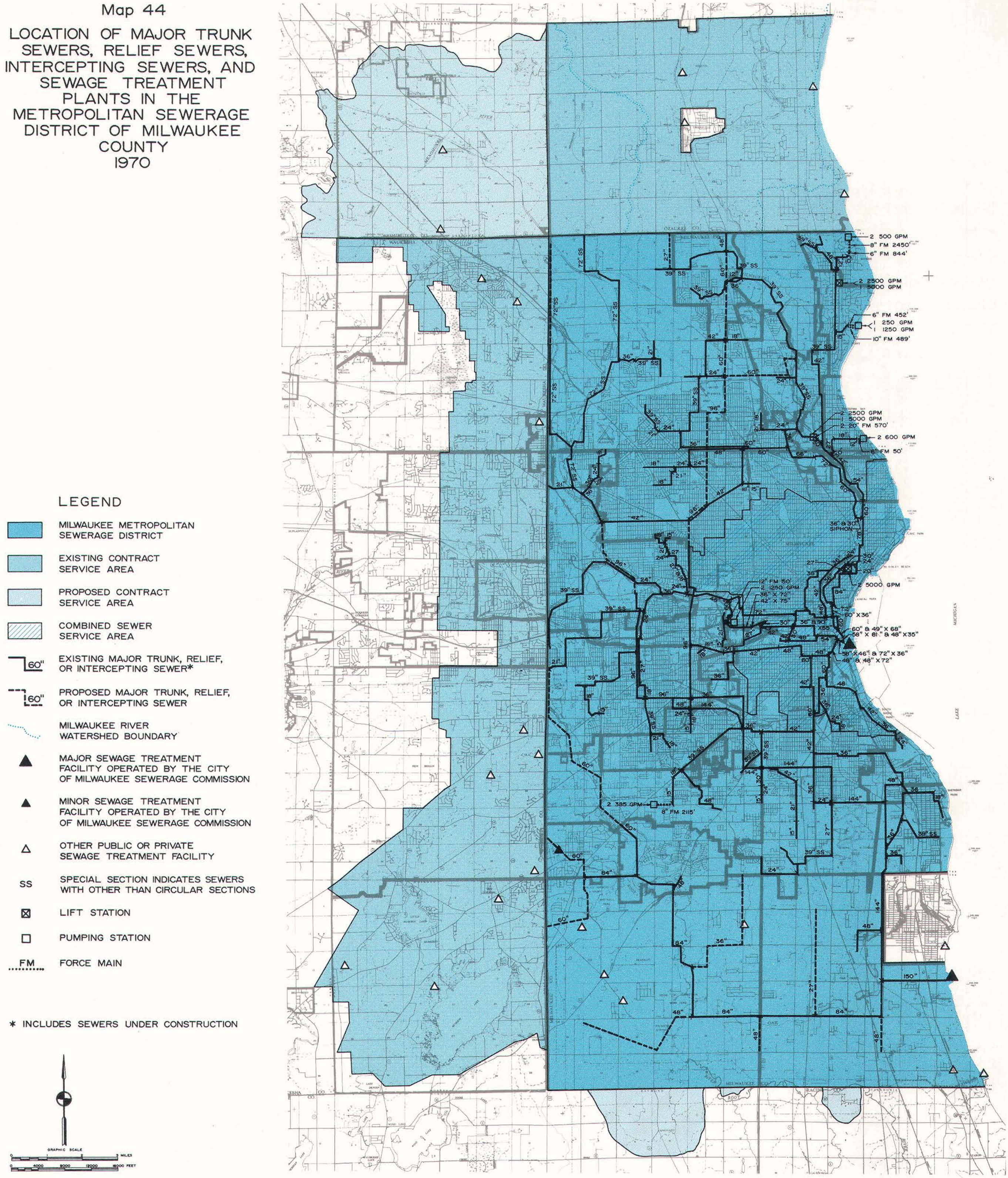
This Commission undertook the construction of an extensive intercepting sewer system and a sewage treatment plant located on Jones Island. Operation of the treatment plant, one of the first large-scale, activated sludge-type plants in the United States, began in 1925. It was also decided that, in all newly developing areas of the City of Milwaukee, separate sewer systems should be built for the collection and conveyance of sanitary sewage and storm water rather than to continue to extend the combined sewer systems that had been built in the past. Thus, the last extensions to the combined sewer system in the Milwaukee area were made in the mid-1920's. Although areas developed for urban use since then are served by separate sewer systems, most of the area that was sewered prior to the mid-1920's is still served by the combined systems. Intercepting sewers were built along the Milwaukee River in areas served by the combined systems to intercept the normal dry-weather flow of sanitary wastes, as well as a portion of the storm flows, and to convey these to the sewage treatment plant. Excess flows during storm periods, however, were and still are discharged directly to the river.

It soon became apparent that, if water pollution was to be abated in the Milwaukee area, an intercepting and trunk sewer system would have to be developed which could collect sewage from all communities in the immediate drainage area and convey them to the Jones Island plant for treatment prior to discharge, since upstream pollution of the rivers by suburban communities would perpetuate the very problem that the proposed intercepting sewers and the sewage treatment plant constructed by the City of Milwaukee were intended to eliminate. Thus, in 1921 State Legislation was sought and obtained, which created the Metropolitan Sewerage Commission of the County of Milwaukee and defined its service area as those portions of Milwaukee County lying within the Milwaukee, Menomonee, and Kinnickinnic River drainage areas. The Commission was charged with the duty and function of constructing trunk sewers outside the City of Milwaukee, but within the same drainage basin, to transport the sewage from the various suburban districts to the intercepting sewer system of the city and then to the treatment facilities. Subsequent legislation empowered the Commissions to enter into contracts with municipalities to provide service to drainage areas tributary to the metropolitan sewerage district. In 1959 State Legislation was obtained permitting the enlargement of the metropolitan sewerage district to include all of Milwaukee County. Today all of Milwaukee County, except the City of South Milwaukee, which elected to remain separated, is serviced by the trunk sewer system of the metropolitan sewerage district, as are certain areas of Ozaukee and Waukesha Counties.

Basic Features of the Sewerage System in Milwaukee County: The sewerage system of the Metropolitan Sewerage District of the County of Milwaukee is planned, constructed, operated, and maintained through its two operating agencies: the Metropolitan Sewerage Commission of the County of Milwaukee and the Sewerage Commission of the City of Milwaukee. At present, there are two major plants treating sewage from a system that serves a resident population in excess of 1 million persons in a service area of about 353 square miles. Of this total, 53.89 square miles, or 15 percent, are located within the Milwaukee River watershed. Map 44 shows the location of the two metropolitan sewage treatment plants and the main and intercepting sewers comprising the sewerage system.

Map 44

LOCATION OF MAJOR TRUNK SEWERS, RELIEF SEWERS, INTERCEPTING SEWERS, AND SEWAGE TREATMENT PLANTS IN THE METROPOLITAN SEWERAGE DISTRICT OF MILWAUKEE COUNTY 1970



Most residents of the lower watershed and, indeed, the entire Milwaukee metropolitan area now take for granted the extensive sewer system and sewage treatment facilities constructed by the joint Milwaukee-Metropolitan Sewerage Commissions subsequent to severe outbreaks of typhoid fever within the Milwaukee area in the early part of this century. Until the mid-1920's, no treatment of sanitary sewage was provided at all in the Milwaukee area, with the raw sewage being discharged directly to watercourses. Since that time the joint Commissions have constructed two large sewage treatment plants, having a combined existing capacity of 320 million gallons per day, and an extensive system of main, relief, and intercepting sewers. When the current construction program is completed, it is expected that all discharges of raw sewage originating in the separate sewered area to watercourses will have been eliminated.

Source: Milwaukee - Metropolitan Sewerage Commissions and SEWRPC.

Sanitary sewer service in the District is provided by two types of sewer systems: separate and combined. The separate, or sanitary sewer, systems are designed to carry only liquid wastes, termed sanitary waste waters, from residences and commercial, industrial, and institutional buildings, together with relatively minor quantities of ground, storm, and surface waters that are not intentionally admitted to the system. The combined sewer systems are designed to carry both sanitary and storm or surface waters and are not only connected to buildings but also to street catch basins and inlets. Storm water runoff in the separately sewered areas is conveyed by a separate storm sewer system directly to the streams or to the lake. All flow in the separate sanitary sewers, the service area of which constitutes 82 percent of the total sewered area in the district, but 90 percent of the sewered area within the Milwaukee River watershed, is conveyed directly to the two treatment plants through the trunk sewers. During periods of high ground water levels and sustained rainfall, when excessive amounts of extraneous flow may enter the sanitary sewer system causing serious surcharging, relief pumping stations, portable pumps, and gravity bypasses may discharge sewage from the separate system directly to storm sewers and watercourses.

All flow in the combined sewers is conveyed through intercepting sewers to the Jones Island treatment plant, except when there is significant runoff from rainfall or snowmelt. Control devices, similar to that shown in Figure 35, pass the dry-weather-sanitary flow from the combined sewers to the intercepting sewers and then to the treatment plant. When the runoff from rainfall or snowmelt exceeds 0.01 inch per hour,[15] the additional flow generally bypasses the control devices and is discharged directly to the streams or to Lake Michigan.

Normally all sewage conveyed to the Jones Island plant is given secondary treatment. The two siphons which convey all flow to the plant have a capacity of 300 mgd. The activated sludge treatment plant has a rated capacity of 200 mgd, with treatment efficiency decreasing during periods of sustained greater flows. To maintain overall plant efficiency, the plant is provided with an overflow facility, which permits the bypassing of excess sewage flows to the harbor. Prior to such bypassing, the bypassed sewage is given rough screening.

The South Shore sewage treatment plant began operation in 1968 and is presently providing only primary treatment and chlorination. Trunk sewers

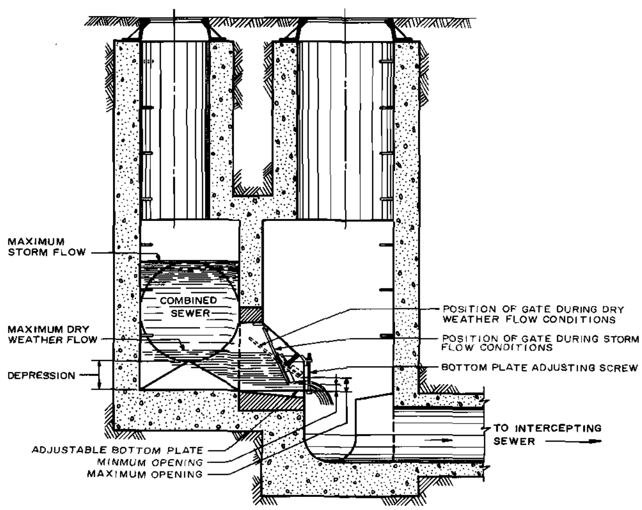
[15] *Walter E. Kroening, Senior Engineer, Sewerage Commission of the City of Milwaukee, The Design, Operation, and Maintenance of Combined Sewage Intercepting Structures, undated report.*

Overflows contributed from separate sanitary sewers to streams in the lower Milwaukee River watershed are estimated to average about 7.5 million gallons per day, or about 2.73 billion gallons annually. These overflows create very intense, short-term shock effects in the receiving streams. Much of this raw sewage comes to the streams through large storm sewers, such as the twin double-box storm conduits shown in the photo at left, located near N. 35th Street and Lincoln Creek in the City of Milwaukee. The middle photo, taken from the top edge of one of the conduits, shows the visual contrast in the waters entering the Creek, indicating the probable discharge of raw sewage to the storm water. Raw sanitary sewage can enter these storm sewers at a number of relief points upstream. The photo at right, taken near the storm sewer outlet at left, shows the extent of concern by local public health officials over the polluted condition of Lincoln Creek.

SEWRPC Photos

Figure 35

TYPICAL FLOW INTERCEPTING DEVICE
COMBINED SEWER AREA MILWAUKEE COUNTY



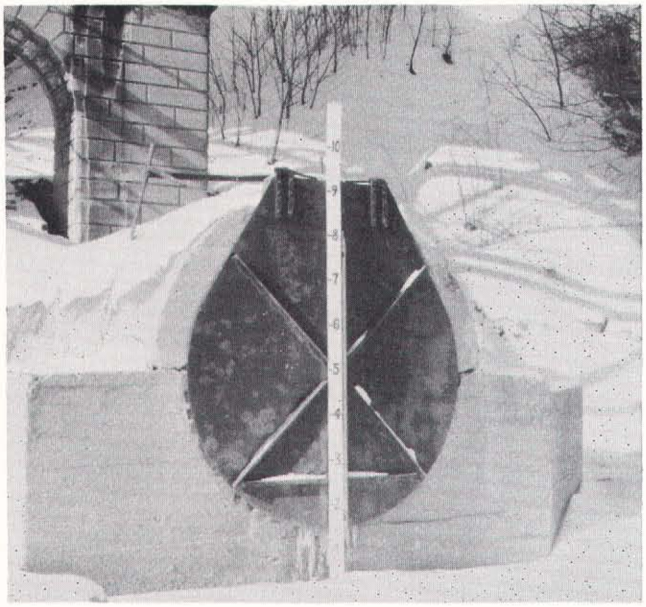
VERTICAL CROSS SECTION
VIEWED UPSTREAM

Source: Sewerage Commission of the City of Milwaukee.

connected to the new plant have been constructed to the vicinity of S. 60th Street and W. National Avenue, and a program of trunk sewer extension is being vigorously pursued. With the completion of this trunk sewer construction program and the scheduled operation in 1972 of 120 mgd of secondary treatment capacity at the South Shore plant, this new plant should be capable of treating sewage flows from all of the Milwaukee urbanized area lying west of 60th Street and east of the subcontinental divide. At that time the loading on the Jones Island plant and the frequency of bypassing at the Jones Island Plant will be greatly reduced. The sewers at junction points between the older sewers and the new trunk sewers are being designed to permit selective routing of sewage from most points in the metropolitan system to either the Jones Island or the South Shore plants, thus utilizing the full capacity of the plants at all critical times.

Sewer Overflow Points: The number and location of all known points in the Milwaukee River watershed and the City of Milwaukee outside the watershed at which combined sewage is discharged directly to streams or to Lake Michigan or at which sanitary sewage is discharged either directly to streams or the lake or indirectly via separate storm sewer systems are summarized in Table 53, and detailed listings are presented in Appendix H. As already noted, no areas in the Milwaukee River watershed outside Milwaukee County are known to be presently served by combined sewers. The total area within Milwaukee County presently served by combined sewers is approximately 17,200 acres, of which 5,800 acres lie within the Milwaukee River watershed and are tributary to the Milwaukee River. The remaining 11,400 acres lie in the Kinnickinnic and Menomonee River watersheds or are directly tributary to Lake Michigan. The only portion of the Milwaukee River watershed that is served by a combined sewer system lies within the City of Milwaukee and the Village of Shorewood. Of the 5,800 acres of combined sewer service area in the Milwaukee River watershed, approximately 2,100 acres are tributary to the Milwaukee River upstream from the North Avenue Dam. The approximate boundaries of the service areas of the combined sewers and the Milwaukee River watershed boundary which divides the total combined sewer service area are shown on Map 45. There are a total of 112 combined sewer outfalls in the Milwaukee metropolitan area from which mixed sewage and storm-water flows are discharged directly to river and lake waters. Sixty-two of these outfalls discharge to the Milwaukee River system between Capitol Drive and the mouth of the river. Of these 62 outfalls, 10 discharge to the river system above the North Avenue Dam, 43 discharge to the river between the North Avenue Dam and the mouth of the Menomonee River, and 9 discharge to the river below the mouth of the Menomonee River. The locations of the 62 combined sewer outfalls that discharge to the Milwaukee River system are shown on Map 46 and are listed in Appendix H.

There are 186 known relief discharge points where sanitary sewage or mixtures of sanitary sewage and storm water are discharged during periods of sewer surcharge either directly to surface waters or indirectly to such waters via the storm sewer system within the watershed and the City of Milwaukee outside the watershed. These relief points consist of gravity-flow crossovers from the sanitary to the storm sewer system, portable pumping stations at which sanitary sewage is discharged to storm sewers or directly to surface water, and permanent pumping stations at which sanitary sewage is discharged to storm sewers or directly to surface waters. Of the 186 known relief discharge points other than the combined sewer outfalls, where untreated sewage may be discharged to surface water in the watershed and the City of Milwaukee outside the watershed either directly or via the storm sewer system, 91 discharge within the boundaries of the Milwaukee River watershed. The location and type of bypass and



Combined sewer overflows, which discharge directly to the Milwaukee River at sixty-two locations in the watershed, have a frequent, severe, adverse impact on the water quality of the Milwaukee River. This large combined sewer outfall, located on the Milwaukee River beneath the Locust Street bridge in the City of Milwaukee, is 78 inches in diameter and can discharge raw sewage to the River at rates in excess of 100,000 gallons per minute. This outfall is one of the smaller outfalls along the banks of the Milwaukee River. Other outfalls range in size from 12 inches in diameter up to a twin conduit having two barrels each, 9 feet by 4-½ feet in size. It is estimated that the combined sewers overflow and discharge a mixture of storm water and raw sanitary sewage to the waterways in the Milwaukee area an average of 52 times a year. One of the major objectives of the watershed study is to explore alternative means of abating this source of water pollution and recommend a method for solving this problem not only in the 5,800 acre combined sewer service area of the Milwaukee River watershed but throughout the entire 17,200 acre combined sewer service area in Milwaukee County.

SEWRPC Photo

TABLE 53

KNOWN COMBINED SEWER OUTFALLS AND FLOW RELIEF FEATURES IN THE MILWAUKEE RIVER WATERSHED AND IN THE CITY OF MILWAUKEE OUTSIDE THE WATERSHED-1967

LOCATION	COMBINED SEWER OUTFALLS[b]	FLOW RELIEF FEATURES[b]			
		CROSSOVERS	BYPASSESS	RELIEF PUMPING STATIONS	PORTABLE PUMPING STATIONS
IN THE MILWAUKEE RIVER WATERSHED					
UPSTREAM FROM NORTH AVENUE DAM............	10	59	6	7	13
NORTH AVENUE DAM TO MENOMONEE RIVER.......	43	0	3	0	0
MENOMONEE RIVER TO MOUTH OF MILWAUKEE RIVER....	9	0	3	0	0
SUBTOTAL	62	59	12	7	13
IN THE MENOMONEE, KINNICK-INNIC AND LAKE MICHIGAN DRAINAGE AREAS[c].............	50	57	10	4	24
TOTAL	112	116	22	11	37

[a]NO COMBINED SEWER OUTFALLS OR FLOW RELIEF FEATURES WERE FOUND IN THE WATERSHED INVENTORY UPSTREAM FROM THE MILWAUKEE COUNTY LINE.

[b]TERMS USED ARE DEFINED IN APPENDIX H.

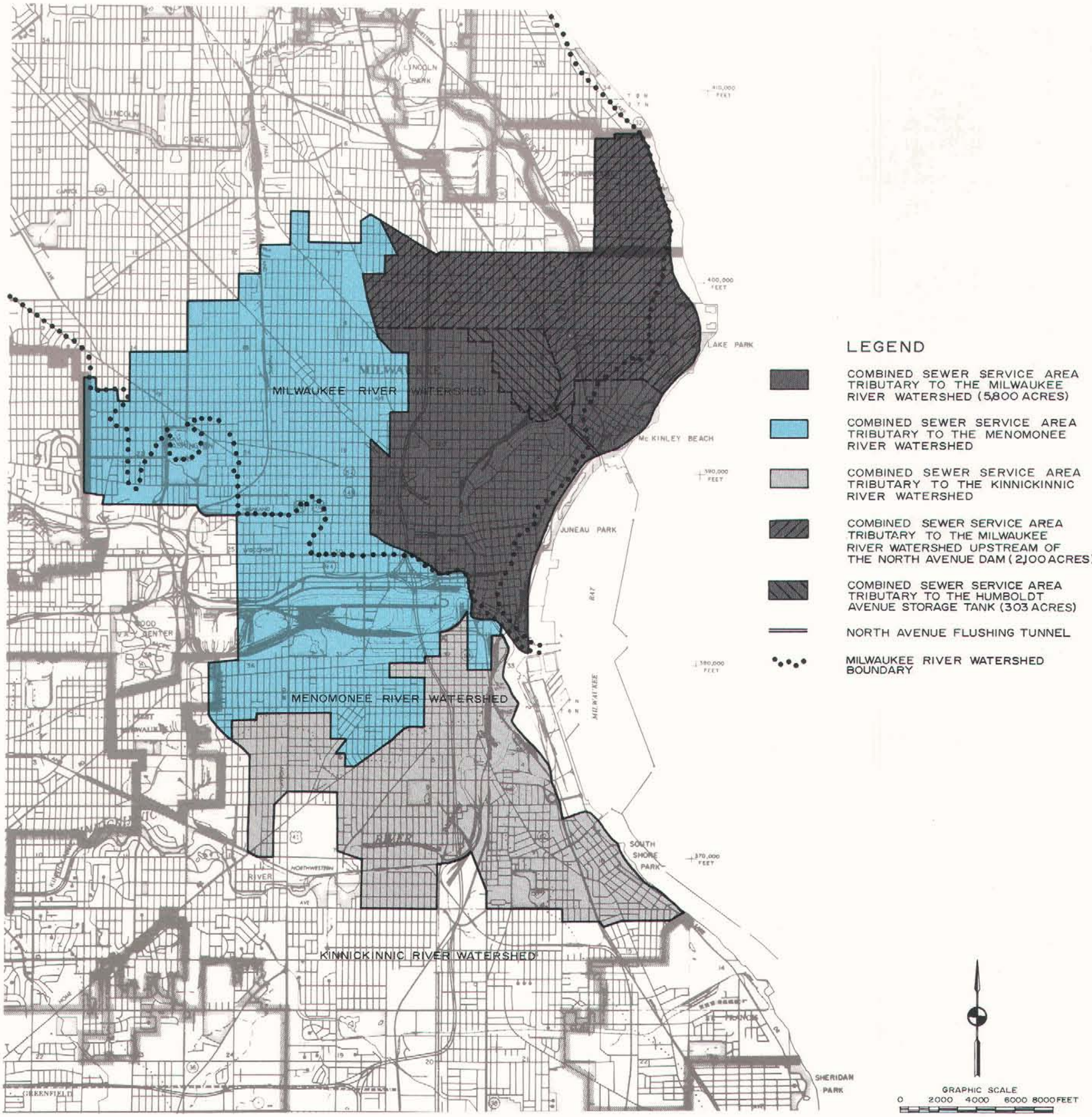
[c]CITY OF MILWAUKEE SEWERAGE SYSTEM ONLY.

SOURCE- CITY OF MILWAUKEE BUREAU OF ENGINEERING AND THE SEWERAGE COMMISSION OF THE CITY OF MILWAUKEE.

Map 45

COMBINED SANITARY AND STORM SEWER SERVICE AREAS IN MILWAUKEE COUNTY

1967



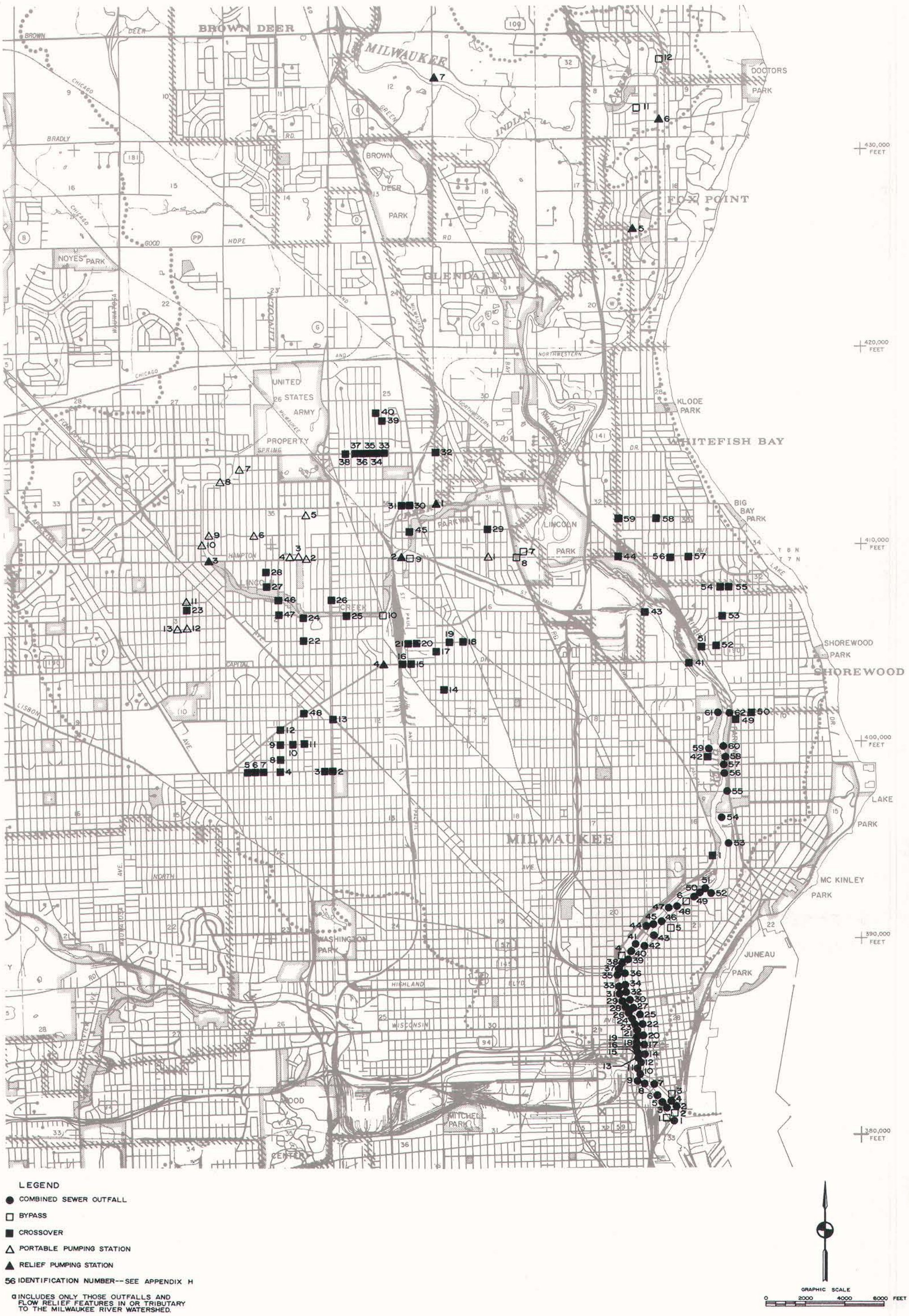
Until the mid-1920's, all development in the Milwaukee area was designed to be served by combined sanitary storm sewers, which sewers discharged directly to watercourses. Most of this area, totaling about 17,200 acres, is still served by the combined systems today. Intercepting sewers have been built in this area to intercept the normal dry-weather flow of sanitary wastes in the combined sewers, as well as a portion of the storm flows, and convey these flows to the Jones Island sewage treatment plant. Excess flows during storm periods, consisting of raw sanitary sewage and storm water, are discharged to watercourses an average of 52 times per year. A total of 62 combined sewer outfalls, serving a 5,800 acre combined sewer service area in the Milwaukee River watershed, discharge directly to the Milwaukee River.

Source: Milwaukee-Metropolitan Sewerage Commissions and City Engineer, City of Milwaukee.

Map 46

KNOWN COMBINED SEWER OUTFALLS AND FLOW RELIEF FEATURES IN THE MILWAUKEE RIVER WATERSHED[a]

1967



Of the 112 combined sewer outfalls which exist in the Milwaukee metropolitan area, 62 discharge to the Milwaukee River between Capitol Drive and the mouth of the River. Of the 186 known relief discharge points on the separate sanitary sewerage system in the metropolitan area, 91 discharge within the boundaries of the Milwaukee River watershed, including 59 crossovers, 12 bypasses, 7 relief pumping stations, and 13 portable pumping stations. These sewer overflow points, which discharge raw sewage to the Milwaukee River system, presently constitute the singularly greatest source of stream water pollution in the lower watershed. One important objective of the Milwaukee River watershed study is to recommend a plan for the alleviation of the pollution caused by sewer overflows to the Milwaukee River.

Source: City of Milwaukee Bureau of Engineering and Sewerage Commission of the City of Milwaukee.

the initial receiving stream for bypassed flows for these 91 relief points are listed in Appendix H. The location of these relief points is indicated on Map 46.

Program for Control of Overflow from Sewers: One important objective of the Milwaukee River watershed study is to recommend a plan for the alleviation of pollution caused by sewer overflows along the Milwaukee River. This objective is given added importance and urgency by the fact that the Secretary of the U. S. Department of the Interior in 1968 convened an interstate conference at Chicago to consider the matter of pollution of the waters of Lake Michigan and its tributary basin. The conferees, which included the State of Wisconsin, agreed upon, and the Secretary of the Interior approved, a recommendation that continual disinfection be provided for all sanitary wastes by 1969; that adequate biological treatment be provided for all of the flow of sanitary sewers by 1972; and that pollution from combined sewers be abated by 1977.

Characteristics of Overflow from Combined Sewers: There is little definitive data available on the amount and character of combined sewer overflows. In a report[16] prepared by the U. S. Public Health Service, it was noted that the average overflow from a combined sewer system may contain from 3 to 5 percent raw sewage and that, during storm peaks, as much as 95 percent of the sanitary sewage in the combined sewer may overflow directly to the receiving stream. In a report[17] prepared in 1957, it was estimated that the combined sewers overflow and discharge a mixture of storm water and raw sanitary sewage to the waterways in the Milwaukee area an average of 56 times a year. That report, however, did not contain any information on the quality of the overflows. Several sewage flow monitoring stations have been constructed in a 570-acre combined sewer service area in the City of Milwaukee. These stations, however, did not become fully operational until July 1969 and, consequently, could provide little data to this study on the quality and quantity of the combined sewer overflows to the Milwaukee River.

Review of the estimate of the frequency of occurrence of overflows from the combined sewers in the Milwaukee area referred to above indicates the estimate to be reasonable. Analysis of rainfall records for a 16-year period, extending from 1949 to 1964 made by the Harza Engineering Company as a part of a similar study in the Chicago area,[18] indicated that an average of 52 rainfall-runoff events could be expected per year. This is the average of some 837 runoff events in excess of the initial rainfall retention capacity.[19]

An indication of the quality of overflows from combined sewers serving an urban area similar to the Milwaukee metropolitan area may be gained by examining the results of studies[20] conducted on overflows in the City of Detroit. The area studied in Detroit consists of residential, commercial, and heavily industrialized areas, as does the combined sewer area in Milwaukee. The results of the studies, in terms of mean concentrations of various constituents in the overflows, are presented in Table 54, together with concentrations of the same parameters in a typical sanitary sewage. The results of laboratory analyses made of "grab" samples collected during periods of overflow from combined sewers in the Milwaukee area are tabulated in Table 55. The results of these analyses,

[16] *Public Health Service Publication No. 1246, Pollutional Effects of Stormwater and Overflows from Combined Sewer Systems, Washington, D. C., 1964.*

[17] *Alvord, Burdick, and Howson, Consulting Engineers, Report on Reduction of Pollution from Sanitary and Combined Sewers, Metropolitan Sewerage District, Milwaukee, Wisconsin, 1957.*

[18] *Hydrologic analyses made as a part of the Southeastern Wisconsin Regional Planning Commission Root River watershed planning program demonstrated that rainfall frequencies and intensities are similar in the Chicago and Milwaukee areas, and data on such frequencies and intensities may be used interchangeably for evaluations of this type.*

[19] *On impervious areas 0.06 inch of rainfall is estimated to be required to satisfy initial rainfall retention and 1.25 inches on pervious areas.*

[20] *See R.J. Burm and R.D. Vaughan, "Bacteriological Comparison Between Combined and Separate Sewer Discharges in Southeastern Michigan," Journal Water Pollution Control Federation, Vol. 28, No. 3, March 1966, and R.J. Burm, G.L. Harlow, and D.F. Krawczyk, "Chemical and Physical Comparison of Combined and Separate Sewer Discharges," Journal Water Pollution Control Federation, Vol. 40, No. 1, January 1968.*

TABLE 54

COMBINED SEWER OVERFLOW ANALYSES[a] DETROIT, MICHIGAN

PARAMETER	MEAN CONCENTRATION COMBINED SEWER OVERFLOW	CONCENTRATION IN SANITARY SEWAGE[b]	CONCENTRATION IN SEPARATE SEWER OVERFLOW
BOD (FIVE-DAY) (MG/1).............	153	350	28
SUSPENDED SOLIDS (MG/1)...........	274	250	2,080
VOLATILE SUSPENDED SOLIDS (MG/1)..	117	160	218
SETTLEABLE SOLIDS (MG/1)..........	238	180	1,590
TOTAL VOLATILE SETTLEABLE SOLIDS (MG/1)..................	97	130	140
TOTAL NITROGEN (MG/1).............	17	30	3.5
TOTAL PHOSPHATE (MG/1)............	15	60	5
(AS PHOSPHORUS) (MG/1)..........	(5)	(10)	--
TOTAL COLIFORMS (MFCC/100ML)......	2,300,000 TO 43,000,000[c]	20,000,000	340,000 TO 4,000,000
FECAL COLIFORMS (MFCC/100ML)......	890,000 TO 7,600,000[c]	5,000,000	10,000 TO 350,000

[a]COMBINED SEWER OVERFLOW QUALITY IS TAKEN FROM THE RESULTS OF THE CITY OF DETROIT STUDIES DESCRIBED IN THE ACCOMPANYING TEXT.

[b]TYPICAL AVERAGE VALUES FOR COMPARATIVE PURPOSES ONLY.

[c]MONTHLY MEDIAN DENSITIES OF THE MEAN TOTAL COLIFORM CONCENTRATION VARIED FROM 2,000,000 TO 43,000,000 FOR THE EIGHT MONTHS OF SAMPLING AND FROM 890,000 TO 7,600,000 FOR FECAL COLIFORM CONCENTRATIONS.

SOURCE- HARZA ENGINEERING COMPANY.

TABLE 55

COMBINED SEWER OVERFLOW ANALYSES MILWAUKEE, WISCONSIN- 1967 AND 1968

PARAMETER	DATE AND TIME OF SAMPLE COLLECTION									
	9/26/67 1:30 P.M.[a]	10/13/67 --[b]	10/24/67 --[b]	10/30/67 --[b]	11/1/67 --[b]	11/2/67 --[b]	4/3/68 12:30 P.M.[c]	4/3/68 3:30 P.M.[c]	4/17/68 --[b]	4/20/68 --[b]
DISSOLVED OXYGEN (MG/L).......	5.59	--	--	--	--	--	--	--	--	--
BOD (FIVE-DAY) (MG/L).........	313 & 294	UL.	372	99	92	55	290	--	119	62
AMMONIA NITROGEN (MG/L).......	3.64	--	2.35	4.5	3.68	1.67	6.7	5.6	1.96	4.56
TOTAL KJELDAHL NITROGEN (MG/L)	10.52[d]	--	13.5	4.6	3.5	6.09	23.1	12.3	6.52	13.68
TOTAL COLIFORMS (MFCC/100ML)..	3,900,000	21,000,000	46,000,000	4,300,000	8,200,000	4,800,000	4,900,000	1,700,000	3,100,000	3,800,000
FECAL COLIFORMS (MFCC/100ML)..	640,000	810,000	1,375,000	710,000	340,000	1,290,000	1,100,000	441,000	630,000	490,000
COD (MG/L).................	--	--	--	--	--	--	920	640	206	458
PH.........................	--	--	--	--	--	--	7.1	7.3	7.3	7.7
CHLORIDE (MG/L)..............	--	--	14.9	23.7	12.0	41.3	111.2	82.2	29.0	48.5
TOTAL SOLIDS (MG/L)..........	--	523	1,066	256	306	395	934	637	380	--
FIXED (MG/L).............	--	--	--	--	--	--	--	--	--	--
VOLATILE (MG/L)..........	--	--	--	--	--	--	--	--	--	--
TOTAL SUSPENDED SOLIDS (MG/L).	--	255	710	87	199	90	885	358	239	--
FIXED (MG/L).............	--	115	604	54	100	23	836	80	98	--
VOLATILE (MG/L)..........	--	140	106	33	99	67	49	278	141	--
TOTAL DISSOLVED SOLIDS (MG/L).	--	268	356	169	107	305	49	279	141	--
FIXED (MG/L).............	--	--	--	--	--	--	--	--	--	--
VOLATILE (MG/L)..........	--	--	--	--	--	--	--	--	--	--

[a]AS REPORTED, RAINFALL BEGAN ABOUT 11:00 A.M., AND THE HIGHEST INTENSITY APPARENTLY OCCURRED ABOUT 1:00 P.M. SAMPLE WAS COLLECTED FROM COMBINED OVERFLOW AT THE 72-INCH DIAMETER OUTFALL IMMEDIATELY NORTH OF HUMBOLDT AVENUE ON THE WEST BANK OF THE MILWAUKEE RIVER.

[b]NO SAMPLE TIME REPORTED. SAMPLE WAS COLLECTED FROM COMBINED OVERFLOW AT AN OUTFALL ON THE WEST BANK OF THE MILWAUKEE RIVER NEAR THE INTERSECTION OF HUMBOLDT AVENUE AND COMMERCE STREET.

[c]SITE UNIDENTIFIED. RAINFALL WAS REPORTED TO HAVE BEGUN SHORTLY BEFORE 12:30 P.M.

[d]AVERAGE OF THREE SAMPLES.

SOURCE- HARZA ENGINEERING COMPANY AND MARQUETTE UNIVERSITY, DEPARTMENT OF CIVIL ENGINEERING.

although considered to be representative of the combined sewer service area upstream from the North Avenue Dam, may not be entirely representative for the entire combined sewer service area of Milwaukee, particularly for those areas in which breweries contribute industrial wastes, which are particularly rich organically and bacteriologically.

Table 56 indicates the potential effect of combined sewer overflows on the Milwaukee River upstream from the North Avenue Dam. The volume of

TABLE 56

POTENTIAL EFFECT OF COMBINED SEWER OVERFLOWS ON THE WATER QUALITY OF THE MILWAUKEE RIVER ABOVE THE NORTH AVENUE DAM[a]

RAINFALL RUNOFF DEPTH (INCHES)	ANNUAL NUMBER[e] OF RUNOFF EVENTS	VOLUME OF COMBINED SEWER OVERFLOWS[b] (ACRE-FEET PER EVENT)	BOD PER EVENT[f] (POUNDS)	RIVER CONDITION IN AUGUST WITH AVERAGE FLOW (170 CFS)[c]						
				WITHOUT OVERFLOW			WITH COMBINED SEWER OVERFLOW			
				VOLUME/DAY (ACRE-FEET)	BOD/DAY (POUNDS)	DO (MG/L)	VOLUME/DAY (ACRE-FEET)	BOD[f] (POUNDS/DAY)	BOD[f] (MG/L)	DO[d] 24 HOUR AFTER OVERFLOW (MG/L)
0-0.05	16	4.4	1,800	340	4,600	5.0	344	6,400	7	3.93
0.05-0.10	8	13.2	5,400	340	4,600	5.0	353	10,000	10	3.07
0.10-0.30	15	35	14,000	340	4,600	5.0	375	18,600	18	0.35
0.30-0.60	9	78	32,000	340	4,600	5.0	418	36,600	32	0
0.60-1.00	3.25	140	58,000	340	4,600	5.0	480	62,600	48	0
1.00-2.00	1.32	260	108,000	340	4,600	5.0	600	112,600	69	0
4.00-5.00	0.12	700	287,000	340	4,600	5.0	1,040	291,600	103	0

[a]FOR PURPOSES OF THIS COMPUTATION, EACH OVERFLOW EVENT IS ASSUMED TO MIX WITH THE VOLUME OF RIVER FLOW FOR ONE DAY.

[b]INTERCEPTOR SEWER CAPACITY ASSUMED TO BE 1.0 DWF, CONTRIBUTING AREA EQUALS 2,100 ACRES.

[c]AVERAGE AUGUST RIVER FLOW BASED ON 16 YEARS OF RECORD (1949-1964) FOR ESTABROOK PARK GAGE. AVERAGE FIVE-DAY 20°C BOD OF RIVER AND COMBINED SEWER OVERFLOW.

[d]DISSOLVED OXYGEN CONCENTRATION AT SUMMER WATER TEMPERATURE OF 25°C (77°F).

[e]FREQUENCY ANALYSIS BASED ON 16 YEARS OF RECORD (1949-1964) IN THE CHICAGO METROPOLITAN AREA.

[f]AVERAGE FIVE-DAY BOD AT 20°C OF 150 MG/L, AS REPORTED BY R. J. BURM, ETAL. IN 1968 FOR OVERFLOWS FROM COMBINED SEWERS OF DETROIT.

SOURCE- HARZA ENGINEERING COMPANY.

rainfall-runoff that may be expected to occur during an average rainfall year from the 2,100-acre combined sewer service area above the Dam and the number of times such runoff may be expected to occur are shown. The runoff volumes tabulated are equivalent to overflows, since it may be assumed that the interceptors would be flowing at capacity when runoff occurs. The biochemical oxygen demand (BOD) was calculated for the volume of overflow using an average value of 150 mg/l. The average annual quantity of BOD discharged to the river above the North Avenue Dam from the combined sewers is estimated as approximately 935,000 pounds, equivalent to the average annual deoxygenating effects of the raw wastes of a population of approximately 15,000 persons.[21] It is estimated that combined sewer overflows contribute about 10 percent of the average BOD arriving in the impoundment of the North Avenue Dam during an average year. The remaining 90 percent of the BOD originates with upstream flows and is contributed to those flows by industrial discharges, surface and storm sewer runoff, and from relief overflows from the sanitary sewer systems.

The 10 percent figure does not indicate, however, the shock effect of combined sewer overflows on the river. The BOD load from the combined sewer overflows occurs as a concentrated loading over a relatively short time interval and, therefore, can be particularly damaging. The average daily discharge of the Milwaukee River during the month of August was 170 cfs during the 16-year period of record, extending from 1949 to 1964, for which the rainfall analyses were made. Measurements of dissolved oxygen levels in the Milwaukee River immediately upstream from the North Avenue Dam average about 5 mg/l. The reduction of the dissolved oxygen in the river due to overflows with different recurrence intervals was calculated for the 24-hour period following commencement of overflow. It was assumed that the average velocity of flow in the river was 0.1 foot per second and that the water temperature was 76°F. Under these conditions an overflow of only 0.025 inch from the tributary drainage area would result in a reduction of dissolved oxygen below 4.0 mg/l. An overflow of 0.1 inch or more may be expected to

[21] *The population equivalent of 15,000 persons was computed assuming the production of approximately 0.17 pound of BOD per capita per day, a value widely used in sanitary engineering. Data for the Jones Island sewage treatment plant indicate that the domestic, commercial, industrial, and urban runoff influent to the plant averages about 0.45 pound of BOD per capita per day. Utilizing this per capita production in the computations would result in an equivalent population of 5,700 persons.*

reduce the dissolved oxygen content of the Milwaukee River above the North Avenue Dam to less than 1.0 mg/l, a level below which anaerobic conditions can develop.

It may be concluded from these analyses, even though necessarily based upon the limited stream and sewer overflow water quality data presently available, that overflows from combined sewers have a frequent, severe, adverse impact on the water quality of the Milwaukee River upstream from the North Avenue Dam and that, in the presence of these overflows, the river will be unfit for whole- or partial-body-contact-recreational use or for the maintenance of a balanced warmwater fishery.

Characteristics of Overflow from Sanitary Sewers: The separate sanitary sewerage systems located in the watershed upstream from the North Avenue Dam are believed to contribute even more severely at present to the overall stream water pollution problem than do the combined sewers, with very intense, short-term shock effects being created in the receiving streams of the Milwaukee River system. As shown in Table 57, overflow contributed from the sanitary sewers is estimated to average about 7.5 mgd, or 2.73 billion gallons annually, in this reach of the river. It is estimated that these overflows contribute 168,000 pounds of phosphorus and about 5 million pounds of BOD to the streams above the North Avenue Dam.

The foregoing estimates of pollutants which enter the stream systems in the Milwaukee area were developed in several steps. Estimates were first made of the number and volume of overflow events which take place from combined sewers utilizing long-term rainfall records. As previously noted, an average of about 50 such events may be expected per year. Flow records on file at the Jones Island sewage treatment plant were then used to verify this estimate. Even though different

TABLE 57

POPULATION EQUIVALENTS AND ANNUAL BOD, PHOSPHORUS, AND VOLUMES OF SEWAGE OVERFLOWS TO STREAMS IN THE MILWAUKEE-METROPOLITAN SEWERAGE DISTRICT[a]

	PERSONS (NUMBER)	BOD (LBS)	PHOSPHORUS (P) (LBS)	ANNUAL OVERFLOW	
				GAL X 10^6	MGD
COMBINED SEWERS					
UPSTREAM NORTH AVENUE DAM (935,000 LBS BOD/YR.) ÷ (165 LBS/CAPITA/YR.) =	5,660	935,000	29,800	745	2.0
REMAINDER OF AREA (17,200 ACRES TOTAL AREA/2100 ACRES UPSTREAM OF DAM) X 5,660 PERSONS − 5,660 =	40,740	6,730,000	214,200	5,360	14.7
FLOWS IN EXCESS OF SEWAGE TREATMENT PLANT CAPACITY (50 MGD) (800 ÷ 24 DAYS) (2/3 X 350 MG/L) (8.3 LB. BOD/M. GAL/MG/L) ÷ (165 LBS. BOD/CAPITA/YR.) =	19,600	3,240,000	103,000	1,670	4.6
SANITARY SEWERS					
UPSTREAM NORTH AVENUE DAM 2734 X 10^6 GAL/YR. X (2/3 X350) (8.3/165) =	32,000	5,280,000	168,500	2,730	7.5
REMAINDER OF AREA SET EQUAL TO UPSTREAM =	32,000	5,280,000	168,500	2,730	7.5
TOTAL EQUIVALENT PERSONS	130,000	21,465,000	684,000	13,235	36.3

CHECK-

PERCENT OF TIME EXCESS FLOWS OCCUR- [(800 HRS) ÷ (365 X 24)] 100 = 9.14%

PERCENT EQUIVALENT POPULATION IS OF PEOPLE SERVED- [(130,000) ÷ (1.1 X 10^6)] 100 = 11.8%

THIS CHECK IS RELATED ENTIRELY TO SEWAGE STRENGTHS AT THE JONES ISLAND WASTE WATER TREATMENT PLANT AND TO POPULATION SERVED. CORRELATION OF POLLUTION LOADINGS TO STREAMS WITH DOMESTIC SEWAGE STRENGTHS COULD DOUBLE OR TRIPLE EQUIVALENT POPULATION.

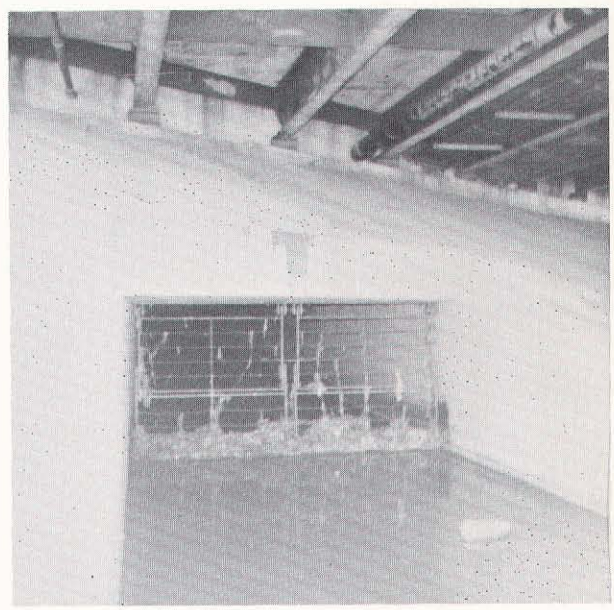
[a]PRIOR TO OPERATION OF THE SOUTH SHORE WASTE WATER TREATMENT PLANT.

SOURCE- HARZA ENGINEERING COMPANY.

basic data were used in the two analyses, flows, both in the combined sewers and at the Jones Island plant, appear, on the average, to exceed facility capacity about 50 times per year. Since the need to bypass sewage at the Jones Island plant is related to large flows in the interceptor and trunk sewers, it may be assumed that sanitary sewers may also be expected to surcharge on the average of about 50 times per year and for a total period of about 800 hours.

As already noted, crossovers and bypasses generally 12 to 15 inches in diameter have been constructed at 71 critical points in the sanitary sewerage system to relieve surcharging. These crossovers and bypasses permit surcharged sanitary sewers to discharge by gravity to storm sewers. At times when the storm sewers also become surcharged, gates close; and the crossover flow from the sanitary sewers ceases. The location of these crossovers and bypasses is indicated in Appendix H and shown on Map 46. These crossovers and bypasses were assumed to operate at a velocity of 1.0 foot per second, or at a flow rate of about 450 gallons per minute. Surcharged separate sanitary sewers are also relieved by portable pumps operated at 13 points in the Milwaukee River watershed and by seven fixed pumping stations. The locations of these pumps and pumping points are also indicated in Appendix H and shown on Map 46. The portable pumps have capacities of 300 to 700 gpm, with one pump having a capacity of 1,300 gpm, for an estimated average capacity of about 500 gpm. The capacity of the fixed pumping stations along the Milwaukee River and tributaries upstream from the North Avenue Dam total 81,500 gpm. In addition, some bypassing occasionally occurs at the Manor Road lift station.

Based on the assumptions as to frequency of sewer overflows and the estimated capacities of the relief facilities, an estimate was made initially of the volume of the overflows from the sanitary sewers which may be expected annually to enter the Milwaukee River upstream from the North Avenue Dam and, subsequently, the entire Milwaukee metropolitan area. It was assumed that the gravity crossovers and bypasses would operate about 400 of the 800 hours that overflows may be expected to occur and that, due to surcharging of storm sewers, would be closed the remaining 400 hours. It was assumed that the



Separate sanitary sewer overflows constitute an even greater source of water pollution in the Milwaukee River watershed than the combined sewer overflows. There are 91 known relief discharge points in the watershed where sanitary sewage is discharged directly to surface waters or indirectly to such waters via connection to the storm sewer system. One of these 91 relief points is a permanent underground pumping station located at N. 63rd Street and W. Hampton Avenue in the City of Milwaukee. The manhole and air vents of this pumping station are shown in the photo at left. This pumping station, with a capacity of 20,000 gallons per minute, relieves a sanitary sewer by pumping raw sewage into a nearby storm sewer. This storm sewer in turn discharges into Lincoln Creek under the Hampton Avenue bridge, as shown in the photo at right. In cases such as this, rivers, streams, and creeks become open sewers.

SEWRPC Photos

portable and fixed pumps would also operate at capacity for about 400 hours annually. The annual volume of overflow was then calculated as:

$$\left[81,500 + (0.2 \times 10,000^{a} + (12 \times 500)\right]$$

$$(400 \times 60) + (450 \times 55) \quad (400 \times 60) =$$

$$(2,140 + 594) \times 10^{6} \text{ gal/yr.} =$$

$$2,734 \times 10^{6} \text{ gal/yr.} = 7.5 \text{ mgd}$$

[a] *Twenty percent of capacity of Manor Road lift station operating over one-half the overflow period.*

The problem of surcharge of sanitary sewers is generally created by excessive infiltration through defective joints, porous or ruptured pipe and manholes, or other sewer appurtenances, together with storm water discharged to the sanitary sewers through foundation drain and downspout connections, which significantly increase flows in, and surcharge the sanitary sewers during, periods of wet weather. It is well known that the additional volume of water contributed from these sources is substantial. In the design of the South Shore sewage treatment plant, the ultimate dry-weather flow is expected to be 135 million gallons per day (mgd); but treatment capacity is being provided for an additional 215 mgd of wet-weather flow, or a total maximum flow of 350 mgd. The experience of the City of Milwaukee Sewerage Commission indicates that this incremental wet-weather capacity, more than one and one-half times the normal dry-weather flow, will be necessary even though the plant will have a tributary drainage area served entirely by separate sanitary sewerage systems.

As an indirect check on the reasonableness of the foregoing estimates of sewer overflows, a budget of wastes and equivalent populations was prepared for the entire metropolitan service area. Due to the limitations of the available data, neither this overall budget nor any of its individual components of sewer pollution should be regarded as a precise measure but rather should be regarded as a crude indication of the relative importance of each source of pollution and of its probable order of magnitude. The estimates are based on the following assumptions:

1. The population served by the Jones Island and South Shore sewage treatment plants is 1.1 million persons.
2. The total daily average flow to the Jones Island and South Shore plants is 200 mgd.
3. The strength of the sewage entering these plants is 350 mg/l five-day BOD and 10.7 mg/l phosphorus during mid-week and averages 300 mg/l BOD and 9.2 mg/l phosphorus on an annual basis.
4. The strength of the sanitary sewer overflows is equal to the strength of the sewage bypassed at the Jones Island plant, or about two-thirds of the mid-week strength of the influent to the Jones Island plant.
5. The strength of the combined sewer overflows averages about 45 percent of mid-week values for inflow to the Jones Island plant and totals 935,000 pounds of BOD and 30,000 pounds of phosphorus per year.
6. Flows in excess of the sewage treatment plant capacity occur about 50 times per year for a total time of 800 hours annually prior to 1969.
7. The bypass and overflow points from the sanitary and combined sewers are as on Map 46.
8. The fixed pump bypass installations have capacities of 81,500 gpm[22] upstream from the North Avenue Dam and 80,000 gpm[23] for the remainder of the metropolitan area.
9. Crossovers and bypasses which operate by gravity have an average capacity of 450 gpm.

Given the foregoing assumptions, the total BOD generated during a year from the Milwaukee system is:

200 mgd x 365 days x 8.3 lbs.

BOD/m.gal/mg/l x 300 mg/l =

182,000,000 lbs/yr. = 165 lbs/cap/yr. =

0.45 lbs/capita/day

[22] *About 15,000 gpm of this capacity was phased out during 1969 as sewers were connected to the new south shore system, and it is planned that about 70,000 gpm capacity in the area south of the North Avenue Dam and 37,500 gpm of capacity upstream from the Dam will be phased out during the next four years.*

[23] *Ibid, footnote 20.*

It is estimated, as shown in Table 57, that about 11.8 percent of this BOD loading was passed to the waterways of the Milwaukee metropolitan area before the South Shore sewage treatment plant was effectively brought into operation. As indicated earlier, it is anticipated that the operation of the South Shore plant will considerably relieve the entry of sewage spills to the waterways. It is doubtful, however, that the system, even with the new plant in operation, can absorb an annual average flow of 36.3 mgd, which is compressed into about 800 hours each year, without significant modification to the existing system in the form of storage capacity, addition of treatment capacity, or elimination of many sources of entry of clear water into sewers.

Storm Sewer Flows: Separate storm sewer, or open channel storm water drainage, systems serve those areas of the watershed served by separate sanitary sewers. These systems discharge to the Milwaukee River system at numerous locations along Lincoln Creek and the Milwaukee River. While the outflows from these sewers have an adverse impact on stream water quality, this impact is less severe than the adverse impact which results from the discharges of the combined and separate sanitary sewer systems. Studies conducted during the summer of 1965 at Ann Arbor, and Detroit, Michigan,[24] showed that BOD, in separate storm sewer discharges, was generally about 20 percent of the BOD observed in the combined sewer overflows. Total phosphate content was found to average about one-fifth as much in storm sewage as in combined sewage. However, it was found that there were 1.4 times as much volatile settleable solids and 7.5 times as much suspended solids in the separate storm sewer discharge as in the combined sewer overflows.

Industrial Sources: Sources from which industrial discharges enter the Milwaukee River in Milwaukee County were identified in a report issued by the Wisconsin Department of Natural Resources in 1969.[25] These sources are listed in Table 58. No information is available concerning the quantity and quality of the discharges; however, 10 of the 26 waste flows consist entirely of cooling water, which may adversely affect the temperature of the receiving waters but does not exert a significant BOD or contribute large quantities of nutrients. Nineteen of these flows enter Lincoln Creek or the Milwaukee River upstream from the North Avenue Dam.

[24] *Benzie, Courchaine, "Discharges from Separate Storm Sewers and Combined Sewers," Journal Water Pollution Control Federation, Vol. 38, No. 3, March 1966.*

[25] *Wisconsin Department of Natural Resources, Division of Environmental Protection, Report on an Investigation of the Pollution of the Milwaukee River, Its Tributaries, and Oak Creek Made During 1968 and 1969, May 27, 1969.*

Basement Sewer Backup and Flooding—Milwaukee County

Basement flooding due to sewer backup has historically been a serious problem in certain areas of the lower Milwaukee River watershed. A total of 4,154 acres, or about 11 percent of the Milwaukee County portion of the Milwaukee River watershed, has historically been seriously affected by this problem (see Map 47). Such basement flooding was reported in the watershed inventory for the City of Milwaukee and the Villages of Brown Deer and Shorewood in the lower watershed. The remaining communities in the lower portion of the watershed either reported no basement sewer backup and flooding problem at all or reported only very minor instances of isolated basement flooding problems. In most instances basement flooding has been caused by the surcharging of separate sanitary sewers primarily due to the extensive amounts of clear water entering these sewers. In a few instances, such flooding has been caused by inadequate combined sewer capacity (see Table 59).

The local relief sewer programs completed to date have been designed to abate the basement flooding problem for about 500 acres, or 12 percent of the area historically experiencing basement flooding problems. In addition, completion of the trunk and relief sewer construction program by the Milwaukee-Metropolitan Sewerage Commissions is expected to abate the basement flooding problem for an additional 3,475 acres, or 84 percent of the area historically flooded. Finally, an additional 115 acres, or 3 percent of the area historically flooded, are expected to be relieved through planned local relief sewer construction programs. It should be noted, however, that the basement flooding abatement program will not be fully effective in most areas without the reconstruction of certain lateral and branch, as well as trunk sewers.

TABLE 58

INDUSTRIAL WASTE WATER ENTERING THE MILWAUKEE RIVER THROUGH STORM SEWERS IN MILWAUKEE COUNTY- 1969[a]

INDUSTRIAL WASTE WATER SOURCE	TYPE OF WASTE	PRETREATMENT
AMERICAN CAN COMPANY	COOLING WATERS	NONE
AMERICAN MOTORS CORPORATION	COOLING WATERS	NONE
AUTOMATIC AUTO WASH	CAR WASHING WATERS	SETTLING BASIN
COMMERCE ST. POWER PLANT, WISCONSIN	ZEOLITE-SOFTENING WASTES	NONE
ELECTRIC COMPANY	COOLING WATERS	NONE
CONTINENTAL CAN COMPANY, INC.	COOLING WATERS	CATCH BASIN
CORNELL PAPERBOARD PLANT, DIVISION OF ST. REGIS PAPER COMPANY	COOLING WATERS FROM POWER HOUSE	NONE
DELTA OIL PRODUCTS CORPORATION, RICKETSON COLOR DIVISION	OILY WASTES	UNDER CONSIDERATION
DICKTEN & MASCH MANUFACTURING COMPANY	COOLING WATER	NONE
EDISON ST. POWER PLANT, WISCONSIN	LIME-SOFTENING WASTES	NONE
ELECTRIC COMPANY	COOLING WATERS	NONE
EVINRUDE MOTORS DIVISION, OUTBOARD MARINE CORPORATION	OILY WASTES	OIL SEPARATOR
HERCULES POWER COMPANY, INC.	COOLING WATERS	NONE
INTERSTATE DROP FORGE COMPANY	OILY WASTES, COOLING WATERS	OIL AND GREASE SEPARATOR
JUMBO'S DRIVE-IN	COOLING WATERS	NONE
CITY OF MILWAUKEE, 5TH DISTRICT POLICE STATION	GARAGE WATERS	CATCH BASIN
CITY OF MILWAUKEE, BUREAU OF ELECTRIC SERVICE	FLOOR WASHING	CATCH BASIN
MILWAUKEE SCHOOL BOARD, MARSHALL HIGH SCHOOL	POOL DRAINAGE	NONE
MODERN CAR-WASH, INC.	CAR WASHING WATERS	SETTLING BASIN
PURE OIL CAPITOL COURT AUTO WASH	CAR WASHING WATERS	SETTLING BASIN
PURE OIL CAR WASH	CAR WASHING WATERS	SETTLING BASIN
JOSEPH SCHLITZ BREWING COMPANY	COOLING WATERS	NONE
PAUL J. SCHMIDT TRUCKING	INORGANIC GRINDING SOLIDS	SETTLING POND
SEALTEST FOODS, DIVISION OF DAIRY PRODUCTS, KRAFTCO CORPORATION	LOADING DOCK WASHING (DAIRY PRODUCT WASTE FROM SPILLAGE)	CATCH BASIN
A. O. SMITH CORPORATION	COOLING WATERS	CATCH BASIN
WISCO 99 CAR WASH	CAR WASHING WATERS	SETTLING BASIN
WISCONSIN GAS COMPANY, NORTH SERVICE CENTER	AUTO & TRUCK WASHING WATERS	SETTLING BASIN
ZINN MALTING COMPANY	COOLING WATERS	NONE

[a]INDUSTRIES ON FILE WITH THE CITY OF MILWAUKEE SEWERAGE COMMISSION.

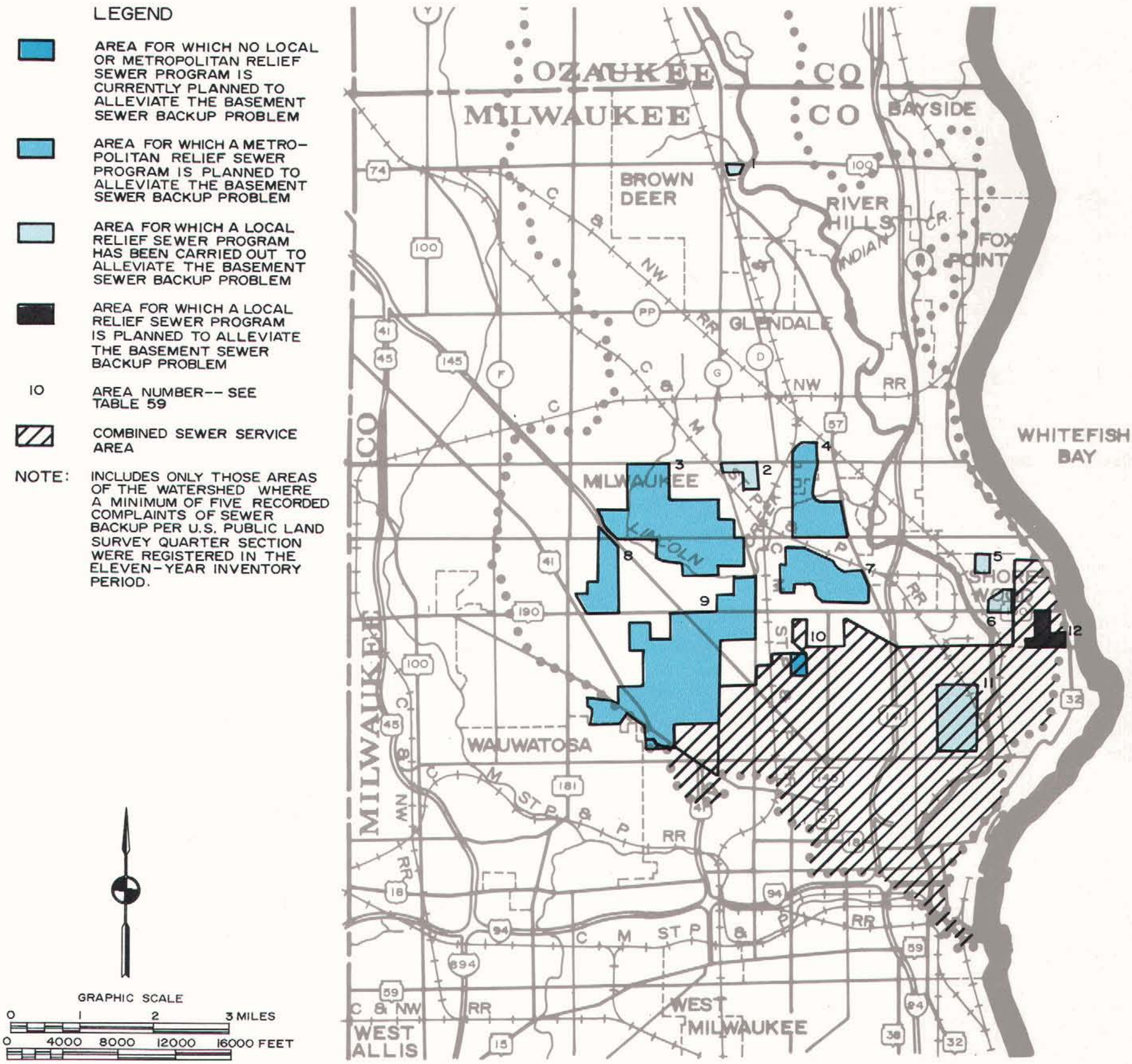
SOURCE- WISCONSIN DEPARTMENT OF NATURAL RESOURCES.

EXISTING AND FUTURE STREAM WATER QUALITY CONDITIONS

Existing water quality conditions and related water pollution problems in the streams of the Milwaukee River watershed are identified on the basis of existing water uses and present stream quality levels, as determined from the stream sampling programs previously described. To identify future conditions and related problems, however, it was necessary to forecast future stream water quality conditions. The forecast conditions, presented in the following discussion of 1990 stream water quality in the Milwaukee River watershed by stream reach, are approximations based on the primary assumption that present sewage treatment and disposal techniques and practices will remain in use through 1990. These forecast conditions, therefore, do not take into account any possible changes in the effectiveness of these techniques and practices. Although recent research in advanced waste treatment techniques has provided new knowledge, and it is reasonable to anticipate future improvement in effluent quality, the rate at which improved non-water-borne and other treatment methods may be developed to a practical level and applied within the watershed, in the absence of a comprehensive watershed plan and implementation of that plan, cannot be foreseen at this time. It was assumed,

Map 47

AREAS EXPERIENCING BASEMENT SEWER BACKUP AND FLOODING IN THE MILWAUKEE COUNTY PORTION OF THE MILWAUKEE RIVER WATERSHED 1959-1969



Over 4,000 acres of the lower Milwaukee River watershed have historically been seriously affected by basement flooding due to sewer backup. In most instances basement flooding has been caused by the surcharging of separate sanitary sewers. As shown on this Map, trunk and relief sewer construction programs have either been completed, are under construction, or are programmed for construction to relieve basement flooding in all but one minor area of the watershed.

Source: City of Milwaukee, Department of Public Works, Sewer Engineering Division; Village Manager, Village of Brown Deer; City Engineer, City of Glendale; Village Manager, Village of Fox Point; Village Manager, Village of Whitefish Bay; Village Planner, Village of Shorewood; Village Manager, Village of River Hills; Superintendent of Public Works, Village of Bayside; and SEWRPC.

TABLE 59

RECORDED BASEMENT SEWER BACKUP COMPLAINTS IN THE MILWAUKEE COUNTY PORTION OF THE MILWAUKEE RIVER WATERSHED- 1959-1969

AREA NUMBER[a]	CIVIL DIVISION	AREA SIZE (SQUARE MILES)	RECORDED COMPLAINTS (1959-1969)	YEAR MOST COMPLAINTS OCCURRED
1	VILLAGE OF BROWN DEER	0.03	--[b]	--[b]
2	CITY OF MILWAUKEE	0.25	17	1960
3	CITY OF MILWAUKEE	1.40	500	1960
4	CITY OF MILWAUKEE	0.60	60	1960
5	VILLAGE OF SHOREWOOD	0.05	2	1964
6	VILLAGE OF SHOREWOOD	0.08	8	1964
7	CITY OF MILWAUKEE	0.60	70	1960
8	CITY OF MILWAUKEE	0.30	70	1961
9	CITY OF MILWAUKEE	2.50	300	1960
10	CITY OF MILWAUKEE	0.10	6	--[b]
11	CITY OF MILWAUKEE	0.40	22	--[b]
12	VILLAGE OF SHOREWOOD	0.18	32	1959

[a]SEE MAP 47. INCLUDES ONLY THOSE AREAS OF THE WATERSHED WHERE A MINIMUM OF FIVE RECORDED COMPLAINTS OF SEWER BACKUP PER U.S. PUBLIC LAND SURVEY QUARTER SECTION WERE REGISTERED IN THE ELEVEN-YEAR INVENTORY PERIOD.

[b]INFORMATION NOT AVAILABLE.

SOURCE- CITY OF MILWAUKEE, DEPARTMENT OF PUBLIC WORKS, SEWER ENGINEERING DIVISION; VILLAGE MANAGER, VILLAGE OF BROWN DEER; CITY ENGINEER, CITY OF GLENDALE; VILLAGE MANAGER, VILLAGE OF FOX POINT; VILLAGE MANAGER, VILLAGE OF WHITEFISH BAY; VILLAGE PLANNER, VILLAGE OF SHOREWOOD; VILLAGE MANAGER, VILLAGE OF RIVER HILLS; SUPERINTENDENT OF PUBLIC WORKS, VILLAGE OF BAYSIDE; AND SEWRPC.

also, that by 1990 all the sewage treatment plants in the watershed will continue providing secondary treatment and will provide disinfection of the effluent and 85 percent phosphorus removal, even in the absence of any water quality management plan. An efficiently operated secondary treatment plant may be expected to remove 85 to 95 percent of the BOD of the raw sewage. Thus, for the following discussion of 1990 conditions, the amount of BOD discharge from each sewage treatment plant was taken as 10 percent of the BOD of the raw sewage.

Forecasts of stream water quality conditions were made using a mathematical simulation model and the anticipated 1990 sewage treatment plant discharges, as shown in Table 60. These estimates of the average flow rates from the sewage treatment plants were projected for a period of critically low streamflow conditions which occur in the summer during dry weather. The projected average daily per capita sewage flows include dry-weather infiltration and sewage from commercial operations. Present per capita sewage flow rates were used based on the assumption that any larger per capita sewage flow which may occur in the future as a consequence of increased water use will be offset by lower infiltration rates that result from improvements in future sewer construction. The relationship between population served and average daily per capita sewage flows was derived, as shown in Figure 36, by using present daily average per capita sewage flows for sewerage systems that service more than 1,000 people each in the Milwaukee and Fox River watersheds. Estimates of 1990 sewage flows were made from this relationship based on population forecasts prepared by the Commission.

A mathematical model was developed and calibrated to simulate the ability of the streams in the Milwaukee River watershed to assimilate waste discharges under various types and degrees of waste treatment and locations of waste discharge. The model is described in Chapter XII of this

TABLE 60

ESTIMATED WASTE DISCHARGES FROM MUNICIPAL SEWAGE TREATMENT PLANTS IN THE MILWAUKEE RIVER WATERSHED - 1990

SOURCE OF WASTES	POPULATION SERVED[a]	SEWAGE FLOW[b] (GALLONS PER CAPITA)	INDUSTRIAL WASTE CONTRIBUTION		TOTAL FLOW PER DAY (MGD)	TOTAL DAILY INFLUENT BOD[c] (POUNDS)
			BOD (POUNDS)	FLOW (MGD)		
VILLAGE OF ADELL	460	150	--	--	0.07	115
VILLAGE OF CAMPBELLSPORT	1,980	144	425	0.10	0.39	920
CITY OF CEDARBURG	13,080	190	--	--	2.48	3,270
VILLAGE OF FREDONIA	1,760	140	--	--	0.23	422
VILLAGE OF GRAFTON	10,160	187	--	--	1.90	2,540
VILLAGE OF JACKSON	1,730	140	--	--	0.24	432
VILLAGE OF KEWASKUM	3,100	157	575	0.25	0.74	1,350
NEWBURG SANITARY DISTRICT	990	120	--	--	0.12	248
VILLAGE OF RANDOM LAKE	1,430	133	--	--	0.19	358
VILLAGE OF SAUKVILLE	2,600	152	--	--	0.40	650
VILLAGE OF THIENSVILLE	3,790	162	--	--	0.61	948
CITY OF WEST BEND	24,250	203	--	--	4.92	6,062

[a]POPULATION PROJECTIONS AS MADE BY SEWRPC.

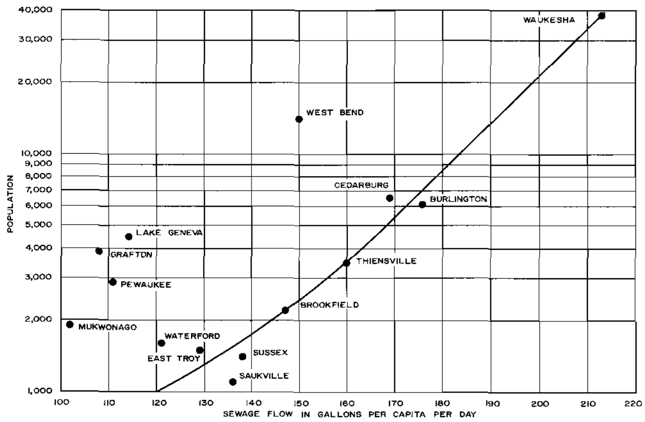
[b]SEE FIGURE 36.

[c]BASED ON 0.25 POUND OF FIVE-DAY BOD PER CAPITA PER DAY AT 20°C.

SOURCE- HARZA ENGINEERING COMPANY AND SEWRPC.

Figure 36

AVERAGE DAILY PER CAPITA SEWAGE FLOW BY POPULATION TRIBUTARY TO SEWAGE TREATMENT PLANTS IN THE SOUTHEASTERN WISCONSIN REGION (POPULATION RANGE 1,000 TO 40,000)



NOTE: PLOTTED POINTS ARE BASED ON 1966 AND 1968 MEASURED INFLOWS TO EXISTING SEWAGE TREATMENT PLANTS INCLUDING DOMESTIC, INDUSTRIAL AND INFILTRATION FLOWS.

Source: Harza Engineering Company.

volume, "River Performance Simulation." The major parameters selected for use in the model to describe water quality conditions were dissolved oxygen (DO), biochemical oxygen demand (BOD), and temperature. These parameters describe the overall level of the water quality, in terms of dissolved oxygen, which would result from organic pollution. Final determination of probable levels of dissolved oxygen, however, must be made by adjusting these calculated oxygen levels for the effects of aquatic plant activity.

Nutrients

In order to formulate and evaluate plans for controlling excessive fertilization of the streams of the Milwaukee River watershed, as for the lakes, it is necessary to know the major sources and amounts of nutrients that are entering these waters. These estimates were prepared in the same manner as similar estimates made for the lakes within the watershed and as described earlier in this chapter. As already noted, although such estimates necessarily represent approximations, they do provide indications of the relative nutrient contributions from each source and thus suggest areas in which corrective actions can be taken.

Estimates of the phosphorus contributions from combined sewer outflows and sanitary sewer overflows were based on analyses of annual volumes of flow to the streams from the sources. Flows from combined sewers were determined, as shown in Table 56; and flows from sanitary sewers were based on estimated pumpage and gravity flows from overflow points, as shown in Table 57. Estimates of the phosphorus contribution from urban runoff were based on the total land area within the watershed in urban use, as determined by SEWRPC land use inventories.

Results: The total amount of phosphorus contributed to the major streams within the watershed was obtained by summing the contributions from each source. In order to check the accuracy of these phosphorus estimates, the total annual contribution of phosphorus to the Milwaukee River system above Brown Deer Road, as estimated by the methods described above, was compared to the actual phosphorus loading of the river at this point, as determined from periodic sampling of the river since 1961 by the Wisconsin Department of Natural Resources, Division of Environmental Protection. The estimated phosphorus contribution as computed was 126,000 pounds per year, while the average phosphorus loading as actually measured was 146,000 pounds per year, indicating a reasonable comparison between the estimated and the actual phosphorus loading of the river at this point[26], with the computed value being conservatively low.

The phosphorus contributions estimated on a value basis for the overflows from the combined and sanitary sewers in Milwaukee were checked as a percentage of the total probable phosphorus carried annually in the sewerage system of Milwaukee. This comparison also indicated that the estimates are reasonable.

The results of the computations of phosphorus contributions to each of the major stream reaches under existing and 1990 land use conditions within the watershed, the latter assuming continued existing trend development in the absence of a watershed plan, are shown in Tables 61 and 62 by the amount contributed from each source and by the proportionate contribution of each source to the total.

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[26] *The literature indicates a range of phosphorus removal in sewage treatment plants from 30 percent to 80 percent. By assuming 30 percent removal, in lieu of 45 percent removal, the total annual phosphorus contribution to the river upstream from Brown Deer Road would approximate the 146,000 pounds per year as measured.*

TABLE 61

MAJOR SOURCES OF PHOSPHORUS IN THE MILWAUKEE RIVER WATERSHED UNDER EXISTING (1967) CONDITIONS (POUNDS PER YEAR)

SOURCE[a]	UNIT AMOUNT OF PHOSPHORUS (AS P)	MILWAUKEE RIVER MAIN STEM								MILWAUKEE RIVER NORTH BRANCH		CEDAR CREEK	
		ABOVE WEST BEND		AT NORTH BRANCH		AT MILWAUKEE COUNTY LINE		AT NORTH AVENUE DAM					
		LBS.	PERCENT	LBS.	PERCENT	LBS.	PERCENT	LBS.	PERCENT	LBS.	PERCENT	LBS.	PERCENT
URBAN RUNOFF............	460 LBS./SQ.MI./YR.	800	4	2,600	5	7,200	7	29,400	9	1,000	8	1,300	6
RURAL AND AGRICULTURAL RUNOFF...............	60 LBS./SQ.MI./YR.	12,500	61	16,000	32	37,000	33	37,000	11	9,000	69	8,000	34
SEWAGE TREATMENT PLANT EFFLUENT.............	1.9 LBS./CAPITA/YR.	6,000	30	29,000	59	60,000	54	60,000	18	2,000	15	13,000	56
PRIVATE SEWAGE DISPOSAL SYSTEMS.....	0.2 LB./CAPITA/YR.	1,000	5	2,000	4	7,000	6	7,000	2	1,000	8	1,000	4
SANITARY SEWER OVERFLOWS............	--[b]	--[b]	--	--[b]	--	--[b]	--	168,000	51	--[b]	--	--[b]	--
COMBINED SEWER OVERFLOWS............	--[c]	--[c]	--	--[c]	--	--[c]	--	30,000	9	--[c]	--	--[c]	--
TOTAL		20,300	100	49,600	100	111,200	100	331,400	100	13,000	100	23,300	100

[a]CONTRIBUTIONS FROM PRECIPITATION ONTO WATER SURFACES AND FROM INDUSTRIES WERE CONSIDERED NEGLIGIBLE.

[b]CONTRIBUTIONS CONSIDERED NEGLIGIBLE IN UPSTREAM AREAS. THE VOLUME OF OVERFLOW THAT TAKES PLACE ANNUALLY IN MILWAUKEE COUNTY UPSTREAM FROM THE NORTH AVENUE DAM WAS ESTIMATED TO BE 2,730 MILLION GALLONS WITH PHOSPHORUS CONCENTRATION AS P EQUAL TO 2/3 OF 10.7 MG/1 (STRENGTH OF BYPASSED INFLUENT JONES ISLAND SEWAGE TREATMENT PLANT).

[c]THERE ARE NO COMBINED SEWER SERVICE AREAS IN THE MILWAUKEE RIVER WATERSHED UPSTREAM FROM MILWAUKEE COUNTY. THE VOLUME OF OVERFLOW THAT TAKES PLACE ANNUALLY UPSTREAM FROM THE NORTH AVENUE DAM WAS ESTIMATED TO BE 745 MILLION GALLONS WITH PHOSPHORUS CONCENTRATIONS AS P EQUAL TO 45 PERCENT OF 10.7 MG/1.

SOURCE- HARZA ENGINEERING COMPANY.

TABLE 62

MAJOR SOURCES OF PHOSPHORUS IN THE MILWAUKEE RIVER WATERSHED UNDER 1990 UNPLANNED CONDITIONS (POUNDS PER YEAR)

SOURCE	UNIT AMOUNT OF PHOSPHORUS (AS P)	MILWAUKEE RIVER MAIN STEM								MILWAUKEE RIVER NORTH BRANCH		CEDAR CREEK	
		ABOVE WEST BEND		AT NORTH BRANCH		AT MILWAUKEE COUNTY LINE		AT NORTH AVENUE DAM					
		LBS.	PERCENT	LBS.	PERCENT	LBS.	PERCENT	LBS.	PERCENT	LBS.	PERCENT	LBS.	PERCENT
URBAN RUNOFF..........	460 LBS./MI.SQ./YR.	800	3	3,000	4	11,400	6	33,600	11	1,000	7	2,000	5
RURAL AND AGRICULTURAL RUNOFF..............	60 LBS./MI.SQ./YR.	12,00	42	14,000	8	35,000	20	35,000	11	8,000	57	7,000	18
SEWAGE TREATMENT PLANT EFFLUENT............	1.9 LBS./CAPITA/YR. (0.525 LB./CAPITA/YR.)[a]	14,000 (4,000)	42	61,000 (17,000)	76	125,000 (34,000)	70	125,000 (34,000)	40	4,000 (1,000)	29	29,000 (8,000)	74
PRIVATE SEWAGE DISPOSAL SYSTEMS....	0.2 LB./CAPITA/YR.	2,000	7	2,000	2	7,000	4	7,000	2	1,000	7	1,000	3
SANITARY SEWER OVERFLOWS...........	--[b]	--[b]	--	--[b]	--	--[b]	--	84,000[c]	27	--[b]	--	--[b]	--
COMBINED SEWER OVERFLOWS...........	--[d]	--[d]	--	--[d]	--	--[d]	--	27,000[e]	9	--[d]	--	--[d]	--
TOTAL		28,800	100	80,300	100	178,400	100	311,600	100	14,000	100	39,000	100

[a]NUMBERS IN PARENTHESES REPRESENT ESTIMATED PHOSPHORUS LOADING TO STREAMS ASSUMING 85 PERCENT REMOVAL IN THE MUNICIPAL SEWAGE TREATMENT PLANTS.

[b]CONTRIBUTIONS CONSIDERED NEGLIGIBLE IN UPSTREAM AREAS.

[c]IT WAS ASSUMED THAT THE ESTIMATED PRESENT-DAY LOADING WOULD BE REDUCED BY 50 PERCENT DUE TO NEW TREATMENT CAPACITY AT THE SOUTH SHORE SEWAGE TREATMENT PLANT, DIVERSITY POTENTIAL IN THE INTERCONNECTED SYSTEM OF JONES ISLAND AND SOUTH SHORE SEWAGE TREATMENT PLANTS, AND A REDUCTION OF THE NUMBER OF SMALLER OVERFLOWS HAVING THE MORE CONCENTRATED WASTES.

[d]THERE ARE NO COMBINED SEWER SERVICE AREAS IN THE MILWAUKEE RIVER WATERSHED UPSTREAM FROM MILWAUKEE COUNTY.

[e]IT WAS ASSUMED, BASED ON RECENT SEWER SEPARATION PROJECTS, THAT ABOUT 10 PERCENT OF THE EXISTING COMBINED SEWERS IN MILWAUKEE COUNTY WILL BE SEPARATED BY 1990.

SOURCE- HARZA ENGINEERING COMPANY.

Existing and Future Water Quality Characteristics of Individual Stream Reaches

The existing water quality of the main stem of the Milwaukee River outside the Milwaukee urbanized area taken, for the purposes of this analysis, as that part of the river system above the Milwaukee-Ozaukee County line, and the existing water quality of most of the major tributaries of the Milwaukee River outside the Milwaukee urbanized area are presently relatively good, particularly as compared to other streams within the Region, such as the Fox and Root Rivers. This is due in part to the fact that the headwater reaches of the Milwaukee River watershed, unlike the headwater reaches of the Fox and Root River watersheds, are still largely in rural land uses. Most of the sources of organic pollution in the upstream area of the watershed have been brought under control; and, with a few exceptions, organic pollution is not presently a major problem. Coliform concentrations are relatively high, however, in many areas of the watershed, primarily due to discharges from municipal sewage treatment plants that do not provide effluent disinfection.

The major water quality problem occurring in the streams of the upper watershed is inorganic pollution in the form of high levels of nutrients that cause overfertilization of the streams. Luxuriant growths of algae and aquatic weeds are present in many sections of the Milwaukee River and its tributaries, resulting in unsightly conditions that greatly detract from the aesthetic value of the streams. As already noted, the aquatic plants produce oxygen during the daylight hours and consume oxygen at night, resulting in a diurnal (daily) fluctuation in dissolved oxygen levels, the magnitude of which is dependent upon the numbers of aquatic plants present in the stream. The major sources of the nutrients that stimulate these growths are waste discharges from the municipal sewage treatment plants and drainage and runoff from agricultural lands within the watershed.

The Milwaukee River and its major tributaries within the Milwaukee urbanized area exhibit serious water quality problems, with both organic and inorganic pollution being high. High concentrations of coliform bacteria and phosphorus and low dissolved oxygen levels frequently occur in streams within the urbanized area. In general, water quality in this section of the watershed does not meet the state-established water use objectives and standards for the Milwaukee River and its major tributaries.

The principal source of organic pollution in the Milwaukee River within the Milwaukee urbanized area is overflow from the separate sanitary and combined sewer systems. Major sources of inorganic pollution originate with these discharges, together with surface runoff from the urban area, waste discharges from the upstream sewage treatment plants, and drainage and runoff from upstream agricultural lands.

Milwaukee River—Headwaters to the City of West Bend: Existing water uses in the reach of the Milwaukee River from its headwaters downstream to the City of West Bend include maintenance of a warm-water fishery, partial- and whole-body-contact-recreational activities, livestock and wildlife watering, irrigation, waste assimilation, and aesthetic uses. State-established water use objectives include all the existing uses, plus industrial and cooling water supply. Waste discharges in this reach are from the sewage treatment plants at Campbellsport and Kewaskum. These plants serve a total population of approximately 3,400 persons and discharge treated effluent to the Milwaukee River at a combined average rate of 1.0 cfs.

Existing water quality data for this stream reach are summarized in Table 63. Minimum dissolved oxygen (DO) levels of less than 4.0 mg/l throughout the reach and less than 1.0 mg/l at several locations within the reach inhibit the development of a warm-water fishery and do not conform to the state-established water use objectives and standards for this reach. The relatively low DO levels are caused by the large numbers of algae and aquatic weeds present in many sections of the river, by the effluents discharged from the sewage treatment plants at Campbellsport and Kewaskum, and by agricultural runoff. Even though secondary treatment facilities are provided at both of these plants, operating problems have resulted in variable treatment efficiencies and occasional discharges of poor quality effluent that degrade water quality in the river downstream from the plant outfalls. An analysis of the waste assimilation capacity of the river downstream from both of the sewage treatment plants indicates that average DO levels should remain above 5.0 mg/l, even during critical low-flow conditions, if the plants were continuously providing the 85 to 90 percent BOD removal that they are capable of providing. Minimum DO levels probably would be slightly less than 4.0 mg/l with the present populations of algae and aquatic weeds.

Figures 33 and 34 present the results of a sampling program carried out by the Harza Engineering Company on the Milwaukee River near Campbellsport on May 2 and from August 5 to 7, 1968. Minimum DO levels were found to be higher than 5.0 mg/l during the May survey and, therefore, except for fish reproduction, conformed to established water use objectives and standards (see Table 47). Average DO levels in August were found to be less than 5.0 mg/l, and minimum values were found to range from 0.5 to 2.0 mg/l at all sampling sites except the one just downstream from the Campbellsport Dam. Reaeration resulting from flow over the Dam supplied enough oxygen to maintain an average level of 6.1 mg/l and a minimum level of 4.3 mg/l immediately downstream from the dam. The low DO levels at the two upstream sampling sites were apparently caused by dense growths of aquatic weeds that completely choked the stream channel and the impoundment upstream from the Campbellsport dam. There are no known major waste discharges upstream from Campbellsport, although there is a large chicken farm located along this reach of the river which could be a contributor of

TABLE 63

WATER QUALITY SURVEY DATA SUMMARY FOR THE MILWAUKEE RIVER (HEADWATERS TO WEST BEND) 1964-1968

SAMPLING LOCATION	DATA	PARAMETER							
					PHOSPHORUS				
		TEMPERATURE (°C)	DO (MG/1)	BOD (MG/1)	SOLUBLE (MG/1)	TOTAL (MG/1)	NITRATE (MG/1)	CHLORIDE (MG/1)	COLIFORM (MFCC/100ML)
UPSTREAM FROM CAMBELLSPORT DAM[a]	NUMBER OF SAMPLES	(46)	(46)	(0)	(4)	(4)	(4)	(0)	(0)
	MAXIMUM	29.0	11.5	--	0.14	0.18	1.8	--	--
	MINIMUM	10.0	0.5	--	0.02	0.04	0.4	--	--
	AVERAGE	21.4	4.8	--	0.08	0.10	1.2	--	--
STH 67 IN CAMPBELLSPORT[a,b]	NUMBER OF SAMPLES	(26)	(26)	(4)	(3)	(3)	(2)	(0)	(2)
	MAXIMUM	27.0	10.2	2.6	0.23	0.34	0.8	--	100,000
	MINIMUM	11.5	4.3	0.9	0.06	0.06	0.6	--	3,900
	AVERAGE	20.2	7.2	1.8	0.13	0.18	--	--	--
0.2 MILES DOWNSTREAM FROM CAMPBELLSPORT SEWAGE TREATMENT PLANT[a,b]	NUMBER OF SAMPLES	(26)	(26)	(4)	(3)	(3)	(3)	(0)	(2)
	MAXIMUM	27.0	10.1	21.0	0.77	1.23	2.8	--	390,000
	MINIMUM	11.5	1.9	3.5	0.18	0.23	1.8	--	40,000
	AVERAGE	20.2	5.5	--	0.52	0.70	2.3	--	--
2.5 MILES UPSTREAM FROM KEWASKUM[c]	NUMBER OF SAMPLES	(17)	(17)	(14)	(3)	(0)	(3)	(17)	(16)
	MAXIMUM	26.0	11.9	6.5	0.38	--	1.3	70	43,000
	MINIMUM	0.0	0.5	0.5	0.04	--	0.2	0	100
	AVERAGE	8.0	7.4	2.7	0.17	--	0.8	27	1,400M[d]
UPSTREAM FROM KEWASKUM DAM[a,b]	NUMBER OF SAMPLES	(12)	(12)	(4)	(0)	(0)	(0)	(0)	(4)
	MAXIMUM	30.0	18.2	4.6	--	--	--	--	230,000
	MINIMUM	12.0	3.9	1.1	--	--	--	--	2,200
	AVERAGE	21.0	7.8	2.5	--	--	--	--	3,300M[d]
DOWNSTREAM FROM KEWASKUM SEWAGE TREATMENT PLANT[a,b,c]	NUMBER OF SAMPLES	(29)	(29)	(16)	(3)	(0)	(3)	(6)	(18)
	MAXIMUM	30.0	13.9	7.8	0.61	--	1.0	35	100,000
	MINIMUM	0.0	0.7	0.8	0.01	--	0.3	5	400
	AVERAGE	15.1	6.8	3.0	0.22	--	0.6	17	9,500M[d]
UPSTREAM FROM BARTON DAM[b]	NUMBER OF SAMPLES	(9)	(9)	(9)	(0)	(0)	(0)	(0)	(9)
	MAXIMUM	26.5	13.6	2.6	--	--	--	--	32,000
	MINIMUM	13.0	3.2	1.4	--	--	--	--	2,000
	AVERAGE	20.3	9.4	2.1	--	--	--	--	5,000M[d]
RAILROAD BRIDGE IN WEST BEND[b]	NUMBER OF SAMPLES	(3)	(3)	(3)	(0)	(0)	(0)	(0)	(3)
	MAXIMUM	25.0	13.4	3.2	--	--	--	--	30,000
	MINIMUM	15.0	9.6	2.5	--	--	--	--	9,000
	AVERAGE	21.3	11.0	2.9	--	--	--	--	--

[a]SAMPLING DONE BY HARZA ENGINEERING COMPANY.

[b]SAMPLING DONE BY WISCONSIN DEPARTMENT OF NATURAL RESOURCES.

[c]SAMPLING DONE BY SEWRPC.

[d]MEDIAN VALUE.

SOURCE- SEWRPC.

nutrients. The low DO levels at the farthest downstream site in the Campbellsport reach were caused by aquatic plant respiration and by effluent discharged from the Campbellsport sewage treatment plant.

Concentrations of coliform in excess of 1,000 MFCC/100 ml throughout this reach of the Milwaukee River indicate that the stream is presently unsuitable for whole-body-contact-recreational activities. Coliform levels greater than 5,000 MFCC/100 ml downstream from the Kewaskum sewage treatment plant make this section of the river unsuitable even for partial-body-contact recreation.

The major water quality problems in this reach of the Milwaukee River are excessive fertilization and potential bacterial pollution. Aquatic plants create nuisance conditions and detract from the aesthetic value of the river. Average total phosphorus concentrations throughout this reach (see Table 63) are substantially greater than the guideline maximum value[27] of 0.10 mg/l total phosphorus in a flowing stream necessary to prevent nuisance growths of aquatic plants. It was estimated that an average of 20,300 pounds of phosphorus per year enters the Milwaukee River upstream from West Bend. Approximately 61 percent of this phosphorus input is contributed by agricultural drainage and runoff; 30 percent is contributed by treated waste discharges from the sewage treatment plants at Campbellsport and Kewaskum; and the remaining 16 percent, from miscellaneous sources, including 11 percent from urban runoff.

Biological sampling in this reach of the river revealed the presence of typical clean-water communities of bottom-dwelling, or benthic, organisms upstream from both the Campbellsport and Kewaskum sewage treatment plants and 2.4 miles downstream from the Campbellsport plant. Sam-

[27]*Ibid, footnote 2.*

ples obtained 0.1 mile downstream from the Campbellsport outfall, however, revealed a clean, but affected, benthic community, consisting of small numbers of organisms intolerant of pollution and large numbers of pollution-tolerant organisms. Thus, waste from the Campbellsport sewage treatment plant is disturbing the general stream ecology downstream from the plant outfall; but recovery to a clean-water ecological community occurs within two and one-half miles of the outfall. Biological samples obtained 0.8 mile downstream from the Kewaskum sewage treatment plant revealed an unbalanced benthic community, consisting mostly of pollution-tolerant organisms. The high number of these organisms, together with prolific growths of weeds and algae at this location, are, in large part, due to waste discharges from the Kewaskum treatment plant. No information was available to indicate where ecological recovery occurs downstream from this location.

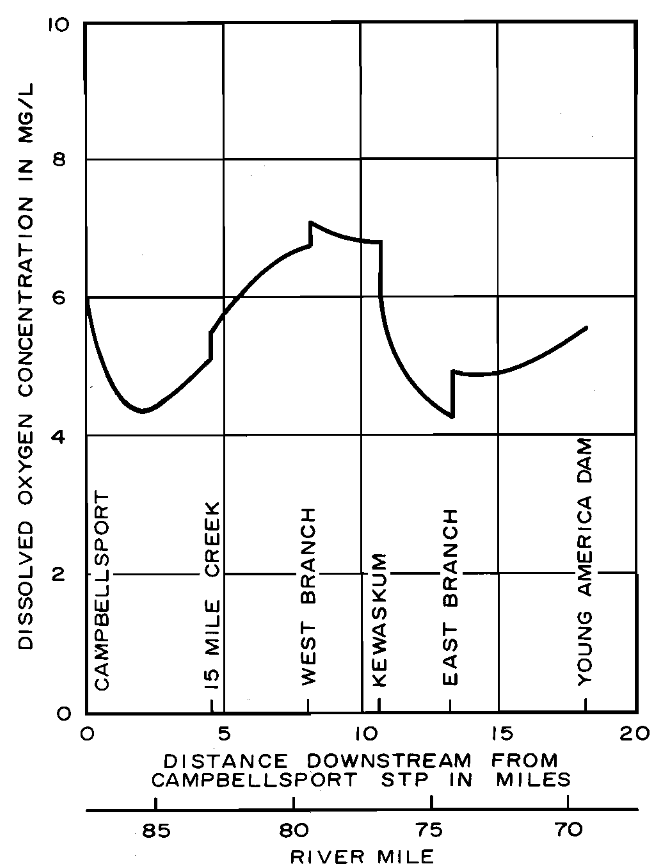
Future major waste discharges in this reach of the Milwaukee River will continue to be from the Campbellsport and Kewaskum sewage treatment plants, which may be expected to serve a total estimated population of 5,080 persons by 1990 and to discharge treated effluent to the river at an average combined rate of 1.8 cfs. If both of these plants continue to rely solely on secondary treatment facilities for waste treatment, but achieve 90 percent BOD removal, the waste loadings on the river by 1990 may be expected to result in average dissolved oxygen levels of 4.3 mg/l at locations approximately two miles downstream from each of the outfalls during critical low-flow conditions (see Figure 37). Dilution and natural purification may be expected to increase average low-flow oxygen levels to greater than 5.0 mg/l at locations approximately four miles downstream from Campbellsport and five miles downstream from Kewaskum. Thus, based on average low-flow conditions, nine miles of this reach of the Milwaukee River will be unsuitable for the maintenance of a warm-water fishery due to waste discharges which will reduce oxygen levels to less than 5.0 mg/l, the 5.0 mg/l being the state-established standard for this reach of the river. Figure 37 indicates that, if an oxygen depression of 1 to 2 mg/l prevailed due to plant respiration, a value of 4.0 mg/l of DO would prevail in only 5 to 10 miles of the 17-mile river reach, the 4.0 mg/l being the state-established standard for the maintenance of a warm-water fishery. If adequate disinfection of the effluents from both plants is provided, bacteriological conditions in the river should be suitable for all recreational uses of the river. If disinfection is not provided, the entire reach of the river from Campbellsport to West Bend would be bacteriologically unsuitable for water-based recreational activities.

Future increases in the population served by each of the sewage treatment plants may be expected to result in increased discharges of phosphorus to the river. By 1990 phosphorus discharges to the Milwaukee River upstream from West Bend may be expected to increase to an estimated 28,800 pounds per year if no specific phosphorus removal measures are undertaken at the Campbellsport and Kewaskum sewage treatment plants or if no other means, such as the placement of legal constraints on the phosphorus content of detergents,

Figure 37

CALCULATED DISSOLVED OXYGEN PROFILE UNDER UNPLANNED 1990 LAND USE DEVELOPMENT CONDITIONS AT 25° C WITH 90 PERCENT BOD REMOVAL AT SEWAGE TREATMENT PLANTS

MILWAUKEE RIVER-CAMPBELLSPORT TO WEST BEND



NOTE: THIS PROFILE IS FOR LOW FLOW CONDITIONS

Source: Harza Engineering Company.

are undertaken. Approximately 48 percent of this phosphorus input would be from the sewage treatment plants and 42 percent from agricultural and rural drainage and runoff. If 85 percent of phosphorus removal is provided at the plants, as specified by outstanding state pollution abatement orders, the total phosphorus contributed to the river in 1990 would be reduced to 18,800 pounds per year, or approximately 93 percent of the present value. It may be expected that these large amounts of phosphorus will continue to stimulate luxuriant aquatic plant growths in the river. These prolific weed and algae growths will probably continue to have adverse effects on oxygen levels in the river by reducing DO concentrations during the nighttime hours and will detract from the aesthetic value of the river.

From the foregoing analysis, it may be concluded that the state-established water use objectives and standards will not be met unless specific measures are taken to assure that average daily DO concentrations are maintained above 5.0 mg/l, with a minimum value of 4.0 mg/l at any time; coliform levels are reduced to less than 1,000 MFCC/100 ml; and growths of algae and aquatic weeds are reduced or eliminated.

Milwaukee River—West Bend to Grafton Dam: Existing water uses in the reach of the Milwaukee River from West Bend to the Grafton Dam include maintenance of a warm-water fishery, partial-body-contact-recreational activities, livestock and wildlife watering, irrigation, waste assimilation, and aesthetic uses. Some of these uses are presently occurring in this reach of the river, even though water quality levels in the reach do not meet state standards for these uses. State-established water use objectives include all the existing uses, plus whole-body-contact-recreational activities and industrial and cooling water supply. Municipal waste discharges within this reach are from the sewage treatment plants at Fredonia, Newburg, Saukville, and West Bend. The treatment plant at West Bend serves a population of 15,000 persons and discharges treated effluent to the Milwaukee River at an average rate of 2.5 cfs. The other three plants serve a total population of 2,400 persons and discharge treated effluent to the river at an average combined rate of 0.4 cfs. Industrial waste sources located within the reach are the River Road Cheese Factory and De Soto Chemical Coatings, Inc., both located near Fredonia.

Existing water quality data for this reach are summarized in Table 64. Minimum DO levels less than 4.0 mg/l downstream from the West Bend sewage treatment plant and in the impoundments at Waubeka and Grafton inhibit the use of these sections of the stream for the maintenance of a warm-water fishery. The low DO levels downstream from the West Bend sewage treatment plant are caused by the effluent discharged from the plant, while the low levels in the Waubeka and Grafton impoundments may be attributed to the extensive weed and algae growths in these areas. Effluent discharges from the Fredonia, Newburg, and Saukville sewage treatment plants have a negligible effect on DO levels in the Milwaukee River. An analysis of the waste assimilation capacity of the river in this reach indicates that, during critical low-flow conditions, effluent from the West Bend sewage treatment plant may be expected to reduce average DO levels below 5.0 mg/l from the plant outfall downstream to the Newburg Dam, a distance of nine miles, with a minimum value of 3.5 to 4.0 mg/l occurring approximately two miles downstream from the plant outfall. Downstream from the Newburg Dam, average oxygen levels may be expected to rise well above 5.0 mg/l and remain at this high level throughout the remainder of this reach of the river.

Although the waste assimilation capacity of the river is sufficient to maintain average DO levels above 5.0 mg/l downstream from the Newburg Dam, growths of algae and aquatic weeds throughout this reach cause wide diurnal fluctuations in DO levels, with minimum early morning concentrations occasionally less than 4.0 mg/l. Figures 38 and 39 show this diurnal fluctuation of the DO as measured in the Milwaukee River near the West Bend Airport during the April-May and July-August 1968 water quality survey. Figures 40 and 41 show the average, maximum, and minimum DO concentrations measured during this water quality survey. During the spring survey, all measured DO levels were found to exceed the minimum standards for all uses by a wide margin. Average DO levels were found to be above 5.0 mg/l throughout the reach during the summer survey, but minimum levels of less than 4.0 mg/l were recorded from the West Bend sewage treatment plant downstream to Newburg and in the impoundment at Waubeka. DO levels ranged from as low as 2.0 to 3.0 mg/l during the early morning hours to as high as 14 to 18 mg/l during the mid-afternoon hours.

TABLE 64

WATER QUALITY SURVEY DATA SUMMARY FOR THE MILWAUKEE RIVER (WEST BEND TO GRAFTON DAM) 1964-1968

		PARAMETER							
					PHOSPHORUS				
SAMPLING LOCATION	DATA	TEMPERATURE (°C)	DO (MG/1)	BOD (MG/1)	SOLUBLE (MG/1)	TOTAL (MG/1)	NITRATE (MG/1)	CHLORIDE (MG/1)	COLIFORM (MFCC/100ML)
UPSTREAM FROM WEST BEND SEWAGE TREATMENT PLANT[a,b]	NUMBER OF SAMPLES	(29)	(29)	(2)	(3)	(3)	(3)	(0)	(1)
	MAXIMUM	25.0	13.5	5.2	0.22	0.34	0.7	--	--
	MINIMUM	1.5	7.2	1.6	0.11	0.14	0.1	--	--
	AVERAGE	18.7	9.0	--	0.18	0.27	0.4	--	3,500
0.5 MILE DOWNSTREAM FROM WEST BEND SEWAGE TREATMENT PLANT[a]	NUMBER OF SAMPLES	(28)	(28)	(0)	(3)	(3)	(3)	(0)	(0)
	MAXIMUM	26.0	13.7	--	1.84	2.02	1.6	--	--
	MINIMUM	11.0	3.2	--	0.46	0.51	0.9	--	--
	AVERAGE	19.0	9.0	--	1.18	1.35	1.2	--	--
3 MILES DOWNSTREAM FROM WEST BEND SEWAGE TREATMENT PLANT[a]	NUMBER OF SAMPLES	(28)	(28)	(0)	(1)	(1)	(1)	(0)	(0)
	MAXIMUM	27.0	13.2	--	--	--	--	--	--
	MINIMUM	10.3	2.8	--	--	--	--	--	--
	AVERAGE	19.0	9.0	--	0.18	0.21	0.5	--	--
6 MILES DOWNSTREAM FROM WEST BEND SEWAGE TREATMENT PLANT[a,b,c]	NUMBER OF SAMPLES	(47)	(47)	(17)	(4)	(1)	(4)	(6)	(18)
	MAXIMUM	26.6	24.2	8.4	1.13	--	1.8	45	53,000
	MINIMUM	0.0	2.4	1.7	0.10	--	0.7	11	100
	AVERAGE	15.6	9.0	4.0	0.38	0.24	1.2	24	5,000M[d]
UPSTREAM FROM NEWBURG DAM[a]	NUMBER OF SAMPLES	(18)	(18)	(0)	(0)	(0)	(0)	(0)	(0)
	MAXIMUM	25.0	14.6	--	--	--	--	--	--
	MINIMUM	19.5	4.6	--	--	--	--	--	--
	AVERAGE	22.6	8.6	--	--	--	--	--	--
DOWNSTREAM FROM NEWBURG DAM[a,b]	NUMBER OF SAMPLES	(31)	(31)	(4)	(3)	(3)	(3)	(0)	(3)
	MAXIMUM	25.0	10.8	4.2	0.70	1.04	1.7	--	29,000
	MINIMUM	10.1	5.6	2.5	0.22	0.28	1.5	--	5,000
	AVERAGE	18.8	8.5	3.5	0.51	0.77	1.6	--	--
5 MILES DOWNSTREAM FROM NEWBURG AT CTH A[a]	NUMBER OF SAMPLES	(28)	(28)	(1)	(3)	(2)	(3)	(0)	(0)
	MAXIMUM	25.5	14.8	--	0.70	0.86	2.9	--	--
	MINIMUM	10.1	4.0	--	0.20	0.26	1.1	--	--
	AVERAGE	18.7	10.0	3.9	0.49	--	1.9	--	--
UPSTREAM FROM WAUBEKA DAM[a]	NUMBER OF SAMPLES	(46)	(46)	(1)	(3)	(3)	(3)	(0)	(0)
	MAXIMUM	26.0	18.4	--	0.37	0.64	1.2	--	--
	MINIMUM	11.0	3.6	--	0.14	0.19	0.7	--	--
	AVERAGE	20.4	9.9	5.2	0.28	0.47	0.9	--	--
DOWNSTREAM FROM WAUBEKA DAM[a,b]	NUMBER OF SAMPLES	(32)	(32)	(4)	(0)	(0)	(0)	(0)	(4)
	MAXIMUM	25.0	13.7	5.1	--	--	--	--	11,000
	MINIMUM	6.0	6.8	1.4	--	--	--	--	1,000
	AVERAGE	17.6	9.2	3.0	--	--	--	--	4,600M[d]
0.1 MILE DOWNSTREAM FROM FREDONIA SEWAGE TREATMENT PLANT[b]	NUMBER OF SAMPLES	(4)	(4)	(4)	(0)	(0)	(0)	(0)	(4)
	MAXIMUM	25.0	13.3	5.1	--	--	--	--	4,000,000
	MINIMUM	6.0	7.4	1.8	--	--	--	--	400
	AVERAGE	15.8	10.4	2.9	--	--	--	--	7,000M[d]
STH 33 IN SAUKVILLE[b,c]	NUMBER OF SAMPLES	(21)	(21)	(18)	(3)	(0)	(3)	(16)	(20)
	MAXIMUM	28.4	14.7	7.8	0.50	--	1.2	35	39,000
	MINIMUM	0.0	4.0	0.7	0.10	--	0.4	5	700
	AVERAGE	10.5	9.4	2.8	0.24	--	0.7	23	3,700M[d]
0.6 MILE BELOW SAUKVILLE SEWAGE TREATMENT PLANT[b]	NUMBER OF SAMPLES	(4)	(4)	(4)	(0)	(0)	(0)	(0)	(4)
	MAXIMUM	25.5	13.6	4.7	--	--	--	--	50,000
	MINIMUM	5.0	4.8	2.3	--	--	--	--	7,000
	AVERAGE	16.4	8.3	3.2	--	--	--	--	21,000M[d]
UPSTREAM FROM GRAFTON DAM[a,c]	NUMBER OF SAMPLES	(30)	(30)	(12)	(3)	(0)	(3)	(6)	(14)
	MAXIMUM	28.9	14.7	10.7	0.35	--	1.2	35	11,000
	MINIMUM	0.0	2.8	2.1	0.10	--	0.3	5	500
	AVERAGE	19.2	8.7	4.2	0.19	--	0.7	17	5,000M[d]

[a] SAMPLING DONE BY HARZA ENGINEERING COMPANY.

[b] SAMPLING DONE BY WISCONSIN DEPARTMENT OF NATURAL RESOURCES.

[c] SAMPLING DONE BY SEWRPC.

[d] MEDIAN VALUE.

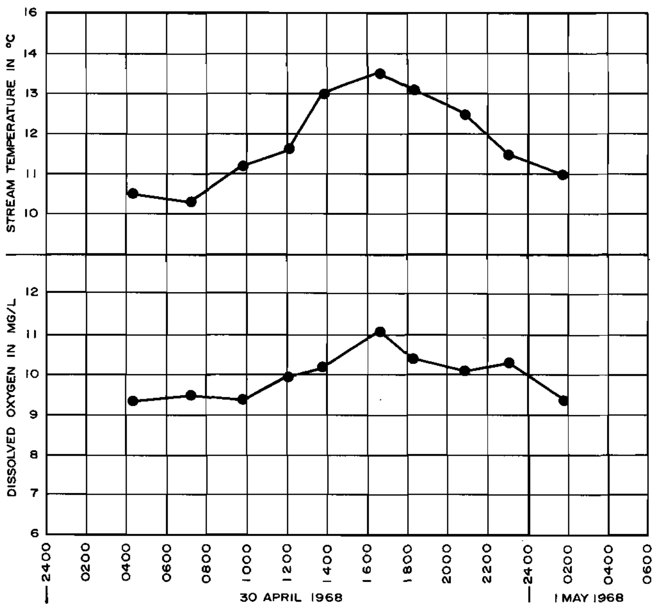
SOURCE- SEWRPC.

Median coliform concentrations in this reach of the Milwaukee River are generally in the range of 4,000 to 6,000 MFCC/100 ml (see Table 64), indicating that the river is of questionable suitability for partial-body-contact-recreational activities and unsuitable for whole-body-contact recreation. Coliform concentrations substantially greater than 5,000 MFCC/100 ml are evident downstream from the Fredonia and Saukville sewage treatment plants, indicating that these sections of the river are unsuitable for any water-based recreational activities. Effluent disinfection is presently practiced throughout the year at the West Bend sewage treatment plant and during the summer months at the Newburg sewage treatment plant. No disinfection is presently provided at the Fredonia and Saukville plants.

Growths of aquatic plants, as described previously, detract from the aesthetic value of the river. Total phosphorus concentrations in this reach were found to range from a minimum of 0.14 mg/l, as measured upstream from the West Bend sewage treatment plant, to a maximum value

Figure 38

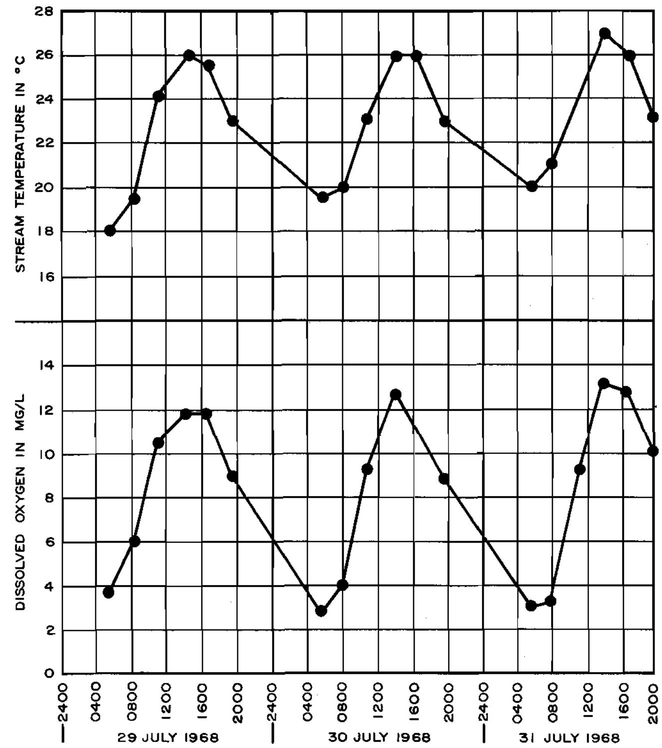
DIURNAL VARIATION OF WATER TEMPERATURE AND DISSOLVED OXYGEN CONTENT IN THE MILWAUKEE RIVER NEAR WEST BEND AIRPORT APRIL–MAY 1968 (RM 60.51)



Source: Harza Engineering Company.

Figure 39

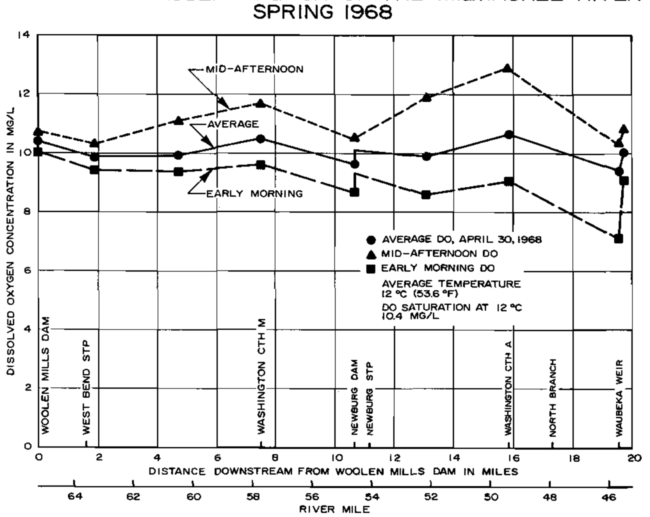
DIURNAL VARIATION OF WATER TEMPERATURE AND DISSOLVED OXYGEN CONTENT IN THE MILWAUKEE RIVER NEAR WEST BEND AIRPORT JULY 1968 (RM 60.51)



Source: Harza Engineering Company.

Figure 40

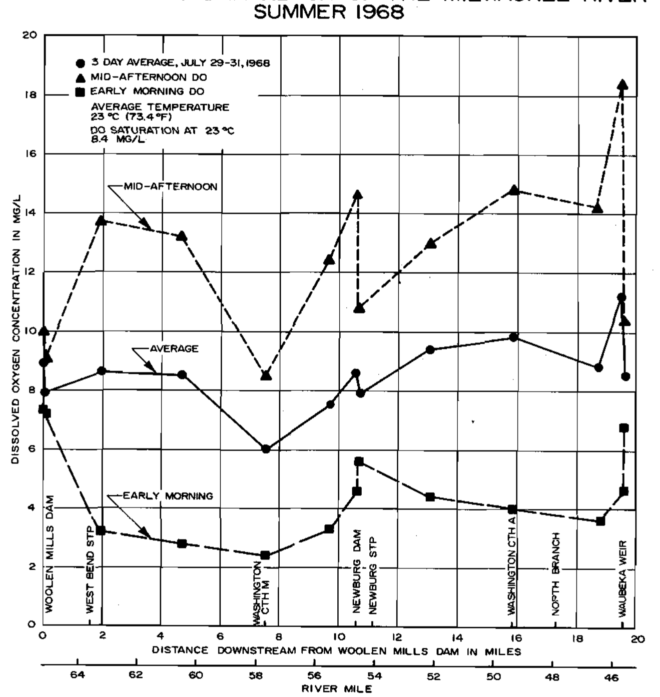
MEASURED DISSOLVED OXYGEN PROFILE WEST BEND-WAUBEKA REACH OF THE MILWAUKEE RIVER SPRING 1968



Source: Harza Engineering Company.

Figure 41

MEASURED DISSOLVED OXYGEN PROFILE WEST BEND-WAUBEKA REACH OF THE MILWAUKEE RIVER SUMMER 1968



Source: Harza Engineering Company.

of 2.02 mg/l downstream from this plant (see Table 64). The average total phosphorus concentration within the reach is 0.64 mg/l, or over six times higher than the guideline maximum value of 0.10 mg/l in a flowing stream necessary to prevent nuisance growths of aquatic plants. It was estimated that an average of 49,600 pounds of phosphorus per year enters the Milwaukee River upstream from its junction with the North Branch.

Approximately 59 percent of this phosphorus input is from treated waste discharges from the sewage treatment plants at Campbellsport, Kewaskum, Newburg, and West Bend, and 32 percent is from agricultural and rural drainage and runoff.

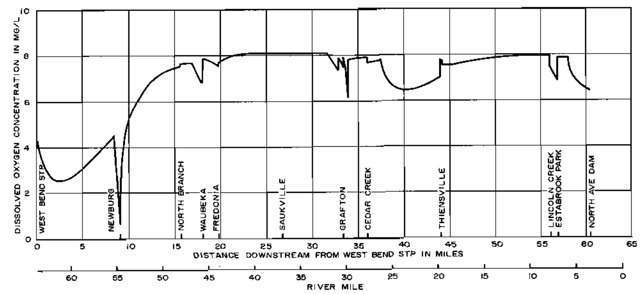
Biological sampling in this reach of the river in 1966 revealed the presence of balanced, clean-water communities of benthic organisms upstream from West Bend and throughout the entire section of the river from CTH M three miles upstream from Newburg downstream to Grafton. Sampling in this section of the river from West Bend downstream to CTH M, however, revealed unbalanced benthic communities and polluted conditions through most of this 10-mile section. The unbalanced and polluted conditions were caused by waste discharges from Line Materials Industries, the West Bend Company, and the old West Bend sewage treatment plant. Since the biological survey was completed, waste-water lines from the two industrial plants have been connected to the West Bend sewerage system; and a new sewage treatment plant, serving the West Bend area and located several miles farther downstream, was placed in operation, the old plant being abandoned. Consequently, the effects of wastes discharged from the new plant on stream biota are not known at this time; but conditions are expected to be considerably improved.

Future waste discharges to this reach of the Milwaukee River will be from the sewage treatment plants serving Fredonia, Newburg, Saukville, and West Bend. These plants may be expected to serve a total estimated population of 29,600 persons by 1990 and to discharge treated effluent to the river at an average rate of 8.6 cfs (see Table 60). Even with continued sole reliance on secondary treatment, waste discharges from the plants at Fredonia, Newburg, and Saukville may be expected to have a negligible effect on DO levels in the Milwaukee River. Effluent from the West Bend plant, however, may be expected to reduce DO levels below 5.0 mg/l from the plant outfall downstream for a distance of approximately 10 miles during critical low-flow conditions, even with 90 percent BOD removal (see Figure 42). Anaerobic conditions may be expected to develop in the impoundment at Newburg. These low oxygen levels will preclude the maintenance of a warm-water fishery; and the septic conditions, with associated offensive odors, that may be expected to develop will prevent use of some sections of this reach for any uses other than waste assimilation.

Figure 42

CALCULATED DISSOLVED OXYGEN PROFILE UNDER UNPLANNED 1990 LAND USE DEVELOPMENT CONDITIONS AT 25° C WITH 90 PERCENT BOD REMOVAL AT SEWAGE TREATMENT PLANTS

MILWAUKEE RIVER - WEST BEND TO NORTH AVENUE DAM



NOTE: THIS PROFILE IS FOR LOW FLOW CONDITIONS EXCLUSIVE OF THE EFFECTS OF ALGAE AND SEWER OVERFLOWS.

Source: Harza Engineering Company.

Dilution and natural purification may be expected to increase oxygen levels to greater than 5.0 mg/l downstream from Newburg, and the average DO concentrations may be expected to remain well above 5.0 mg/l throughout the remainder of this reach of the Milwaukee River.

Further increases in the population served by the sewage treatment plants may be expected to result in increased discharges of phosphorus to the river. By 1990 phosphorus discharges to the Milwaukee River upstream from the North Branch may be expected to increase to an estimated 80,300 pounds per year if no specific phosphorus removal is undertaken at the upstream sewage treatment plants. Approximately 76 percent of this phosphorus input would be contributed by the upstream sewage treatment plant discharges and 22 percent from urban runoff and rural-agricultural runoff and drainage. If 85 percent phosphorus removal for the basin is provided at the sewage treatment plants, as presently ordered by the state, the total phosphorus contributed to the river in 1990 would be reduced to 36,300 pounds per year, or approximately 73 percent of the present amount. It may be expected that these large amounts of phosphorus will continue to stimulate profuse growths of aquatic plants in the river. These weed and algae growths may be expected to continue to have adverse effects on oxygen levels in the river by reducing DO concentrations during the night-time hours and to detract from the aesthetic value of the river.

If adequate disinfection of the effluents from the four sewage treatment plants located within this reach is provided, bacteriological conditions should be suitable for all recreational uses of the river, although the septic conditions that may be expected to occur downstream from the West Bend sewage treatment plant would preclude use of this section of the river for any recreational activities. If disinfection is not provided, the entire reach of the river from the West Bend sewage treatment plant downstream to Grafton would be bacteriologically unsuitable for any water-based recreational activities.

Milwaukee River—Grafton Dam to Lincoln Creek: Existing water uses in the reach of the Milwaukee River from the Grafton dam downstream to Lincoln Creek include maintenance of a warm-water fishery, partial-body-contact-recreational activities, livestock and wildlife watering, irrigation, waste assimilation, and aesthetic uses. Some of these uses are presently being made of this reach of the river even though water quality levels in the reach do not meet state standards for these uses. State-established water use objectives include all the existing uses plus whole-body-contact-recreational activities and industrial and cooling water supply. Municipal waste discharges within the reach are from the sewage treatment plants at Grafton and Thiensville and from the Ville du Parc and Lac du Cours subdivisions in Mequon.[28] These plants serve a total population of 8,410 persons and discharge treated effluent to the Milwaukee River at an average rate of 1.5 cfs. The only industrial waste discharge in this reach is from the Badger Worsted Mills, Inc. in Grafton.

Existing water quality data for this reach are summarized in Table 65. Minimum DO levels of less than 4.0 mg/l have been measured in the impoundments upstream from the Chair Factory and Lime Kiln Dams in Grafton, at CTH C in Mequon, and at Brown Deer Road in Milwaukee County. These occasional low DO levels may be attributed primarily to the substantial growths of algae and aquatic weeds present throughout this reach of the river. Effluent discharges from the sewage treatment plants at Grafton and Thiensville and untreated waste discharges from the Badger Worsted Mills, Inc. may also occasionally adversely affect DO levels in this reach of the river; but the waste assimilation capacity of the river is generally sufficient to maintain average DO levels well above 5.0 mg/l under normal waste loadings from these sources. Growths of algae and aquatic weeds, however, cause large daily fluctuations in DO levels throughout the reach. DO concentrations measured during water quality surveys of the river carried out on May 1 and from August 1 through 3, 1968, are shown in Figures 43 and 44. Minimum DO levels were found to be greater than 9.0 mg/l throughout the reach in May; and minimum levels were found to be greater than 4.0 mg/l in August, except in the impoundment upstream from the Lime Kiln Dam at CTH C, with the measured August average exceeding 5.0 mg/l DO throughout the reach.

Concentrations of coliform in excess of 5,000 MFCC/100 ml from Grafton downstream to Cedar Creek and from the Thiensville sewage treatment plant downstream to Brown Deer Road indicate that these sections of the river are unsuitable for any water-based recreational activities. The remaining sections of this reach are bacteriologically suitable for partial-body-contact-recreational activities. The major sources of the coliform organisms are effluents discharged from the sewage treatment plants located in the reach.

The major water quality problems in this reach of the river are excessive fertilization and potential presence of disease-bearing bacteria. High concentrations of phosphorus stimulate growths of aquatic plants which occasionally cause DO levels lower than the minimum required for maintenance of a warm-water fishery and which detract from the aesthetic value of the river. The average total phosphorus concentration in the reach was found to be 0.45 mg/l, or more than four times the guideline maximum value of 0.10 mg/l required to prevent nuisance growths of aquatic plants in a flowing stream. It is estimated that an average of 111,200 pounds of phosphorus per year enters the Milwaukee River upstream from the Milwaukee County line. Approximately 54 percent of this phosphorus input is contributed by upstream sewage treatment plant effluent, 33 percent by rural-agricultural drainage and runoff, and 7 percent by urban runoff.

Biological sampling from Grafton downstream to the Milwaukee County line revealed the presence of balanced, clean-water communities of benthic organisms at all locations sampled, except for a location immediately downstream from the Badger Worsted Mills outfall, where a clean, but affected, community was observed. The reduction in the number of clean-water organisms was probably

[28] *The sewage treatment plants serving the Ville du Parc and Lac du Cours subdivisions in the City of Mequon were abandoned in 1968 and the tributary sewer service areas connected to the Milwaukee metropolitan system.*

TABLE 65

WATER QUALITY SURVEY DATA SUMMARY FOR THE MILWAUKEE RIVER (GRAFTON DAM TO LINCOLN CREEK) 1964-1968

SAMPLING LOCATION	DATA	PARAMETER							
					PHOSPHORUS				
		TEMPERATURE (°C)	DO (MG/1)	BOD (MG/1)	SOLUBLE (MG/1)	TOTAL (MG/1)	NITRATE (MG/1)	CHLORIDE (MG/1)	COLIFORM (MFCC/100ML)
UPSTREAM FROM CHAIR FACTORY DAM IN GRAFTON[a]	NUMBER OF SAMPLES	(4)	(4)	(4)	(0)	(0)	(0)	(0)	(4)
	MAXIMUM	26.0	10.1	3.7	--	--	--	--	480,000
	MINIMUM	13.0	4.5	2.1	--	--	--	--	900
	AVERAGE	20.8	6.8	2.7	--	--	--	--	22,000M[b]
DOWNSTREAM FROM CHAIR FACTORY DAM[c]	NUMBER OF SAMPLES	(21)	(21)	(0)	(3)	(3)	(2)	(0)	(0)
	MAXIMUM	25.0	10.9	--	0.31	0.49	0.5	--	--
	MINIMUM	11.0	5.8	--	0.11	0.20	0.2	--	--
	AVERAGE	20.6	8.0	--	0.24	0.36	--	--	--
UPSTREAM FROM LIME KILN DAM IN GRAFTON[a,c]	NUMBER OF SAMPLES	(25)	(25)	(5)	(3)	(3)	(2)	(0)	(4)
	MAXIMUM	26.5	12.0	7.1	0.34	0.74	0.5	--	450,000
	MINIMUM	11.0	3.2	2.3	0.14	0.25	0.3	--	4,000
	AVERAGE	20.7	7.8	4.8	0.26	0.48	--	--	36,000M[b]
DOWNSTREAM FROM LIME KILN DAM[c]	NUMBER OF SAMPLES	(21)	(21)	(0)	(1)	(1)	(0)	(0)	(0)
	MAXIMUM	25.5	11.7	--	--	--	--	--	--
	MINIMUM	11.0	5.9	--	--	--	--	--	--
	AVERAGE	20.8	8.6	--	0.10	0.18	--	--	--
CTH C IN OZAUKEE COUNTY[c,d]	NUMBER OF SAMPLES	(36)	(36)	(3)	(6)	(3)	(6)	(6)	(14)
	MAXIMUM	29.4	17.8	6.1	0.57	0.77	2.2	40	27,000
	MINIMUM	0.0	2.6	0.6	0.08	0.18	1.0	15	100
	AVERAGE	16.6	11.1	2.6	0.32	0.51	1.5	25	3,800M[b]
CTH M IN OZAUKEE COUNTY[a,c]	NUMBER OF SAMPLES	(24)	(24)	(3)	(1)	(1)	(1)	(0)	(3)
	MAXIMUM	26.0	15.6	2.0	--	--	--	--	31,000
	MINIMUM	10.0	5.1	1.7	--	--	--	--	2,000
	AVERAGE	21.2	9.0	1.8	0.12	0.21	2.8	--	--
UPSTREAM FROM THIENSVILLE DAM[a,c]	NUMBER OF SAMPLES	(22)	(22)	(2)	(3)	(3)	(3)	(0)	(1)
	MAXIMUM	26.0	13.6	6.8	0.37	0.58	2.7	--	--
	MINIMUM	11.2	9.5	5.1	0.13	0.21	0.2	--	--
	AVERAGE	21.2	11.5	--	0.28	0.41	1.1	--	1,300
DOWNSTREAM FROM THIENSVILLE DAM[a,c]	NUMBER OF SAMPLES	(24)	(24)	(3)	(0)	(0)	(0)	(0)	(3)
	MAXIMUM	25.5	11.3	4.6	--	--	--	--	13,000
	MINIMUM	11.5	6.5	2.3	--	--	--	--	900
	AVERAGE	21.0	9.4	3.5	--	--	--	--	--
DOWNSTREAM FROM THIENSVILLE SEWAGE TREATMENT PLANT AT STH 167[a,c,d]	NUMBER OF SAMPLES	(40)	(40)	(17)	(6)	(3)	(6)	(6)	(18)
	MAXIMUM	30.6	15.8	8.6	0.64	0.64	2.9	45	150,000
	MINIMUM	0.0	5.0	0.7	0.10	0.21	0.4	15	800
	AVERAGE	17.6	10.0	3.4	0.32	0.47	1.1	27	9,000M[b]
COUNTY LINE ROAD[a]	NUMBER OF SAMPLES	(3)	(3)	(3)	(0)	(0)	(0)	(0)	(3)
	MAXIMUM	27.5	10.9	4.3	--	--	--	--	24,000
	MINIMUM	12.0	6.9	2.1	--	--	--	--	5,000
	AVERAGE	22.0	9.2	3.5	--	--	--	--	--
BROWN DEER ROAD[a,e]	NUMBER OF SAMPLES	(77)	(77)	(82)	(19)	(19)	(19)	(82)	(80)
	MAXIMUM	27.0	16.5	15.0	0.93	1.04	1.6	95	190,000
	MINIMUM	0.0	2.4	0.5	0.10	0.16	0.1	2	200
	AVERAGE	15.0	8.2	2.7	0.38	0.47	0.6	23	5,500M[b]
GREEN TREE ROAD[e]	NUMBER OF SAMPLES	(30)	(30)	(30)	(0)	(0)	(0)	(30)	(30)
	MAXIMUM	24.5	13.1	6.8	--	--	--	32	45,000
	MINIMUM	12.5	5.1	1.0	--	--	--	8	700
	AVERAGE	19.4	8.1	2.5	--	--	--	22	3,500M[b]
SILVER SPRING ROAD[f]	NUMBER OF SAMPLES	(32)	(31)	(4)	(4)	(0)	(0)	(32)	(32)
	MAXIMUM	11.5	15.4	4.1	0.84	--	--	49	3,200
	MINIMUM	0.0	9.3	2.7	0.30	--	--	21	80
	AVERAGE	2.3	13.0	3.2	0.49	--	--	34	360M[b]

[a] SAMPLING DONE BY WISCONSIN DEPARTMENT OF NATURAL RESOURCES.

[b] MEDIAN VALUE.

[c] SAMPLING DONE BY HARZA ENGINEERING COMPANY.

[d] SAMPLING DONE BY SEWRPC.

[e] SAMPLING DONE BY MILWAUKEE SEWERAGE COMMISSION.

[f] SAMPLING DONE BY CONSOER, TOWNSEND & ASSOCIATES.

SOURCE- SEWRPC.

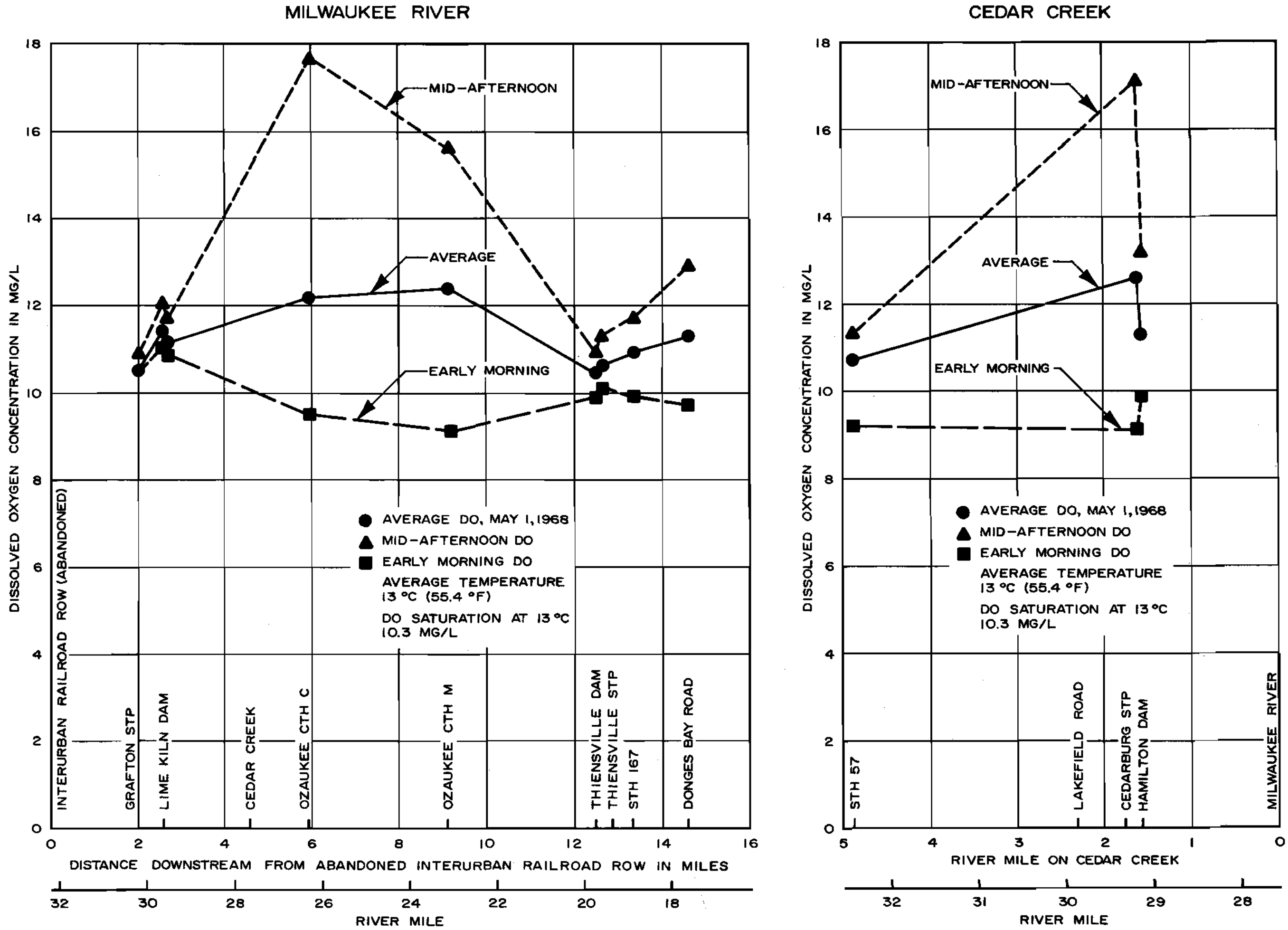
caused by the discharge of dyeing and washing wastes from the Badger Worsted Mills. Recovery to a typical well-balanced, clean-water benthic community was observed 0.5 mile downstream from the Mill.

Future waste discharges to this reach of the Milwaukee River will be from the sewage treatment plants serving Grafton and Thiensville.[29] These plants may be expected to serve a total estimated

[29] *It is assumed that, by 1990, all that part of the City of Mequon lying within the Milwaukee River watershed will be served by the Metropolitan Sewerage Commission of the County of Milwaukee, thereby eliminating any waste discharge from Mequon to the Milwaukee River.*

Figure 43

MEASURED DISSOLVED OXYGEN PROFILE GRAFTON-THIENSVILLE REACH OF THE MILWAUKEE RIVER AND A SELECTED PORTION OF CEDAR CREEK SPRING 1968



Source: Harza Engineering Company.

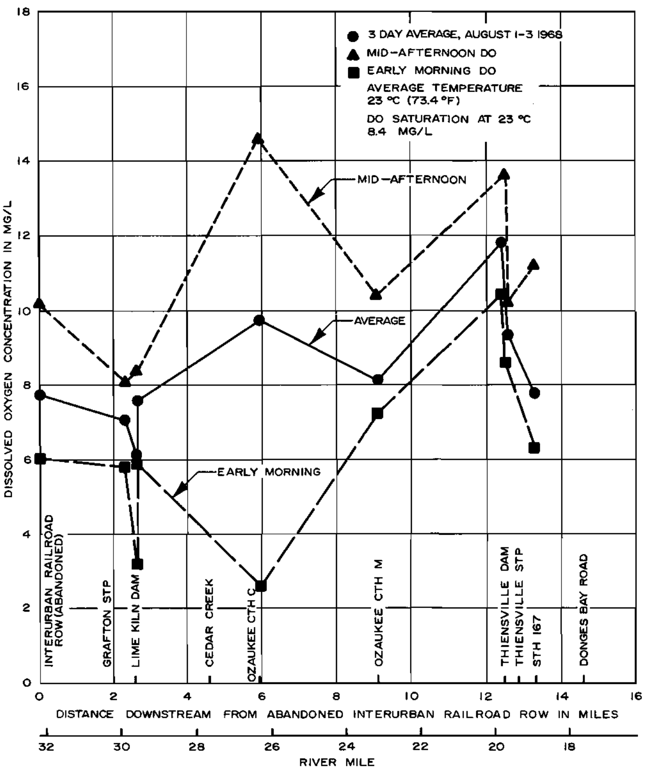
population of 13,950 persons by 1990 and to discharge treated effluent to the river at an average rate of 3.4 cfs. Even with continued sole reliance on secondary treatment at these plants, their effluents will have only minor effects on DO levels in the river. Exclusive of the effects of aquatic plants, average DO levels throughout this reach of the river should remain well above 5.0 mg/l, even during critical low-flow conditions. As indicated in Figure 44, however, the DO may be drastically reduced by the effects of plant respiration.

If adequate disinfection of the sewage treatment plant effluent is provided, bacteriological conditions in the river should be suitable for all recreational uses. If disinfection is not provided, however, most of the reach may be expected to become unsuitable for any water-based recreational activities.

Increases in the population served by sewage treatment plants located along the reach of the river and in the amount of developed urban area in the watershed will result in increased discharges of phosphorus to the river. By 1990 phosphorus discharges to the Milwaukee River upstream from the Milwaukee County line may be expected to increase to an estimated 178,400 pounds per year, or to 160 percent of the present amount, if no specific phosphorus removal measures are undertaken at the upstream sewage treatment plants. Approximately two-thirds of this phosphorus input

Figure 44

MEASURED DISSOLVED OXYGEN PROFILE
GRAFTON-THIENSVILLE REACH OF THE MILWAUKEE RIVER
SUMMER 1968



Source: Harza Engineering Company.

may be expected to be contributed by sewage treatment plant effluent. If 85 percent phosphorus removal is provided at the treatment plants, the total phosphorus contributed to the river in 1990 would be reduced to 87,400 pounds per year, or approximately 79 percent of the present amount. Of this 87,400 pounds, approximately 39 percent would be contributed by the residual in the treatment plant effluent; 13 percent would be contributed by urban runoff; and 40 percent would be contributed by rural-agricultural drainage and runoff. It may be expected that these large amounts of phosphorus will continue to stimulate aquatic plant growths in the river and thereby to affect adversely water quality by reducing DO concentrations during the night-time hours, as well as detracting from the aesthetic value of this reach of the river.

<u>Milwaukee River—Lincoln Creek to North Avenue Dam</u>: Existing water uses in the reach of the Milwaukee River from Lincoln Creek downstream to the North Avenue Dam include maintenance of a warm-water fishery, partial-body-contact recreation, waste assimilation, and aesthetic uses. Some of these uses are presently being made of this reach of the river, even though water quality levels in the reach do not meet state standards for these uses. State-established water use objectives include all the existing uses plus whole-body-contact recreation and industrial and cooling water supply. There are no sewage treatment plants located within the reach. There are, however, 11 industries which discharge sewage through the storm sewer system to the Milwaukee River within the reach. The area tributary to this reach is almost entirely urban and served by the Milwaukee metropolitan sewerage system. Wastes from this area are transported to the Jones Island and South Shore sewage treatment plants for treatment and then discharged to Lake Michigan. The principal sources of pollution in this reach, consequently, are overflows from the sanitary and combined sewers and urban runoff.

Existing water quality data for this reach are summarized in Table 66. Average dissolved oxygen levels of less than 5.0 mg/l in the impoundment upstream from the North Avenue Dam and minimum levels substantially lower than 4.0 mg/l in this impoundment and in the impoundment upstream from the Estabrook Park Dam inhibit the maintenance of a warm-water fishery. The only section of this reach in which DO levels are suitable for the maintenance of a healthy fishery is from the Estabrook Park Dam downstream to Capitol Drive, the reaeration resulting from the flow of water over the Dam, increasing DO levels above 5.0 mg/l. This level is then maintained until the stream enters the North Avenue Dam impoundment at Capitol Drive. These low DO levels may be attributed primarily to the effects of the discharges from both the combined and separate sewerage systems. There are 10 combined sewer outfalls that discharge untreated sewage to the river upstream from the North Avenue Dam during storm periods and 85 relief points where untreated sanitary sewage is discharged from the separate sanitary sewers to Lincoln Creek and to the Milwaukee River upstream from the North Avenue Dam, as necessary, to relieve the overloaded sanitary sewers system. The large amounts of organic wastes contained in these discharges adversely affect water quality in this reach of the Milwaukee River by lowering the DO concentration to levels unsuitable for fish life. DO concentrations less than 1.0 mg/l have been measured in this reach of the river.

TABLE 66

WATER QUALITY SURVEY DATA SUMMARY FOR THE MILWAUKEE RIVER (LINCOLN CREEK TO NORTH AVENUE DAM) 1964-1968

SAMPLING LOCATION	DATA	PARAMETER							
					PHOSPHORUS				
		TEMPERATURE (°C)	DO (MG/1)	BOD (MG/1)	SOLUBLE (MG/1)	TOTAL (MG/1)	NITRATE (MG/1)	CHLORIDE (MG/1)	COLIFORM (MFCC/100ML)
UPSTREAM FROM ESTABROOK PARK DAM[a,b,c]	NUMBER OF SAMPLES	(48)	(48)	(44)	(3)	(0)	(3)	(47)	(47)
	MAXIMUM	29.4	13.9	11.0	0.44	--	1.0	170	7,900,000
	MINIMUM	0.0	0.4	1.7	0.13	--	0.8	11	1,400
	AVERAGE	16.7	7.7	4.6	0.25	--	0.9	32	65,000M[d]
DOWNSTREAM FROM ESTABROOK PARK DAM AT RAILROAD TRESTLE[a,b,e]	NUMBER OF SAMPLES	(36)	(36)	(36)	(3)	(0)	(1)	(34)	(35)
	MAXIMUM	24.5	14.0	7.6	0.38	--	--	37	2,100,000
	MINIMUM	1.0	4.1	2.1	0.22	--	--	8	1,500
	AVERAGE	19.1	7.6	4.1	0.30	--	0.6	26	50,000M[d]
UPSTREAM FROM NORTH AVENUE DAM[a,b,e]	NUMBER OF SAMPLES	(37)	(37)	(37)	(3)	(0)	(1)	(33)	(35)
	MAXIMUM	25.0	12.5	13.2	0.42	--	--	37	10,700,000
	MINIMUM	1.5	0.7	2.3	0.23	--	--	6	6,000
	AVERAGE	18.3	4.5	5.5	0.33	--	0.6	25	170,000M[d]

[a] SAMPLING DONE BY WISCONSIN DEPARTMENT OF NATURAL RESOURCES.

[b] SAMPLING DONE BY MILWAUKEE SEWERAGE COMMISSION.

[c] SAMPLING DONE BY SEWRPC.

[d] MEDIAN VALUE.

[e] SAMPLING DONE BY CONSOER, TOWNSEND & ASSOCIATES.

SOURCE- SEWRPC.

The amount of BOD from the combined sewer overflows estimated to be entering the Milwaukee River upstream from the North Avenue Dam is shown in Table 56 to be 935,000 pounds per year, or an average of about 2,560 pounds per day. This is more than two times the amount of BOD contributed by all the sewage treatment plants in the entire Milwaukee River watershed (see Table 50). Raw sewage discharged from separate sanitary sewers is estimated to contribute five times the BOD of the combined sewer discharges upstream from the North Avenue Dam, or more than 10 times the amount contributed by all the sewage treatment plants in the entire watershed.

Coliform concentrations (see Table 66) many times higher than the limit of 5,000 MFCC/100 ml for water-based recreation render the entire reach of the river from Lincoln Creek downstream to the North Avenue Dam unsuitable for any water-based recreational activities. The major sources of these coliform organisms are the untreated waste discharges from the combined and separate sewer systems.

Excessive fertilization is also a problem in this reach of the river. High concentrations of phosphorus stimulate growths of aquatic plants throughout the reach. These growths of aquatic plants have an adverse effect on DO levels in the river during the night-time hours and are aesthetically objectionable. It is estimated that an average of 331,400 pounds of phosphorus per year enters the Milwaukee River upstream from the North Avenue Dam. Approximately 60 percent of this phosphorus input is contributed by overflows of the combined and sanitary sewers, 9 percent by urban runoff, 18 percent by upstream sewage treatment plants, and 11 percent by rural-agricultural drainage and runoff.

Future water quality conditions in this reach of the river, in the absence of a sound water quality management plan and its implementation, may be expected to remain at about the same level as at present. Pollution caused by the combined sewer overflows and the untreated waste discharges from separate sewers may be expected to continue to render the stream unsuitable for most uses. The large amounts of phosphorus discharged to the river from urban runoff and upstream sewage treatment plant effluents may be expected to stimulate luxuriant growths of aquatic plants that detract from the aesthetic value of the river.

Since the area directly tributary to this reach of the Milwaukee River is already fully urbanized, it is not expected that there will be a significant increase in future waste discharges to the river. Urbanization in upstream areas, however, will result in increased amounts of phosphorus in this reach of the river. It is estimated that, by 1990, the average amount of phosphorus discharged to the Milwaukee River will increase to 200,600 pounds per year, exclusive of combined and sanitary sewer discharges in Milwaukee County, if no specific phosphorus removal measures are undertaken at upstream sewage treatment plants. If 85 percent phosphorus removal is provided at these plants, the total phosphorus contributed to the river in 1990, exclusive of sewer overflows, would be reduced to 109,600 pounds per year, or approximately 82 percent of the present amount, exclusive of combined and sanitary sewer overflows (see Tables 61 and 62). Of this 109,600 pounds, 31 percent would be contributed by urban runoff, 31 percent by the residual remaining in the treatment plant effluent, and 32 percent by rural-agricultural drainage and runoff.

East Branch of the Milwaukee River: Existing water uses in the East Branch of the Milwaukee River include maintenance of a warm-water fishery, partial- and whole-body-contact-recreational activities, livestock and wildlife watering, and aesthetic uses. State-established water use objectives for the East Branch include all of the existing uses. The area tributary to the East Branch is almost entirely rural in character, with substantial recreational development around Mauthe Lake and Long Lake. There are no major waste discharges to the East Branch.

Water quality data available for the East Branch are not sufficient to describe adequately the existing water quality conditions in the river. It may be inferred, however, from the limited amount of existing data and from the fact that there are no waste discharges to the river, that water quality throughout the stream is suitable for all existing water uses. Substantial growths of aquatic plants have been observed in several sections of the river, which would indicate that nutrients are present in amounts sufficient to stimulate these growths.

Future water quality conditions in the river may be expected to remain the same as at present, and water quality should be suitable for all desirable future uses. No major change is expected in the general rural character of the area, nor is any significant urban development likely.

North Branch of the Milwaukee River and Its Tributaries: Existing uses of the North Branch of the Milwaukee River and its tributaries include maintenance of a warm-water fishery, partial-body-contact-recreational activities, livestock and wildlife watering, waste assimilation, and aesthetic uses. All of the existing uses, plus whole-body-contact-recreational uses, are included in the state-established water use objectives. Municipal waste discharges in the area tributary to the North Branch are from the sewage treatment plant at the Village of Random Lake, which discharges to Silver Creek, and the sewage treatment plant at the Village of Adell, which discharges to an unnamed tributary of the North Branch. These plants serve a total population of 1,330 persons and discharge treated effluent at a combined average rate of 0.2 cfs. Industrial waste discharges are from the Krier Preserving Company at Random Lake, which occasionally discharges canning wastes to Silver Creek as a result of runoff from their spray irrigation facilities used for treating the wastes, and from Foremost Foods, Inc., at Adell, which discharges industrial wastes to the Adell tributary after treatment in an aerated lagoon. The Passini Cheese Company located near Plymouth formerly discharged milk-processing wastes to the North Branch as a result of overflow from their treatment lagoon, but operations were discontinued at this location in 1967.

Water quality data for the main stem of the North Branch are available at only one location along the stream—at CTH M, 2.2 miles upstream from the mouth of the North Branch. Average dissolved oxygen concentrations measured at this location are well above 5.0 mg/l, with a minimum value of 5.1 mg/l.[30] DO measurements made at this location on July 29 through 31, 1968, revealed a substantial diurnal fluctuation, with minimum values near 6.0 mg/l during the early morning hours and maximum levels of 13.0 to 16.0 mg/l during the late afternoon. The DO levels measured are sufficient to maintain a warm-water fishery in the stream. It may be assumed that DO levels throughout most of the main stem of the North Branch should be similar to the values measured at the CTH M location, since there are no major waste discharges to the main channel.

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[30] *A DO value of 0.4 mg/l was measured at the CTH M location on July 24, 1954, but this measurement has not been included in this discussion as it was the result of a very unusual rainfall event. A rainfall of almost eight inches during the week preceding the sampling date flushed large quantities of vegetal material from marsh areas tributary to the North Branch. This heavy vegetal loading, together with large quantities of organic material contained in the rural and agricultural runoff, are believed to have caused the unusually low DO level measured.*

Dissolved oxygen levels in Silver Creek and the Adell tributary are generally less than 5.0 mg/l, with minimum values of 0.0 to 1.0 mg/l. These low levels are caused by the existing municipal and industrial waste discharges to the streams. Waste discharges make up the entire flow of these two tributaries except during storm periods; and, consequently, no dilution is available for the waste discharges. These two streams are unsuitable for the maintenance of a warm-water fishery. It appears, however, that neither stream has a significant adverse effect on DO levels in the main stem of the North Branch because of the very low flows in the tributaries as compared to the flow of the North Branch.

A median coliform concentration of 1,400 MFCC/100 ml in the North Branch at CTH M indicates that the river is generally suitable for partial-body-contact-recreational activities but is of questionable suitability for whole-body-contact recreation. Coliform concentrations substantially in excess of 5,000 MFCC/100 ml along Silver Creek and the Adell tributary render these two small streams completely unsuitable for any water-based recreational activities.

Phosphorus concentrations in the North Branch in excess of 0.10 mg/l during the summer months stimulate aquatic plant growth in the stream and, in turn, cause diurnal fluctuations in DO levels. It is estimated that an average of 13,000 pounds of phosphorus per year enters the North Branch. Approximately 69 percent of this phosphorus input is contributed by rural-agricultural drainage and runoff, 8 percent by urban runoff, 15 percent by sewage treatment plants, and 8 percent by private sewage disposal systems.

Biological sampling in the Adell tributary revealed a balanced benthic community below the Foremost Foods waste lagoon, probably due to artificial aeration from the lagoon dam. A sample further downstream, but above the Adell sewage treatment plant, revealed an unbalanced community due to a poor physical site and the upstream lagoon. The stream is affected biologically for several miles because the base flow consists of the treated effluents of an industrial treatment facility, a municipal sewage treatment plant, and the poor quality of water from marsh drainage. Biological sampling in Silver Creek revealed unbalanced and affected benthic communities where downstream from the Krier Preserving Company and the Random Lake sewage treatment plant. Heavy slimes, sludge deposition, septic odors, and cloudy water conditions characterize the stream downstream from the waste sources. An unbalanced benthic community was also evident upstream from these waste sources, and it may be possible that there are unknown waste sources upstream. Recovery to a balanced benthic population was observed approximately four miles downstream from the sewage treatment plant.

The total lengths of the Silver Creek and Adell tributaries, 7.1 and 3.0 miles, respectively, do not meet one or more of the standards for one or more of either the existing water uses or the state-established water use objectives. Future water quality conditions in the North Branch and its tributaries may be expected to remain similar to the present conditions. The main stem of the North Branch should be suitable for all future uses throughout most of its length, since it is not anticipated that there will be any significant waste discharges to it. Silver Creek and the Adell tributary, however, will remain unsuitable for all uses if continued reliance is placed on secondary treatment or its equivalent for the municipal and industrial wastes at Random Lake and Adell.

Cedar Creek: Existing water uses in Cedar Creek include maintenance of a warm-water fishery, partial- and whole-body-contact-recreational activities, livestock and wildlife watering, irrigation, waste assimilation, and aesthetic uses. State-established water use objectives include all of the existing uses plus industrial and cooling water supply at Cedarburg. Municipal waste discharges to Cedar Creek are from the sewage treatment plants at Jackson, which serves 500 persons and discharges treated effluent at an average rate of 0.06 cfs, and at Cedarburg, which serves 7,000 persons and discharges treated effluent at an average rate of 1.7 cfs. Industrial waste discharges are from the Libby, McNeill, and Libby plant in Jackson, the Level Valley Dairy near West Bend, and the Kiekhaefer Corporation in Cedarburg.

Existing water quality data for Cedar Creek are summarized in Table 67. About 25 miles of the 31.5 mile-length of Cedar Creek do not meet one or more of the standards for one or more of either the existing water uses or the state-established water use objectives. Minimum dissolved oxygen concentrations of less than 4.0 mg/l downstream from Cedarburg inhibit the use of these sections of the stream for the maintenance of a healthy

TABLE 67

WATER QUALITY SURVEY DATA SUMMARY FOR THE MILWAUKEE RIVER (CEDAR CREEK) 1964-1968

		PARAMETER							
					PHOSPHORUS				
SAMPLING LOCATION	DATA	TEMPERATURE (°C)	DO (MG/1)	BOD (MG/1)	SOLUBLE (MG/1)	TOTAL (MG/1)	NITRATE (MG/1)	CHLORIDE (MG/1)	COLIFORM (MFCC/100ML)
UPSTREAM FROM JACKSON AT SHERMAN ROAD[a]	NUMBER OF SAMPLES	(5)	(5)	(5)	(0)	(0)	(0)	(0)	(5)
	MAXIMUM	20.5	10.6	2.3	--	--	--	--	16,000
	MINIMUM	6.0	5.8	1.7	--	--	--	--	10,000
	AVERAGE	17.1	8.3	2.0	--	--	--	--	13,000M[b]
STH 60 NEAR JACKSON[a]	NUMBER OF SAMPLES	(5)	(5)	(5)	(0)	(0)	(0)	(0)	(5)
	MAXIMUM	22.0	10.9	3.0	--	--	--	--	29,000
	MINIMUM	8.0	4.3	1.0	--	--	--	--	11,000
	AVERAGE	17.7	7.8	2.5	--	--	--	--	12,000M[b]
1.5 MILES DOWNSTREAM FROM JACKSON SEWAGE TREATMENT PLANT[a]	NUMBER OF SAMPLES	(4)	(4)	(4)	(0)	(0)	(0)	(0)	(4)
	MAXIMUM	22.5	10.7	3.4	--	--	--	--	45,000
	MINIMUM	8.0	3.4	1.1	--	--	--	--	19,000
	AVERAGE	17.9	6.0	2.4	--	--	--	--	24,000M[b]
DOWNSTREAM FROM JACKSON MARSH CTH M[c]	NUMBER OF SAMPLES	(14)	(14)	(11)	(3)	(0)	(3)	(5)	(13)
	MAXIMUM	32.8	11.6	10.5	0.22	--	4.0	26	120,000
	MINIMUM	0.0	4.8	1.7	0.02	--	0.5	20	100
	AVERAGE	11.3	7.2	4.1	0.09	--	2.6	21	24,000M[b]
UPSTREAM FROM CEDARBURG AT STH 60[c]	NUMBER OF SAMPLES	(17)	(17)	(14)	(3)	(0)	(3)	(17)	(15)
	MAXIMUM	29.4	13.4	4.7	0.72	--	2.2	130	40,000
	MINIMUM	0.0	0.4	1.1	0.06	--	0.3	15	100
	AVERAGE	9.3	7.9	2.6	0.29	--	1.5	28	1,000M[b]
UPSTREAM FROM CEDARBURG SEWAGE TREATMENT PLANT AT LAKEFIELD ROAD[a,d]	NUMBER OF SAMPLES	(26)	(26)	(4)	(2)	(2)	(2)	(0)	(4)
	MAXIMUM	27.5	18.2	3.1	0.18	0.40	0.9	--	190,000
	MINIMUM	10.0	2.8	1.5	0.18	0.23	0.7	--	2,600
	AVERAGE	21.4	10.9	2.4	--	--	--	--	16,000M[b]
DOWNSTREAM FROM CEDARBURG SEWAGE TREATMENT PLANT ABOVE HAMILTON DAM[d]	NUMBER OF SAMPLES	(27)	(27)	(1)	(0)	(0)	(0)	(0)	(0)
	MAXIMUM	25.5	15.2	--	--	--	--	--	--
	MINIMUM	10.0	2.8	--	--	--	--	--	--
	AVERAGE	19.7	9.2	3.0	--	--	--	--	--
DOWNSTREAM FROM HAMILTON DAM[a,d]	NUMBER OF SAMPLES	(31)	(31)	(4)	(3)	(3)	(3)	(0)	(4)
	MAXIMUM	25.5	14.2	5.0	0.68	0.80	3.6	--	1,500,000
	MINIMUM	10.0	5.7	3.0	0.04	0.12	2.3	--	140,000
	AVERAGE	19.1	8.9	3.8	0.44	0.59	2.8	--	410,000M[b]

[a] SAMPLING DONE BY WISCONSIN DEPARTMENT OF NATURAL RESOURCES.

[b] MEDIAN VALUE.

[c] SAMPLING DONE BY SEWRPC.

[d] SAMPLING DONE BY HARZA ENGINEERING COMPANY.

SOURCE- SEWRPC.

warm-water fishery. These low DO levels may be attributed to municipal and industrial waste discharges in Jackson and Cedarburg, by drainage from the large marsh areas tributary to Cedar Creek, and by the large growths of aquatic plants in the stream. Dissolved oxygen levels of less than 4.0 mg/l have also been measured on the North Branch of Cedar Creek downstream from the Level Valley Dairy outfall.

Median coliform concentrations which are substantially higher than 5,000 MFCC/100 ml at all locations other than STH 60 upstream from Cedarburg indicate that water quality throughout most of Cedar Creek is bacteriologically unsuitable for any water-based recreational activities. The major sources of these coliform organisms are the municipal and industrial waste discharges to the stream. The source of the high coliform concentrations upstream from Jackson (see Table 67) is not known, but it is suspected that they may be caused by upstream barnyard runoff and septic tank overflows.

High concentrations of phosphorus in Cedar Creek stimulate luxuriant growths of aquatic plants which have adverse effects on DO levels in the stream and which detract from the aesthetic value of Cedar Creek. It is estimated that an average of 23,300 pounds of phosphorus per year enters Cedar Creek. Approximately 56 percent of this phosphorus input is contributed by sewage treatment plant effluent, primarily from the Cedarburg plant; 34 percent by rural-agricultural runoff and drainage; and 6 percent by urban runoff.

Biological sampling in Cedar Creek and the North Branch of Cedar Creek revealed the presence of clean-water balanced benthic communities at all locations sampled except those downstream from Libby, McNeill, and Libby; the Jackson sewage treatment plant; and Level Valley Dairy. A clean-water benthic community was observed downstream from the Libby, McNeill, and Libby lagoon; but there was a large increase of pollution-tolerant organisms at this location. The biological evidence suggests that wastes are entering the stream from the lagoon and are affecting the stream ecology. An unbalanced benthic community indicative of pollution was sampled downstream from the Jackson sewage treatment plant. Recovery to a clean, balanced community occurred five miles downstream from the plant outfall. Sampling downstream from the Level Valley Dairy on the North Branch of Cedar Creek revealed an unbalanced and affected benthic community resulting from intermittent waste discharges from the Dairy. Bottom sludge deposits, slimes, septic odors, and floating organic wastes were observed at this location.

Future municipal waste discharges to Cedar Creek will be from the sewage treatment plants at Jackson and Cedarburg, which may be expected to serve a total estimated population of 14,810 persons by 1990 and to discharge treated effluent to the river at an average rate of 4.2 cfs. Increases in the amounts of industrial waste discharged to the stream may also be expected in the future. If adequate secondary treatment is provided for future waste discharges in the Jackson area, the natural waste assimilation capacity of the stream will be sufficient to maintain average dissolved oxygen levels greater than 5.0 mg/l. If adequate effluent disinfection is provided and the upstream sources of coliform contamination are eliminated, water quality should be bacteriologically suitable for all recreational uses.

Continued utilization of secondary treatment at the Cedarburg sewage treatment plant will not be sufficient to maintain average daily dissolved oxygen levels in excess of 5.0 mg/l downstream from the plant outfall in the future. Waste discharges from the plant by 1990 may be expected to lower DO levels 2.0 to 3.0 mg/l in the impoundment upstream from the Hamilton Dam so that this reach of Cedar Creek will not be suitable for the maintenance of a warm-water fishery. If effluent disinfection is provided, the stream should be bacteriologically suitable for recreational uses.

Increases in population and urban area will result in increased discharges of phosphorus to the stream, particularly in the reach of Cedar Creek in, and downstream from, Cedarburg. By 1990 phosphorus discharges to Cedar Creek will increase from an estimated 23,300 pounds per year to an estimated 39,000 pounds per year if no specific phosphorus removal measures are undertaken at the municipal sewage treatment plants. Approximately 74 percent of this phosphorus input would be contributed by treatment plants. If 85 percent phosphorus removal is accomplished at these plants, the total phosphorus contributed to the river in 1990 would be reduced to 18,000 pounds per year, or approximately 77 percent of the present amount entering the river. Approximately 23 percent of this amount would still be contributed by the treatment plants, 9 percent by urban runoff, and 26 percent by rural-agricultural drainage and runoff. It is to be expected that these large amounts of phosphorus will continue to stimulate substantial aquatic plant growths in the stream.[31]

Lincoln Creek: Lincoln Creek has a small, almost entirely urban, drainage area. Its principal uses are for carrying storm waters, for waste assimilation, and for aesthetic purposes. State-established water use objectives include the existing uses plus partial-body-contact recreation. During dry-weather periods, the stream has a low flow composed primarily of clear, cooling waters discharged from industrial plants. The major waste discharge to the stream is untreated sanitary sewage that is discharged from the sanitary sewer system during periods of wet weather to prevent surcharge of the sanitary sewers. There are 60 such relief points that result in untreated sewage being discharged to Lincoln Creek.

Water quality measurements made during 1965 in Lincoln Creek just upstream from its mouth indicate that the stream is severely polluted. The total length of Lincoln Creek, about 7.1 miles, does not meet one or more of the standards for one or more of either the existing water uses or the state-established water use objectives. Dissolved oxygen concentrations averaged 2.1 mg/l, with more than 50 percent of the values measured being between 0.0 and 1.0 mg/l. (The BOD concentrations ranged from 4.4 to 77.0 mg/l and averaged 19.2 mg/l.) The coliform concentrations ranged from 140,000 to 22,000,000 MFCC/100 ml, with a median value of 1,500,000 MFCC/100 ml.

[31] *Water quality sampling data collected by the Wisconsin Department of Natural Resources during the period from 1968 through 1970 indicates a substantial improvement in the water quality of Cedar Creek, primarily due to the correction of malfunctioning septic tank systems located in the watershed area tributary to Cedar Creek and to the improvement of the waste treatment facilities serving the Libby, McNeill, and Libby, Inc. cannery at Jackson. Such corrective action and improvements have been largely due to the efforts of the Cedar Creek Restoration Council, a citizens' organization.*

Essentially, the stream is serving as an open sewer and is presently unsuitable for any other use. In addition, discharge of polluted water from Lincoln Creek to the Milwaukee River adversely affects downstream water quality in the Milwaukee River. High coliform concentrations in the river downstream from the mouth of Lincoln Creek render it unsuitable for any water-based recreational activities. Future water quality conditions in Lincoln Creek may be expected to remain similar to present conditions until the discharge of untreated sewage to the stream is eliminated.[32]

Minor Streams: In the Milwaukee River watershed, there are numerous small streams that have not been discussed in the preceding sections. Most of these streams are not of areawide significance because of their relatively small size and limited use. Although there is little or no water quality information available concerning these minor streams, it is thought that the stream water quality is generally suitable for all reasonable stream uses, with the exceptions noted below, since there are no known waste discharges to these streams. Future water quality in the minor streams of the Milwaukee River watershed may be expected to remain at a level suitable for all reasonable uses provided that no major waste discharges are made to them.

Minor streams in the watershed that receive waste discharges and experience a poor quality of water include two small unnamed tributaries to the Milwaukee River near Fredonia, Pigeon Creek near Thiensville, and Indian Creek in River Hills. A small tributary to the Milwaukee River that flows through Fredonia occasionally receives industrial wastes from De Soto Chemical Coatings, Inc. Biological evidence, however, indicated that there was no severe environmental damage to the tributary from this waste source. A second small tributary to the Milwaukee River, located approximately two miles south of Fredonia, receives waste discharges from the River Road Cheese Factory. The wastes are processed through a septic tank and then discharged to a lagoon located in a swampy area near the plant. After seeping through the ground, the wastes become the headwaters of the tributary. Low dissolved oxygen levels have been measured 0.7 mile downstream from the waste discharge. DO levels at the mouth of the tributary, however, increase to well above 5.0 mg/l.

Pigeon Creek, located north and west of Thiensville, receives waste discharges from the Federal Foods processing plant. The wastes are treated in septic tanks and discharged to a swampy area west of STH 57, from which they enter Pigeon Creek. Dissolved oxygen levels in Pigeon Creek downstream from the waste discharge are generally less than 5.0 mg/l and occasionally less than 1.0 mg/l. Coliform levels as high as 22,000,000 MFCC/100 ml have been measured downstream from the waste discharge. Many complaints have been made by residents along the creek relative to the nuisance odors in the area. Biological sampling revealed unbalanced and affected benthic communities, sludge deposits, and slime growths downstream from the waste discharge. Recovery to a clean-water benthic community was noted approximately one mile downstream from the waste discharge.

Indian Creek occasionally receives sewage wastes from bypasses of sanitary sewage at the Manor Road lift station and from portable pumps operated in periods of wet weather by the Village of Fox Point. The state has designated that only the minimum standards be maintained for water use in this stream. The total length of Indian Creek, about 1.9 miles, does not meet one or more of the standards for one or more of either the existing water uses or the state-established water use objectives.

LAKE WATER QUALITY CHARACTERISTICS OF THE WATERSHED

Water quality in a lake varies with the depth of the lake, as well as the season of the year. In shallow lakes the body of water is well mixed, and water quality is fairly uniform throughout the entire depth. In lakes deeper than about 20 feet, however, three separate zones or layers of water tend to develop during the summer months. The upper zone, or epilimnion, consists of a well-mixed layer of relatively warm water of uniform temperature. The bottom zone, or hypolimnion, consists of the densest, coldest water in the lake. These two zones are separated by a layer of water known as the thermocline, in which there is a rapid drop in temperature with increasing

[32] *In 1970 public health officials of the City of Milwaukee became very concerned over the hazards to public health created by the discharge of raw sewage directly to Lincoln Creek from sewer overflows located along the Creek. Signs were posted by the City warning the general public of the polluted condition of the Creek waters.*

depth. The thermocline acts as a barrier that prevents mixing of the upper layer of water with the bottom layer of water and thus maintains the thermal-stratification of the lake during the summer months.

The seasons induce a cycle of physical and chemical changes in the water that are often conditioned by temperature. For a few weeks in the spring, water temperatures may be homogeneous from the top of a water body to the bottom. Vertical water density is also homogeneous, and it becomes possible for the wind to mix the water in a lake, distributing nutrients and flocculent bottom solids from the deeper waters. Oxygen is mixed throughout the water during this time. The advance of summer quickly checks circulation by warming the surface waters. As these waters warm, they become lighter, resting over colder water of greater density. Thus, a thermal stratification is formed. As autumn comes the standing body of water cools; the epilimnion increases in thickness until the lake becomes homothermous, and again a period of complete circulation begins. This occurs from late September to December, depending upon the area and depth of the lake and its geographic and climatic location. It lasts until changes in density occur from November to January, varying with lake and season and geographic locations. Circulation then ceases until the spring.[33]

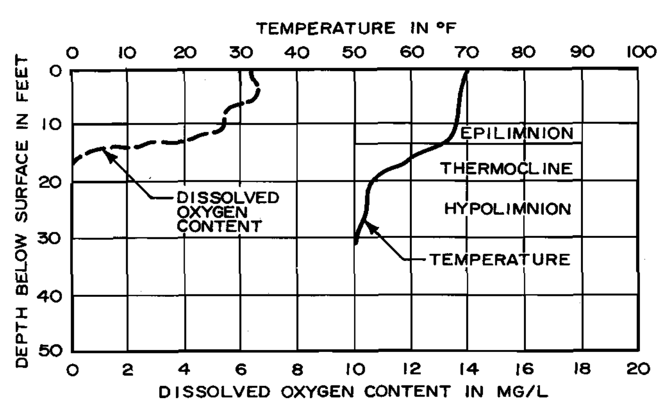
Of the 21 major lakes in the Milwaukee River watershed, eight have a maximum depth of less than 22 feet and, consequently, are generally not stratified. These unstratified lakes include the following: Barton, Lucas, Mud (Fond du Lac County), Mud (Ozaukee County), Random, Smith, Spring, and West Bend Pond. The remaining 13 major lakes experience thermal stratification during the summer months. Figure 45 indicates the temperature and dissolved oxygen profiles of Crooked Lake as measured during the summer of 1968. These profiles show conditions that are typical of all of the stratified lakes in the watershed. Dissolved oxygen levels in the epilimnion of all of the stratified lakes are generally in the range of 6 to 9 mg/l, and temperatures range from 73^{o} to 77^{o}F. In the hypolimnion, however, dissolved oxygen levels decrease to 0 in all of the lakes; and temperatures generally range from 56^{o} to 74^{o}F. Table 68 indicates the temperature ranges of the epilimnion and hypolimnion of the stratified major lakes within the watershed, as found in a survey conducted as a part of the watershed study in August of 1968. Temperature and dissolved oxygen levels in the unstratified major lakes of the watershed are generally similar to those existing in the epilimnion of the stratified lakes during the summer months, with oxygen levels near or above saturation and temperatures generally in the range of 70^{o} to 85^{o}F. Table 69 indicates the temperature ranges found in the unstratified major lakes.

Figure 46 indicates the maximum depth and the depth to the thermocline of the 21 major lakes within the watershed. It should be noted from the figure that the deepest lake, Big Cedar, does not have the deepest thermocline and that the shallowest of stratified lakes, Twelve Lake, does not have the shallowest thermocline. This apparent discrepancy is due to the fetch, which is the surface area and geographic orientation of the lake which, if relatively large and oriented with the longest dimension in the direction of the prevailing winds, tends to drive the thermocline deeper. Other physical characteristics of the lakes may also tend to influence the depth to the thermocline so that no direct relationship between total depth and depth to the thermocline exists.

During the winter months, the dissolved oxygen content of the shallow lakes is depressed under the existing ice cover to levels critical for fish life, and frequent "winterkills" of fish are experienced in most of these lakes. These low oxygen levels result from the utilization of the dissolved

Figure 45

DISSOLVED OXYGEN AND TEMPERATURE PROFILES OF CROOKED LAKE, SHEBOYGAN COUNTY 1968



Source: Wisconsin Department of Natural Resources.

[33] *U. S. Public Health Service Publication No. 1167, Limnological Aspects of Recreational Lakes, 1964.*

TABLE 68

TEMPERATURE RANGES OF THE MAJOR LAKES WHICH STRATIFY IN THE MILWAUKEE RIVER WATERSHED- AUGUST 1968

LAKE	MAXIMUM DEPTH (FEET)	HYPOLIMNION TEMPERATURE RANGE (°F)		EPILIMNION TEMPERATURE RANGE (°F)	
		LOW	HIGH	LOW	HIGH
BIG CEDAR					
NORTH END......	42	59.0	72.5	72.5	73.4
CENTER.........	10	50.0	72.5	72.5	73.4
SOUTH END......	105	49.1	73.4	73.4	74.3
CROOKED...........	32	50.0	66.2	66.2	69.8
ELLEN.............	42	66.2	69.8	69.8	73.4
FIFTEEN...........	29	50.0	68.0	68.0	70.7
FOREST............	32	53.6	80.6	80.6	80.6
GREEN.............	37	57.2	78.8	78.8	82.4
KETTLE MORAINE....	30	57.2	65.3	65.3	73.4
LITTLE CEDAR......	56	51.8	72.5	72.5	77.9
LONG					
NORTH END......	30[a]	60.8	69.8	69.8	75.2
SOUTH END......	30[a]	60.8	69.8	69.8	74.3
MAUTHE............	23	57.2	77.9	77.9	82.4
SILVER............	47	53.6	75.2	75.2	77.9
TWELVE............	20	71.6	82.4	82.4	83.3
WALLACE...........	35	57.2	79.3	79.3	80.6

[a]THE MAXIMUM DEPTH OF LONG LAKE IS 47 FEET NEAR THE CENTER OF THE LAKE.

SOURCE- WISCONSIN DEPARTMENT OF NATURAL RESOURCES.

TABLE 69

TEMPERATURE RANGES OF THE MAJOR LAKES WHICH DO NOT STRATIFY IN THE MILWAUKEE RIVER WATERSHED AUGUST 1968

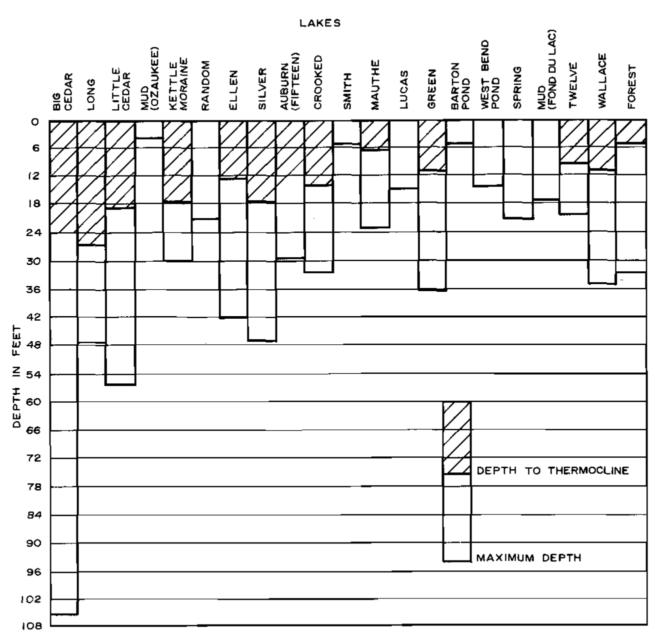
LAKE	MAXIMUM DEPTH (FEET)	TEMPERATURE RANGE (°F)	
		LOW	HIGH
BARTON POND	5	78.3	80.6
LUCAS	15	73.8	80.1
MUD (FOND DU LAC)	17	66.2	70.7
RANDOM	21	66.2	71.6
SMITH	5	76.5	79.2
SPRING	22	62.6	66.6
WEST BEND POND	14	77.0	81.5
MUD (OZAUKEE)	4	NO DATA	NO DATA

SOURCE- WISCONSIN DEPARTMENT OF NATURAL RESOURCES.

oxygen present in the water by the organic matter present in the water at a time when the ice cover prevents reaeration of the lake water from the atmosphere. Thus, the oxygen originally present in the lake at the time of the autumn freeze over is depleted; and no new oxygen is added from the atmosphere.

Figure 46

MAXIMUM DEPTH OF ALL MAJOR LAKES AND DEPTH TO THERMOCLINE IN THE STRATIFIED MAJOR LAKES IN THE MILWAUKEE RIVER WATERSHED SUMMER 1968



Source: Wisconsin Department of Natural Resources.

Lakes in the Milwaukee River watershed are generally classified as being moderately hard, alkaline, fertile lakes. The average chemical composition of the 21 major lakes in the watershed is shown in Table 70. The high alkalinity and relatively large amounts of nutrients (nitrogen and phosphorus) present in the lake waters are indicative of lakes in a region of fertile soils and limestone bedrock conditions. The Niagara dolomite underlying much of the watershed accounts for the high magnesium concentration relative to the calcium concentration.

Concentrations of chloride and sodium ions in a lake substantially greater than the average regional level indicate the possibility of pollution. Of the 21 major lakes in the watershed, five have chloride concentrations indicative of pollution; and the same five also have sodium levels indicative of pollution. These lakes and their respective chloride and sodium concentrations are listed in Table 71.

TABLE 70

AVERAGE CHEMICAL AND PHYSICAL COMPOSITION OF THE MAJOR LAKES IN THE MILWAUKEE RIVER WATERSHED- 1968

COMPOSITION	AVERAGE CONCENTRATION VALUE
MAGNESIUM	29.77 MG/1
CALCIUM	28.61 MG/1
SODIUM	4.76 MG/1
POTASSIUM	1.65 MG/1
IRON	0.06 MG/1
SULPHATE	26.29 MG/1
CHLORIDE	7.50 MG/1
PHOSPHATE (DISSOLVED)	0.30 MG/1
PHOSPHATE (TOTAL)	0.40 MG/1
NITRATE NITROGEN	0.78 MG/1
TOTAL ALKALINITY	190.86 MG/1
PH	8.20 UNITS
SPECIFIC CONDUCTANCE	343.68 MICROMHOS/CM

SOURCE- WISCONSIN DEPARTMENT OF NATURAL RESOURCES.

TABLE 71

MAJOR LAKES IN THE MILWAUKEE RIVER WATERSHED CONTAINING SODIUM AND CHLORIDE IN CONCENTRATIONS INDICATIVE OF POLLUTION 1968 AND 1969

LAKE	CHLORIDE ION (MG/1)		SODIUM ION (MG/1)	
	MAY 1963	AUGUST 1968	MAY 1969	AUGUST 1969
RANDOM	7.4	13.0	6.8	6.4
ELLEN	7.9	12.9	7.3	7.6
BARTON POND	10.5	15.8	9.0	9.2
WEST BEND POND	9.5	19.1	4.6	8.4
WALLACE	4.5	19.7	5.2	9.5

SOURCE- WISCONSIN DEPARTMENT OF NATURAL RESOURCES.

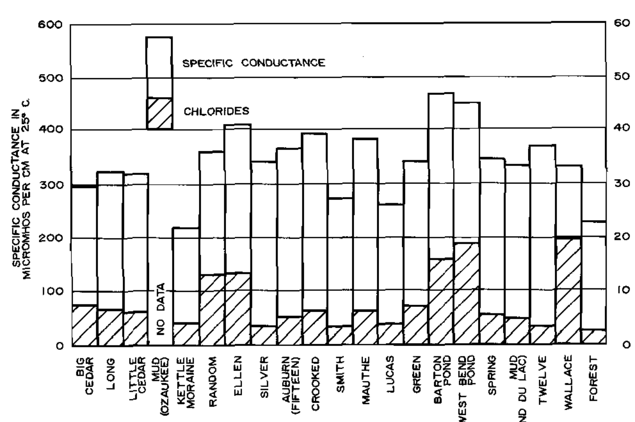
Figure 47 shows a comparison of chlorides and specific conductance in the 21 major lakes. This comparison does not show a relationship which might be expected between these two parameters. In some lakes chloride concentrations are not high when specific conductance is high, and in other lakes the reverse is true. This lack of a relationship indicates that other dissolved solids, as well as chlorides, are responsible for the high specific conductance in some lakes.

Coliform bacteria determinations made during the summer of 1968 indicated that coliform levels in three of the 21 major lakes exceed 1,000 MFCC/100 ml, the maximum concentration permitted by the Wisconsin Water Quality Standards for whole-body-contact-recreation activities (see Table 72). The major sources of the coliform organisms were not identified, however; and as a result the sanitary significance of these high coliform levels is not known.

Concentrations of the fertilizing elements, nitrogen and phosphorus, in the major lakes of the Milwaukee River watershed, as measured during the spring and summer of 1968, are listed in Table 73. Thirteen lakes listed in Table 73 contained dissolved phosphate concentrations in the spring that are less than 0.035 mg/l, the approximate threshold concentration for the occurrence of algal blooms in the lakes in southeastern Wisconsin. These 13 lakes may be classified as only slightly fertile. The second group of eight lakes listed in Table 73 is characterized by spring dis-

Figure 47

COMPARISON OF SPECIFIC CONDUCTANCE AND CHLORIDE CONCENTRATION FOR THE MAJOR LAKES IN THE MILWAUKEE RIVER WATERSHED SUMMER 1968



Source: Wisconsin Department of Natural Resources.

solved phosphate concentrations greater than the threshold level of 0.035 mg/l and, in some cases, even greater than the average dissolved phosphorus level of 0.05 mg/l of the lakes within the Region. This second group of lakes may be considered highly fertile and experience frequent problems from nuisance growths of algae and aquatic weeds. Of these eight fertile lakes, two—Barton Pond and West Bend Pond—also contain high levels of the chloride and sodium ions indicative of pollution, and three lakes—Ellen, Little Cedar, and Mauthe—contain high levels of coliform counts, as indicated in Table 72.

The relatively high phosphate concentration in excess of the threshold level of 0.035 mg/l in eight of the 21 major lakes, together with the summer depletion of oxygen in the hypolimnion of the stratified lakes, the winter depletion of oxygen in unstratified lakes under an ice cover, and the frequent occurrence of large growths of algae and aquatic weeds, indicates that many of the lakes in the Milwaukee River watershed are in a relatively advanced state of eutrophication. Dieldrin, DDT, and other pesticide residue analyses have been conducted on various lakes and streams throughout the Southeastern Wisconsin Region; however, no lakes within the Milwaukee River watershed

TABLE 72

COLIFORM COUNTS FOR THE MAJOR LAKES IN THE MILWAUKEE RIVER WATERSHED SUMMER 1968

LAKES	TOTAL COLIFORM (MFCC/100ML)
BARTON POND.........	NO DATA
BIG CEDAR...........	<100
CROOKED.............	400
ELLEN...............	2100
FIFTEEN.............	<100
FOREST..............	NO DATA
GREEN...............	400
KETTLE MORAINE......	600
LITTLE CEDAR........	7200
LONG................	900
LUCAS...............	NO DATA
MUD (FOND DU LAC)...	NO DATA
MUD (OZAUKEE).......	NO DATA
MAUTHE..............	1900
RANDOM..............	300
SILVER..............	100
SMITH...............	NO DATA
SPRING..............	NO DATA
TWELVE..............	200
WALLACE.............	100
WEST BEND POND......	NO DATA

SOURCE- WISCONSIN DEPARTMENT OF NATURAL RESOURCES.

TABLE 73

NITROGEN AND PHOSPHORUS CONCENTRATIONS IN THE MAJOR LAKES OF THE MILWAUKEE RIVER WATERSHED- 1968 (MG/L)

LAKE	SPRING			SUMMER					
				EPILIMNION			HYPOLIMNION		
	PHOSPHORUS		NITRATE NITROGEN	PHOSPHORUS		NITRATE NITROGEN	PHOSPHORUS		NITRATE NITROGEN
	TOTAL	DISSOLVED		TOTAL	DISSOLVED		TOTAL	DISSOLVED	
CROOKED............	0.13	0.02	0.05	0.15	0.04	0.13	0.16	0.17	--
ELLEN..............	0.01	0.01	0.03	0.80	1.50	0.28	0.99	0.09	--
FIFTEEN (AUBURN)....	0.08	<0.01	0.24	0.06	0.01	0.30	0.05	0.06	--
GREEN..............	0.07	<0.01	0.05	0.66	0.33	--	0.34	0.04	--
KETTLE MORAINE......	0.05	0.01	0.02	0.12	0.12	--	0.16	0.16	--
LONG...............	0.19	0.03	0.01	0.48	0.28	0.13	0.11	0.12	--
LUCAS..............	0.05	0.02	0.03	0.08	0.04	0.22	0.08	0.03	--
MUD (OZAUKEE).......	0.08	0.03	0.10	0.22	0.05	0.28	--	--	--
RANDOM.............	0.01	0.01	0.02	0.17	0.01	0.01	0.06	0.03	--
SILVER.............	0.10	0.03	0.01	0.10	0.10	<0.01	0.07	0.03	--
SPRING.............	0.03	<0.01	0.01	0.03	0.01	0.09	0.10	0.08	--
SMITH..............	0.12	<0.01	0.08	0.06	0.00	<0.01	--	--	--
WALLACE............	0.07	<0.01	0.04	0.08	0.04	--	0.08	0.06	--
BARTON POND.........	0.42	0.50	0.05	1.18	0.54	--	1.40	0.52	--
BIG CEDAR...........	0.50	0.39	0.02	0.56	0.75	0.01	0.64	0.93	--
FOREST.............	0.12	0.12	0.01	0.14	0.12	--	0.17	0.13	--
LITTLE CEDAR........	0.58	0.36	0.01	0.52	0.50	0.10	0.52	0.32	--
MAUTHE.............	0.15	0.04	0.08	0.36	0.13	0.09	2.30	2.00	--
MUD (FOND DU LAC)...	0.23	0.10	0.06	0.18	0.08	0.16	--	--	--
TWELVE.............	0.12	0.05	0.14	0.13	0.11	0.50	0.18	0.11	--
WEST BEND POND......	0.28	0.22	0.12	0.73	0.53	--	0.80	0.65	--

SOURCE- WISCONSIN DEPARTMENT OF NATURAL RESOURCES.

were investigated. For the Region as a whole, average concentrations of DDT and dieldrin in whole fish are 1.702 mg/l and 0.017 mg/l, respectively,[34] relatively high with respect to recommended criteria.[35]

Figure 48 illustrates a comparison between dissolved and total phosphates in the major lakes. No positive correlation seems to exist between the amount of total phosphates and the percentage of dissolved phosphates in the water. Phosphates may be contributed to lakes from three principal sources, two of which are related to human activities in the tributary watershed; agricultural and urban storm water runoff, and sewage effluent; and one of which is natural, being contributed by wildlife and decomposing vegetation. This is illustrated by the fact that Mauthe Lake, which has no permanent residential development around it, has the highest total phosphate content of the major lakes in the watershed. Random Lake, on the other hand, which has a village of the same name situated on its western shore, has one of the lowest of total phosphate contents and the lowest dissolved phosphate content in the watershed.

LAKE WATER QUALITY PROBLEMS

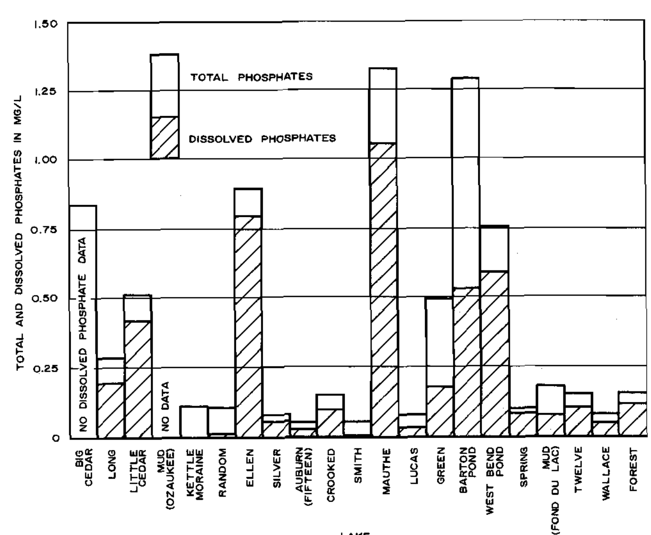
The existing water uses of the 21 major lakes within the Milwaukee River watershed are almost exclusively related to recreational activities, the aquatic life and wildlife that support some of these activities, and aesthetic enjoyment. Other water uses of lakes, such as low streamflow augmentation and flood retention, may be desirable future uses for some of the lakes but would probably remain accessory to the basic recreational uses. Waste assimilation use may exist as a result of accidental or illegal waste discharges into a lake, although there is no such use presently being made of any lake in the watershed by design. The existing recreational water uses of the major lakes are listed in Table 74. Although partial-body-contact-recreational use is made of all 21 major lakes and whole-body-contact recreation, of 18 major lakes, this does not imply that the water quality in the lakes is necessarily suitable for these uses.

As already noted, future uses of the major lakes may be expected to continue to be primarily recreational-related, and any other use may be expected to be accessory to the basic recreational uses and permissible only if compatible with the basic recreational use. Acceptable future uses of all of the 21 major lakes within the watershed will include full-body-contact recreation, preservation of fish and wildlife, and use for aesthetic enjoyment. Uses that are generally considered undesirable include industrial and cooling water use, livestock watering, irrigation, and waste assimilation.

The major water-associated problems of the lakes in the Milwaukee River watershed are generally related to health hazards and overfertilization. Sanitary problems are indicated by the high coliform concentrations and the high chloride concentrations in a few of the lakes. The high coliform levels suggest a water quality unsuitable for whole-body-contact recreation; and, in a few lakes, the coliform counts are high enough that they suggest an unsuitable water for all forms of recreational

Figure 48

DISSOLVED PHOSPHATES AS A PART OF TOTAL PHOSPHATES IN THE MAJOR LAKES IN THE MILWAUKEE RIVER WATERSHED SUMMER 1968



Source: Wisconsin Department of Natural Resources.

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[34] *Information obtained from the Wisconsin Department of Natural Resources Technical Bulletin No. 41, Occurrence and Significance of DDT and Dieldrin Residues in Wisconsin Fish.*

[35] *To date maximum residual levels for DDT and dieldrin content have not been set by any regulatory agency for fish used as human food. DDT residues in whole fish samples taken from lakes within the Milwaukee River watershed have been found to approach or exceed the DDT tolerances established for many other foods. Dieldrin residues in fish samples from the lower Milwaukee River were found to be considerably higher than the dieldrin tolerances established for other foods.*

TABLE 74

EXISTING RECREATIONAL WATER USES OF THE MAJOR LAKES IN THE MILWAUKEE RIVER WATERSHED- 1968[a,b]

LAKE	PRESERVATION AND ENHANCEMENT OF AQUATIC LIFE AND WILDLIFE			RECREATION							AESTHETIC USES
				PARTIAL-BODY CONTACT				WHOLE-BODY CONTACT			
	MARSH FUR BEARERS	WATERFOWL REARING	SPAWNING AREAS	FISHING	WATERFOWL HUNTING	ROWING AND CANOEING	SPEED BOATING	SWIMMING	WATER SKIING	SKIN DIVING	
BARTON POND.......	3-E	3-E	2-P	3-E	4-N	1-P	3-N	4-E	4-N	4-E	3-E
BIG CEDAR.........	3-P	3-P	1-P	2-E	3-P	3-P	1-R	2-E	1-R	1-P	2-E
CROOKED...........	2-P	2-P	1-P	1-P	2-P	1-P	3-R	2-P	3-R	2-P	1-E
ELLEN.............	1-P	1-P	2-P	2-P	2-P	2-P	2-R	2-E	2-R	2-P	2-E
FIFTEEN (AUBURN)..	2-P	2-P	1-P	1-P	2-P	2-P	2-R	2-E	2-R	2-P	1-P
FOREST............	3-P	3-P	2-P	2-P	3-P	1-P	3-N	2-E	3-N	2-P	2-E
GREEN.............	2-P	2-P	1-P	2-E	2-P	1-P	3-N	2-E	3-N	1-P	2-E
KETTLE MORAINE....	2-P	2-P	1-P	2-E	2-P	2-P	2-R	2-E	2-R	2-P	2-E
LITTLE CEDAR......	2-P	2-E	1-P	2-E	2-P	2-P	2-R	2-E	2-R	2-P	2-E
LONG..............	1-P	1-P	1-P	1-P	2-P	2-P	2-R	1-P	2-R	1-P	1-E
LUCAS.............	2-P	2-P	1-P	1-P	3-P	1-P	3-N	1-E	3-N	1-P	1-P
MAUTHE............	2-P	3-P	2-P	1-P	3-P	1-P	3-N	1-P	3-N	2-P	1-P
MUD (FOND DU LAC).	1-P	2-P	2-P	1-E	1-P	1-P	3-N	3-E	3-N	3-P	2-P
MUD (OZAUKEE).....	1-P	1-P	4-N	4-N	1-P	1-P	4-N	3-N	4-N	4-N	1-P
RANDOM............	2-P	2-P	1-P	2-E	3-P	2-P	2-R	1-P	2-P	2-P	2-E
SILVER............	3-P	3-P	1-P	1-P	2-P	1-P	2-R	1-P	2-R	1-P	2-E
SMITH.............	2-P	2-P	2-P	2-E	2-P	1-P	3-N	3-E	3-N	2-P	1-P
SPRING............	1-P	2-P	1-P	1-P	2-P	1-P	4-N	2-E	4-N	2-P	1-P
TWELVE............	2-P	2-P	1-P	2-E	2-P	1-P	3-N	2-E	3-N	2-E	1-P
WALLACE...........	3-P	3-P	2-P	2-E	3-P	1-P	3-N	2-E	3-N	2-P	2-E
WEST BEND POND....	3-E	3-E	2-P	3-E	3-E	1-P	3-N	4-E	4-N	4-E	3-E

[a] THE FOLLOWING NUMBER CODE IS UTILIZED IN THIS TABLE TO INDICATE EXISTING RECREATION QUALITY-
1--HIGH
2--MEDIUM
3--LOW
4--NONE

[b] THE FOLLOWING LETTER CODE IS UTILIZED IN THIS TABLE TO INDICATE THE DESIRED RECREATION NEED-
P--PRESERVATION
E--ENHANCEMENT
R--RESTRICTIVE USE
N--DO NOT ALLOW OR DOES NOT APPLY

SOURCE- WISCONSIN DEPARTMENT OF NATURAL RESOURCES.

use. The source of the high concentrations of coliform bacteria in several of the lakes is not known, however; and, since coliform bacteria may originate from sources other than the human intestinal tract, direct evidence of the sanitary hazard is not available. A study of the 21 major lakes, with emphasis on Big Cedar, Ellen, Little Cedar, Long, Random, and Silver, indicated that septic tank drainage directly to the lake is not a major source of high coliform levels. However, since the conditions of urban development around 13 of the major lakes are all similar, it would appear that sanitary hazards may exist at several of the lakes due to the increasing sodium and chloride levels, as well as the increasing luxuriant weed and algal growths. Increasing recreational use of the lakes in the future will further intensify any sanitary problems that presently exist unless appropriate corrective action is taken. On any lakes in which a public health hazard is suspected, a comprehensive sanitary survey will be required to identify the major sources of pathogenic organisms; and these sources will need to be eliminated or controlled.

The other major water quality problem of the lakes in the Milwaukee River watershed relates to the biological productivity of the lakes. The addition of plant nutrients to a body of water increases the biological productivity of the water over extended periods of time, and this fertilization produces large crops of aquatic weeds and organisms which eventually choke out the desirable forms of aquatic life and reduce the value of a body of water for most of the desirable uses, such as recreation. This aging of lakes is a natural process in all surface waters and generally requires hundreds of thousands of years to complete. This process can be greatly accelerated, however, by artificial means.

The amount of aquatic weeds and organisms produced in a lake is often limited by the nutrient element that is present in the limiting concentration. Generally, the elements thought to limit the fertility of a lake are the nitrogen and phosphorus compounds. The rate of which these plant nutrients enter a body of water determines the rate of eutrophication. Depending upon the source of the plant nutrients, the fertilization process causing eutrophication in a lake may be classified as either natural or artificial. Nutrients derived from rainfall, ground water, and runoff from marshes, forests, and other areas are indicative of natural eutrophication. Most of the lakes in the Milwaukee River watershed receive nutrients from all of these natural sources. Nutrients derived from human activities in the watershed include such sources as agricultural runoff, waste-water effluents, urban runoff, and septic tank drainage and are indicative of cultural eutrophication. While the natural eutrophication of a lake takes place in hundreds or thousands of years, the increased rate of nutrient inflow from human activities can render a lake eutrophic in only a few decades.

Most of the lakes in the Milwaukee River watershed are presently in an advanced eutrophic state, as evidenced by frequent algal blooms; large growths of aquatic weeds; dissolved oxygen depletion in the hypolimnion of the stratified lakes; and frequent winter fish kills in the shallow lakes. While eutrophication was basically a natural phenomenon in the past, nutrient inflow resulting from human activities in the watershed has increased the rate of eutrophication in recent years. The estimated contribution of nutrients from the various sources to the 19 major natural lakes of the watershed is shown in Table 75. These figures indicate that over 90 percent of the phosphorus and 41 percent of the nitrogen presently entering the lakes are derived from man's activities in the watershed. The major artificial sources

TABLE 75

ESTIMATES OF NUTRIENTS CONTRIBUTED TO THE MAJOR LAKES IN THE MILWAUKEE RIVER WATERSHED- 1968

LAKE	NUTRIENT	SOURCE								
		MUNICIPAL WASTE WATER (PERCENT)	SEPTIC TANKS (PERCENT)	RURAL RUNOFF (PERCENT)	MANURED LAND (PERCENT)	URBAN RUNOFF (PERCENT)	PRECIPITATION (PERCENT)	GROUND WATER (PERCENT)	TOTAL	
									PERCENT	POUNDS PER YEAR
AUBURN (FIFTEEN)......	NITROGEN	0	16	2	13	0	20	49	100	4366
	PHOSPHORUS	0	14	20	57	0	4	5	100	338
BIG CEDAR.............	NITROGEN	0	37	2	3	0	41	17	100	18170
	PHOSPHORUS	0	44	24	18	0	12	2	100	1040
CROOKED...............	NITROGEN	0	14	5	6	0	19	56	100	3870
	PHOSPHORUS	0	14	43	31	0	5	7	100	260
ELLEN.................	NITROGEN	0	35	2	8	0	50	5	100	1960
	PHOSPHORUS	0	32	17	38	0	12	1	100	143
FOREST................	NITROGEN	0	61	1	2	0	36	0	100	1105
	PHOSPHORUS	0	73	3	13	0	11	0	100	62
GREEN.................	NITROGEN	0	59	1	5	0	35	0	100	1611
	PHOSPHORUS	0	58	9	24	0	9	0	100	109
KETTLE MORAINE........	NITROGEN	0	11	0	1	0	36	52	100	5121
	PHOSPHORUS	0	33	5	15	0	28	19	100	115
LITTLE CEDAR[a].........	NITROGEN	0	40	2	4	0	49	5	100	3940
	PHOSPHORUS	0	42	25	20	0	13	0	100	250
LONG..................	NITROGEN	0	20	4	18	0	38	20	100	8571
	PHOSPHORUS	0	13	21	58	0	6	2	100	894
LUCAS[b]................	NITROGEN	0	25	9	0	0	66	0	100	943
	PHOSPHORUS	0	20	67	0	0	13	0	100	82
MAUTHE[c]...............	NITROGEN	0	0	2	10	0	17	71	100	3740
	PHOSPHORUS	0	0	20	55	0	5	20	100	224
MUD (FOND DU LAC COUNTY)...............	NITROGEN	0	0	0	2	0	13	85	100	3525
	PHOSPHORUS	0	0	12	32	0	14	42	100	59
MUD (OZAUKEE COUNTY)[d]..	NITROGEN	0	0	3	14	0	83	0	100	2347
	PHOSPHORUS	0	0	22	59	0	19	0	100	183
RANDOM[e]...............	NITROGEN	0	12	3	14	30	33	8	100	4646
	PHOSPHORUS	0	8	16	45	25	5	1	100	510
SILVER................	NITROGEN	0	59	1	0	0	30	10	100	3140
	PHOSPHORUS	0	73	15	0	0	11	1	100	167
SMITH.................	NITROGEN	0	7	3	16	0	50	24	100	1381
	PHOSPHORUS	0	5	22	61	0	10	2	100	123
SPRING................	NITROGEN	0	26	1	6	0	58	9	100	797
	PHOSPHORUS	0	32	14	34	0	18	2	100	44
TWELVE[d]...............	NITROGEN	0	12	11	58	0	19	0	100	1879
	PHOSPHORUS	0	3	26	70	0	1	0	100	575
WALLACE...............	NITROGEN	0	52	2	10	0	36	0	100	1118
	PHOSPHORUS	0	40	13	40	0	7	0	100	97

[a]DOES NOT INCLUDE NUTRIENTS CONTAINED IN OUTFLOW FROM CEDAR LAKE.

[b]DOES NOT INCLUDE NUTRIENTS CONTAINED IN OUTFLOW FROM SILVER AND HACKBARTH LAKES.

[c]DOES NOT INCLUDE NUTRIENTS CONTAINED IN OUTFLOW FROM LONG LAKE.

[d]GROUND WATER INFLOW AND OUTFLOW ASSUMED TO BE IN BALANCE.

[e]DOES NOT INCLUDE NUTRIENTS CONTAINED IN OUTFLOW FROM SPRING LAKE.

SOURCE- HARZA ENGINEERING COMPANY.

in most of the lakes are drainage from septic tanks and runoff from agricultural lands on which artificial fertilizer and manure have been spread while the soil is frozen.

The increase in the nutrient influx in recent years has caused similar problems in many of the lakes. Prolific growths of aquatic weeds have severely limited the use of many of the lakes for swimming, boating, and fishing. Frequent algal blooms have greatly decreased the value for some of the lakes for swimming and aesthetic enjoyment. Lowering of dissolved oxygen levels at various times of the year has reduced the game fish population and has given rise to increased populations of rough fish, such as carp and suckers. A more detailed description of the specific water quality and related problems occurring in each of the major lakes in the Milwaukee River watershed is presented in the individual lake study reports prepared as a part of the Milwaukee River watershed study but published separately.[36]

Unless effective water quality management programs are mounted, the rapid rate of eutrophication of the lakes within the watershed may be expected to continue; existing water quality problems will be intensified; and new problems will develop in the lakes presently suitable for recreational uses. It may be expected that, unless appropriate action is taken, the number of lakes suitable for recreation and aesthetic enjoyment will continue to decrease in the future. This will, in the face of a rising demand for recreation, especially water-based recreation, constitute a serious problem within the watershed.

SUMMARY

This chapter has described surface water quality conditions in the Milwaukee River watershed; the factors affecting surface water quality, including major waste discharges in the watershed; the water quality standards and water use objectives established by the State of Wisconsin for the streams within the watershed; and the existing and potential surface water pollution problems in the watershed. Eight water quality indicators: dissolved oxygen, biochemical oxygen demand, coliform bacteria, chlorides, nitrogen, phosphorus, temperature, and aquatic organisms were investigated. Three of these—dissolved oxygen, coliform bacteria, and temperature—were selected as the most significant parameters for use in the description and evaluation of stream water quality in the Milwaukee River watershed because of their direct relationship to the state-established water quality standards.

The existing stream water quality data collated and the new stream water quality data collected under the Milwaukee River watershed study indicate that, although water quality conditions vary greatly from the upper to the lower reaches of the watershed, pathogenic contamination and nutrient pollution, as indicated by coliform count and phosphorus concentrations, are serious problems throughout almost all of the watershed. Organic pollution, as indicated by dissolved oxygen levels, is not yet as serious a problem in the Milwaukee River watershed as in other watersheds of the Region, particularly in the Root and Fox River watersheds, but relatively long reaches of the Milwaukee River, nevertheless, exist in which dissolved oxygen levels drop below the minimum levels required to sustain fish life during the night-time hours of the summer months. Inorganic and thermal pollution is not widespread but constitutes a constant danger, while aesthetic pollution is clearly in evidence, particularly in the lower reaches of the watershed.

Water quality conditions do not, considering the watershed as a whole, meet established standards for either the existing water uses or for the state-established water use objectives. Over 84 miles, or about 85 percent of the total length of the main stem of the Milwaukee River from its source in the Town of Osceola, Fond du Lac County, to its discharge to the Lake Michigan estuary at the North Avenue Dam in Milwaukee, presently does not meet one or more of the standards for one or more of either the existing water uses or the state-established water use objectives. The latter include the maintenance of a warm-water fishery and whole-body-contact-recreational use for all streams in the watershed except Lincoln and Indian Creeks and, in addition, industrial and cooling water use of the entire main stem of the Milwaukee River and of Cedar Creek at Cedarburg. Similarly, over 44 miles, or about 20 percent of the total length of the 29 major tributaries of the Milwaukee River, do not meet one or more of the standards for one or more of either the

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[36] *Individual lake use recreation plans for the 21 major lakes within the Milwaukee River watershed may be obtained on a limited basis from the Southeastern Wisconsin Regional Planning Commission and the Wisconsin Department of Natural Resources.*

existing water uses or the state-established water use objectives. Stream water pollution, while generally widespread throughout the watershed, is particularly severe below the Milwaukee County line; and the Milwaukee River and its tributaries in the lower reaches of the watershed may be considered to be grossly polluted. Table 76 summarizes the suitability of existing and probable future water quality conditions in the watershed for various beneficial water uses.

Municipal sewage treatment plant discharges are presently the major cause of water pollution in the middle and upper reaches of the Milwaukee River watershed, while sanitary and combined sewer overflows are the major cause in the lower reaches of the watershed. Industrial waste discharges, agricultural and urban runoff, and malfunctioning septic tank systems all contribute to stream pollution in local areas of the watershed; but the overall effect of these sources on stream water quality conditions is presently overshadowed by the effects of the municipal waste discharges and sewer overflows. Almost all of the organic waste loading on the stream system above the Milwaukee County line, consisting of 1,200 pounds of biochemical oxygen demand per day, is contributed by municipal sewage treatment plants. Approximately 7 percent of the organic waste loading above the North Avenue Dam, consisting of 1,200 pounds of biochemical oxygen demand per day, is contributed by sewage treatment plants, and 93 percent by sewer overflows.

Dissolved oxygen levels below 5.0 mg/l occur in the following reaches of the Milwaukee River: downstream from the West Bend sewage treatment plant, in the Newburg impoundment, in the Grafton impoundments, in the vicinity of CTH C in Mequon, in the vicinity of the Brown Deer Road in Milwaukee County, and in the impoundment upstream from the North Avenue Dam. The Milwaukee River and its major tributaries above Campbellsport generally exhibit higher dissolved oxygen levels.

Organic pollution is a major problem in Lincoln Creek and in the Milwaukee River downstream from the mouth of Lincoln Creek. In this reach dissolved oxygen levels in the Milwaukee River are frequently below 5.0 mg/l, while dissolved oxygen levels in Lincoln Creek frequently are below 1.0 mg/l, thus rendering both streams unsuitable for the maintenance of a warm-water fishery. The principal sources of pollution are overflows from the combined sewers that serve part of the urbanized drainage area tributary to these two stream reaches and discharges of untreated sewage overflow from the separate sanitary sewers that serve the remainder of the tributary area.

TABLE 76

EXISTING AND FUTURE SUITABILITY OF WATER QUALITY FOR MAJOR WATER USES IN STREAMS OF THE MILWAUKEE RIVER WATERSHED- 1968 AND 1990

STREAM	PRESERVATION AND ENHANCEMENT OF AQUATIC LIFE		RECREATION: WHOLE-BODY CONTACT		RECREATION: PARTIAL-BODY CONTACT		INDUSTRIAL AND COOLING WATER SUPPLY		LIVESTOCK WATERING		WILDLIFE WATERING		IRRIGATION		AESTHETICS	
	EXISTING	1990	EXISTING	1990	EXISTING	1990	EXISTING	1990	EXISTING	1990	EXISTING	1990	EXISTING	1990	EXISTING	1990
MILWAUKEE RIVER HEADWATERS TO WEST BEND	U	U	U	S	U	S	S	S	S	S	S	S	S	S	U	U
WEST BEND TO GRAFTON	U	U	U	S	U	S	S	U	S	U	S	U	S	U	U	U
GRAFTON TO LINCOLN CREEK	U	U	U	S	U	S	S	S	S	S	S	S	S	S	U	U
LINCOLN CREEK TO NORTH AVENUE DAM	U	U	U	U	U	U	U	U	S	U	S	U	S	U	U	U
WEST BRANCH	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
EAST BRANCH	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
NORTH BRANCH	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
SILVER CREEK (SHEBOYGAN COUNTY)	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U
SILVER CREEK (WASHINGTON COUNTY)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
CEDAR CREEK	S	S	U	S	U	S	U	U	S	S	S	S	S	S	U	U
LINCOLN CREEK	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U

NOTE- THE SYMBOLS USED IN THE TABLE REPRESENT THE FOLLOWING-

U - UNSUITABLE WATER QUALITY.
S - SUITABLE WATER QUALITY FOR THE SPECIFIED USE.
NA - NOT ADEQUATE FOR THE SPECIFIED USE FOR REASONS NOT RELATED TO WATER QUALITY, SUCH AS INADEQUATE STREAMFLOW.
ND - NO DATA.
THESE RATINGS INDICATE WATER QUALITY SUITABILITY ONLY AND DO NOT CONSIDER OTHER FACTORS SUCH AS QUANTITY FOR COOLING OR IRRIGATION.

SOURCE- SEWRPC.

High coliform counts are found in major reaches of the Milwaukee River. Coliform counts of 9,500 MFCC/100 ml are found below the Kewaskum sewage treatment plant; 5,000 MFCC/100 ml above the Barton Dam; 19,500 MFCC/100 ml in the vicinity of the railroad bridge in West Bend; 5,000 MFCC/100 ml in a reach extending six miles downstream from the West Bend sewage treatment plant; 22,000 MFCC/100 ml above the Chair Factory Dam; 36,000 MFCC/100 ml above the Limekiln Dam in Grafton; 65,000 MFCC/100 ml above the Estabrook Park Dam; 50,000 MFCC/100 ml downstream from Estabrook Park Dam; and 170,000 MFCC/100 ml upstream from the North Avenue Dam in Milwaukee. Coliform concentrations greater than 1,000 MFCC/100 ml throughout the Milwaukee River, Cedar Creek, Lincoln Creek, the lower reaches of the North Branch, and several small tributaries indicate that these streams are all unsuitable bacteriologically for whole-body-contact-recreational use. Coliform concentrations in excess of 5,000 MFCC/100 ml throughout all, or most of, Cedar Creek, Silver Creek (Sheboygan County), the Adell tributary, and Lincoln Creek and for major reaches of the Milwaukee River downstream from Kewaskum, Fredonia, Saukville, Grafton, Thiensville, and Lincoln Creek indicate that the streams of the watershed in these areas are bacteriologically unsuitable for any recreational use. The principal causes of these high coliform levels outside the Milwaukee urbanized area are effluent discharges from municipal sewage treatment plants. High coliform levels in streams within the Milwaukee urbanized area are principally caused by untreated sewage discharges from the combined and separate sewer systems serving the area tributary to the stream network.

Although low dissolved oxygen concentrations and high coliform counts indicate that organic pollution and pathogenic contamination are serious problems, the major surface water quality problem existing in the Milwaukee River watershed is excessive fertilization. This problem affects all of the river and its major tributaries. High nutrient levels, particularly phosphorus, stimulate luxuriant growths of algae and aquatic weeds in many of the streams and lakes of the watershed. These growths of aquatic plants cause large diurnal fluctuations in dissolved oxygen levels and create unsightly conditions that serve to destroy the aesthetic value of the streams and lakes. Minimum dissolved oxygen levels of less than 4.0 mg/l during the early-morning hours were measured at various locations throughout the stream system during the period of the watershed study. These low levels of dissolved oxygen may be attributed primarily to the large growths of aquatic plants present in the streams. The major sources of phosphorus reaching the streams of the watershed are waste discharges from the municipal sewage treatment plants, agricultural runoff, urban runoff, and overflows from both the combined and separate systems serving the Milwaukee urbanized area.

Approximately 54 percent of the nutrient loading on the stream system above the Milwaukee County line is contributed by municipal sewage treatment plants; approximately 33 percent by agricultural runoff; approximately 7 percent by urban runoff; and the remaining 6 percent by all other sources. In direct contrast, approximately 18 percent of the nutrient loading on the stream system above the North Avenue Dam is contributed by municipal sewage treatment plant effluent; approximately 11 percent by agricultural runoff; approximately 9 percent by urban runoff; approximately 60 percent from sanitary sewer and combined sewer overflows; and the remaining 2 percent from all other sources.

The municipal sewage treatment plants located in the watershed above West Bend presently serve a connected population of about 3,400 persons and discharge treated sewage to the stream at an average rate of 1.0 cfs. By the year 1990, these plants may be expected to serve a population of about 5,100 persons and to discharge treated sewage to the upper reaches of the Milwaukee River at the rate of 1.8 cfs. The municipal sewage treatment plants located within the watershed along the East Branch, the North Branch, and Cedar Creek presently serve a connected population of about 8,800 persons and discharge treated sewage to the streams at the rate of 2.0 cfs. By 1990 it is anticipated that these sewage treatment plants will serve a population of about 17,000 persons and discharge treated sewage at the rate of 4.6 cfs to the receiving streams, with more than 15,000 persons being served by the plants at Jackson and Cedarburg. The municipal sewage treatment plants located within the watershed between West Bend and the Grafton Dam presently serve a connected population of about 17,530 persons and discharge treated sewage to the river at an average rate of 2.9 cfs. By 1990 these plants may be expected to serve a population of about 29,000 persons and discharge treated sewage at a rate of 8.7 cfs. This increase in sewage effluent may be expected to reduce the dissolved oxygen content of the river to less than 5.0 mg/l for a distance of at least 10 miles downstream from the West Bend sewage treatment plant. Municipal sewage treatment plants located within the watershed between the Grafton Dam and Lincoln Creek presently serve a connected population of about 8,400 persons and discharge treated sewage to the stream at an average rate of 1.5 cfs. By 1990 these plants may be expected to serve a population of about 14,000 persons and discharge treated sewage to the stream at an average rate of 3.4 cfs. The reach of the Milwaukee River below its confluence with Lincoln Creek does not receive direct discharges from sewage treatment plants, since the sanitary sewers serving the area are all connected to the Milwaukee metropolitan system. Dissolved oxygen levels, however, may be expected to remain at levels below 4.0 mg/l during low-flow periods; and the overall quality of the stream water may be expected to continue to be very poor due to the large waste loading discharged to the river annually through the combined and sanitary sewer overflows.

Thus, the connected population served by municipal sewage treatment plants discharging to the Milwaukee River system above the Milwaukee County line may be expected to increase from about 38,000 persons at the present time to about 65,000 persons by 1990; and the average rate at which these plants discharge treated sewage to the stream network may be expected to increase from the present level of about 7 cfs to almost 19 cfs. This increase may be expected to take place even though the Mequon area may be connected to the Milwaukee metropolitan system by the year 1990. About 23 percent of the sustained low flow of the Milwaukee River at the Milwaukee County line presently consists of sewage treatment plant effluent, and this proportion may be expected to increase to 44 percent by the year 1990.

If adequate disinfection of the effluent from all of the municipal sewage treatment plants in the watershed is provided, the streams of the watershed outside Milwaukee County may be expected to be bacteriologically suitable for all recreational uses. Within Milwaukee County, however, the streams may be expected to remain unsuitable for any water-based recreational uses because of the pollutional effects of the untreated sewage overflows from both the separate and combined sewer systems serving this area of the watershed.

The major surface water quality problem throughout the watershed may be expected to continue to be excessive fertilization, with its associated algae and weed growths. These growths may be expected to limit the use of all of the surface waters below West Bend for recreational use and aesthetic enjoyment. In addition, over 20 percent of the total length of the main stem of the Milwaukee River may be expected to have dissolved oxygen levels below those required for the maintenance of a warm-water fishery. Even if 85 percent phosphorus removal is provided at all of the existing municipal sewage treatment plants in the watershed, the total amount of phosphorus discharged to the surface waters of the Milwaukee River watershed upstream from the Milwaukee County line by 1990 would remain at approximately the same amount as is presently entering these surface waters and causing luxuriant aquatic plant growths.

Application of the stream water quality model, as described in Chapter XII of this volume, to evaluate the effectiveness of alternative pollution abatement measures indicates that there are three measures that could be used to obtain stream water quality levels suitable for the water use objectives and standards established for the Milwaukee River watershed. These measures are: 1) the provision of higher levels of treatment for major waste discharges in the watershed, including nutrient removal; 2) the elimination of waste discharge to streams within the watershed; and 3) the provision of clean water to dilute waste discharges during periods of low, natural streamflow. Several combinations of these measures will be evaluated in the plan design process in terms of the resultant improvements in water quality.

With respect to lake water quality, the study found that several of the lakes of the Milwaukee River watershed, including Little Cedar, Mauthe, Mud (Fond du Lac County), Random, Smith, and Twelve Lakes, are in an advanced state of eutrophication, as indicated by high phosphorus contents, low dissolved oxygen contents, and excessive growths of algae and aquatic weeds. Coliform levels and concentrations of ions indicative of pollution were found to be high in some of the lakes of the watershed, including Ellen and Little Cedar, and are indicative of a sanitary hazard resulting from domestic sewage discharges from urban-type residential land use development around the lakes. High pesticide levels already exist in the surface waters of the watershed and may become a serious problem, adversely affecting the maintenance of a healthy environment for fish and wildlife in the watershed and full recreational enjoyment of the surface waters.

Existing and future water uses of the major lakes in the Milwaukee River watershed are, and may be expected to remain, exclusively related to recreational activities. Present water quality problems include public health hazards and overfertilization. The existence of a sanitary hazard resulting from septic tank discharges to Little Cedar and Ellen Lakes has been shown, and other lakes are suspected of constituting a public health hazard for the same reason. Overfertilization has occurred in most of the lakes in the watershed, with the result that nuisance growths of algae and aquatic weeds have interfered with use of the lakes for recreational activities. The primary cause of this overfertilization is the plant nutrients being supplied to the lakes from natural sources and, more importantly, from human activities in the watershed. Future water quality problems in the lakes may be expected to be similar to the existing problem, but more intensive and widespread, especially on those lakes where intensive urbanization is occurring in the tributary drainage area. Unless appropriate action is taken, the number of lakes suitable for various types of recreational activities may be expected to continue to decrease in the future from 18 at the present time to 11 in 1990.

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Chapter X

GROUND WATER QUALITY AND POLLUTION

INTRODUCTION

The natural environment of the watershed has been, to date, a far more important determinant of ground water quality than have the effects of human activities within the watershed. The ground water resources, in contrast to the surface water resources, are not as readily subject to contamination from urban and rural runoff and waste discharges. As indicated in Chapter IV of this volume, three major aquifers underlie the Milwaukee River watershed. In order from land surface downward, they are: 1) the sand and gravel deposits in the glacial drift; 2) the shallow dolomite strata in the underlying bedrock; and 3) the deeper sandstone, dolomite, siltstone, and shale strata. Because of their relative nearness to the land surface and because of their interconnection, the first two aquifers are commonly referred to collectively as the "shallow aquifer," while the latter is referred to as the "deep aquifer." The aquifers are normally supplied with water from zones known as recharge areas. The shallow aquifers in the Milwaukee River watershed are recharged locally by direct rainfall or by stream or lake water entering the ground through recharge areas of porous soil or rock directly overlying the aquifer. The deep aquifer is recharged by stream or lake water or direct rainfall entering the ground through recharge areas lying west of the watershed where the Maquoketa shale, which separates the deep aquifer from the shallow aquifer, is absent and flowing through the porous rock to the deeper reaches of the earth's crust.

GROUND WATER QUALITY

Source of Dissolved Constituents

The amount and kind of dissolved minerals in ground water differ greatly throughout the watershed and depend upon such factors as the amount and type of organic material in the soil; the solubility of rock over or through which the water moves; the length of time the ground water is in contact with the soil and rock; and the temperature and pressure of the water. Some kinds of rock contain highly soluble minerals, and ground water passing through or over such rock will become highly mineralized. Other kinds of rock, however, consist of relatively insoluble minerals which impart relatively small amounts of mineralization to ground water.

A water analysis is a statement of the chemical composition of a water solution. The chemical substances in solution are reported as ion concentrations in milligrams per liter (mg/l). Positive ions, or cations, that are commonly determined during analysis are: iron, manganese, calcium, magnesium, sodium, and potassium. Negative ions, or anions, that are determined are: bicarbonate, carbonate, sulfate, chloride, fluoride, nitrate, and nitrite. Other substances, chemical characteristics, or physical properties commonly reported in water analyses are: silica, dissolved solids, hardness, alkalinity, hydrogen ion concentration (pH), and temperature. The principal sources of these substances, as present in ground water, are summarized in Table 77. For a more complete discussion of these chemical substances and properties, see SEWRPC Technical Report No. 4, Water Quality and Flow of Streams in Southeastern Wisconsin, 1966.

Chemical Quality of Ground Water Related to Water Use

The term "water quality," as used in this chapter, refers to the chemical characteristics of ground water rather than to its physical, biological, or bacteriological characteristics. The chemical substances in ground water result from ground water interaction with solids, liquids, and gases in the environment.

The chemical quality of ground water in the Milwaukee River basin is generally good, and the water is suitable for most uses. High concentrations of certain dissolved substances, however, are present in the deeper parts of the dolomite and sandstone aquifers in the eastern part of the watershed and may limit the use of the ground water from these aquifers for some purposes.

The natural chemical and physical characteristics of the ground water supplies are extremely important to domestic, municipal, and industrial water users. The presence of some substances in

TABLE 77

SOURCE OF DISSOLVED MINERAL CONSTITUENTS AND PROPERTIES OF WATER

CONSTITUENT OR PROPERTY	SOURCE
SILICA (SIO_2)..........................	CHEMICAL BREAKDOWN OF SILICATE MINERALS DURING WEATHERING.
IRON (FE)..............................	DISSOLVED FROM PRACTICALLY ALL ROCKS, SOILS, WELL CASINGS, PIPES, AND STORAGE TANKS.
MANGANESE (MN).........................	DISSOLVED FROM SOILS AND CLAY MINERALS.
CALCIUM (CA) AND MAGNESIUM (MG)......	DISSOLVED FROM PRACTICALLY ALL SOILS AND ROCKS BUT ESPECIALLY FROM LIMESTONE, DOLOMITE, AND GYPSUM.
SODIUM (NA) AND POTASSIUM (K)........	DISSOLVED FROM PRACTICALLY ALL TYPES OF ROCKS AND SOILS. ALSO PRESENT IN SEA WATER, INDUSTRIAL WASTES, AND SEWAGE.
BICARBONATE (HCO_3) AND CARBONATE (CO_3)..............................	INTERACTION OF DISSOLVED CARBON DIOXIDE AND WATER ON CARBONATE ROCKS SUCH AS LIMESTONE AND DOLOMITE. DECOMPOSITION OF ORGANIC MATTER.
SULFATE (SO_4).........................	DISSOLVED FROM ROCKS AND SOILS CONTAINING IRON SULFIDE, GYPSUM, AND OTHER SULFUR COMPOUNDS. SULFATE REDUCTION BY BACTERIA. PRESENT IN SEA WATER, PRECIPITATION, AND SOME INDUSTRIAL WASTES.
CHLORIDE (CL)..........................	DISSOLVED FROM ROCKS AND SOILS. PRINCIPAL ION IN SEA WATER. PRESENT IN INDUSTRIAL WASTES AND SEWAGE.
FLUORIDE (F)...........................	DISSOLVED FROM ROCKS AND SOILS CONTAINING FLUORIDE BEARING MINERALS.
NITRATE (NO_3) AND NITRITE (NO_2)......	FORMED BY BACTERIAL ACTION IN SOILS AND PLANTS. CONCENTRATED IN PLANT AND ANIMAL WASTES, FERTILZERS, SEWAGE, AND SEPTIC-TANK EFFLUENT. NITRATE IS ALSO PRESENT IN PRECIPITATION.
DISSOLVED SOLIDS......................	CHIEFLY INORGANIC MINERAL CONSTITUENTS DISSOLVED IN WATER BUT ALSO INCLUDES ORGANIC CONSTITUENTS.
HARDNESS AS $CACO_3$.....................	NEARLY ALL HARDNESS IS DUE TO CALCIUM AND MAGNESIUM IONS IN WATER THAT ARE DISSOLVED FROM SOILS AND CARBONATE ROCKS.
ALKALINITY............................	CAUSED BY ALL NEGATIVE IONS (ANIONS) ENTERING INTO HYDROLYSIS REACTIONS. THESE ARE CHIEFLY BICARBONATE, CARBONATE, AND HYDROXIDE.
HYDROGEN ION CONCENTRATION (PH)......	CAUSED BY THE EXCESS OR DEFICIENCY OF HYDROGEN IONS IN A SOLUTION.

SOURCE- U.S. GEOLOGICAL SURVEY.

water may cause problems that limit its use for particular purposes. Table 78 indicates the concentrations of substances and properties that limit the use of water for each of 18 major uses. Because untreated ground water supplies domestic water needs throughout the watershed, it must also be safe in its natural condition for human consumption. Although safe limits of concentrations of mineral substances in drinking water are difficult to establish because of the wide range of tolerance and consumption among individuals, the U. S. Public Health Service in 1962 established desirable quality standards for drinking water used on interstate common carriers. These standards, recommended by the Regional Planning Commission, are listed in Table 78. Mandatory upper limits for seven additional substances in drinking water, as listed in Table 79, have been established by the U. S. Public Health Service because they are relatively toxic in very small concentrations. In addition, maximum upper limits have been established for chromium, cyanide, and fluoride, as shown in Table 79, which are higher than the desirable standards recommended for these substances in Table 78. Many of the wells in the watershed are pumping and using water which contains some of these substances in concentrations greater than the recommended limits. The percentages of samples exceeding the recom-

TABLE 79

DRINKING WATER LIMITATIONS OF HEAVY METALS AND OTHER TOXIC CHEMICALS

CHEMICAL CONSTITUENT	RECOMMENDED LIMIT (MG/1)	MAXIMUM ALLOWABLE (MG/1)
ARSENIC.........	0.01	0.05
BARIUM..........	--[a]	1.00
CADMIUM.........	--[a]	0.01
CHLORIDE........	250.00	--[a]
CHROMIUM........	0.05	0.05
COPPER..........	1.00	--[a]
CYANIDES........	0.01	0.20
FLUORIDE........	1.50	3.00
IRON............	0.30	--[a]
LEAD............	--[a]	0.05
MANGANESE.......	0.05	--[a]
NITRATE.........	45.00	45.00
SELENIUM........	--[a]	0.01
SILVER..........	--[a]	0.05
SULFATE.........	250.00	--[a]

[a]NO RECOMMENDED STANDARD.

SOURCE- U.S. PUBLIC HEALTH SERVICE.

TABLE 78

WATER QUALITY STANDARDS FOR MAJOR WATER USES RECOMMENDED BY THE SEWRPC[a]

PARAMETER[b]	MUNICIPAL (PUBLIC) WATER SUPPLY		INDUSTRIAL WATER SUPPLY													COOLING	LIVESTOCK AND WILDLIFE WATERING	IRRIGATION
	RAW	TREATED	BAKING	BOILER FEED (PRESSURE IN PSI) 0-150	150-250	250-400	400	BREWING	CARBONATED BEVERAGES	DAIRY INDUSTRY	FOOD CANNING AND FREEZING	FOOD EQUIPMENT WASHING	INDUSTRIAL PROCESS WATER (GENERAL)	LAUNDERING	TANNING			
SILICA.....................	---	---	---	40	20	5	1	50	---	---	---	---	---	---	---	---	---	---
IRON.......................	---	0.3	0.2	---	---	---	---	0.1	0.2	0.3	0.2	0.2	0.2	0.2-1.0	2.0	0.5	---	---
MANGANESE..................	---	0.05	0.2	---	---	---	---	0.1	0.2	0.1	0.2	---	0.1	0.2	0.2	0.5	---	---
CHROMIUM (HEX.)............	---	0.05	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
CALCIUM....................	---	---	---	---	---	---	---	100-500	---	---	---	---	---	---	---	---	---	---
MAGNESIUM..................	---	---	---	---	---	---	---	30	---	---	---	---	---	---	---	---	---	---
SODIUM.....................	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
BICARBONATE................	---	---	---	50[c]	30[c]	5[c]	0[c]	---	---	---	---	---	---	---	---	---	---	---
CARBONATE..................	---	---	---	200	100	40	20	50-68	---	---	---	---	---	---	---	---	---	---
SULFATE....................	---	250	---	---	---	---	---	---	250	60	---	---	---	---	---	---	---	---
CHLORIDE...................	50-250	250	---	---	---	---	---	60-100	250	30	---	250	250	---	---	---	1,500	---
FLUORIDE...................	1.7	1.7	---	---	---	---	---	1.0	1.0	---	1.0	1.0	---	---	---	---	---	---
NITRITE....................	---	---	---	---	---	---	---	0	---	0	---	---	---	---	---	---	---	---
NITRATE....................	---	45	---	---	---	---	---	10[d]	---	30	15	---	---	---	---	---	---	---
PHOSPHORUS.................	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
CYANIDE....................	---	0.01	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
OIL........................	---	---	---	---	---	---	---	0	---	---	---	---	---	---	---	---	---	---
DETERGENTS.................	---	0.5	---	---	---	---	---	---	---	---	---	---	1.0	---	---	---	---	---
DISSOLVED SOLIDS...........	---	500	---	---	---	---	---	500-1500	850	---	850	850	750	---	---	---	7,000	2,000
HARDNESS...................	---	---	---	80	40	10	2	---	250	180	75-400	10	---	50	513	1,000	---	---
ALKALINITY (TOTAL).........	---	---	---	---	---	---	---	75-150	128	---	---	---	---	60	135	---	---	---
PH.........................	6.0-9.0	---	---	8.0M	8.4M	9.0M	9.6M	6.5-7.0	---	---	7.5M	---	5.0-9.0	6.0-6.8	6.0-8.0	5.0-9.0	5.0-9.0	---
SPECIFIC CONDUCTANCE.......	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	3,000
COLOR......................	20-150	15	10	80	40	5	2	10	10	0	---	20	50	---	100	---	---	---
TURBIDITY..................	10-250	5	10	20	10	5	1	10	2	---	10	1.0	250	---	20	50	---	---
BIOCHEMICAL OXYGEN DEMAND..	---[e]	---	---	---	---	---	---	---	---	---	---	---	10	---	---	---	---	---
DISSOLVED OXYGEN...........	---[f]	---	---	2.0[c]	0.2[c]	0.0[c]	0.0[c]	---	---	---	---	---	1.0M	---	---	---	---	---
COLIFORM COUNT.............	5,000	1	---	---	---	---	---	---	---	100	1	1	5,000	---	---	---	---	---
TEMPERATURE (°F)...........	---	65	---	---	---	---	---	---	---	---	---	---	80	---	---	90	---	---

[a]WATER QUALITY STANDARDS SET FORTH IN SEWRPC TECHNICAL REPORT NO. 4 WATER QUALITY AND FLOW OF STREAMS IN SOUTHEASTERN WISCONSIN, NOVEMBER 1966. LIMITS ARE RECOMMENDED MAXIMUM OR MAXIMUM PERMISSIBLE VALUES, EXCEPT MINIMUM LIMITS WHICH HAVE THE SUFFIX M. SEVERAL STANDARDS ARE PRESENTED AS A RANGE OF LIMITING VALUES.

[b]THE LIMITING VALUES OF THE CHEMICAL, PHYSICAL, BIOCHEMICAL, AND BACTERIOLOGICAL PARAMETERS ARE EXPRESSED IN PPM (MG/1) EXCEPT PH, SPECIFIC CONDUCTANCE, COLOR, TURBIDITY, COLIFORM COUNT, AND TEMPERATURE.

[c]LIMITS APPLICABLE ONLY TO FEED WATER ENTERING BOILER, NOT TO ORIGINAL WATER SUPPLY.

[d]NITRATE AS NO 3-N.

[e]SURFACE WATER SOURCES BETWEEN 3.0 AND 4.0 AND 0.0 FROM GROUND WATER SOURCES.

[f]SURFACE WATER SOURCES BETWEEN 4.6 AND 6.5 GROUND WATER SHOULD BE NEAR ZERO TO MINIMIZE OXIDATION OF WELL CASINGS, SCREENS, AND PUMPING EQUIPMENT.

SOURCE- SEWRPC.

mended standards are shown in Table 80. The presence of any of the substances listed in Table 79 in concentrations exceeding the maximum allowable limits constitutes a basis for rejecting the water. Fortunately, most of these substances are rare in ground water and are not normally determined on analyses unless dangerous amounts are suspected. The limits for the other chemical substances in drinking water, as listed in Table 78, are only suggested limits because the objections to them are based primarily upon aesthetic grounds. At concentrations exceeding the recommended limits, these substances may impart undesirable tastes, colors, or odors to the drinking water. Water with chemical substances exceeding the recommended limits is used for drinking in many areas without any apparent ill effects.

Ground Water Quality by Aquifers

The results of the chemical analyses of 111 ground water samples drawn from 66 wells tapping the three aquifers underlying the watershed are presented in Tables 81, 82, 83, and 84. The analyses were made by the Wisconsin State Laboratory of Hygiene and the U. S. Geological Survey, and the locations of the wells sampled are shown on Map 48. Several samples are drawn from the same well but at irregular intervals over a period of time. The concentrations of chemical substances

TABLE 80

PERCENT OF GROUND WATER SAMPLES IN THE MILWAUKEE RIVER WATERSHED EXCEEDING DRINKING WATER QUALITY STANDARDS

AQUIFER	IRON		MANGANESE		CALCIUM		MAGNESIUM		SODIUM		BICARBONATE		SULPHATE		CHLORIDE	
	NUMBER OF SAMPLES	PERCENT OF SAMPLES EXCEEDING STANDARD (0.3 MG/1)[a]	NUMBER OF SAMPLES	PERCENT OF SAMPLES EXCEEDING STANDARD (0.05 MG/1)[a]	NUMBER OF SAMPLES	PERCENT OF SAMPLES EXCEEDING STANDARD ( )[b]	NUMBER OF SAMPLES	PERCENT OF SAMPLES EXCEEDING STANDARD ( )[b]	NUMBER OF SAMPLES	PERCENT OF SAMPLES EXCEEDING STANDARD ( )[b]	NUMBER OF SAMPLES	PERCENT OF SAMPLES EXCEEDING STANDARD ( )[b]	NUMBER OF SAMPLES	PERCENT OF SAMPLES EXCEEDING STANDARD (250 MG/1)[a]	NUMBER OF SAMPLES	PERCENT OF SAMPLES EXCEEDING STANDARD (250 MG/1)[a]
SAND AND GRAVEL.........	14	7.14	12	8.33	14	--	13	--	5	--	14	--	14	0.00	14	0.00
DOLOMITE................	68	39.70	65	1.53	63	--	63	--	50	--	68	--	68	15.38	68	0.00
SANDSTONE...............	7	71.42	6	16.66	8	--	8	--	4	--	9	--	9	44.44	9	0.00
SANDSTONE AND DOLOMITE..	19	73.67	17	5.88	20	--	19	--	16	--	20	--	20	25.00	20	5.00
TOTAL...................	108	43.51	100	4.00	105	--	103	--	75	--	111	--	111	17.11	111	0.90

AQUIFER	FLOURIDE		NITRATE		NITRITE		TOTAL SOLIDS		HARDNESS		ALKALINITY		PH	
	NUMBER OF SAMPLES	PER CENT OF SAMPLES EXCEEDING STANDARD (1.7 MG/1)[a]	NUMBER OF SAMPLES	PER CENT OF SAMPLES EXCEEDING STANDARD (45 MG/1)[a]	NUMBER OF SAMPLES	PER CENT OF SAMPLES EXCEEDING STANDARD ( )[b]	NUMBER OF SAMPLES	PER CENT OF SAMPLES EXCEEDING STANDARD (500 MG/1)[a]	NUMBER OF SAMPLES	PER CENT OF SAMPLES EXCEEDING STANDARD ( )[b]	NUMBER OF SAMPLES	PER CENT OF SAMPLES EXCEEDING STANDARD ( )[b]	NUMBER OF SAMPLES	PER CENT OF SAMPLES EXCEEDING STANDARD (6.0 - 9.0)[c]
SAND AND GRAVEL................................	13	0.00	5	0.00	5	--	14	7.14	14	--	13	--	5	0.00
DOLOMITE.......................................	62	0.00	32	0.00	29	--	67	27.94	68	--	62	--	27	0.00
SANDSTONE......................................	7	0.00	2	0.00	2	--	9	44.44	9	--	8	--	3	0.00
SANDSTONE AND DOLOMITE.........................	18	5.55	12	0.00	9	--	19	63.15	20	--	16	--	8	0.00
TOTAL..	100	1.00	51	0.00	45	--	109	33.02	111	--	99	--	43	0.00

[a]WATER QUALITY STANDARDS SET FORTH IN SEWRPC TECHNICAL REPORT NO. 4 WATER QUALITY AND FLOW OF STREAMS IN SOUTHEASTERN WISCONSIN, NOVEMBER 1966 AND THE U.S. PUBLIC HEALTH SERVICE DRINKING WATER STANDARDS 1962.

[b]NO STANDARD ESTABLISHED.

[c]SEWRPC STANDARD.

SOURCE- U.S. GEOLOGICAL SURVEY AND SEWRPC.

TABLE 81

CHEMICAL ANALYSES OF GROUND WATER FROM THE SAND AND GRAVEL AQUIFER IN THE MILWAUKEE RIVER WATERSHED[a]

OWNER	LOCATION	DEPTH OF WELL (FEET)	ALTITUDE OF BOTTOM (FEET-MSL)	DATE OF COLLECTION	GROUND WATER QUALITY PARAMETERS: IRON (FE)	MANGANESE (MN)	CALCIUM (CA)	MAGNESIUM (MG)	SODIUM (NA)	BICARBONATE (HCO_3)	SULPHATE (SO_4)	CHLORIDE (CL)	FLUORIDE (F)	NITRATE (NO_3)	NITRITE (NO_2)	DISSOLVED SOLIDS	HARDNESS AS CA CO_3	ALKALINITY AS CA CO_3	PH (FIELD)
CITY OF CEDARBURG.	T10N,R21E,SEC.27	47	773	7- 6-66	0.03	0.03	89	44	--	359	78	31.00	0.20	0.30	0.00	522	404	294	--
				3-23-66	0.24	0.04	89	44	11.00	359	78	31.00	0.20	0.30	0.00	431	404	294	7.00
				11- 7-56	0.04	0.00	90	39	--	354	84	6.00	0.10	--	--	394	402	290	7.40
				5-10-45	0.20	0.00	82	38	--	361	60	8.00	0.10	--	--	414	385	296	7.30
U.S. ARMY.........	T 8N,R22E,SEC. 5	150	500	5- 3-63	0.05	--	16	--	--	330	62	8.00	--	--	--	367	306	--	--
CITY OF WEST BEND.	T11N,R19E,SEC.14	88	802	11-28-67	0.04	--	72	39	3.10	332	46	7.50	0.40	--	--	378	340	272	7.30
				4- 6-66	0.06	0.04	76	38	3.20	349	44	6.00	0.20	6.80	0.00	360	344	286	--
CITY OF WEST BEND.	T11N,R19E,SEC.14	92	888	7- 7-66	0.06	0.06	83	41	3.30	356	55	10.00	0.20	1.80	0.01	450	380	292	7.30
				4-19-61	0.03	0.04	78	39	--	356	54	4.50	0.10	3.50	0.02	364	352	293	--
				3-24-52	0.00	0.00	75	40	--	351	50	5.00	1.20	--	--	350	334	288	--
				8-27-46	0.00	0.00	76	28	--	344	38	6.50	0.10	--	--	356	300	282	--
				8- 5-46	0.00	0.00	72	32	--	345	40	12.00	0.10	--	--	342	355	283	--
				4-27-45	0.00	0.00	68	34	--	376	12	4.20	0.10	--	--	332	355	308	--
MINIMUM					0.00	0.00	16	28	3.10	330	12	4.50	0.10	0.30	0.00	332	300	272	7.00
MEAN					0.08	0.04	73	38	5.10	357	51	10.12	0.24	2.54	0.01	384	355	291	7.30
MAXIMUM					0.24	0.06	90	44	11.00	376	84	31.00	1.20	6.80	0.02	522	404	308	7.40

[a]ANALYSES IN MG/1 EXCEPT PH, WHICH IS IN UNITS.

NOTE- UNDERLINED VALUES EXCEED THE U.S. PUBLIC HEALTH SERVICE RECOMMENDATIONS FOR DRINKING WATER QUALITY.

SOURCE- U.S. GEOLOGICAL SURVEY.

TABLE 82

CHEMICAL ANALYSES OF GROUND WATER FROM THE DOLOMITE AQUIFER IN THE MILWAUKEE RIVER WATERSHED[a]

					GROUND					WATER				QUALITY		PARAMETERS			
OWNER	LOCATION	DEPTH OF WELL (FEET)	ALTITUDE OF BOTTOM (FEET-MSL)	DATE OF COLLECTION	IRON (FE)	MAN-GANESE (MN)	CAL-CIUM (CA)	MAGNE-SIUM (MG)	SO-DIUM (NA)	BICAR-BONATE (HCO_3)	SUL-PHATE (SO_4)	CHLO-RIDE (CL)	FLUO-RIDE (F)	NI-TRATE (NO_3)	NI-TRITE (NO_2)	DIS-SOLVED SOLIDS	HARDNESS AS CA CO_3	ALKALINITY AS CA CO_3	PH (FIELD)
VILLAGE OF ADELL..............	T13N,R21E,SEC. 2	445	450	6-22-66	0.11	0.03	85	46	3.80	366	92.00	6.50	0.20	1.80	0.00	508	402	300	--
ARMSTRONG CHURCH..............	T14N,R19E,SEC. 2	189	895	11-10-55	1.40	0.00	54	32	4.00	361	0.40	1.00	0.10	--	--	300	276	296	--
VILLAGE OF BAYSIDE (VISTA DEL MAR SUBDIVISION).	T 8N,R22E,SEC. 5	300	368	8-25-66	0.42	0.03	79	33	13.00	317	65.00	10.00	0.60	1.80	0.01	390	336	260	7.3
VILLAGE OF BROWN DEER (BRADLEY ESTATES)...........	T 8N,R21E,SEC.14	302	395	10-26-61	0.70	0.03	90	36	22.00	227	230.00	4.00	0.80	--	--	496	187	186	7.6
VILLAGE OF BROWN DEER (BRADLEY ESTATES)...........	T 8N,R21E,SEC.10	300	400	10-26-61	0.80	0.03	92	37	14.00	325	134.00	3.00	0.80	--	--	469	382	266	7.5
VILLAGE OF BROWN DEER (BRADLEY ESTATES)...........	T 8N,R21E,SEC.10	295	400	10-26-61	0.44	0.03	75	36	6.00	332	69.00	1.50	0.90	--	--	352	330	272	7.5
VILLAGE OF BROWN DEER (BRADLEY ESTATES)...........	T 8N,R21E,SEC.14	300	396	10-26-61	0.44	0.03	94	41	--	315	150.00	3.50	0.80	--	--	453	388	258	--
VILLAGE OF BROWN DEER (CORONADO SUBDIVISION)......	T 8N,R21E,SEC.11	350	322	10-26-61	0.40	0.03	30	14	28.00	146	68.00	1.00	1.00	--	--	546	422	272	--
VILLAGE OF BROWN DEER (COUNTY LINE ESTATES).......	T 8N,R21E,SEC. 2	540	123	10-20-61	1.10	0.03	78	26	64.00	105	380.00	12.00	0.90	--	--	614	300	--	7.7
VILLAGE OF BROWN DEER (GOLFVIEW CREST SUBDIVISION)	T 8N,R21E,SEC.14	240	480	10-26-61	1.32	0.03	100	43	0.00	386	98.00	2.00	0.40	--	--	435	408	316	7.3
				11-11-59	0.40	0.00	79	36	9.00	327	88.00	3.00	0.70	--	--	404	344	268	7.2
				4-17-57	0.70	0.00	83	34	2.00	366	45.00	2.00	0.60	--	--	380	349	300	7.3
VILLAGE OF BROWN DEER (GOLFVIEW CREST SUBDIVISION)	T 8N,R21E,SEC.14	467	233	10-26-61	0.66	0.03	97	28	22.00	232	217.00	4.00	0.80	--	--	483	360	190	7.1
				11-11-59	0.20	0.00	81	30	22.00	234	165.00	4.00	0.70	--	--	460	314	192	7.4
VILLAGE OF BROWN DEER (GREENKNOLL SUBDIVISION)....	T 8N,R21E,SEC.11	300	388	10-26-61	2.28	0.03	118	39	19.00	361	170.00	16.00	0.20	--	--	543	468	296	7.3
VILLAGE OF BROWN DEER (GREENKNOLL SUBDIVISION)....	T 8N,R21E,SEC.11	390	388	10-26-61	0.76	0.03	65	43	17.00	332	78.00	5.50	0.60	--	--	373	328	272	7.6
				11-11-59	0.30	0.00	110	38	7.00	332	155.00	8.00	0.60	--	--	540	420	272	7.4
VILLAGE OF BROWN DEER (ROSEDALE SUBDIVISION)......	T 8N,R21E,SEC.11	300	380	10-26-61	0.50	0.03	93	38	9.00	293	150.00	7.00	0.60	--	--	442	378	240	7.4
VILLAGE OF BROWN DEER (ROSEDALE SUBDIVISION)......	T 8N,R21E,SEC.11	301	384	11-11-59	0.40	0.00	108	40	6.00	332	155.00	8.00	0.60	--	--	546	422	272	7.3
VILLAGE OF BROWN DEER (ROSEDALE SUBDIVISION)......	T 8N,R21E,SEC.11	300	376	10-26-61	0.46	0.03	68	34	0.80	312	65.00	1.00	0.60	--	--	330	302	256	7.6
VILLAGE OF BROWN DEER (WILLOW BROOK SUBDIVISION)..	T 8N,R21E,SEC.11	302	369	10-26-61	0.20	0.03	92	36	0.00	344	92.00	5.50	0.90	--	--	399	370	282	7.4
VILLAGE OF FREDONIA...........	T12N,R21E,SEC.26	360	449	7- 6-66	0.27	0.03	253	62	5.20	250	610.00	2.10	0.80	1.80	0.01	1240	859	205	7.3
VILLAGE OF FREDONIA...........	T12N,R21E,SEC.26	457	380	5-10-45	0.30	0.00	139	37	--	310	285.00	6.00	0.40	--	--	670	482	254	--
CITY OF GLENDALE (CORRALS WATER TRUST).......	T 8N,R22E,SEC.20	255	453	6-21-60	0.44	0.00	119	37	0.00	366	106.00	0.30	1.00	--	--	478	394	--	--
VILLAGE OF GRAFTON............	T10N,R21E,SEC.24	518	237	7- 6-66	0.03	0.03	70	37	10.00	351	24.00	11.00	0.40	1.80	0.01	376	329	288	--
VILLAGE OF GRAFTON............	T10N,R21E,SEC.24	546	215	7- 6-66	0.59	0.03	63	43	14.00	365	28.00	16.00	0.40	1.80	0.01	408	335	299	7.5
				5-16-62	0.44	0.03	62	42	--	377	29.00	18.00	--	2.10	0.26	356	328	309	--
				9- 9-56	0.40	0.00	59	42	--	378	20.00	15.00	0.40	--	--	354	326	310	--
				1-30-56	0.30	--	--	--	41.00	259	20.00	17.00	--	--	--	--	209	212	--
				2-21-46	0.10	0.00	75	35	--	370	55.00	16.00	0.20	--	--	400	395	303	--
CITY OF MEQUON (CENTURY ESTATES SUB).......	T 9N,R21E,SEC.14	346	344	8-29-66	0.20	0.04	63	34	28.00	211	185.00	3.50	0.70	1.80	0.03	458	304	173	7.5
CITY OF MEQUON (CENTURY ESTATES SUB).......	T 9N,R21E,SEC.14	350	355	8-16-66	0.21	0.03	56	47	27.00	244	140.00	3.20	0.70	3.10	0.03	428	287	200	7.6
CITY OF MEQUON (CENTURY ESTATES SUB).......	T 9N,R21E,SEC.14	573	148	8-25-66	0.70	0.03	52	43	15.00	311	53.00	7.00	0.70	1.80	0.33	378	310	255	--
CITY OF MEQUON (LAUREL ACRES SUBDIVISION)..	T 9N,R21E,SEC.14	586	119	8-18-66	0.19	0.03	77	40	21.00	268	148.00	7.00	0.80	2.60	0.20	472	358	--	--
CITY OF MEQUON (VILLE DU PARC SUBDIVISION).	T 9N,R21E,SEC.13	350	330	8-25-66	0.39	0.03	136	43	22.00	256	320.00	3.60	0.60	1.80	0.09	774	519	217	--
MILWAUKEE COUNTY (MC GOVERN PARK)............	T 8N,R21E,SEC.35	500	170	3-11-47	1.50	--	137	48	17.00	298	310.00	8.00	0.80	0.20	--	726	540	--	--
NORTHWAY WATER COOP 2.........	T 8N,R22E,SEC. 5	205	480	8-25-66	0.19	0.03	79	47	17.00	368	99.00	14.00	0.80	1.80	0.21	478	395	302	7.2
NORTHWAY WATER COOP 2.........	T 8N,R22E,SEC. 5	200	487	8-25-66	0.18	0.03	79	49	17.00	368	108.00	14.00	0.80	1.80	0.13	476	478	302	7.2
PRIVATE.......................	T13N,R18E,SEC.17	100	960	6-15-68	0.06	0.01	--	--	--	352	38.00	31.00	--	5.50	--	478	384	288	--
PRIVATE.......................	T13N,R20E,SEC. 2	88	900	10-16-60	2.80	0.03	--	--	--	400	6.00	2.00	--	--	0.00	312	332	--	--
VILLAGE OF RANDOM LAKE........	T13N,R21E,SEC.34	536	342	9- 2-66	0.18	0.04	112	34	6.10	329	165.00	5.00	0.40	0.40	0.00	560	420	270	--
				6-22-66	0.26	0.03	180	35	6.20	305	340.00	4.00	0.60	0.60	0.01	822	595	250	--
				3- 4-66	0.26	0.04	180	35	6.20	305	340.00	4.00	0.60	0.40	0.02	822	595	250	--
VILLAGE OF RANDOM LAKE........	T13N,R21E,SEC.35	555	325	9- 2-66	0.18	0.04	112	34	6.10	329	165.00	5.00	0.40	0.40	0.00	560	420	270	--
				6-22-66	0.26	0.03	180	35	6.20	305	340.00	4.00	0.60	0.60	0.01	822	595	250	--
				3- 4-66	0.26	0.04	180	35	6.20	305	340.00	4.00	0.60	0.40	0.02	822	595	250	--
				11-16-45	0.10	0.00	130	38	39.00	312	290.00	7.00	0.40	--	--	700	520	256	--
RED GATE PIG FARM.............	T14N,R19E,SEC.34	113	927	6-15-68	0.29	0.20	--	--	--	390	11.00	26.00	--	4.60	--	376	330	320	--
VILLAGE OF SAUKVILLE..........	T11N,R21E,SEC.35	492	268	7- 6-66	0.08	0.03	72	37	3.60	370	23.00	1.50	0.20	1.80	0.01	358	335	303	--
				7-21-66	0.04	0.04	73	35	--	376	14.00	2.00	0.20	--	--	334	326	308	--
				10-28-54	0.10	0.00	70	36	0.70	376	16.00	1.00	0.20	--	--	310	316	306	--
				4- 4-46	0.05	0.00	69	34	--	373	18.00	8.00	0.20	--	--	316	310	306	--
VILLAGE OF SAUKVILLE..........	T11N,R21E,SEC.35	485	285	7- 6-66	0.06	0.03	68	33	7.10	345	25.00	1.20	0.40	1.80	0.02	336	307	283	7.2
				7-21-61	0.04	0.04	68	30	--	344	20.00	1.50	0.20	--	--	316	296	282	--
VILLAGE OF THIENSVILLE (VILLAGE HEIGHTS SUB).......	T 9N,R21E,SEC.22	559	191	7-29-66	0.47	0.03	72	29	18.00	233	130.00	3.30	0.70	1.80	0.03	702	300	191	--
CITY OF WEST BEND.............	T11N,R19E,SEC.11	275	635	7- 7-66	0.03	0.03	73	40	2.90	373	24.00	4.10	0.20	3.10	0.01	406	349	306	7.2
				4-19-61	0.06	0.04	72	40	0.00	373	23.00	2.00	0.00	5.90	0.00	356	336	306	--
				3-24-52	0.00	0.00	69	39	--	376	17.00	5.00	0.80	--	--	308	324	308	--
CITY OF WEST BEND.............	T11N,R19E,SEC.14	380	605	7- 7-66	0.03	0.03	68	38	4.40	361	21.00	2.40	0.40	1.80	0.01	364	327	296	7.2
				4-19-61	0.36	0.04	67	38	--	364	20.00	1.00	0.40	1.00	0.02	320	314	298	--
CITY OF WEST BEND.............	T11N,R19E,SEC.14	298	602	7- 7-66	0.03	0.03	91	44	8.00	401	54.00	18.00	0.20	3.10	0.01	516	412	329	7.3
				4-19-61	0.03	0.04	73	41	--	371	25.00	20.00	1.00	5.00	0.00	332	336	304	--
				3-24-52	0.00	0.00	74	41	--	373	36.00	6.00	0.60	--	--	352	344	306	--
				8- 5-46	0.00	0.00	72	32	--	376	30.00	10.00	0.10	--	--	352	295	308	--
				4-27-45	0.00	0.00	74	37	--	378	39.00	6.80	0.10	--	--	360	370	310	--
WIS DEPT OF NATURAL RESOURCES (KETTLE MORAINE STATE PARK).	T13N,R19E,SEC.11	270	711	6-15-68	0.03	0.02	--	--	--	286	70.00	3.00	--	0.90	--	354	306	234	--
WISCONSIN STATE BOYS SCHOOL...	T15N,R20E,SEC.31	352	738	2-15-63	0.08	--	55	31	4.40	312	14.00	3.00	--	--	--	222	298	--	--
					0.04	0.04	52	29	0.00	296	5.00	0.40	0.00	--	--	256	266	256	--
MINIMUM					0.00	0.00	30	14	0.00	105	0.40	0.40	0.00	0.20	0.00	222	187	173	7.1
MEAN					0.42	0.03	90	38	13.95	325	117.39	6.37	0.55	2.03	0.06	468	376	271	7.4
MAXIMUM					2.80	0.20	253	49	64.00	401	380.00	26.00	1.00	5.90	0.33	1240	859	329	7.7

[a]ANALYSES IN MG/L EXCEPT PH, WHICH IS IN UNITS.

NOTE- UNDERLINED VALUES EXCEED THE U.S. PUBLIC HEALTH SERVICE RECOMMENDATIONS FOR DRINKING WATER QUALITY.

SOURCE- U.S. GEOLOGICAL SURVEY.

TABLE 83

CHEMICAL ANALYSES OF GROUND WATER FROM THE SANDSTONE AQUIFER IN THE MILWAUKEE RIVER WATERSHED[a]

					GROUND					WATER				QUALITY		PARAMETERS			
OWNER	LOCATION	DEPTH OF WELL (FEET)	ALTITUDE OF BOTTOM (FEET-MSL)	DATE OF COLLECTION	IRON (FE)	MANGA-NESE (MN)	CAL-CIUM (CA)	MAGNE-SIUM (MG)	SO-DIUM (NA)	BICAR-BONATE (HCO_3)	SUL-PHATE (SO_4)	CHLO-RIDE (CL)	FLUO-RIDE (F)	NI-TRATE (NO_3)	NI-TRITE (NO_2)	DIS-SOLVED SOLIDS	HARDNESS AS CA CO_3	ALKALINITY AS CA CO_3	PH (FIELD)
BADGER METER COMPANY...	T 8N,R21E,SEC.11	1,286	-611	6-14-62	0.66	--	86	56	96	438	267	12	--	--	--	724	445	--	--
CITY OF CEDARBURG......	T10N,R21E,SEC.27	1,000	-210	11- 7-56	0.04	0.00	82	28	--	317	60	5	0.20	--	--	390	337	260	7.50
				3-22-51	--	--	85	26	15	281	105	8	1.00	--	--	386	320	230	--
				5-10-45	0.20	0.00	94	30	--	310	140	10	0.20	--	--	452	368	254	--
MILWAUKEE COUNTY (MC GOVERN PARK).....	T 8N,R21E,SEC.35	1,407	-731	1-30-52	0.36	0.13	--	--	--	273	125	7	1.60	--	--	400	320	224	--
HERBERT A NIEMAN CO....	T10N,R21E,SEC.26	1,250	-468	3- 6-61	--	0.00	620	55	--	195	1,650	27	0.70	--	--	2,520	1,700	160	--
PRIVATE................	T11N,R20E,SEC.30	890	- 30	6-11-62	7.20	--	90	34	--	170	680	160	--	--	--	1,390	365	139	--
MINIMUM					0.04	0.00	82	26	15	170	60	5	0.20	--	--	386	320	139	7.50
MEAN					1.69	0.03	176	38	55	283	432	33	0.74	--	--	900	551	211	7.50
MAXIMUM					7.20	0.13	620	56	96	438	1,650	160	1.60	--	--	2,520	1,700	260	7.50

ANALYSES IN MG/L EXCEPT PH, WHICH IS IN UNITS.

NOTE- UNDERLINED VALUES EXCEED THE U.S. PUBLIC HEALTH SERVICE RECOMMENDATIONS FOR DRINKING WATER QUALITY.

SOURCE- U.S. GEOLOGICAL SURVEY.

TABLE 84

CHEMICAL ANALYSES OF GROUND WATER FROM THE SANDSTONE AND DOLOMITE AQUIFERS IN THE MILWAUKEE RIVER WATERSHED[a]

					GROUND				WATER				QUALITY			PARAMETERS			
OWNER	LOCATION	DEPTH OF WELL (FEET)	ALTITUDE OF BOTTOM (FEET-MSL)	DATE OF COLLECTION	IRON (FE)	MANGANESE (MN)	CALCIUM (CA)	MAGNESIUM (MG)	SODIUM (NA)	BICARBONATE (HCO_3)	SULPHATE (SO_4)	CHLORIDE (CL)	FLUORIDE (F)	NITRATE (NO_3)	NITRITE (NO_2)	DISSOLVED SOLIDS	HARDNESS AS CA CO_3	ALKALINITY AS CA CO_3	PH (FIELD)
BAYSHORE SHOPPING CENTER.	T 8N,R22E,SEC.29	1,618	- 977	6-15-62	0.52	--	179	54	79.00	148	670	16.00	--	--	--	1,110	669	--	--
VILLAGE OF BAYSIDE (PELHAM HEATH SUB).....	T 8N,R22E,SEC. 9	1,756	-1,096	8-25-66	1.10	0.04	204	29	24.00	246	450	11.00	1.20	2.20	0.02	946	631	202	7.40
BOSTON STORE..............	T 7N,R22E,SEC.29	1,757	-1,163	5- 5-47	--	--	139	43	26.00	389	196	36.00	0.90	0.20	--	725	516	--	--
VILLAGE OF CAMPBELLSPORT.	T13N,R19E,SEC.18	1,284	- 243	6-23-66	0.63	0.03	119	33	14.00	355	140	5.00	1.60	1.80	0.03	546	402	291	--
				11-10-64	0.82	0.03	106	33	--	355	140	5.00	1.60	0.50	0.03	546	400	291	--
				2-18-58	0.52	0.00	118	33	21.00	315	184	24.00	0.80	0.80	--	610	430	--	--
				9- 8-55	1.00	0.00	110	33	24.00	346	116	7.00	1.10	--	--	526	410	284	--
				4-26-55	0.70	0.00	110	30	26.00	337	150	14.00	1.00	--	--	538	398	276	--
VILLAGE OF CAMPBELLSPORT.	T13N,R19E,SEC.18	875	115	6-23-66	1.10	0.03	107	35	7.60	357	100	4.00	1.20	1.80	0.42	480	411	293	--
				11-10-64	0.66	0.03	94	35	--	357	100	4.00	1.20	1.10	0.42	480	383	293	--
				2-18-58	0.70	0.00	99	36	3.00	368	102	4.00	0.90	1.10	0.42	488	439	302	--
CITY OF CEDARBURG........	T10N,R21E,SEC.27	1,210	- 290	11-29-66	0.46	0.04	84	36	6.70	296	120	10.00	0.30	0.50	0.01	500	360	243	7.40
CITY OF CEDARBURG........	T10N,R21E,SEC.34	1,002	- 215	7- 6-66	0.20	0.03	76	37	6.30	349	53	6.00	0.30	2.50	0.00	396	344	286	7.20
				3-23-66	0.06	0.04	76	37	6.30	349	53	6.00	0.30	2.50	0.00	355	344	286	7.20
				11- 7-56	0.00	0.00	70	33	7.90	349	35	3.00	0.10	--	--	354	331	286	7.30
				10- 6-59	0.04	0.00	74	34	9.00	355	47	2.50	0.20	--	--	368	336	291	7.30
C & NW RR CO.............	T 9N,R22E,SEC.29	1,420	- 743	5- 7-07	--	--	452	56	358.00	310	1,770	28.00	--	--	--	2,550	1,370	254	--
CITY OF GLENDALE..........	T 8N,R22E,SEC.29	1,182	- 457	6-15-62	0.50	--	98	27	54.00	258	234	10.00	--	--	--	564	550	--	--
VILLAGE OF GRAFTON.......	T10N,R21E,SEC.13	1,200	- 465	9-20-65	0.46	0.04	272	28	11.00	282	610	9.50	0.70	0.00	0.01	1,140	795	231	7.20
VILLAGE OF GRAFTON.......	T10N,R22E,SEC.19	1,100	- 310	9- 8-57	0.05	0.00	76	33	--	349	51	6.00	0.30	--	--	358	325	286	7.40
CITY OF MEQUON (LAC DU COURS SUB).....	T 9N,R21E,SEC.36	1,550	- 895	8-18-66	0.34	0.04	416	52	78.00	168	1,130	48.00	1.00	3.10	0.02	1,810	1,260	138	7.30
MILWAUKEE COUNTY (BROWN DEER PARK)......	T 8N,R21E,SEC.13	1,526	- 822	6-14-61	0.36	0.13	--	--	--	352	145	8.00	1.00	0.50	--	--	434	288	7.20
U.S. ARMY................	T 8N,R22E,SEC. 5	1,216	- 516	10-12-56	1.40	0.00	545	61	1,610.00	212	2,250	1,890.00	2.30	--	--	6,690	1,720	174	--
MINIMUM					0.00	0.00	70	27	3.00	148	47	2.50	0.10	0.00	0.00	354	325	138	7.20
MEAN					0.58	0.04	165	38	124.83	313	384	94.00	0.90	1.33	0.15	1,004	576	263	7.30
MAXIMUM					1.40	0.13	545	61	1,610.00	368	2,250	1,890.00	2.30	3.10	0.42	6,690	1,720	302	7.40

[a]ANALYSES IN MG/1 EXCEPT PH, WHICH IS IN UNITS.

NOTE- UNDERLINED VALUES EXCEED THE U.S. PUBLIC HEALTH SERVICE RECOMMENDATIONS FOR DRINKING WATER QUALITY.

SOURCE- U.S. GEOLOGICAL SURVEY.

in these samples were found to vary somewhat but indicated that no significant changes in ground water quality took place during the time periods represented. The chemical analyses indicate the variability in ground water quality within the watershed, as well as the overall level of quality of the ground water. Because knowledge of the significance of the water quality indicators is basic to any study of ground water resources, the major chemical constituents and physical characteristics of the resources and the significance thereof are discussed below.

Iron: Because iron is one of the more abundant metallic elements of the earth's crust, it is dissolved from nearly all rock and soil. Objectionable amounts of iron occur in most ground waters and range to more than 7.2 mg/l in parts of the watershed. The occurrence of iron appears to be unpredictable, and high iron concentrations are found randomly throughout the watershed. An important factor, however, appears to be that shallow wells yielding objectionable concentrations of iron often are located in or near swamp or marsh areas. Iron content may also be excessive in areas where ground water movement is extremely slow.

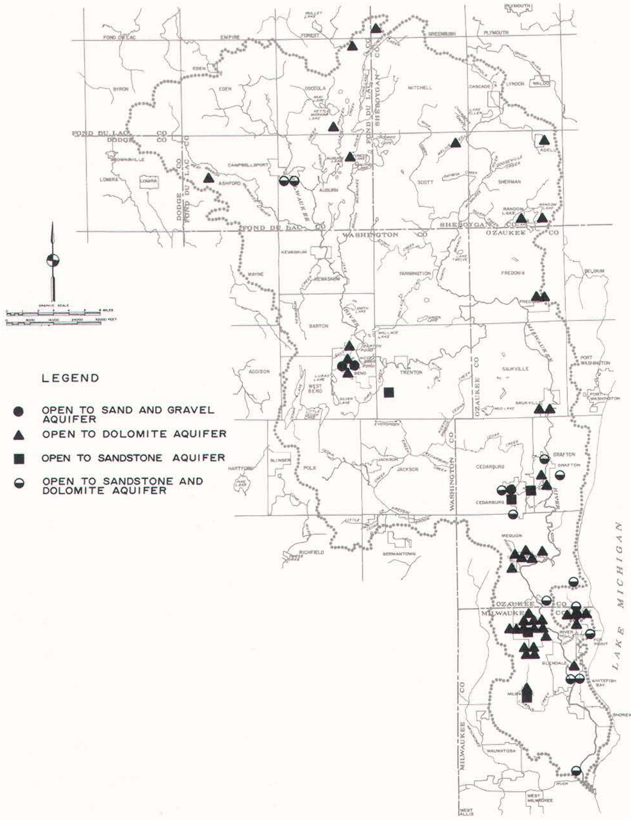
Many uses of water are adversely affected by high iron content. Concentrations higher than about 0.3 mg/l stain laundry, porcelain, and enamelware; and iron in water supplies is objectionable for food processing, beverage manufacturing, dyeing, bleaching, ice manufacturing, and brewing. High iron concentrations cause an unpleasant, bitter taste and favor the growth of iron bacteria. When exposed to air for even a short time, iron in ground water tends to oxidize and form an objectionable reddish-brown precipitate. Iron concentrations in water supplies are recommended to not exceed 0.3 mg/l. Tables 81, 82, 83, and 84 indicate that at least 47 wells exist within the watershed which produce water containing iron concentrations in excess of this amount.

Calcium and Magnesium: Calcium and magnesium are contained in both the shallow and deep aquifer within the watershed, being dissolved from limestone, dolomite, and other rock and soil. As shown in Tables 81, 82, 83, and 84, calcium concentrations in the ground water range from no measurable amounts to 620 mg/l and average about 106 mg/l. Magnesium concentrations range from no measurable amounts to 62 mg/l and average about 37 mg/l. High calcium and magnesium concentrations, that is, concentrations in excess of the standards set forth in Table 79, in the ground water are the major causes of hardness and scale-forming properties. Ground water containing small concentrations of dissolved calcium and magnesium, however, is preferable for certain industrial processes, including electroplating, tanning, dyeing, and textile manufacturing.

Sodium: Sodium is a common element contained in nearly all soil and rock; and, because most sodium salts are very soluble, all ground water will normally contain sodium. Sodium may also

Map 48

LOCATION OF U.S. GEOLOGICAL SURVEY GROUND WATER QUALITY SAMPLING WELLS IN THE MILWAUKEE RIVER WATERSHED AND ENVIRONS 1967



The 63 public and private water supply wells shown on this map were important sources of water samples for chemical analyses to determine ground water quality in the Milwaukee River watershed. Chemical analyses were performed on the samples for the following constituents of water: iron, calcium, magnesium, sodium, bicarbonate, carbonate, sulfate, chloride, flouride, nitrite, nitrate, and dissolved solids. In addition, the properties of water known as hardness, alkalinity, and hydrogen ion concentration were measured.

Source: U.S. Geological Survey.

enter the ground water system through industrial and municipal waste discharges containing sodium compounds. The sodium concentrations in the ground water within the watershed range from no measurable amounts to 1,610 mg/l and average about 44.6 mg/l, as shown in Tables 81, 82, 83, and 84.

No recommended limiting or maximum permissible concentration of sodium is established in the U. S. Public Health Service Drinking Water Standards 1962. Persons with heart, kidney, or circulatory diseases, however, require drinking and culinary water that contains little or no sodium. More than 50 mg/l sodium and potassium in the presence of suspended matter causes foaming, which in turn accelerates scale formation and corrosion in boilers. Sodium and potassium carbonate in circulating cooling water can cause deterioration of wood in cooling towers, and more than 65 mg/l of sodium can cause problems in ice manufacturing. Irrigation water high in sodium content may be toxic to plants and adversely affect soil conditions.

Bicarbonate and Carbonate: Bicarbonate and carbonate anions in ground water are primarily the result of the interaction of carbon dioxide and water with calcium and magnesium carbonate rocks (limestone and dolomite). Carbonate salts, however, are generally insoluble, and, therefore, are seldom present in ground water.

Bicarbonate anions are present in all aquifers in the watershed in concentrations that may limit water use. The ground water supplies in the Milwaukee River watershed are relatively high in bicarbonate content, ranging from 105 to 438 mg/l and exceeded 300 mg/l in most analyses. The presence of the bicarbonate anion in water produces alkalinity, which affects the corrosiveness of water. Bicarbonates of calcium and magnesium decompose in steam boilers and hot-water facilities to form carbonate scale and release corrosive carbon dioxide. Bicarbonate concentrations in water have little public health significance. If present in large quantities, however, taste is affected.

Sulfate: Sulfate concentrations in ground water result primarily from the leaching and oxidation of sulfide and sulfate minerals contained in the soil and rock of the watershed. Sulfate may also enter the ground water system through the percolation of waste discharges from industries that use sulfates or sulfuric acid or that produce sulfates in their manufacturing processes. Sulfate is also contributed from atmospheric sources through precipitation. In the Milwaukee River watershed, the concentration of sulfate was found to range from 0.4 mg/l to 2,250 mg/l and averages about 182.5 mg/l. Concentrations greater than 250 mg/l exceed the recommended limiting sulfate concentrations for drinking water, imparting a taste to water and acting as a laxative. Sulfate concentrations exceed 250 mg/l in both the dolomite and the sandstone aquifers in two relatively large areas of the watershed, as shown on Maps 51 and 52. The areas of high sulfate content in the sandstone aquifer are more extensive and contain higher concentrations of sulfate and dissolved solids than those of the dolomite aquifer.

Chloride: The chloride content of ground water results primarily from leaching of rock and soil minerals. Human activity may also introduce chloride to the ground water system through the percolation of sewage, water-softening wastes, industrial wastes, and runoff of salt applied for ice control. In all, the chloride concentration in ground water of the watershed is low. As shown in Tables 81, 82, 83, and 84, concentrations range from less than 1 mg/l to 1,890 mg/l; and over 71 percent of the water samples had chloride concentrations of less than 10 mg/l. Only one of the ground water samples tested, as indicated in Tables 81, 82, 83, and 84, contained chloride concentrations that were substantially in excess of the 250 mg/l recommended for drinking water. Chlorides in drinking water in excess of 250 mg/l impart an undesirable taste and, if used in industry, can cause or increase the normal corrosive action of water on boilers, pumps, pipes, and other related appurtenances.

Fluoride: Fluoride compounds are not naturally abundant and occur in relatively small quantities within the watershed. The fluoride content of ground water within the watershed was found to range from no measurable amount to 2.3 mg/l in public and private water supplies and to average about 0.59 mg/l. In general, the highest concentrations of fluoride occur within the Niagara dolomite aquifer in eastern portions of the watershed.

The presence of fluoride in drinking water may be either beneficial or harmful, depending upon its concentration and water consumption. Fluoride in drinking water reduces tooth decay when the water is consumed during the period of enamel calcification. Fluoride may, however, cause mottling of the teeth, depending upon the concentration of the fluoride, the amount of the drinking water consumed, and the age and susceptibility of the individual. The concentration of fluoride recommended varies with the annual average maximum daily air temperature. In southeastern Wisconsin, where the annual average maximum daily air temperature is between 50.0 and 53.7°F, the maximum fluoride concentration recommended is 1.7 mg/l.

Nitrate and Nitrite: Nitrate in ground water is the result of decaying organic matter, nitrate compounds in soil, domestic and municipal sewage, fertilizer, or waste discharges of food and milk processing industries. Nitrate is also contributed from atmospheric sources through precipitation. Analyses of ground water in the Milwaukee River watershed indicate that excessive concentrations of nitrate are uncommon. As might be expected, shallow wells and springs are more likely to produce water with high nitrate content than are deep wells, due to the relative ease with which the shallow aquifers are recharged with surface water.

Drinking water standards established by the U. S. Public Health Service[1] recommend that the nitrate content (as NO_3) not exceed 45 mg/l, as there is evidence that higher concentrations may cause methemoglobinemia in infants (blue babies). Nitrate in water in concentrations much greater than the local average may suggest contamination by sewage or other organic matter. In concentrations less than 45 mg/l, nitrate has no adverse effect on most water uses. Within the watershed concentrations of nitrate were found to range from no measurable amount to 6.8 mg/l, as shown in Tables 81, 82, 83, and 84.

Nitrite is produced by bacteria from soil ammonia. Like nitrate, the nitrite content of ground water in the Milwaukee River watershed is in relatively small quantities when it is present and is not considered a threat to public health. In general, the shallower wells are more likely to produce water high in nitrite concentrations. Within the watershed concentrations of nitrite (as NO_2) were found to range from no measurable amount to 0.42 mg/l, as shown in Tables 81, 82, 83, and 84.

Nitrite is unstable in the presence of oxygen and is present in only minute quantities in most natural waters. The presence of nitrite in water sometimes indicates organic pollution. Nitrite is toxic but rarely occurs in large enough concentrations to cause a health hazard. The recommended limits for nitrite differ widely; and, although a generally accepted limiting concentration for drinking water is 2 mg/l, more stringent limits of as low as 0.1 mg/l have been proposed.

Dissolved Solids: The dissolved solids content of water generally represents the total quantity of mineral constituents dissolved in the water regardless of source. In ground water the source

[1] *U. S. Public Health Service Drinking Water Standards 1962.*

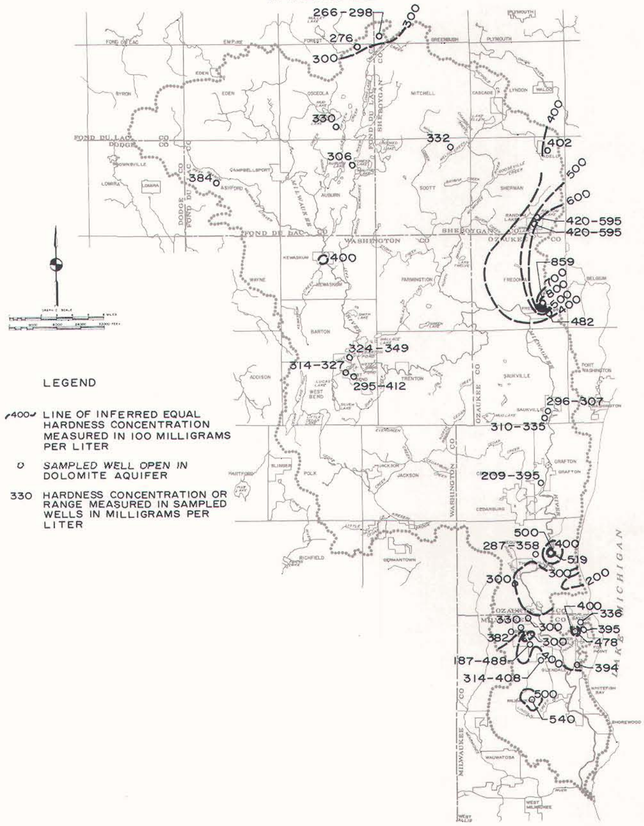
of dissolved minerals is primarily the rock and soil through, and over which, the ground water passes. Concentrations of dissolved solids are relatively high in ground water supplies of public and private utilities in the watershed, ranging from 222 mg/l to 6,690 mg/l and averaging about 586 mg/l. As indicated in Tables 81, 82, 83, and 84, 23 wells produced water with concentrations higher than the recommended limiting concentration for drinking water of 500 mg/l. High dissolved solids concentrations are common to both shallow and deep wells within the watershed. Dissolved solids above 500 mg/l from the dolomite and sandstone aquifers are mainly attributable to high concentrations of sulfate. High concentrations of sulfate and dissolved solids in the bedrock aquifers may be influenced by the geologic structure, because areas of high concentrations in the bedrock aquifers generally coincide with broad synclines or downwarps of the sedimentary rock formations.

Hardness: Hardness is a property of water rather than a constituent. This property is commonly related to the use of soap and the formation of boiler scale. Water is considered to be "hard" when sodium or potassium stearate soaps form little suds and lots of insoluble curd, which floats upon the water and adheres to sinks and tubs, or when water, upon being heated, forms scales or deposits in boilers, hot-water heaters, and in pipes or on the cooking surfaces of pots. "Soft" water reacts with soap to form much suds and little or no curd. Upon heating, "soft" water does not tend to develop scale.

Hard ground water is common in the Milwaukee River watershed. Maps 49 and 50 indicate the geographical distribution of hardness within the shallow aquifer and deep aquifer of the watershed, respectively. The hardness in some wells within the watershed is greater than 500 mg/l, and water from public and private water utilities averages about 426 mg/l. However, there are no water utilities serving the communities within the Milwaukee River watershed which treat their raw water to remove part of the hardness. Many homeowners, both served by private and public water supplies, however, operate their own water-softening units. Table 85 is useful in the evaluation of ground water hardness and, in a general way, as to its suitability for public and domestic water supplies.

Map 49

HARDNESS OF GROUND WATER FROM SHALLOW WELLS IN THE MILWAUKEE RIVER WATERSHED



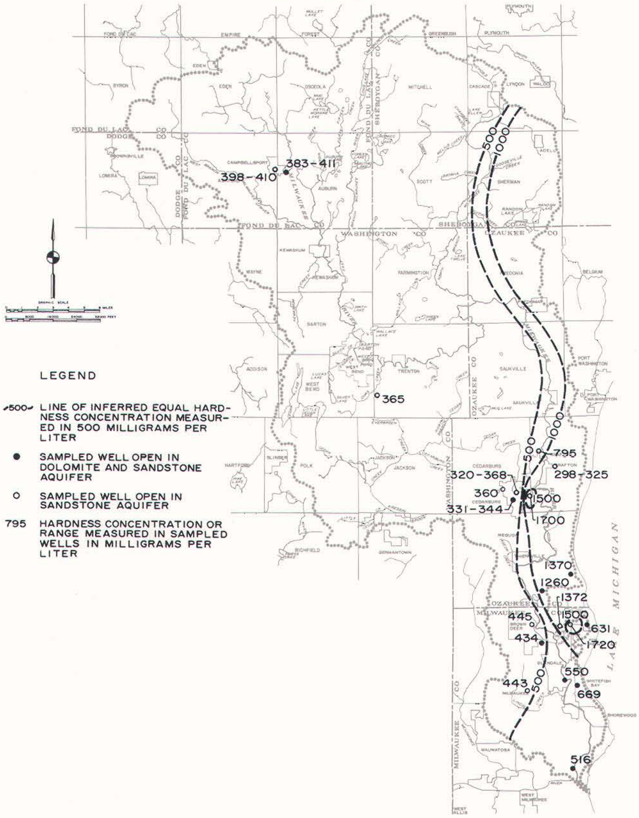
The ground water in the shallow aquifer underlying the Milwaukee River watershed exceeds 500 mg/1 in only one small area of the watershed, namely, in the Town of Fredonia, Ozaukee County, and the Town of Sherman, Sheboygan County, along the eastern watershed boundary. Most of the shallow wells sampled in the watershed yielded hardness concentrations under 400 mg/1.

Source: U.S. Geological Survey.

Alkalinity: Like hardness, alkalinity is a property of water rather than a specific constituent. This property involves the ability of water to neutralize acid and is due primarily to the presence of bicarbonate and carbonate anions. The alkalinity of ground water used by public and private utilities in the Milwaukee River watershed is relatively high, ranging from 138 mg/l to 320 mg/l and averaging about 269 mg/l, as shown in Tables 81, 82, 83, and 84. This level of alkalinity is, however, acceptable for most water uses.

Map 50

HARDNESS OF GROUND WATER FROM DEEP WELLS IN THE MILWAUKEE RIVER WATERSHED



The ground water in the deep sandstone aquifer underlying the Milwaukee River watershed exceeds 500 mg/1 along the entire eastern boundary of the watershed, reaching a maximum concentration of 1,700 mg/1 in the Village of River Hills, Milwaukee County. Most of the deep wells sampled in the watershed yielded hardness concentrations under 450 mg/1.

Source: U.S. Geological Survey.

Hydrogen Ion Concentration: The hydrogen ion concentration of water, expressed in pH units, is a measure of the relative acidity or basicity and depends upon the dissolved substances, both solids and gases, contained in the water. A pH of 7.0 indicates neutrality of a solution; values higher than 7.0 denote increasing basicity; and values lower than 7.0 indicate increasing acidity. Acids, acid-generating salts, and free carbon dioxide tend to lower the pH, while carbonates, bicarbonates, hydroxides, phosphates, silicates, and borates tend to raise the pH.

Within the Milwaukee River watershed, raw water supplies used by public and private water utilities are generally slightly basic in character. Of the samples shown in Tables 81, 82, 83, and 84, about 36 percent of the pH values lie within the range 7.2 to 7.4; and the average pH value is 7.3. Water treatment, as provided by the ground water utilities serving the watershed, does not remove objectionable mineral constituents, as indicated by the analyses in Tables 81, 82, 83, and 84.

Ground Water Analysis by Aquifer

The analyses in Tables 81, 82, 83, and 84 are listed according to aquifer from the shallowest to the deepest. The available chemical quality data for the shallow sand and gravel and for the deep sandstone aquifers were not as uniformly distributed over the watershed as were data for the shallow dolomite aquifer. The following discussion of ground water quality in each aquifer is limited to the occurrence and distribution of the chemical substances that limit the use of the water.

The Shallow Sand and Gravel Aquifer Ground Water Quality: Water from the sand and gravel aquifer is generally of good quality (see Table 81) and is suitable for most uses. Bicarbonate concentrations range between 330 and 384 mg/l; sulfate concentrations, between 6 and 84 mg/l; dissolved solids concentrations, between 332 and 522 mg/l; and hardness, between 300 and 404 mg/l. The highest concentration of nitrate (6.8 mg/l) in any of the ground water samples was found in a sample drawn from a well in the sand and gravel aquifer in Section 14, Town 11 North, Range 19 East, Washington County. Nitrate content, a qualitative indicator of organic pollution, however, was found to be well below the recommended 45 mg/l limit for drinking water. The high permeability and shallow depth of the sand and gravel aquifer make it more susceptible to pollution than the deeper aquifers.

The Shallow Dolomite Aquifer Ground Water Quality: Ground water in the dolomite aquifer is also generally of good quality in most of the watershed but contains high concentrations of sulfate and dissolved solids in two areas of the watershed. These areas occur along the easterly side of the watershed near the Sheboygan-Ozaukee County line in the north and near the Ozaukee-Milwaukee County line in the south. Map 51 shows the distribution of dissolved solids concentrations in the dolomite aquifer and outlines the areas of high

TABLE 85

U. S. GEOLOGICAL SURVEY WATER HARDNESS RATINGS

HARDNESS RANGE AS CACO3 (IN MG/1)	DESIGNATION	REMARKS
0 - 60	SOFT WATER	SUITABLE FOR PUBLIC OR DOMESTIC USE WITHOUT SOFTENING.
61 - 120	MODERATELY HARD WATER	CAN BE USED FOR PUBLIC OR DOMESTIC USE WITHOUT SOFTENING. SOFTENING MAY BE DESIRABLE TO REDUCE SOAP CONSUMPTION AND ACCUMULATION OF SCUM ON WATER FIXTURES.
121 - 180	HARD WATER	EXCEPT FOR DIRECT HUMAN CONSUMPTION, GENERALLY UNSUITABLE FOR PUBLIC OR DOMESTIC USE WITHOUT SOFTENING.
MORE THAN 180	VERY HARD WATER	EXCEPT FOR DIRECT HUMAN CONSUMPTION, REQUIRES SOFTENING FOR ALMOST ALL USES OTHER THAN IRRIGATION.

SOURCE- U. S. GEOLOGICAL SURVEY.

concentration. The highest sulfate and dissolved solids concentrations in the northern area were 610 and 1,240 mg/l, respectively, with both occurring in the same well. In the southern area, the maximum sulfate and dissolved solids concentrations were 380 and 774 mg/l, respectively. These concentrations may be compared to the average values for the dolomite aquifer samples of 117 mg/l of sulfate and 468 mg/l of dissolved solids.

Dissolved solids in the aquifer probably increase with depth, but the available data do not consistently support this generalization. The inconsistencies may be due to the nonuniform permeability of the aquifer at each well. If so, the principal water-producing zones differ in depth from well to well and result in varying degrees of water dilution in each well.

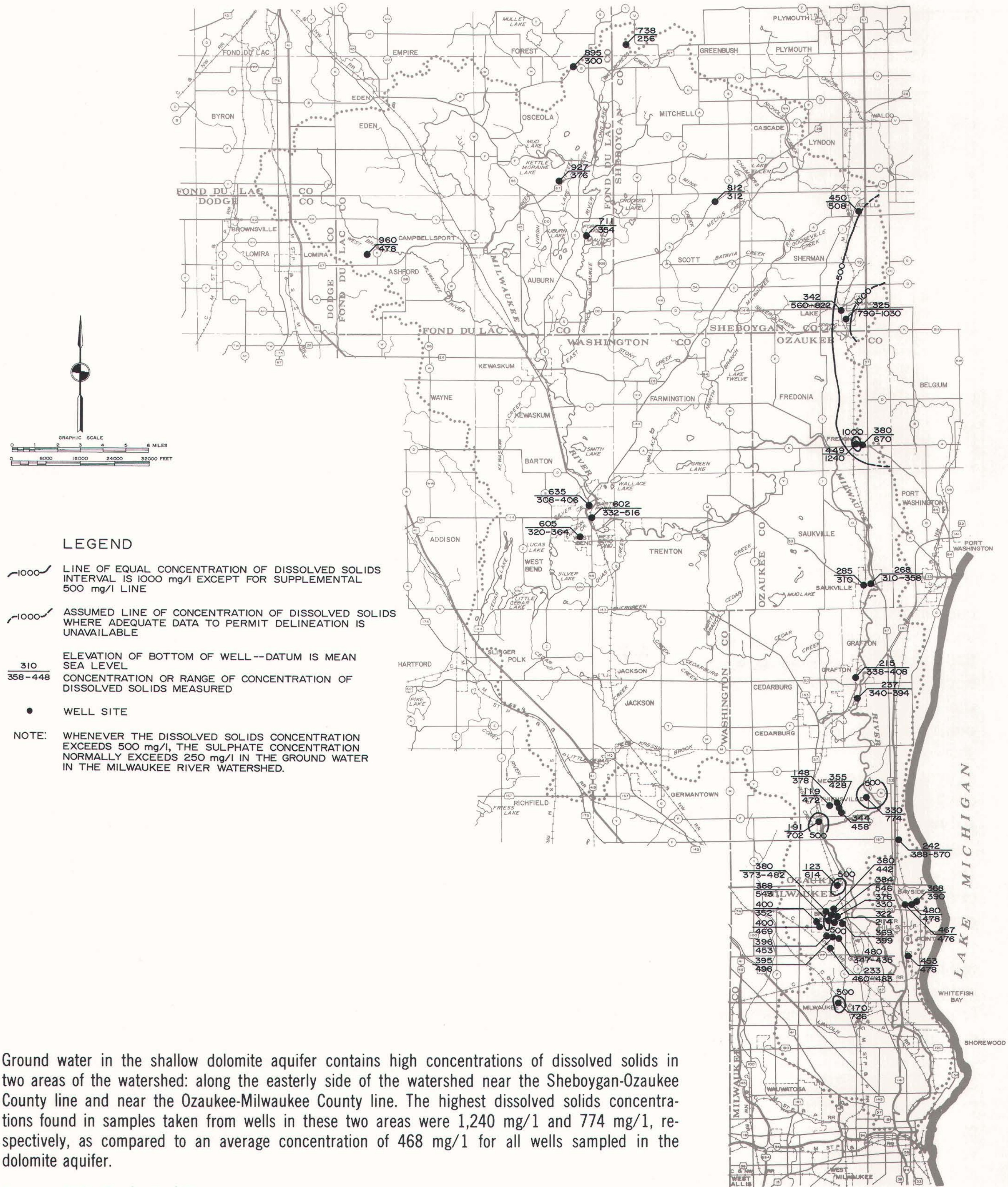
The concentration of iron in ground water samples from the dolomite aquifer ranged between no measurable amount and 2.88 mg/l, the average value being about 0.4 mg/l. The iron exceeded 0.3 mg/l in most of the samples taken from the aquifer in the Milwaukee area of the watershed.

The Deep Sandstone Aquifer Ground Water Quality: Ground water from the deep sandstone aquifer is generally more highly mineralized than water from the shallow aquifers. This is particularly true along the easterly side of the watershed, where the concentrations of dissolved solids in the aquifer exceed 1,000 mg/l over a large area. Water containing more than 1,000 mg/l of dissolved solids is considered saline. The altitude of the top of this saline ground water probably increases gradually toward the east but also varies considerably in a north-south direction.

Map 52 shows the approximate distribution of dissolved solids in the sandstone aquifer. The contours are based on analyses of water samples from the sandstone aquifer and also of composite water samples from wells open to both the sandstone and the dolomite aquifers. Because ground water in the dolomite aquifer in the watershed is rarely saline, the saline water in composite samples may be attributed primarily to the sandstone aquifer. The data generally support this assumption but are not conclusive. A composite sample from a well located in Section 5, Town 8 North, Range 22 East, Milwaukee County, contained the

Map 51

APPROXIMATE DISTRIBUTION OF DISSOLVED SOLIDS IN THE DOLOMITE AQUIFER IN THE MILWAUKEE RIVER WATERSHED 1967



LEGEND

1000 — LINE OF EQUAL CONCENTRATION OF DISSOLVED SOLIDS INTERVAL IS 1000 mg/l EXCEPT FOR SUPPLEMENTAL 500 mg/l LINE

1000 — ASSUMED LINE OF CONCENTRATION OF DISSOLVED SOLIDS WHERE ADEQUATE DATA TO PERMIT DELINEATION IS UNAVAILABLE

310 — ELEVATION OF BOTTOM OF WELL--DATUM IS MEAN SEA LEVEL

358-448 — CONCENTRATION OR RANGE OF CONCENTRATION OF DISSOLVED SOLIDS MEASURED

• WELL SITE

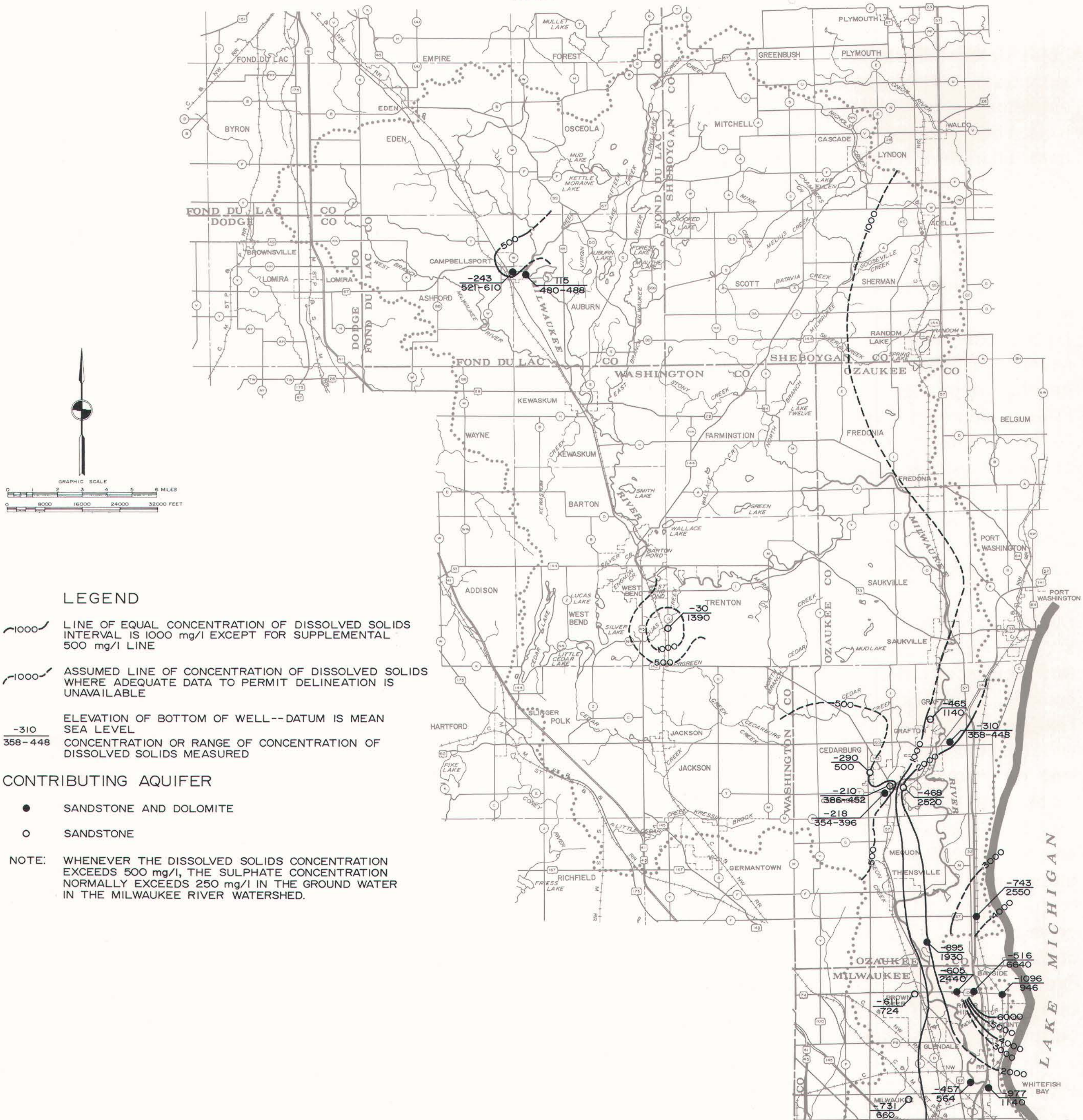
NOTE: WHENEVER THE DISSOLVED SOLIDS CONCENTRATION EXCEEDS 500 mg/l, THE SULPHATE CONCENTRATION NORMALLY EXCEEDS 250 mg/l IN THE GROUND WATER IN THE MILWAUKEE RIVER WATERSHED.

Ground water in the shallow dolomite aquifer contains high concentrations of dissolved solids in two areas of the watershed: along the easterly side of the watershed near the Sheboygan-Ozaukee County line and near the Ozaukee-Milwaukee County line. The highest dissolved solids concentrations found in samples taken from wells in these two areas were 1,240 mg/1 and 774 mg/1, respectively, as compared to an average concentration of 468 mg/1 for all wells sampled in the dolomite aquifer.

Source: U.S. Geological Survey.

Map 52

APPROXIMATE DISTRIBUTION OF DISSOLVED SOLIDS IN THE SANDSTONE AQUIFER IN THE MILWAUKEE RIVER WATERSHED 1967



Ground water in the deep sandstone aquifer contains high concentrations of dissolved solids in one relatively large area straddling the Ozaukee-Milwaukee County line. Well samples in this area yielded dissolved solids concentrations in excess of 2,000 mg/1, reaching a maximum concentration of over 6,600 mg/1 in northern Milwaukee County. This maximum concentration of over 6,600 mg/1 of dissolved solids is extremely high compared to the average dissolved solids concentration of 900 mg/1 for all wells sampled in the sandstone aquifer and 1,004 mg/1 for all wells sampled in the dolomite and sandstone aquifers.

Source: U.S. Geological Survey.

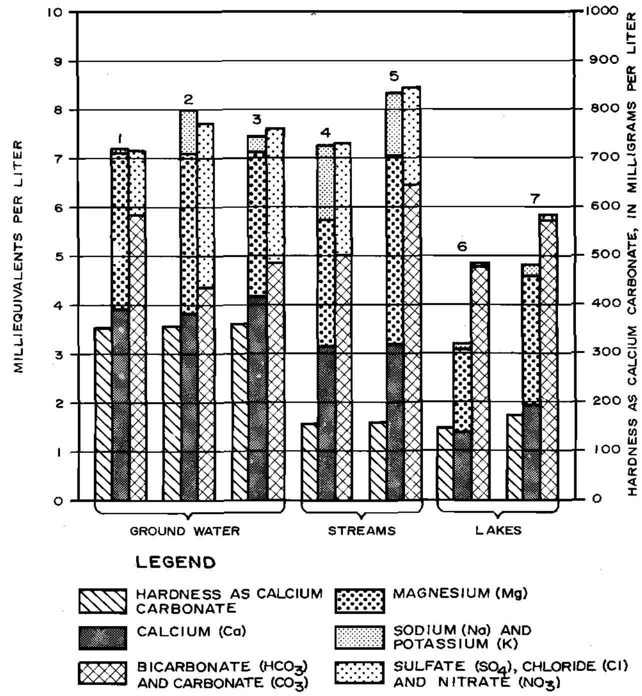
highest concentrations of sulfate (2,250 mg/l), chloride (1,890 mg/l), sodium (1,610 mg/l), and dissolved solids (6,690 mg/l) measured in the watershed. This sample was also the only water sample from watershed aquifers in which the chloride concentration exceeded the 250 mg/l limit recommended for drinking water. Data from the sandstone aquifer in Sheboygan County east of the watershed indicate that chloride is the most abundant chemical substance present in the ground waters of some areas there. High chloride concentrations may be expected to be found beneath a more extensive area than the data show.

The distribution of data for the aquifer permits only a general evaluation of their water quality. During the drilling of new, deep wells in the watershed, water samples should be taken at regular depth intervals to obtain more reliable information on the specific source of poor quality water in the bedrock aquifer. The quality of the ground water supplies of the watershed is, in general, superior to the stream water quality. Municipal and industrial waste discharges and urban and rural runoff result in stream contamination and markedly reduced water quality.

During periods of base flow (low discharge), stream water in most of the watershed is similar to water from wells in terms of dissolved mineral content. This is to be expected because at base flow most of the stream water results from ground water seepage. A comparison of the mineralization of ground water, streams at base flow, and lakes at selected locations is provided in Figure 49. Like ground water, stream water at base flow can be classified as hard to very hard; and calcium, magnesium, and bicarbonate comprise most of the dissolved constituents. The range of concentrations of dissolved substances, however, is often less in surface water than in ground water, due to the mixing action of ground water seepage into the stream from various sources and the precipitation of dissolved minerals in the streams.

Figure 49

MINERALIZATION OF GROUND WATERS, STREAM WATER AT BASE FLOW, AND LAKE WATER IN THE MILWAUKEE RIVER WATERSHED



SOURCE

1. FROM 92-FT. WELL IN SAND AND GRAVEL. SEC. 14, T. 11 N., R. 19 E., CITY OF WEST BEND, WASHINGTON COUNTY (4-19-66)
2. FROM 586-FT. WELL IN DOLOMITE. SEC. 21, T. 9 N., R 21 E., VILLAGE OF THIENSVILLE, OZAUKEE COUNTY (8-18-66)
3. FROM 1210-FT. WELL IN SANDSTONE SEC. 27, T. 10 N., R. 21 E., CITY OF CEDARBURG, OZAUKEE COUNTY (11-29-66)
4. MILWAUKEE RIVER AT MILWAUKEE, BASE FLOW ON JUNE 29, 1964
5. CEDAR CREEK AT CEDARBURG, BASE FLOW ON FEBRUARY 26, 1964
6. FOREST LAKE, FOND DU LAC CO., ON JULY 31, 1968, DEPTH 18 FT.
7. GREEN LAKE, WASHINGTON CO., ON AUGUST 7, 1969, DEPTH 18 FT.

Source: U.S. Geological Survey and SEWRPC.

PRESENT AND POTENTIAL GROUND WATER POLLUTION

Ground Water Pollution from the Activities of Man

Pollution of ground water by wastes from human activity is a local problem in the watershed. Man generates a great variety of pollutants from municipal, industrial, and agricultural wastes. Seepage of these wastes into shallow ground water may occur from many potential sources of ground water pollution that exist in the Milwaukee River watershed. These include, but are not restricted to, private underground sewage disposal systems (septic tanks), refuse dumps, barnyards, cesspools and sewage lagoons, privies and dry wells, influent (losing) streams and lakes, industrial spillages, and leakage from community sewerage systems, all of which are more apt to affect the shallow aquifer than the deep aquifer. Problems involving pollution of ground water generally are much more difficult to solve than problems involving surface water, because the hidden paths of ground water contaminants cannot be easily traced. Other potential forms of ground water pollution of both the shallow and deep aquifers have not been, and cannot as yet be, fully evaluated. These include the long-term effects of detergents,[2] insecticides, and herbicides on ground water quality.

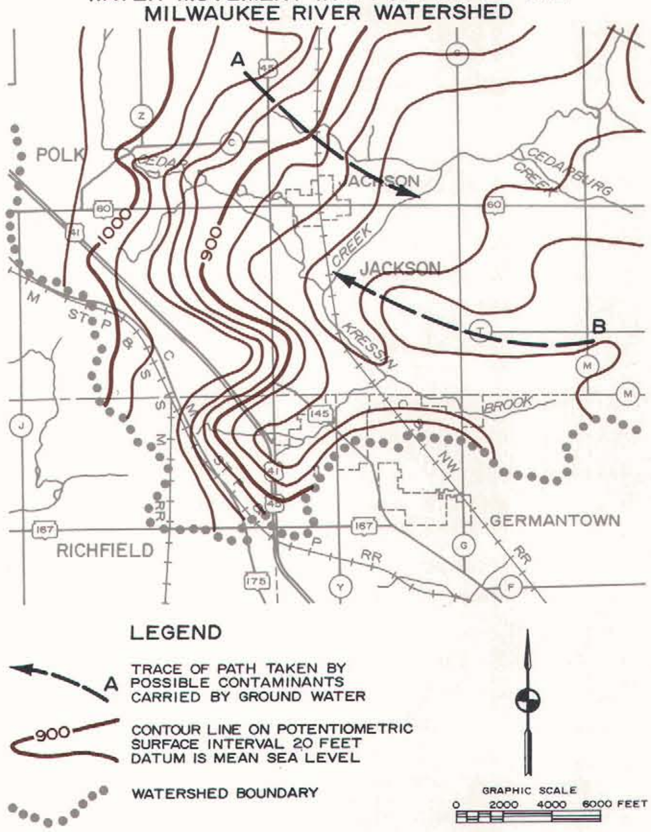
Pollutants may enter aquifers by continuous seepage through highly pervious material or by intermittent seepage during periods of ground water recharge. In the Milwaukee River basin, natural recharge to shallow aquifers usually occurs in the spring of the year. Pollutants may be injected directly into unsealed wells, or they can be transferred by wells from the shallow aquifer to the deep aquifer. Pollutants can also reach the water table rapidly if they enter through creviced limestone or dolomite exposed in quarries or at natural outcroppings. In most cases, however, a pollutant seeps down slowly and takes days or even months to reach the water table, depending on the amount of recharge, the depth to the water table, and the character of the overlying soil and rock. Once the contaminant enters the aquifer, it moves with the ground water; and its velocity and direction of travel can be determined by the hydraulics of the ground water system.

From a source of seepage, a pollutant percolates to the water table, then moves laterally in the saturated zone down the hydraulic gradient toward a discharge area, which usually is a surface stream. The velocity at which it moves in the subsurface depends upon the permeability of the materials and the hydraulic gradient. Ground water velocities normally range between five feet per day and five feet per year. In uniform materials dispersion and dilution of the pollutant should occur as it moves toward the discharge area. In the sand and gravel and the dolomite aquifers, the approximate flow path of a contaminant from any site may be determined from the potentiometric surface map (see Map 33). Detailed site studies are required to define precise flow paths at any locality.

Map 53 shows a portion of the potentiometric map of the shallow dolomite aquifer in the Milwaukee River watershed. Generally, water in an aquifer moves at right angles to the potentiometric contours. Thus, a contaminant starting at point "A," for example, will follow a curved path southeastward to empty into Cedar Creek near Jackson. It could enter a pumping well anywhere along the way. A contaminant starting at point "B" will follow a path northwestward to Cedar Creek. Ground water usually moves slowly and, in most aquifers, only a few inches or feet a day. Years may, therefore, elapse before a contaminant moves a single mile. The other extreme, however, is illustrated by a test conducted near Sussex in 1965 by the

Map 53

POTENTIOMETRIC MAP OF THE SHALLOW DOLOMITE AQUIFER SHOWING GENERAL DIRECTION OF GROUND WATER MOVEMENT IN A PORTION OF THE MILWAUKEE RIVER WATERSHED



Generally, water in an aquifer will move along paths at right angles to the potentiometric contours, as shown on this map. Contaminants entering the aquifer at any point will follow these paths to pumped wells or other points or areas of discharge and in so doing may create a public health hazard.

Source: U.S. Geological Survey.

[2] *Since December 31, 1965, the sale of non-biodegradable (hard) detergents containing Alkyl benzene sulfonate has been prohibited in Wisconsin by Section 144.14 of the Wisconsin Statutes. In accordance with this legislation, the detergent industry has developed biologically degradable (soft) detergents and placed these on the market so that today all detergents presently being sold in Wisconsin are of the "soft" type.*

Waukesha County Health Department, in which contaminants moved more than 500 feet per day through the creviced bedrock. A condition such as this can pose a severe public health problem if the contaminated aquifer is used as a source for drinking water. Because of the high velocity of movement in such creviced rock, harmful bacteria or virus may not remain in the water flow long enough to die before ingestion by humans.

Soils and granular mineral deposits, such as sand, silt, and clay, can assimilate and naturally purify some waste material through bacterial action, base exchange processes, selective absorption, or filtering. Organic wastes often decompose and are removed by filtration within relatively short distances of their source, whereas soluble minerals, synthetic detergents, phenols, and similar substances persist. In fissured rocks, such as dolomite, however, the capacity to assimilate wastes may be small because some openings are large and transmit unaltered wastes for long distances.

The glacial deposits overlying the dolomite in most of the watershed are sufficiently thick to prevent direct pollution of the dolomite aquifer. In the area enclosed by 50-foot saturated thickness contours (see Map 54), the dolomite crops out or is covered only by thin glacial deposits and is less protected. Within these areas there is potential for pollution of the dolomite aquifer; however, the thin glacial material is relatively impermeable till and moraine deposits, which may significantly retard the seepage of pollutants.

Pumping disrupts the natural pattern of ground water movement and diverts water from a large area toward the well. Pollutants within the area of pumping influence can be induced to flow toward, and eventually discharge to, the well. The probability of pollution of the well supply is high if the well is close to the source of pollution. The degree of pollution depends upon the hydraulic properties at the site and factors such as the type, toxicity, concentration, quantity of pollutant, and the duration of its contact with geologic environment. At each location, therefore, many factors must be determined to evaluate the pollution hazard.

Pollution of domestic supply wells by seepage of effluent from septic tanks is a relatively common occurrence. Pollution generally results from spacing wells and septic tanks too closely for the existing hydrogeologic conditions. It also is aggravated by improperly functioning septic tanks and by poorly sealed well casings, which allow vertical movement of ground water around the casing. Areas in which fissured rocks are only thinly buried are particularly susceptible. Pollution from septic tank effluent may be avoided or reduced by proper location, design, and construction of septic tanks and wells, adequate lot sizes, or development of community sewage systems and public water-supply systems.

If alternative solutions to the problem of waste disposal are not practical, sites selected for waste disposal should be located in thick, relatively impermeable sediments that have little or no water-supply potential. Movement of contaminants in such materials is extremely slow and is generally limited to local areas.

Problem Areas: The pollution of ground water is a potential problem in many local areas of the Milwaukee River watershed. An increased probability of pollution exists in areas where:

1. Residential land uses are concentrated and waste is discharged into septic tank systems or into dry wells and pit privies.

2. The water supply is obtained from shallow wells pumping water from just beneath the water table.

3. The water table is close to the land surface.

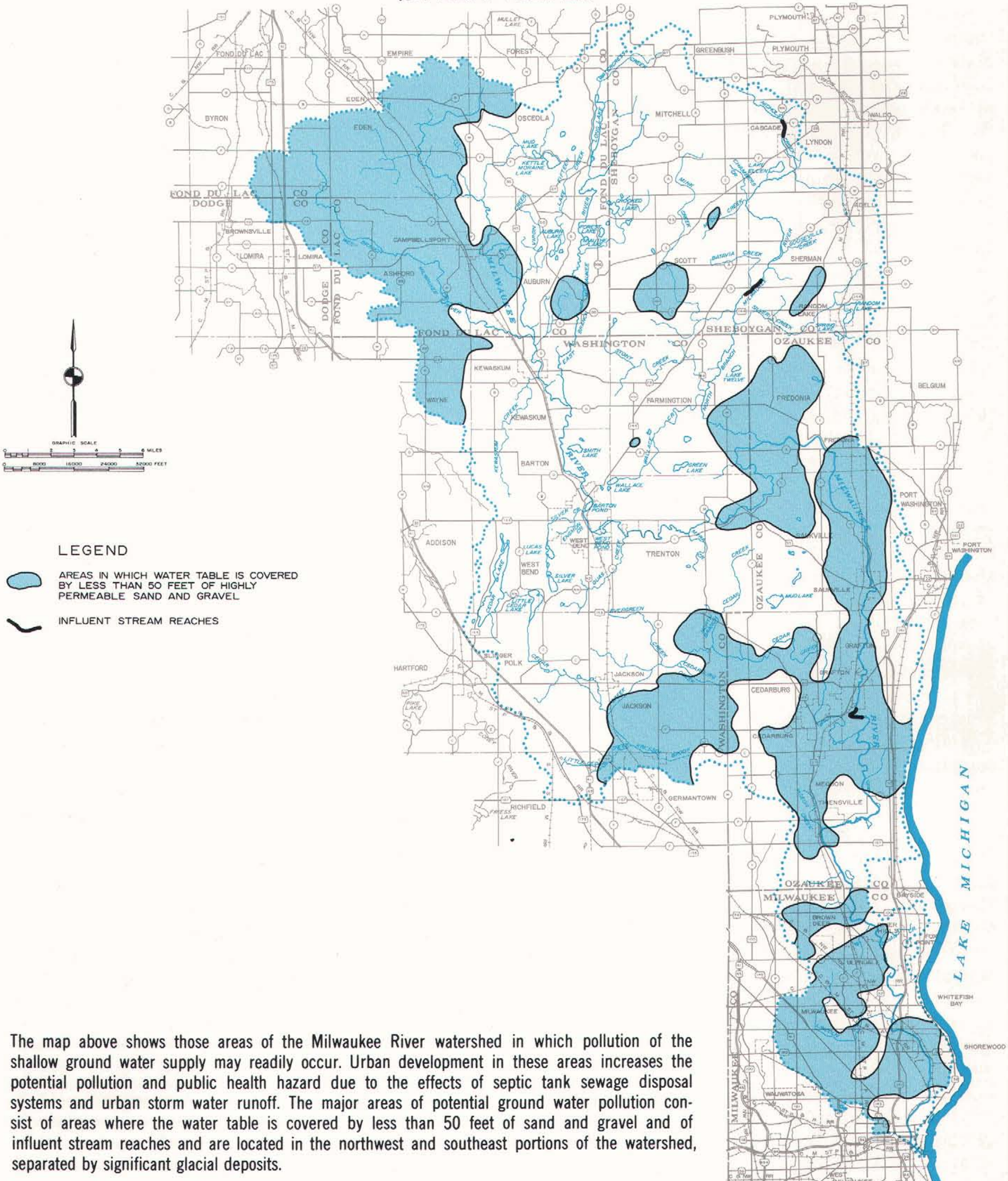
4. The soil is highly pervious and pollutants move readily through the soil.

5. The aquifer is creviced dolomite bedrock that extends to or near the land surface.

Sanitary surveys of private water supplies have not been conducted for any subdivision within the Milwaukee River watershed. Moreover, the Wisconsin Department of Natural Resources staff can recall only isolated cases of well-water pollution caused by human activities within the watershed and, in particular, only one serious case where nitrate concentrations exceeding 80 ppm were found due to the proximity of a well to a silo and barnyard. The corrective measures which can be taken to alleviate such a problem are to relocate the well away from the pollution source or to deepen the well beyond the area affected by the pollution source. As previously indicated, many

Map 54

POTENTIAL AREAS OF GROUND WATER POLLUTION IN THE MILWAUKEE RIVER WATERSHED (SHALLOW AQUIFER)



The map above shows those areas of the Milwaukee River watershed in which pollution of the shallow ground water supply may readily occur. Urban development in these areas increases the potential pollution and public health hazard due to the effects of septic tank sewage disposal systems and urban storm water runoff. The major areas of potential ground water pollution consist of areas where the water table is covered by less than 50 feet of sand and gravel and of influent stream reaches and are located in the northwest and southeast portions of the watershed, separated by significant glacial deposits.

Source: U.S. Geological Survey.

of the private wells within the lower watershed have extremely hard water supplies (see Tables 81 through 84).

Map 54 shows the areas of the Milwaukee River watershed covered by outwash sand and gravel soils and having a water table within 50 feet of the land surface. Ground water in these areas may be readily subject to pollution because the deposits transmit water readily. Water may move at a rate of up to 10 feet per hour through some of these highly permeable soils. Bacteria, virus, or other infectious agents can be quickly transported to drinking water supplies through such soils in a time interval so short that very few of the microorganisms would die off or be filtered out. Sanitary surveys have not been conducted in these areas, but it is known that water from similar deposits in Waukesha County is contaminated and must be disinfected before use.

Ground Water Pollution from Natural Sources

Saline ground water is a potential pollutant that occurs naturally within the sandstone aquifer and to a much lesser extent within the dolomite aquifer. Lateral movement of saline water undoubtedly occurs in these aquifers, particularly under the stress of pumping; but it is extremely slow and difficult to detect. Vertical movement of saline water is also very slow, but wells cased in both the dolomite and sandstone aquifers allow rapid vertical movement of saline ground water under certain hydraulic conditions.

Vertical movement of ground water between the dolomite and the sandstone aquifers through the confining stratum of the Maquoketa shale occurs as extremely slow seepage through the shale and its fracture openings and also through wells open to both aquifers. The hydraulic gradient and direction of ground water movement between these aquifers is downward from the dolomite into the sandstone. The downward gradient is maintained because the potentiometric surface of the combined dolomite aquifer and glacial deposits (see Map 33) is higher than the potentiometric surface of the sandstone aquifer (see Map 32). Water in the dolomite aquifer is generally less mineralized than water in the sandstone aquifer; and, as a result, no increased mineralization of the sandstone aquifer is anticipated. Heavy pumping of the dolomite aquifer, however, can reverse the hydraulic gradient between the aquifers and allow local upward movement of saline water from the sandstone aquifer. The probability of significant mineralization of the dolomite aquifer in this manner is small and can be reduced by sealing off wells where the sandstone aquifer contains highly saline water.

A stream or reach of a stream is influent with respect to ground water if it contributes water to the zone of saturation (see Figure 49). The upper surface of such a stream stands higher than the water table or other piezometric surface of the aquifer to which it contributes. An effluent stream receives water from the zone of saturation. Influent and effluent streams are sometimes simply called losing and gaining streams, respectively. A stream may, in certain parts, be influent; in others, effluent; and in still others, neither losing nor gaining because of impervious material in its bed.

Three reaches of perennial streams in the Milwaukee River are influent, as shown on Map 54. Influent streams may pollute adjacent ground water supplies if the influent water is polluted. The general direction of ground water movement from these streams can be determined by analyses of the piezometric surface (see Map 33). Heavily pumped wells located near streams may induce polluted surface water to move into the ground water supply and, eventually, into the wells.

SUMMARY

The natural hydrologic and geologic environment of the watershed has been, to date, a far more important determinant of ground water quality than have the effects of human activities within the watershed. This situation may be expected to continue with respect to the deep aquifer but not with respect to the shallow aquifer. Unless certain preventive measures are taken, local pollution of the shallow aquifer may be expected to become a serious problem within the watershed. The shallow aquifer, which constitutes the most important source of water available to meet small, highly dispersed demands, such as those generated by residential development not served by public water supply systems, is highly susceptible to man-made contamination from septic tank sewage disposal systems, urban storm drainage, land fills, and agricultural runoff. Once contaminated, the shallow aquifers are exceedingly difficult to reclaim for water supply. For this reason alone, any comprehensive watershed plan should contain provisions for the prevention of potential, and the abatement of existing, ground water pollution. Improperly located and constructed septic tank sewage disposal systems constitute a particularly serious existing and potential source of pollution of the shallow ground water supply.

If protected from pollution, the natural quality of the ground water from both the shallow and deep aquifers underlying the watershed is adequate to meet most domestic, municipal, and industrial water supply needs. The ground water of both the shallow and deep aquifers is generally good throughout the watershed but hard, containing high concentrations of calcium, magnesium, and sulfate, among other dissolved solids. The deep sandstone aquifer, however, contains saline water in localized areas of the eastern portion of the watershed which may migrate with increased pumpage of the aquifer and thereby contaminate other portions of the sandstone aquifer. Other important chemical constituents of ground water supply include iron, manganese, sodium, bicarbonate, chloride, fluoride, and nitrate. Physically, the ground water from both aquifers is generally clear and cool. Through the institution of good water management projects, as well as the institution of good pollution prevention and abatement programs, the use of this extremely important natural resource can be assured for future generations.

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Chapter XI

WATER USE AND SUPPLY

INTRODUCTION

Ground water is presently the principal source of domestic, municipal, agricultural, and industrial water supply in that part of the Milwaukee River watershed located above the Milwaukee County line. Below the Milwaukee County line, Lake Michigan is the principal source of water within the watershed for all of these uses. It is extremely important, therefore, that an understanding of the major existing and potential problems of both ground and surface water use and supply be developed as a basis for the preparation of a comprehensive plan for the physical development of the Milwaukee River watershed.

Although the major water use and supply problems within the Milwaukee River watershed are associated with urban development, the rural portions of the watershed have special water use and management problems associated with agricultural land use. Poor or improper drainage of surface floodwaters is a generally widespread and persistent problem in the rural portions of the watershed. Other rural water use and management problems are specifically related to special agricultural practices, such as irrigation. Any comprehensive watershed plan must consider all of these rural and urban water use and management problems, since they not only affect the hydraulic and pollution loadings on the river system but also the use of land and, hence, the overall pattern of development within the watershed.

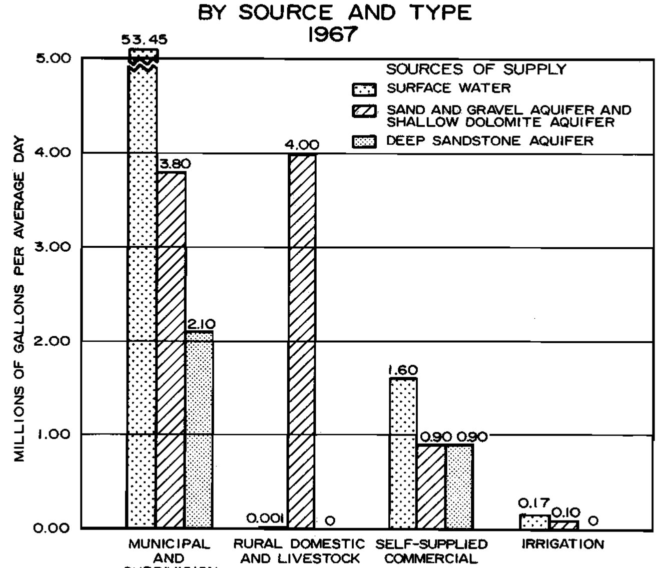
For convenience, as well as clarity, a discussion of only the quantitative aspects of water use and supply and of related water use and management problems within the watershed is presented in this chapter. A discussion of the qualitative aspects of water use and supply and of potential problems relating to the impairment of water quality, that is, of surface and ground water pollution, was presented in Chapters IX and X, respectively, of this volume.

TOTAL WATER USE

Approximately 24.4 billion gallons of ground and surface water were used in the Milwaukee River watershed during calendar year 1967 for all domestic, municipal, industrial, and agricultural purposes. This is equivalent to an average rate of use of 67 million gallons per day (mgd). Of this total use, an estimated 17 percent was supplied by ground water sources, while an estimated 83 percent was supplied by surface water sources—lakes, streams, and impoundments. About 89 percent of the water pumped in the basin during 1967, averaging about 60 mgd, was used for municipal purposes. The remaining 11 percent, averaging about 8 mgd, was used by self-supplied industrial, commercial, and domestic users and for irrigation. Water withdrawal by source and type of use within the watershed is shown graphically in Figure 50. The total quantity of water used in the basin averages about 123 gallons per capita per day, based upon the estimated 1967 pumpage rate of 67 mgd and an estimated 1967 resident watershed population of about 544,000 people.

Figure 50

WATER USE IN THE MILWAUKEE RIVER WATERSHED BY SOURCE AND TYPE 1967



Source: U.S. Geological Survey and SEWRPC.

Significantly, most of the water used in the watershed is ultimately discharged as waste water into streams and watercourses and thereby contributes to streamflow (see Table 50). In reference to Table 50, it should be noted that, although the per capita sewage flows generally exceed the per capita water use, not all of the water used may, in fact, be discharged to the sewer system. For example, water used for lawn sprinkling does not normally find its way into the sanitary sewer system. Any such losses, however, are usually more than offset by ground and storm water infiltration.

SURFACE WATER USE

Approximately 20.1 billion gallons of surface water were withdrawn from Lake Michigan and from the streams in the Milwaukee River watershed during calendar year 1967 for domestic, municipal, industrial, and agricultural purposes. This is equivalent to an average rate of use of 55 mgd. Almost all of this total, about 53 mgd, was pumped from Lake Michigan, with the remainder being obtained from inland lakes and streams throughout the watershed. The total average per capita amount of surface water use within the basin averages about 119 gallons per capita per day, about 15 percent less than the total average per capita amount of ground water use of 142 gallons per capita per day. The 1967 resident population of the Milwaukee River watershed utilizing surface water sources is estimated at about 461,000 persons, or 85 percent of the total watershed population, with almost all of these persons residing within the Milwaukee County portion of the watershed.

Municipal Surface Water Use

The greatest amount of surface water is used by the municipal public water supply utilities which serve almost all of the urban areas of the Milwaukee County portion of the watershed. In 1967 public water supply systems utilizing surface water as a source of supply served a total combined area of 52.23 square miles, or 7.5 percent of the total area of the watershed, and, as already noted, a total connected population of approximately 461,000 people, or 85 percent of the total population of the watershed. Two major publicly owned and operated water supply systems in the watershed utilize Lake Michigan as the source of supply. These are: the City of Milwaukee municipal water utility, which, within the watershed, serves the City of Milwaukee and the Villages of Brown Deer and Shorewood, and the North Shore water utility, which, within the watershed, serves the City of Glendale and the Villages of Fox Point and Whitefish Bay. These two municipal utilities together provided almost 19.5 billion gallons of water to residences and business establishments located within the Milwaukee County portion of the watershed during 1967. The present municipal surface water use for these communities is indicated in Table 86.

In 1967 the City of Milwaukee municipal water utility served a population within the watershed of about 428,000 people residing in a 43.32 square-mile service area in three different communities and was by far the largest public water supply system within the basin in terms of both area and population served and in terms of the quantity of surface water delivered for domestic, commercial, and industrial purposes. In 1967 within the City of Milwaukee, the municipal water utility served a population within the watershed of 400,300 persons living in a 36.86 square-mile area, or about 94 percent of the total population and 38 percent of the total service area of the City of Milwaukee municipal water utility. About 39 percent of the total annual pumpage of 43.3 bil-

TABLE 86

MUNICIPAL SURFACE WATER USE
IN THE MILWAUKEE RIVER WATERSHED- 1967

MUNICIPALITY	PRESENT WATERSHED AREA SERVED (SQUARE MILES)	TOTAL WATER PUMPED (GALLONS)	RESIDENTIAL CONSUMPTION (GALLONS)	COMMERCIAL CONSUMPTION (GALLONS)	INDUSTRIAL CONSUMPTION (GALLONS)	PRESENT AVERAGE CONSUMPTION (GALLONS PER DAY)	MAXIMUM CONSUMPTION (GALLONS PER DAY)	ESTIMATED POPULATION PRESENTLY SERVED	AVERAGE PER CAPITA WATER USE (GALLONS PER DAY)	AVERAGE PER CAPITA RESIDENTIAL WATER USE (GALLONS PER DAY)
BROWN DEER....	4.37	342,000,000	246,650,000	32,593,000	62,757,000	936,986	1,998,000	11,600	81	58
FOX POINT.....	1.21	142,000,000	137,726,000	4,274,000	--	389,041	951,000	3,800	102	99
GLENDALE......	5.85	935,000,000	387,744,000	133,612,000	413,644,000	2,561,643	4,700,000	12,800	200	83
MILWAUKEE.....	34.96	16,900,000,000	6,219,200,000	2,856,100,000	7,824,700,000	46,301,369	86,000,000	400,300	116	43
SHOREWOOD.....	1.45	539,000,000	278,555,000	260,445,000	--	1,476,712	3,230,000	15,650	94	49
WHITEFISH BAY.	1.85	650,000,000	514,475,000	135,525,000	--	1,780,821	4,278,000	17,010	105	83
WATERSHED TOTAL AND AVERAGE	49.69	19,508,000,000	7,784,350,000	3,422,549,000	8,301,101,000	53,446,572	--	461,160	116	46

SOURCE- SEWRPC.

lion gallons (16.9 billion gallons) was delivered in 1967 to the watershed portion of the total utility service area. The entire area—4.37 square miles—and population—11,600 persons—of the Village of Brown Deer is served by the City of Milwaukee municipal water utility and lies within the watershed. In 1967, 342 million gallons of water were delivered to this service area. Within the Village of Shorewood, which is also served by the City of Milwaukee municipal water utility, a population of about 15,650 persons, or 94 percent of the total population of the Village, resided within the 1.45 square-mile area of the Village lying within the watershed, which area constituted 91 percent of the total area of the Village. About 92 percent of the total annual pumpage of 588 million gallons (539 million gallons) delivered to the Village of Shorewood in 1967 was delivered to the watershed portion of the total village service area.

The other major water utility operating in the Milwaukee County portion of the watershed is the North Shore municipal water utility which, as already noted, provides water to the City of Glendale and to the Villages of Fox Point and Whitefish Bay. These three communities in 1957 formed a cooperative contract commission under the provisions of Section 66.30 of the Wisconsin Statutes for the purpose of providing treated water to the three communities. The utility in 1967 served a total population within the watershed of 33,610 persons residing in an 8.91 square-mile area, or about 87 percent of the total population and 81 percent of the total area served by the North Shore municipal water utility. About 85 percent of the total annual pumpage of 2 billion gallons (1.7 billion gallons) in 1967 was delivered to the watershed portion of the total utility service area. Approximately 3,800 persons residing in a 1.21 square-mile area were served by the North Shore municipal water utility in the watershed portion of the Village of Fox Point. This constitutes about 48 percent of the total population and 42 percent of the total area of the Village of Fox Point. About 42 percent of the total annual pumpage of 337 million gallons (142 million gallons) was delivered in 1967 to the watershed portion of the Village. Approximately 12,800 persons residing in a 5.85 square-mile area were served by the North Shore municipal water utility in the watershed portion of the City of Glendale. This constitutes 95 percent of the total population and 98 percent of the total area of the City of Glendale. About 99 percent of the total annual pumpage of 948 million gallons (935 million gallons) was delivered in 1967 to the watershed portion of the City. Approximately 15,650 persons residing in a 1.85 square-mile area were also served by the North Shore municipal water utility in the watershed portion of the Village of Whitefish Bay. This constitutes about 90 percent of the total population and 87 percent of the total area of the Village of Whitefish Bay. About 88 percent of the total annual pumpage of 745 million gallons (650 million gallons) was delivered in 1967 to the watershed portion of the Village.

Commercial and Industrial Use

Commercial and industrial firms in the watershed used approximately 11.7 billion gallons of municipally supplied surface water in 1967. This is equivalent to an average rate of use of 32 mgd. The uses of this water were primarily for cooling, condensing, air conditioning, manufacturing processes, sanitation, and fire protection. Commercial and industrial firms located within the watershed and within the City of Milwaukee alone used 10.7 billion gallons in 1967, or 91 percent of the total municipally supplied surface water for commercial and industrial use. Commercial firms in the watershed used 3.4 billion gallons of surface water in 1967, or an equivalent average rate of use of 9.3 mgd, while industrial firms in the watershed used 8.3 billion gallons of surface water in 1967, or an equivalent average rate of use of 22.7 mgd. The 11.7 billion gallons of surface water used for commerce and industry represents about 60 percent of the total surface water used in the watershed in 1967. The other 40 percent, or 7.8 billion gallons, was used for residential purposes. A graphic summary of water use within the Milwaukee River watershed portion of the City of Milwaukee from 1940 to 1967 is shown in Figure 51.

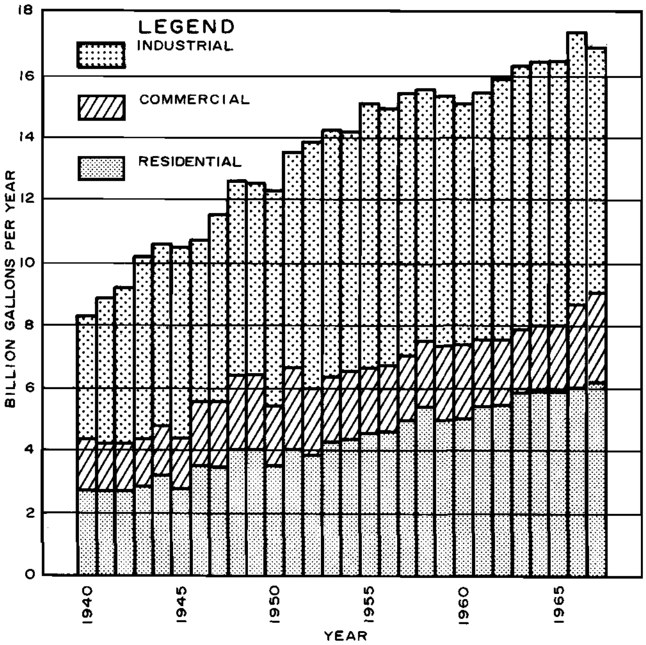
Four firms—Line Material Industries in the City of West Bend; and A. F. Gallun & Sons Corporation; Pfister & Vogel Tanning Company, Inc.; and St. Regis Paper Company, all in the City of Milwaukee—were found to be withdrawing water from the Milwaukee River for self-supplied industrial use. The total pumpage of river water by these four firms in 1967 was approximately 587 million gallons, or 1.6 mgd.

GROUND WATER USE

Approximately 4.3 billion gallons of ground water were withdrawn from the aquifers underlying the Milwaukee River watershed during calendar year 1967 for domestic, municipal, industrial, and

Figure 51

HISTORICAL TRENDS IN WATER USE
CITY OF MILWAUKEE[a]
1940 – 1967



[a] INCLUDES ONLY THAT PORTION OF THE CITY OF MILWAUKEE LYING WITHIN THE MILWAUKEE RIVER WATERSHED.

Source: SEWRPC.

agricultural purposes. This is equivalent to an average rate of use of 11.8 million gallons per day (mgd). Of this total, about 65 percent, or 7.7 mgd, was pumped from the shallow dolomite aquifer. About 26 percent, or 3.1 mgd, was pumped from the deep sandstone aquifer; and about 9 percent, or 1.0 mgd, was pumped from the sand and gravel aquifer. Table 87 summarizes the 1967 ground water pumpage in the watershed by community. The total quantity of ground water pumped in the basin averages about 142 gallons per capita per day, based upon the estimated 1967 withdrawal rate of 11.8 mgd at an estimated 1967 ground water user population of 82,630, or 15 percent of the watershed population. All but 3,380 of these people live outside Milwaukee County, which, with the exceptions of the Villages of Bayside and River Hills, is served chiefly by surface water from Lake Michigan.

Municipal Ground Water Use

Seven villages and two cities within the watershed but outside Milwaukee County have municipal water systems. These systems delivered a total of 2.1 billion gallons of ground water to approximately 34,020 persons in 1967. The location of the wells supplying these municipal systems and the aquifers used are shown on Map 55. Water use by county and by aquifer is summarized in Table 88.

Private water supply systems serving isolated residential subdivisions served a combined area of 1.33 square miles and a total population of approximately 2,400 people within the watershed in 1967, or less than 1 percent of the watershed area and about 0.4 percent of the watershed population. These private water supply systems are listed in Table 89, and the geographic locations of the systems are shown on Map 11. The amount of water pumped for the subdivisions is not known, as no accurate records of water use are kept by the small utilities. The average per capita water use in the areas supplied by these systems was estimated at 80 gallons per day and the total pumpage in 1967, at 0.19 mgd, or 70.5 million gallons per year. All water used by the private subdivision water supply systems was pumped from ground water sources.

TABLE 87

MUNICIPAL GROUND WATER USE IN THE MILWAUKEE RIVER WATERSHED- 1967

MUNICIPALITY	PRESENT WATERSHED AREA SERVED (SQUARE MILES)	TOTAL WATER PUMPED (GALLONS)	RESIDENTIAL CONSUMPTION (GALLONS)	COMMERCIAL CONSUMPTION (GALLONS)	INDUSTRIAL CONSUMPTION (GALLONS)	PRESENT AVERAGE CONSUMPTION (GALLONS PER DAY)	MAXIMUM CONSUMPTION (GALLONS PER DAY)[a]	ESTIMATED POPULATION PRESENTLY SERVED	AVERAGE PER CAPITA WATER USE (GALLONS PER DAY)	AVERAGE PER CAPITA RESIDENTIAL WATER USE (GALLONS PER DAY)
VILLAGE OF ADELL.........	0.13	11,316,000	3,785,000	1,754,000	2,916	31,000	154,000	380	82	36
VILLAGE OF CAMPBELLSPORT.	0.46	81,833,000	--[b]	--[b]	--[b]	224,000	417,000	1,590	141	--[b]
CITY OF CEDARBURG........	2.20	512,603,000	120,874,000	33,118,000	269,897	1,404,000	2,210,000	7,000	200	47
VILLAGE OF FREDONIA......	0.49	34,762,000	15,779,000	2,239,000	3,943	95,000	245,000	900	106	48
VILLAGE OF GRAFTON.......	1.70	251,962,000	78,450,000	16,537,000	100,196	690,000	1,341,000	5,100	135	42
VILLAGE OF KEWASKUM......	0.58	189,853,000	24,461,000	9,771,000	99,946	520,000	2,286,000	1,800	288	37
VILLAGE OF RANDOM LAKE...	0.66	101,538,000	--[b]	--[b]	--[b]	278,000	771,000	950	293	--[b]
VILLAGE OF SAUKVILLE.....	0.44	99,857,000	13,502,000	3,486,000	71,272	274,000	636,000	1,200	228	31
CITY OF WEST BEND........	4.09	802,424,000	290,357,000	110,430,000	280,960	2,198,000	4,300,000	15,100	146	53
WATERSHED TOTAL AND AVERAGE	10.75	2,086,150,000	--[b]	--[b]	--[b]	635,000	--	34,020	168	--[b]

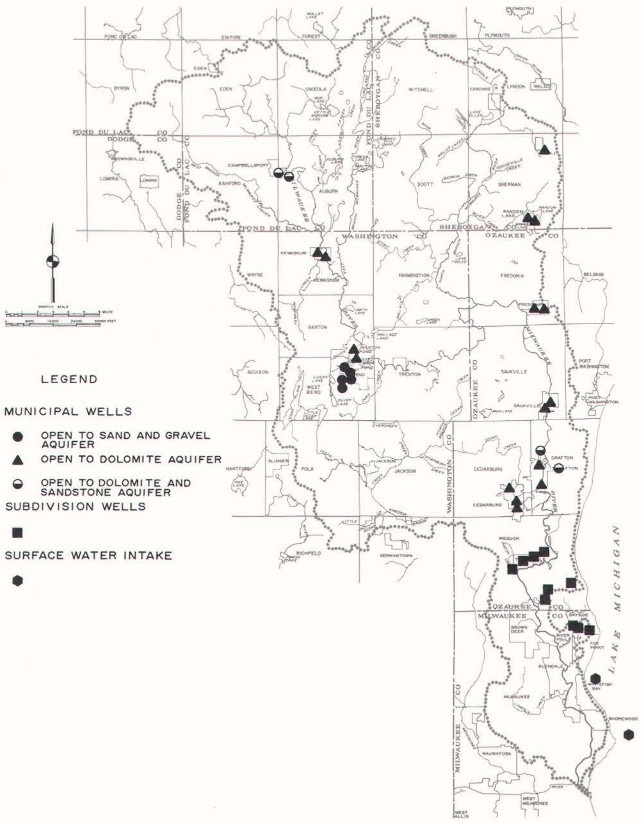
[a] SINCE SUPPLY SYSTEM WAS ESTABLISHED.

[b] ACCURATE ESTIMATE NOT AVAILABLE.

SOURCE- U.S. GEOLOGICAL SURVEY AND WISCONSIN PUBLIC SERVICE COMMISSION.

Map 55

MUNICIPAL WELLS, SUBDIVISION WELLS, AND SURFACE WATER INTAKES IN THE MILWAUKEE RIVER WATERSHED
1967



In 1967 there were 25 municipal wells, 10 subdivision wells, and 2 surface water intakes in the Milwaukee River watershed which supply water to systems serving approximately 497,000 persons, or 91 percent of the watershed population. These 37 water sources pumped approximately 60 million gallons per day, or 88 percent of all the water pumped in the Milwaukee River watershed. Five of the municipal wells are in the sand and gravel aquifer, 16 are in the dolomite aquifer, and 4 are in the dolomite and sandstone aquifer. The two surface water intakes draw their water from Lake Michigan.

Source: U.S. Geological Survey and SEWRPC.

Self-Supplied Commercial and Industrial Use

Wells owned and operated by industrial and commercial firms in the watershed pumped about 0.67 billion gallons in 1967. This is equivalent to an average rate of use of 1.8 mgd. The uses of this water were for boiler feed, cooling, condensing, air conditioning, manufacturing processes, sanitation, and fire protection. Self-supplied industrial pumpage in the watershed is summarized by county and aquifer in Table 90. Industrial water use requirements in Fond du Lac and Ozaukee Counties were met by municipal supplies. There was no industrial pumpage in the Dodge County portion of the watershed in 1967.

TABLE 88

GROUND WATER PUMPAGE IN THE MILWAUKEE RIVER WATERSHED BY COUNTY BY AQUIFER- 1967 (THOUSANDS OF GALLONS)

COUNTY	TOTAL PUMPAGE	AQUIFER: SAND AND GRAVEL	AQUIFER: DOLOMITE[a]	AQUIFER: SANDSTONE[b]
DODGE......	6,643	--	6,643	--
FOND DU LAC	236,890	--	155,057	81,833
MILWAUKEE..	512,377	--	177,551	334,826
OZAUKEE....	1,478,370	--	792,279	686,091
SHEBOYGAN..	459,726	--	459,726	--
WASHINGTON.	1,488,144	385,357	1,102,787	--
TOTAL	4,182,150	385,357	2,694,043	1,102,750

[a] A SMALL QUANTITY OF WATER OBTAINED FROM THE SAND AND GRAVEL AQUIFER THROUGH INDIVIDUAL DOMESTIC SUPPLY WELLS IS INCLUDED.

[b] INCLUDES SOME WATER FROM THE DOLOMITE AQUIFER BECAUSE MANY DEEP WELLS ARE UNCASED IN BOTH AQUIFERS.

SOURCE- U. S. GEOLOGICAL SURVEY.

The major use of ground water by industry and commerce within the watershed is for cooling, boiler feed, sanitation, and drinking purposes. About one-half of the self-supplied commercial and industrial ground water use is from the sandstone aquifer, a supply of high reliability and dependable quality; and the other half is from the dolomite aquifer. The high cost of drilling and operating deep wells is probably the major reason for the relatively small ground water pumpage within the watershed for self-supplied commercial and industrial use. Industrial and commercial establishments apparently prefer to purchase water directly from the municipal water utilities, which can provide a more dependable and possibly better quality supply through a network of wells and require little capital investment by the industries. For these reasons, future commercial and industrial water use in the Milwaukee River watershed may be expected to continue to rely primarily on municipal water systems as the principal source of supply. Industrial water use is shown by county, by aquifer, and by major industrial water user in Table 91.

Self-Supplied Domestic and Agricultural Use

In 1967 private wells provided water to approximately 48,610 persons, or about 9 percent of the total population of the watershed residing in the 631.49 square miles, or 91 percent of the watershed not served by public water supply systems (see Map 11). This domestic water use is summarized in Figure 50. The installation of modern plumbing facilities and appliances in rural homes, coupled with the increasing water requirements of agriculture, has resulted in significant

TABLE 89

PRESENT GROUND WATER USE BY SUBDIVISIONS HAVING A COOPERATIVE WATER SUPPLY IN THE MILWAUKEE RIVER WATERSHED- 1967

SUBDIVISION	CIVIL DIVISION	ESTIMATED POPULATION SERVED[a]	ESTIMATED TOTAL WATER USED[b] (GALLONS)	PRESENT AVERAGE CONSUMPTION (GALLONS PER DAY)	PRESENT AREA SERVED (SQUARE MILES)
NORTHWAY..............	VILLAGE OF BAYSIDE	104	3,036,800	8,320	0.07
PELHAM HEATH..........	VILLAGE OF BAYSIDE	440	12,848,000	35,200	0.13
VISTA DEL MAR.........	VILLAGE OF BAYSIDE	107	3,124,400	8,560	0.02
BONNIE LYNN HIGHLANDS.	CITY OF MEQUON	51	1,489,200	4,080	0.11
CENTURY ESTATES.......	VILLAGE OF THIENSVILLE	498	14,541,600	39,840	0.16
LAC DU COURS..........	CITY OF MEQUON	187	5,460,400	14,960	0.29
LAUREL ACRES..........	VILLAGE OF THIENSVILLE	627	18,308,400	50,160	0.14
NORTH SHORE ESTATES...	CITY OF MEQUON	43	1,255,600	3,440	0.20
VILLAGE HEIGHTS.......	VILLAGE OF THIENSVILLE	263	7,679,600	21,040	0.12
VILLE DU PARC.........	CITY OF MEQUON	94	2,744,800	7,520	0.09
TOTAL		2,414	70,488,800	193,120	1.33

[a]BASED ON HOUSE COUNTS MADE ON 1"=400' 1967 AERIAL PHOTOGRAPHS AND ON AN ASSUMED AVERAGE HOUSEHOLD POPULATION OF 3.8 PERSONS.

[b]BASED ON AN ASSUMED CONSUMPTION RATE OF 80 GALLONS PER CAPITA PER DAY.

SOURCE- WISCONSIN DEPARTMENT OF NATURAL RESOURCES AND SEWRPC.

TABLE 90

SELF-SUPPLIED INDUSTRIAL AND COMMERCIAL GROUND WATER USE IN THE MILWAUKEE RIVER WATERSHED-1967 (THOUSANDS OF GALLONS)

COUNTY	TOTAL PUMPAGE	AQUIFER[a] DOLOMITE	SANDSTONE
DODGE......	--	--	--
FOND DU LAC	--	--	--
MILWAUKEE..	450,520	115,694	334,826
OZAUKEE....	260	260	--
SHEBOYGAN..	187,000	187,000	--
WASHINGTON.	33,493	33,493	--
TOTAL	671,273	336,447	334,826

[a]NO SIGNIFICANT QUANTITY OF GROUND WATER WAS WITHDRAWN FROM THE SAND AND GRAVEL AQUIFER BY INDUSTRIAL AND COMMERCIAL WATER USERS.

SOURCE- U.S. GEOLOGICAL SURVEY.

increases in private rural well-water use in recent years. In 1967 private wells provided about 1.05 billion gallons of water, or the equivalent of 2.87 mgd to suburban and rural homes in the watershed. Nearly all of this water was supplied by wells tapping the shallow dolomite aquifer, with a small amount being supplied by wells tapping the sand and gravel aquifer. In addition, an estimated 0.41 billion gallons of water, or 1.11mgd, were pumped within the watershed for livestock watering in 1967 (see Table 92).

The amount of water pumped for isolated rural homes and for suburban homes not served by common subdivision water supply systems is not known, as no accurate records of water use are kept for such uses. This water use was estimated by assuming a 50 gallon per capita per day use throughout all of the watershed except the Milwaukee County and southern Ozaukee County portions of the watershed, where 80 gallons per capita per day were used. The total pumpage for all such self-supplied domestic users throughout the watershed in 1967 was estimated at about 0.007 mgd, or 2.8 million gallons per year.

Irrigation

Excluding household lawn watering, approximately 35 million gallons of ground water were used for irrigation within the watershed during 1967. Most of this water was used by golf courses, cemetaries, and nurseries between the months of May and September. Surface water use for lawn watering was estimated by assuming that about one-third of the residential property owners along the main stem of the Milwaukee River and its major tributaries tap the surface streams for lawn irrigation, pumping at an average rate of 5 gallons per minute for one hour per day during 60 days of the year. Thus, the total surface water use for lawn watering within the watershed was estimated at 62 million gallons per year.

Irrigation for agricultural purposes, although still a relatively minor use of water in the watershed, is becoming increasingly important. Sod, vegetables, and fruit are the leading crops irrigated; and, although such irrigation is not extensively practiced within the Milwaukee River watershed, the number of acres under irrigation has shown an increase in recent years. Agricultural irrigation in southeastern Wisconsin is applied during the

TABLE 91

SELF-SUPPLIED INDUSTRIAL AND COMMERCIAL GROUND WATER USERS IN THE MILWAUKEE RIVER WATERSHED 1967

COUNTY	INDUSTRY	WATER USE (THOUSANDS OF GALLONS)
MILWAUKEE	A. F. GALLUN & SONS CORPORATION	1,179
	GOLDEN GUERNSEY DAIRY CO-OPERATIVE	30,000[a]
	MILWAUKEE GEAR COMPANY	5,000[a]
	JOSEPH SCHLITZ BREWING COMPANY	242,826
	SQUARE D COMPANY	43,961
	ALBERT TROSTEL & SONS COMPANY	92,000
	WEISEL & COMPANY	35,554
OZAUKEE	KREMERS-URBAN INTERNATIONAL CORPORATION	260
SHEBOYGAN	FOREMOST DAIRIES INCORPORATED	180,000[a]
	THE KRIER PRESERVING COMPANY	7,000[a]
WASHINGTON	BADGER LABORATORIES, INCORPORATED	2,600[a]
	LIBBY, MC NEILL AND LIBBY	30,000[a]
	STOLPER PLASTICS, INCORPORATED	893
TOTAL		671,273

[a] ESTIMATES BASED ON PUMPAGE RATES AND ANNUAL OPERATING TIME.

SOURCE- U.S. GEOLOGICAL SURVEY.

TABLE 92

GROUND WATER PUMPAGE FOR DOMESTIC AND LIVESTOCK USES IN THE MILWAUKEE RIVER WATERSHED-1967

COUNTY	TOTAL PUMPAGE (BILLIONS OF GALLONS)	DAILY PUMPAGE (MGD)	PERCENT OF TOTAL PUMPED
DODGE......	0.007	0.019	0.5
FOND DU LAC	0.155	0.425	10.6
MILWAUKEE..	0.117	0.320	8.1
OZAUKEE....	0.564	1.545	38.7
SHEBOYGAN..	0.160	0.438	11.0
WASHINGTON.	0.453	1.241	31.1
TOTAL	1.456	3.980	100.0

SOURCE- U.S. GEOLOGICAL SURVEY.

growing season primarily to supplement rainfall and to provide protection against frost damage. Supplemental irrigation is also practiced to control wind erosion, to increase crop yields, to provide earlier maturity of crops, and to produce crops of a higher quality. The feasibility of establishing agricultural irrigation systems is determined by economics, legal considerations associated with the right to use either surface or ground water for irrigation, soil characteristics, topography, and the quantity and quality of water available for irrigation.

Not all soils within the watershed are irrigable. Some soils, because of their slope, permeability, water-holding capacity, or impaired drainage characteristics, cannot be economically irrigated. Information obtained from detailed operational soils maps of the Milwaukee River watershed indicates that approximately 129,000 acres, or about 34 percent of the nonurban area of the watershed, are covered by soils having characteristics that make them potentially irrigable. In addition, many poorly drained soils could be irrigated under proper water management practices that included agricultural drainage improvements. A listing of all of the soil types within the watershed that are potentially irrigable can be found in SEWRPC Planning Report No. 8, Soils of Southeastern Wisconsin, June 1966.

The water used for irrigation must come from either surface water or ground water supplies. Potential surface water supplies are streamflow, lake storage, and on-stream or off-stream artificial storage reservoirs. Generally, streamflow is the cheapest source of irrigation water; but it is the least dependable, and the right to its use by riparians may be denied if the use conflicts with public interests. Such a water use conflict is apt to occur since peak irrigation demands occur during hot, dry weather and thus conflict with recreational water demand and waste dilution needs. Natural lakes are also a potential source of irrigation water. The withdrawal of water from this source, however, is also subject to severe restrictions due to conflicting uses. The feasibility of constructing on-stream reservoirs is limited in most areas of the watershed by topography. Small-scale off-stream reservoirs may provide some potential storage, but most future demands for irrigation water will probably have to be supplied by ground water withdrawn from the shallow aquifer underlying the watershed.

No known problems exist in the quality of surface or ground water supplies that would preclude use for agricultural irrigation. Ground water, however, has the advantage of being free from weed seeds and debris, a particularly important consideration in sprinkler irrigation. Although the application of irrigation water may be made by sprinkler, surface, or subsurface irrigation systems, the surface or subsurface methods of application are not presently being used in the watershed. An estimated 2,000 acres, or about 0.5 percent of the total area of the watershed, however, are presently under sprinkler system irrigation.[1] A forecast of the number of acres that may be expected to be under irrigation within the watershed by 1990 is difficult to make without detailed economic analyses. If the present rate of increase in agricultural irrigation is continued, however, the number of acres under irrigation by 1990 could be five times the present acreage.[2]

The total volume of irrigation water applied per acre during any one year will vary with the total amount of precipitation, the distribution of the precipitation, and the type of crops being irrigated. In southeastern Wisconsin four to six inches of irrigation water are applied to most crops in an average year. This is equivalent to a demand of approximately 136,000 gallons per acre per year and exceeds the average annual recharge of the shallow ground water aquifer, which is estimated to be about two inches, or 54,020 gallons per acre per year.

Drainage

No permanent well installations have been constructed specifically for draining or dewatering land. However, drainage ditches and tiled fields locally drain some ground water from fields and wetlands. The amount of ground water drained in this manner cannot be readily determined but may be significant. Individual construction projects sometimes require temporary local dewatering of saturated foundation soils, but the quantity pumped for this purpose is not significant.

Agricultural land drainage in a semi-humid region, such as southeastern Wisconsin, may be defined as the removal of free water, both from the land surface and from the soil of the root zone of plants. In modern farming the term is understood to include the control of the elevation of the ground water table within the root zone so as to provide the best results in the production of crops. The purpose of drainage is to remove all free water from the surface of cropped fields and from the root zone as quickly as practicable after it accumulates. This is necessary because, if free water rises around crop plant roots and stands for very long periods of time, it will seriously interfere with the root growth functions and quickly injure and often kill the plants. Agricultural drainage of wet soils usually improves the productivity of the soils. This is accomplished through improved soil bacterial action, improved soil ventilation, and increased plant root zone area, all of which together allow the soil to warm more quickly. Poorly drained land, moreover, does not permit proper timing of tillage operations and can hamper harvest operations, resulting in lower crop yields. In irrigated areas subsurface drainage is frequently needed for relief of artesian pressure, interception of seepage, and removal of alkali conditions from the root zone.

Visual evidences of inadequate drainage are surface wetness, high water table, weed growth, dark soil color, and crop stands of irregular color and growth. The factors causing this situation relate to the site and can be grouped into three generally recognized categories which may exist separately or in various combinations:

---

[1] *The acreage under sprinkler irrigation was estimated by U. S. Soil Conservation Service Work Unit Conservationists as the maximum number of acres that could be so irrigated with the existing capital investment in irrigation equipment. The actual number of acres irrigated in any one year would probably be somewhat less than this amount.*

[2] *This value was established by extrapolating to 1990 the trends in the amount of land irrigated in southeastern Wisconsin as these trends were indicated by data published in the U. S. Census of Agriculture for the years 1954, 1959, and 1964.*

1. Lack of a ravine, valley, or other surface depression to serve as a natural open-drainage outlet. Sites without such drainage outlets are particularly common in glaciated areas where geologically young drainage systems are still in the process of development.

2. Lack of sufficient land slope to establish and maintain a free flow of water to an open outlet. Areas with flat slopes are found in the irregular and pitted surfaces of glaciated land, above constrictions and natural barriers of entrenched valley floodplains, or above dams.

3. Insufficient permeability of the soil to permit ready escape to the ground water aquifer of rainfall and runoff trapped in innumerable surface depressions or in the soil profile into which it has soaked or seeped. Many soils have a heavy subsoil, rock formation, or compacted (hardpan) layers below the ground surface but within the normal root zone of many useful plants.

Impermeable subsurface barriers and lack of surface ridges often cause local concentrations of water in sufficient amounts to aggravate drainage problems resulting from other factors.

Optimum agricultural water management, particularly related to the production of truck crops, would include both drainage to remove free water from the root zone and a timely application of water by irrigation to maintain the best possible water condition for maximum crop production. Such agricultural water management systems are being utilized in several areas of the watershed.

Farm drainage districts have been organized within the Milwaukee River watershed to provide landowners and operators with a legal means to accomplish satisfactory drainage. Eight such drainage districts, covering a combined total area of 30 square miles, have been organized within the watershed; but only one—the Jackson-Germantown Drainage District in the Towns of Germantown and Jackson and in the Village of Germantown in Washington County—covering an area of 11 square miles, remains active under the present state law (Chapter 88 of the 1965 Wisconsin Statutes). In addition to the legally constituted drainage districts, other groups of farmowners and operators have accomplished drainage improvements through group enterprise ventures; and at least four such group ventures presently exist within the watershed. Individual farmers have also installed drainage improvements on individual farmsteads, but no public records of either such group or individual improvements exist. Map 3 indicates the location of the legally established farm drainage districts and of certain other relatively large areas within which known agricultural drainage improvements have been made.

Detailed operational soils maps prepared by the U. S. Department of Agriculture, Soil Conservation Service, in cooperation with the Commission, indicate that approximately 124,400 acres, or 28 percent of the watershed, are covered by soils with restricted natural drainage that could be improved for agricultural use by implementing good drainage practices. U. S. Soil Conservation Service records indicate that drainage improvements, tile systems, and surface drains have been installed on approximately 13,200 acres in the watershed.[3] Table 93 lists the extent of soils with restricted natural drainage that could be expected to respond favorably to drainage and the acreage of drainage improvement in the watershed by county.

The installation of agricultural drainage improvements in areas that are not now adequately drained may be expected to enhance the agricultural economic base, as well as to improve the general economic situation within the watershed. Improving drainage on lowlands presently in agricultural use to improve yields generally helps to remove the need to farm steeper areas that are

[3] *This figure does not include 8,100 acres of agricultural land which have been improved for drainage by main channel improvements and areas within drainage districts which are not actually artificially drained.*

TABLE 93

MILWAUKEE RIVER WATERSHED
WET SOILS 1967

COUNTY	WATERSHED AREA (ACRES)	WET SOIL AREA (ACRES)	INSTALLED DRAINAGE IMPROVEMENTS (ACRES)
DODGE......	2,982	1,000	--
FOND DU LAC	87,149	26,500	600
MILWAUKEE..	36,461	12,400	--
OZAUKEE....	96,346	22,700	3,000
SHEBOYGAN..	78,547	26,200	500
WASHINGTON.	142,566	35,600	9,100
TOTAL	444,051	124,400	13,200

SOURCE- U.S. SOIL CONSERVATION SERVICE.

now intensively cropped and, therefore, serves to reduce soil erosion, sedimentation, and stream deterioration. It is important to note, however, that wetlands, when drained or filled, release relatively large amounts of bound nutrients, particularly nitrogen. Also, when used for agriculture, as much as two-thirds of the phosphorus applied in fertilizers to the drained wetlands may leach into adjacent surface waters. Careful monitoring of changing land use patterns within the watershed will be necessary to assure continued recognition of the need for both prime natural wildlife habitat areas and agricultural use areas, since both of these rural types of land uses within the watershed are subject to rapid conversion to urban uses. Sound agricultural land use can contribute significantly to the scenic beauty of the landscape and enhance wildlife habitat, fishery, and other needed recreational use opportunities for use by residents of the watershed and of the Region.

HISTORIC TRENDS IN WATER USE

An analysis of historic trends in water use is a prerequisite to the preparation of forecasts of probable future water use within the watershed. Unfortunately, adequate records have not been kept by all water users within the watershed; and, therefore, only estimates of past water use can be derived from the available data. Reliable records of municipal water pumpage are available from 1940 to the present, although the establishment of some of the municipal utilities dates back to before the turn of the century. Only estimates are available for all other pumpages. Limited pumpage records exist for self-supplied commercial and industrial users and for private domestic or agricultural water users. There are no records of water used for irrigation purposes. It should be noted, however, that, taken together, all nonmunicipal water uses were estimated to be less than 10 percent of the total pumpage in 1967 within the watershed. Therefore, only municipal pumpages from the year 1940 to the present have been tabulated and utilized in preparing forecast water use.

Population growth, increased industrial production, and a rising standard of living have caused a significant increase in the per capita use of water and of total pumpage within the watershed. The increased total and per capita use are summarized in Table 94 by municipal utility for the period 1940 through 1967. Figure 52 shows the change in total annual municipal pumpage within

TABLE 94

HISTORIC MUNICIPAL WATER USE IN THE MILWAUKEE RIVER WATERSHED- 1940-1967

	1940			1950			1960			1967			
MUNICIPALITY	WATER CONSUMED (MGD)	ESTIMATED POPULATION SERVED	AVERAGE PER CAPITA USE (GPD)	WATER CONSUMED (MGD)	ESTIMATED POPULATION SERVED	AVERAGE PER CAPITA USE (GPD)	WATER CONSUMED (MGD)	ESTIMATED POPULATION SERVED	AVERAGE PER CAPITA USE (GPD)	WATER CONSUMED (MGD)	ESTIMATED POPULATION SERVED	AVERAGE PER CAPITA USE (PGD)	CONSUMPTION PERCENT INCREASE (1940-1967)
GROUND WATER													
VILLAGE OF ADELL..........	--[a]	--	--	--[a]	--	--	--[a]	--	--	0.031	380	82	--[b]
VILLAGE OF BROWN DEER....	--[a]	--	--	--[a]	--	--	0.399	11,280	35	--[c]	--	--	--
VILLAGE OF CAMPBELLSPORT.	0.067	1,094	61	0.096	1,254	76	0.168	1,472	140	0.244	1,590	153	264
CITY OF CEDARBURG........	0.185	2,245	83	0.342	2,810	121	0.795	5,191	153	1.404	7,000	200	659
VILLAGE OF FREDONIA......	--[a]	--	--	0.027	471	57	0.058	710	80	0.095	900	106	252[d]
VILLAGE OF GRAFTON.......	0.088	1,150	77	0.177	1,489	119	0.531	3,748	142	0.690	5,100	135	684
VILLAGE OF KEWASKUM......	0.091	880	104	0.235	1,183	199	0.443	1,572	282	0.520	1,800	288	471
VILLAGE OF RANDOM LAKE...	0.033	613	54	0.046	679	67	0.099	858	115	0.278	950	293	742
VILLAGE OF SAUKVILLE.....	--[a]	--	--	0.023	699	33	0.109	1,038	105	0.274	1,200	228	1,091[d]
CITY OF WEST BEND........	0.401	6,352	74	0.799	7,888	101	1.483	11,538	129	2.198	15,100	146	448
SUBTOTAL	0.865	12,334	76	1.745	16,473	97	4.085	37,407	109	5.734	34,020	169	563
SURFACE WATER													
VILLAGE OF BROWN DEER....	--[a]	--	--	--[a]	--	--	--[a]	--	--	0.937	11,600	81	511[e]
VILLAGE OF FOX POINT.....	0.055	570	96	0.143	1,200	119	0.305	3,510	87	0.389	3,800	102	607
VILLAGE OF GLENDALE......	--[a]	--	--	--[a]	--	--	--[a]	--	--	2.562	12,800	200	209[f]
CITY OF MILWAUKEE........	22.665	318,100	71	34.315	345,500	99	41.356	404,540	102	46.301	400,300	116	104
VILLAGE OF SHOREWOOD.....	1.138	14,300	79	1.388	15,300	90	1.435	15,180	95	1.477	15,650	94	30
VILLAGE OF WHITEFISH BAY.	0.701	7,900	89	1.301	12,100	108	1.556	17,720	88	1.781	17,010	105	154
SUBTOTAL	24.559	340,870	72	37.147	374,100	99	44.652	440,950	101	53.447	461,160	116	118
TOTAL	25.424	353,204	72	38.892	390,573	99	48.737	478,357	102	59.181	495,180	120	133

[a] NO MUNICIPAL WATER UTILITY IN OPERATION.

[b] PERCENT INCREASE IS INFINITY AND CAN NOT BE DETERMINED.

[c] THE VILLAGE OF BROWN DEER WAS SERVED BY GROUND WATER BETWEEN 1958 AND 1965. SINCE THAT TIME, IT HAS PURCHASED WATER FROM THE CITY OF MILWAUKEE MUNICIPAL WATER UTILITY.

[d] INCREASE 1950-1967.

[e] INCREASE 1965-1967.

[f] INCREASE 1963-1967.

SOURCE- U.S. GEOLOGICAL SURVEY AND SEWRPC.

the watershed since 1940. Total municipal pumpage in 1967 was 21.8 billion gallons, or more than twice the municipal pumpage in 1940. Although all other water uses combined have been insignificant relative to the total municipal use, such other uses totaled about 2.86 billion gallons in 1967. This is, however, only a 4 percent increase over the estimated 1940 water use within the watershed for all other purposes except municipal.

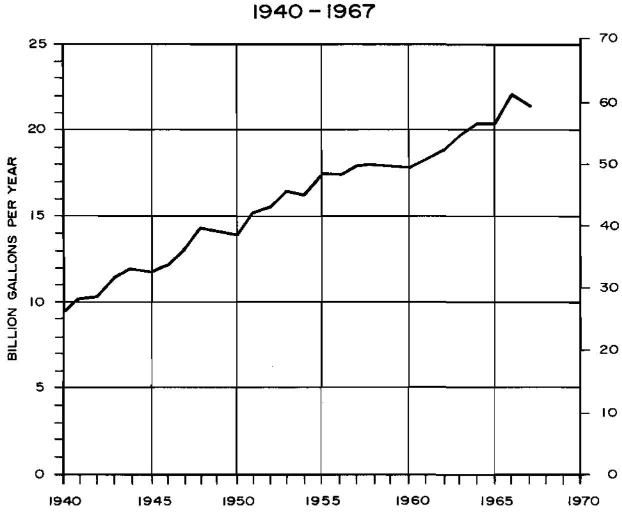
Historic Trends in Ground Water Use

Municipal pumpage comprises, and may be expected to continue to comprise, the largest demand upon the ground water resources of the watershed. The number of persons served by municipal ground water systems increased from about 12,300 in 1940 to about 34,000 in 1967, a 176 percent increase, while total ground water consumption increased from 0.31 billion gallons to 2.09 billion gallons, an almost sixfold increase. The average per capita use rose from about 76 gallons per day to 169 gallons per day, more than doubling over the same period. These estimates include water furnished to industrial and commercial, as well as residential, users; public uses, such as for street-cleaning and firefighting; and distribution losses. Figure 53 shows the change in total annual municipal pumpage of ground water in the watershed since 1940.

Ground water pumpage by self-supplied industrial and commercial users in the watershed has increased from 3.3 million gallons per day in 1935 to 5.0 million gallons per day in 1940 and to a peak of 6.8 mgd in 1949 and has declined sporadically from 6.8 mgd in 1949 to 1.8 mgd in 1967. This decline is due to a shift from self-supplied sources to better quality or more adequate municipal supplies and to the closing of certain large self-supplied water use industries. Self-supplied industrial and commercial ground water use within the watershed but outside Milwaukee County totaled only 0.22 billion gallons in 1967, or 5 percent of the total ground water pumped in the watershed, a demand which has not changed appreciably in the past 30 years. Within the Milwaukee County portion of the watershed, however, ground water withdrawals for self-supplied commercial and industrial use have fluctuated since 1940. Ground water pumpage for these uses rose from about 4.4 mgd in 1940 to a peak of more than 6 mgd in 1949. From 1949 to 1967, such use had declined from 6 mgd to 1.2 mgd. Ground water withdrawals by self-supplied industrial and commercial users in the Milwaukee County portion of the watershed, however, are not expected to decline much below the 1967 rate of 1.2 mgd. This determination is based upon the recent slowing of the rate of decline of the use of the deep aquifer. No pumpage records exist for the other ground water uses, such as private domestic, agricultural, and irrigation uses. However, it is estimated that ground water withdrawals for self-supplied private domestic, agricultural and livestock watering, and irrigation uses total less than 4.1 mgd, or 36 percent of the total ground water pumpage within the watershed. Increases in pumpage for these uses have been very slow

Figure 52

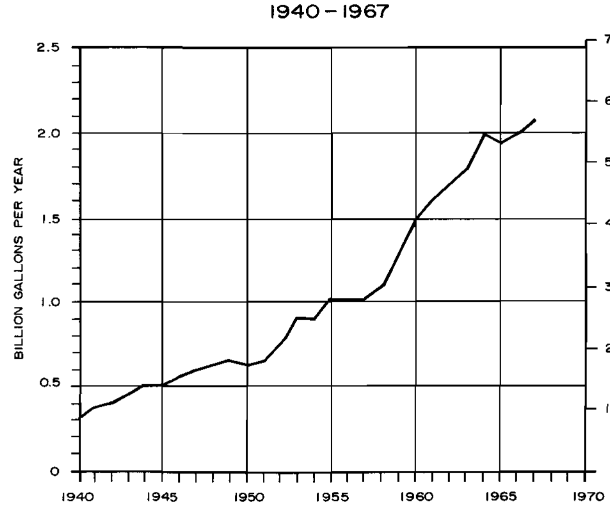
TOTAL ANNUAL MUNICIPAL WATER PUMPAGE IN THE MILWAUKEE RIVER WATERSHED 1940 - 1967



Source: SEWRPC.

Figure 53

ANNUAL MUNICIPAL GROUND-WATER PUMPAGE IN THE MILWAUKEE RIVER WATERSHED 1940 - 1967



Source: SEWRPC.

and gradual, and it is estimated that they have increased from 2.5 mgd in 1940 to 4.1 mgd in 1967. High-capacity well operators must obtain permits from the Wisconsin Department of Natural Resources for their use if their well capacity is larger than 100,000 gpd (70 gpm). Annual pumpage records must also be maintained for such wells. No permit is required for smaller capacity wells.

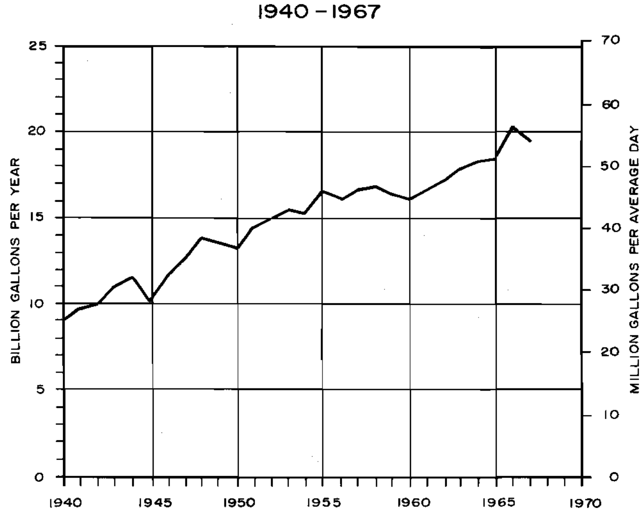
Historic Trends in Surface Water Use

Municipal pumpage also comprises, and may be expected to continue to comprise, the largest demand upon Lake Michigan and the surface water resources of the watershed. From 1940 through 1967, the general trend has been toward an increasing municipal pumpage of surface water for all categories of use and geographic areas within the watershed (see Figure 54). Municipal water systems using surface water supplies have served a steadily increasing number of people within the watershed, with the population being served increasing from about 341,000 in 1940 to about 488,000 in 1967, or an increase of 43 percent. Municipal pumpage for all uses increased from about 8.9 billion gallons in 1940 to about 19.5 billion gallons in 1967, more than doubling, while the average per capita use rose from about 72 gpd in 1940 to about 116 gpd in 1967, a 61 percent increase.

As already noted, various industrial and commercial establishments have, since 1940, for various reasons, abandoned self-supplied ground water sources and have become customers of the municipal water utilities serving the Milwaukee County portion of the watershed. Certain large processing industries, especially the major breweries in the City of Milwaukee, greatly increased the use of the surface water supply when these industries began to use such supply through the municipal water utilities. The eventual abandonment of all private industrial and commercial ground water sources in the Milwaukee County portion of the watershed and the conversion to the use of municipally supplied Lake Michigan water can be anticipated.

Figure 54

ANNUAL MUNICIPAL SURFACE WATER PUMPAGE IN THE MILWAUKEE RIVER WATERSHED 1940 - 1967



Source: SEWRPC.

The use of surface water for self-supplied domestic and livestock watering purposes is minimal and totaled only an estimated 0.001 mgd in 1967. The use of surface water for irrigation totaled only about 0.17 mgd in 1967, most of which was used by farmers having Wisconsin Department of Natural Resources permits to withdraw water from rivers and creeks for irrigation purposes. Permits for domestic irrigation uses, such as lawn and garden watering, are not required, nor are pumpage records maintained. The legal ramifications of using surface water for irrigation purposes are discussed in detail in Chapter XV of this volume.

FORECAST OF FUTURE WATER USE

By the plan design year of 1990, the resident population of the Milwaukee River watershed may be expected to total about 678,000 persons, an increase of about 134,000 persons over the 1967 watershed population level (see Chapter VII, Volume 1, of this report). Total water use from all sources of supply may be expected to increase with this increase in population by more than 51 percent, from 67 mgd in 1967 to 103 mgd by 1990. The estimated 1990 water use by category of use is summarized in Table 95. Almost 90 percent of the total water use may be expected to be public municipal, sanitary district, and subdivision supply, while the self-supplied industrial, commercial, domestic, and agricultural uses together may be expected to account for the remaining 10 percent of water use. Of this 10 percent, about one-half of the use may be expected to be for self-supplied industrial, commercial, and domestic uses, while the remainder may be expected to be for agricultural uses, primarily irrigation. The municipal use of water by 1990 may thus be expected to be by far the most important use of water in the basin, totaling approximately 92 million gallons per day.

TABLE 95

FORECAST GROUND AND SURFACE WATER CONSUMPTION
IN THE MILWAUKEE RIVER WATERSHED BY TYPE OF USE- 1990

TYPE OF USE	WATER USE (MGD)		PERCENTAGE OF TOTAL USE	
	GROUND WATER	SURFACE WATER	GROUND WATER	SURFACE WATER
MUNICIPAL, SANITARY DISTRICT, AND SUBDIVISION......	15.4	76.6	62.8	98.0
SELF-SUPPLIED COMMERCE AND INDUSTRY.........	4.0	1.5	16.9	2.0
DOMESTIC............	3.5[a]	--	12.3	--
AGRICULTURE				
LIVESTOCK........	1.4	--	5.9	--
IRRIGATION.......	0.5	0.2	2.1	--
TOTAL	24.8	78.3	100.0	100.0

[a]THIS FORECAST ASSUMES THAT MUNICIPAL WATER UTILITIES WILL NOT BE ESTABLISHED FOR THE FOLLOWING URBAN AREAS- CITY OF MEQUON, VILLAGES OF BAYSIDE, CASCADE, JACKSON, RIVER HILLS, AND THIENSVILLE AND THE UNINCORPORATED VILLAGES OF NEWBURG AND WAUBEKA.

SOURCE- U.S. GEOLOGICAL SURVEY AND SEWRPC.

Ground water use within the watershed may be expected to reach a total of approximately 24.8 mgd for all uses, an increase of 14.3 mgd over the 1967 level. Surface water use may be expected to reach 78.3 mgd for all uses, an increase of 22.9 mgd over the 1967 level. Of the anticipated total population of about 678,000 persons within the watershed, approximately 535,000, or 78 percent, may be expected to reside in the Milwaukee County portion of the watershed if the adopted regional land use plan is implemented, and, therefore, to be served by established municipal utilities utilizing surface water withdrawn from Lake Michigan as the source of supply. About 57,000 persons, or about 9 percent of the total watershed population, may be expected to reside in outlying urban communities of the watershed having established municipal water utilities utilizing ground water as the source of supply if the adopted regional land use plan is implemented. An increase of about 56,000 persons, or about 9 percent of the total watershed population, may be expected to reside in urban communities served by newly established municipal water utilities utilizing either ground or surface water as a source of supply. About 30,000 persons, or 4 percent of the total watershed population, may be expected to reside in rural areas of the watershed and to be served by self-supplied domestic wells. Ground water pumpage for municipal use in the watershed may be expected to increase from about 6 mgd for 1967 to a total of about 11 mgd by 1990, a 98 percent increase. Table 96 summarizes the forecast 1990 ground water use by municipality. The historic and forecast trends in ground water use by municipality are shown graphically in Figure 55.

Surface water pumpage for municipal use in the watershed may be expected to increase from about 53 mgd in 1967 to a total of about 77 mgd in 1990, a 43 percent increase. Table 97 summarizes the forecast 1990 surface water use for each municipality. The remaining pumpage is expected to be utilized for self-supplied industrial and commercial and for irrigation purposes. The total use for these purposes may be expected to remain at about the 1967 level through 1990. The historic and forecast trends in surface water use by municipality are shown graphically in Figure 55.

For forecast purposes, it was assumed that sanitary district and isolated subdivision pumpage of ground water in the watershed would increase from about 0.19 mgd in 1967 to 4.05 mgd in 1990.

TABLE 96

FORECAST MUNICIPAL GROUND WATER USE IN THE MILWAUKEE RIVER WATERSHED- 1990[a]

MUNICIPALITY	WATER USE 1967 (MGD)	PERCENT CHANGE 1967-1990	FORECAST WATER USE 1990 (MGD)	FORECAST POPULATION TO BE SERVED 1990	ESTIMATED PER CAPITA WATER USE (GPD)
VILLAGE OF ADELL........	0.03	133	0.07	440	159
VILLAGE OF CAMPBELLSPORT	0.22	118	0.48	1,950	246
CITY OF CEDARBURG.......	1.41	90	2.68	13,401[b]	200
VILLAGE OF FREDONIA.....	0.10	80	0.18	1,691	165
VILLAGE OF GRAFTON......	0.69	121	1.53	10,200[b]	150
VILLAGE OF KEWASKUM.....	0.52	61	0.84	2,814	298
VILLAGE OF RANDOM LAKE..	0.28	32	0.37	1,170	316
VILLAGE OF SAUKVILLE....	0.28	110	0.59	2,325	255
CITY OF WEST BEND.......	2.21	108	4.61	23,061[b]	200
TOTAL	5.74	97	11.35	57,052	199

[a]BY 1990, MUNICIPAL WATER UTILITIES MAY ALSO BE ESTABLISHED AT THE VILLAGES OF CASCADE AND JACKSON AND THE UNINCORPORATED VILLAGES OF NEWBURG AND WAUBEKA.

[b]THIS FIGURE INCLUDES PERSONS LIVING IN THOSE PLANNED DEVELOPED URBAN AREAS CONTIGUOUS TO THE VILLAGE OF GRAFTON AND THE CITIES OF CEDARBURG AND WEST BEND.

SOURCE- U. S. GEOLOGICAL SURVEY.

TABLE 97

FORECAST MUNICIPAL SURFACE WATER USE IN THE MILWAUKEE RIVER WATERSHED- 1990[a]

MUNICIPALITY	WATER USE 1967 (MGD)	PERCENT CHANGE 1967-1990	FORECAST WATER USE 1990 (MGD)	FORECAST POPULATION TO BE SERVED 1990	ESTIMATED PER CAPITA WATER USE (GPD)
VILLAGE OF BROWN DEER...	0.94	123	2.20	14,693	150
VILLAGE OF FOX POINT....	0.39	79	0.70	4,678	150
CITY OF GLENDALE........	2.56	53	3.91	19,547	200
CITY OF MILWAUKEE.......	46.30	41	65.30	466,464	140
VILLAGE OF SHOREWOOD....	1.48	20	1.77	14,731	120
VILLAGE OF WHITEFISH BAY	1.78	55	2.76	15,331	180
TOTAL	53.45	43	76.64	535,444	143

[a]BY 1990, MUNICIPAL WATER UTILITIES MAY ALSO BE ESTABLISHED AT THE VILLAGES OF BAYSIDE, RIVER HILLS, AND THIENSVILLE AND THE CITY OF MEQUON.

SOURCE- SEWRPC.

It should, however, be recognized that many such districts and subdivisions may be expected to be connected to centralized municipal water utilities by 1990. As indicated in Table 95, relatively small increases in ground water pumpage are forecast by 1990 for self-supplied industrial, commercial, domestic, and agricultural use.

WATER SUPPLY PROBLEMS

A good water supply, comprised of both ground water and surface water from Lake Michigan, does exist within the Milwaukee River watershed and is adequate to meet all foreseeable municipal, indus-

Figure 55

HISTORIC AND FORECAST TRENDS IN MUNICIPAL WATER USE IN THE MILWAUKEE RIVER WATERSHED 1940-1990

MUNICIPAL GROUND WATER PUMPAGES

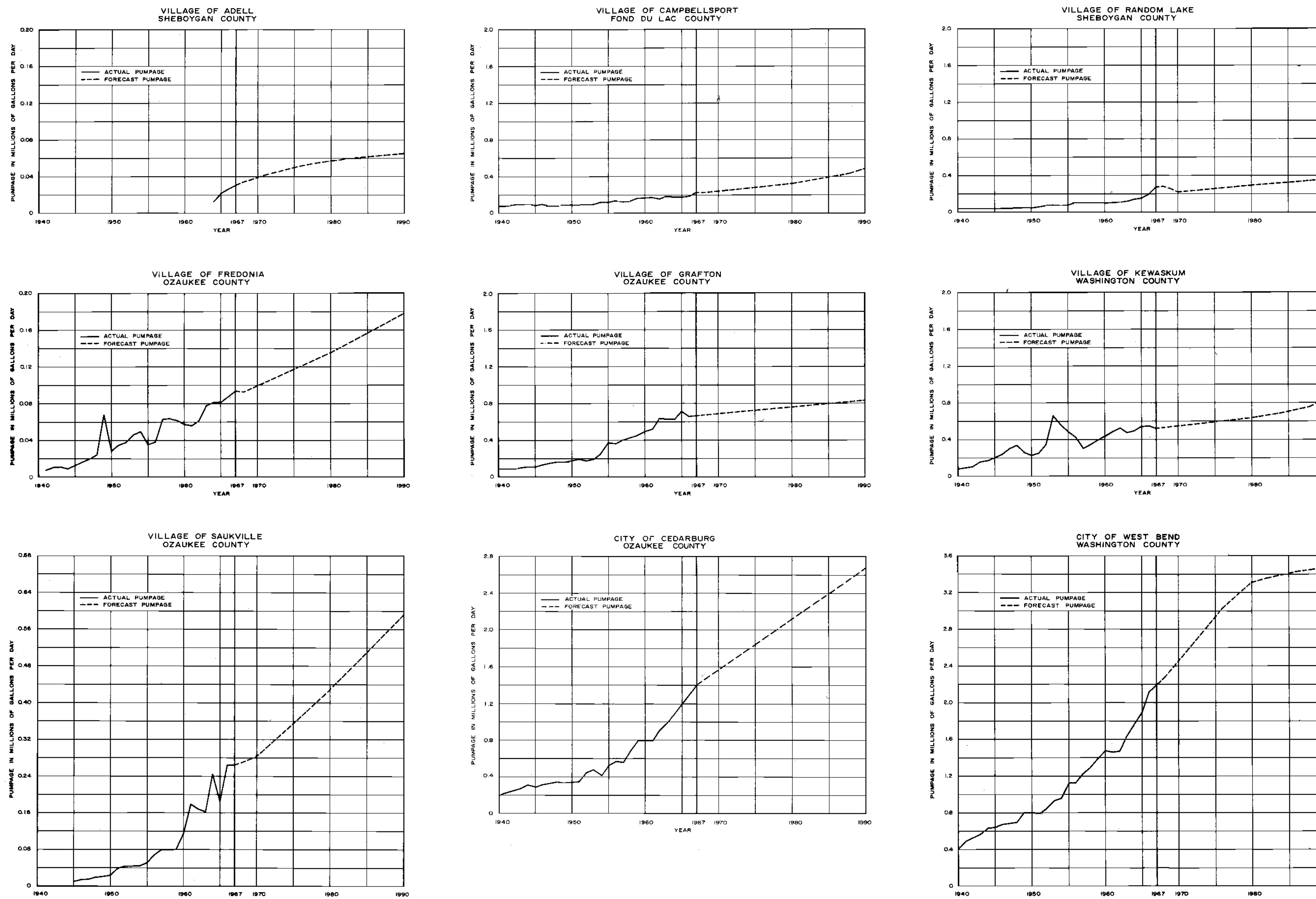
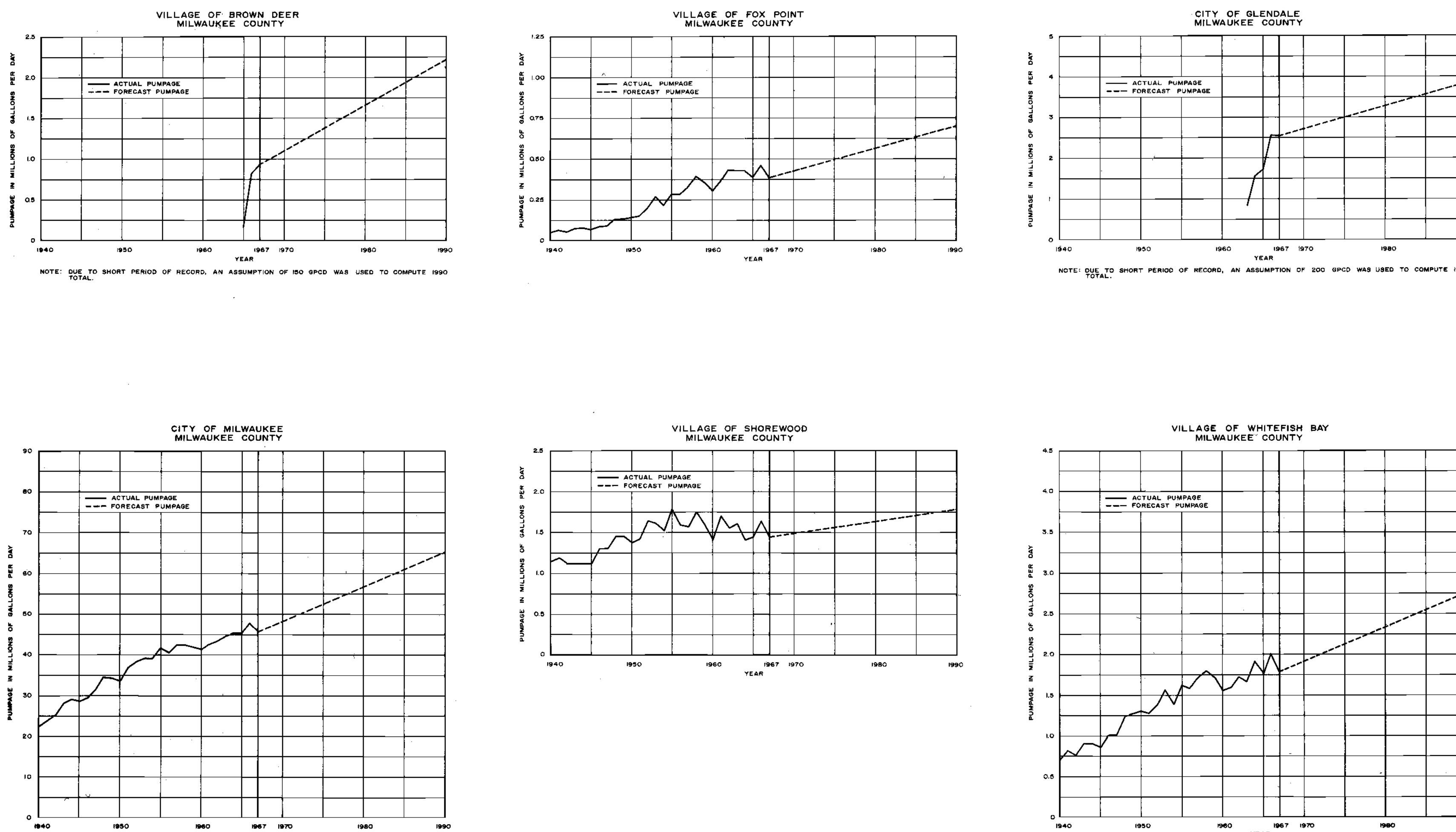


Figure 55 (continued)

HISTORIC AND FORECAST TRENDS IN MUNICIPAL WATER USE IN THE MILWAUKEE RIVER WATERSHED 1940-1990

MUNICIPAL SURFACE WATER PUMPAGES



Source: U.S. Geological Survey.

trial, domestic, and agricultural needs within the watershed. Milwaukee County and the southern portion of Ozaukee County together comprise the area of the watershed in which the greatest increases in water use may be expected, accompanying anticipated increases in population levels. Primary reliance cannot continue to be placed on the shallow dolomite aquifer as a source of water supply within certain portions of the lower watershed without creating increasingly severe problems of declining water levels. A more reliable supply of ground water in the area exists in the deep sandstone aquifer. The deep aquifer in this area, however, contains water high in dissolved solids content, exceeding 1,000 mg/l and, therefore, considered saline. Continued heavy pumpage of the deep aquifer in this part of the watershed can be expected, as water levels in the aquifer continue to decline, to accelerate the intrusion of saline waters and further limit the usefulness of this source of supply.

Population growth in the middle and upper reaches of the watershed may be expected to be more moderate and problems of inadequate water supply to remain rare. Small-to-moderate well yields to meet most self-supplied domestic and agricultural needs can be obtained almost everywhere within the central and upper reaches of the watershed from either the shallow sand and gravel or the dolomite aquifer. Larger yields of water, sufficient for both municipal and self-supplied industrial and commercial needs, are available in the central and upper reaches of the watershed within the deep sandstone aquifer (see Map 32). It should not be inferred, however, that no water supply problems could arise within the central and upper portions of the watershed. If such problems are to be avoided, a sound ground water resource management program must be formulated to ensure that the potential of the available ground water supply can be fully realized both in the central and upper reaches of the watershed, as well as in the lower reaches of the watershed, with its more difficult water supply problems.

In 1967 about 11,000 people lived in the City of Mequon and the Village of Thiensville portion of the watershed, with neither municipality providing public water supply service. By 1990, 47,000 persons may be expected to reside within these two communities, an increase of 36,000 persons over the 1967 population level; and a minimum of 4.7 mgd of water will be required to serve this forecast population level, an increase of about 3.8 mgd over the 1967 water use within these two communities. If major declines in dolomite and deep sandstone aquifer water levels and the possible concomitant natural pollution of the deep aquifer by the intrusion of saline waters is to be avoided in the face of this increased water demand, either the ground water aquifers will have to be very carefully managed or alternative sources of supply developed. Lake Michigan is an excellent alternate source of supply for this area and could be utilized either through creation of a new public water utility with its own intake to serve the Mequon-Thiensville area or through purchase of water from one of the two existing water utilities now utilizing Lake Michigan as a source of supply and serving adjacent areas to the south.

Similarly, in 1967 about 3,400 people lived in the Village of Bayside and Village of River Hills portion of the watershed, with neither municipality providing public water supply service. By 1990 about 4,400 persons may be expected to reside in these two communities, an increase of about 900 persons over the 1967 population level; and a minimum of about 1 mgd of water will be required to serve this forecast population level, an increase of approximately 0.7 mgd over the 1967 water use within these two communities. This increase could be supplied either by the continued use of ground water or by the purchase of surface water from either the existing City of Milwaukee or the North Shore municipal water utilities, both of which utilize Lake Michigan as a source of supply, or by purchase of water from any new utility created to serve the Mequon-Thiensville area.

Along with the aforementioned four communities, four others—the Villages of Cascade and Jackson and the unincorporated Villages of Newburg and Waubeka within the watershed—do not presently provide public water supply services. As indicated in Table 98, seven of these eight communities may be expected to have population densities in excess of 1,000 persons per square mile by the year 1990 in the urban quarter sections, warranting the provision of a public water supply (see Table 99). The four outlying communities, however, may be expected to utilize the deep ground water aquifer as the source of supply.

As indicated in Table 98, all but one of these eight communities within the watershed without a municipal water supply, the Village of Jackson,

TABLE 98

URBAN COMMUNITIES IN THE MILWAUKEE RIVER WATERSHED WITHOUT A MUNICIPAL WATER SUPPLY SYSTEM- 1967

COMMUNITY	PRESENT PRIMARY WATER SOURCE (AQUIFER)	EXISTING COMMUNITY AREA IN THE WATERSHED (SQ. MI.)	ESTIMATED POPULATION IN THE WATERSHED 1967	POPULATION DENSITY FOR THE ENTIRE COMMUNITY 1967 (PERSONS/SQ.MI.)	POPULATION DENSITY FOR THE URBAN QUARTER SECTIONS IN THE COMMUNITY 1967 (PERSONS/SQ.MI.)	ESTIMATED WATER CONSUMPTION 1967 (MGD)	FORECAST POPULATION 1990	FORECAST POPULATION DENSITY FOR THE ENTIRE COMMUNITY 1990 (PERSONS/SQ.MI.)	FORECAST POPULATION DENSITY FOR THE URBAN QUARTER SECTIONS IN THE COMMUNITY 1990 (PERSONS/SQ.MI.)
VILLAGE OF BAYSIDE.....	DOLOMITE	0.63	2,080	3,300	2,970	0.166[a]	2,100	3,340	2,840
VILLAGE OF CASCADE.....	DOLOMITE	0.75	500	667	2,500	0.025[b]	500	700	2,210
VILLAGE OF JACKSON.....	DOLOMITE	0.51	500	980	3,130	0.074[c]	1,500	2,980	4,280
CITY OF MEQUON.........	DOLOMITE AND SANDSTONE	31.57	8,330	264	885	0.666[a]	43,800	1,380	2,480
VILLAGE OF NEWBURG..... (UNINCORPORATED)	DOLOMITE	1.00[d]	414[e]	410	2,760	0.021[b]	1,100	1,100	3,340
VILLAGE OF RIVER HILLS.	DOLOMITE	4.11	1,300	316	441	0.104[a]	2,200	550	620
VILLAGE OF THIENSVILLE.	DOLOMITE	1.03	3,000	2,910	3,060	0.240[a]	3,600	3,470	3,140
VILLAGE OF WAUBEKA..... (UNINCORPORATED)	DOLOMITE	1.00[f]	366[g]	360	1,740	0.017[b]	600	560	2,350
TOTAL	--	40.60	16,490	--	--	1.306	55,400	--	--

COMMUNITY	ESTIMATED WATER CONSUMPTION 1990 (MGD)	ESTIMATED PER CAPITA WATER USE 1990 (GPD)	EXISTING SEWERAGE SYSTEM SERVING COMMUNITY	PRESENTLY SERVED BY FIRE PROTECTION SYSTEM[h]	FIRE PROTECTION SYSTEM NEEDED BY 1990[i]	PRESENT WATER SOURCES OF SUPPLY ARE OF GOOD QUANTITY	FIRE INSURANCE RATING BUREAU CLASSIFICATION	FIRE INSURANCE ANNUAL PREMIUM ($20,000 HOME)[j]	MUNICIPAL WATER SUPPLY SYSTEM NEEDED BY 1990
VILLAGE OF BAYSIDE.....	0.201	100	YES	NO[k]	YES	YES[l]	8 & 9[m]	$24 & 36[n]	YES
VILLAGE OF CASCADE.....	0.042	80	NO	NO	YES	YES	9	36	YES
VILLAGE OF JACKSON.....	0.169[o]	80	YES	YES	YES	YES	7	22	YES
CITY OF MEQUON.........	4.380	100	YES	NO	YES	YES[l]	9	36	YES
VILLAGE OF NEWBURG..... (UNINCORPORATED)	0.088	80	YES	NO	YES	YES	9	36	YES
VILLAGE OF RIVER HILLS.	0.225	100	YES	NO	NO	YES	9	36	NO
VILLAGE OF THIENSVILLE.	0.357	100	YES	NO	YES	YES	9	36	YES
VILLAGE OF WAUBEKA..... (UNINCORPORATED)	0.045	80	NO	NO	YES	YES	9	36	YES
TOTAL	5.507	99	--	--	--	--	--	--	--

[a]BASED ON AN ASSUMED CONSUMPTION RATE OF 80 GALLONS PER CAPITA PER DAY.

[b]BASED ON AN ASSUMED CONSUMPTION RATE OF 50 GALLONS PER CAPITA PER DAY.

[c]BASED ON AN ASSUMED CONSUMPTION RATE OF 50 GALLONS PER CAPITA PER DAY PLUS 17,600,000 GALLONS USED BY LIBBY, MCNEIL AND LIBBY.

[d]FOR THE PURPOSES OF THIS ANALYSIS, IT WAS ASSUMED THAT THE AREA OF 'NEWBURG' WAS ALL OF SECTION 12, TOWN 11 NORTH, RANGE 20 EAST, IN WASHINGTON COUNTY.

[e]BASED ON THE ESTIMATED 1967 POPULATION IN SECTION 12, TOWN 11 NORTH, RANGE 20 EAST, IN WASHINGTON COUNTY.

[f]FOR THE PURPOSES OF THIS ANALYSIS, IT WAS ASSUMED THAT THE AREA OF 'WAUBEKA' WAS ALL OF SECTION 28, TOWN 12 NORTH, RANGE 21 EAST, IN OZAUKEE COUNTY.

[g]BASED ON THE ESTIMATED 1967 POPULATION IN SECTION 28, TOWN 12 NORTH, RANGE 21 EAST, IN OZAUKEE COUNTY.

[h]'SERVED' DEFINED AS A SYSTEM OF WATER MAINS, FIRE HYDRANTS, AND WATER STORAGE FACILITIES.

[i]A FIRE PROTECTION SYSTEM IS CONSIDERED TO BE FEASIBLE WHERE THERE IS AT LEAST MEDIUM-DENSITY (7.3-22.8 PERSONS PER RESIDENTIAL ACRE) RESIDENTIAL DEVELOPMENT OR A SUBSTANTIAL CONCENTRATION OF COMMERCIAL AND INDUSTRIAL DEVELOPMENT.

[j]THESE FIGURES REPRESENT ANNUAL PREMIUMS FOR STRICTLY FIRE-BASED DAMAGE INSURANCE COVERAGE ON A $20,000 HOME.

[k]THE VILLAGE OF BAYSIDE PRESENTLY HAS NO FIRE PROTECTION SYSTEM AS DEFINED ABOVE, ALTHOUGH IT DOES HAVE SEVEN CISTERNS IN THE VILLAGE FOR LOCAL FIRE PROTECTION PURPOSES.

[l]ASSUMES SOUND MANAGEMENT AND SPACING OF WELLS. WELLS MUST BE SPACED GREATER THAN 5,000 FEET APART, PUMPING AT THE RATE OF A MAXIMUM OF 300 GALLONS PER MINUTE.

[m]THE ENTIRE VILLAGE OF BAYSIDE HAS A CLASSIFICATION OF 9, EXCEPT THOSE AREAS WITHIN 1,000 FEET OF SEVEN CISTERNS, WHICH AREAS HAVE A CLASSIFICATION OF 8.

[n]THE $24 PREMIUM IS FOR THE AREA CLASSIFIED AS 8 AND THE $36 PREMIUM IS FOR THE AREA CLASSIFIED AS 9.

[o]BASED ON AN ASSUMED CONSUMPTION RATE OF 80 GALLONS PER CAPITA PER DAY PLUS 17,600,000 GALLONS USED BY LIBBY, MCNEIL AND LIBBY.

SOURCE- FIRE INSURANCE RATING BUREAU AND SEWRPC.

has a fire insurance rating of 9 and does so in part because no municipal water supply is available. The Village of Jackson does have a water system consisting of water mains, fire hydrants, and some water storage solely for fire protection and, therefore, has a fire insurance rating of 7. The urban population densities which exist in all but one of these areas, together with the inadequate fire protection provided, combine to create an unduly high fire hazard to life and property and result in higher fire insurance premiums. Consequently, an additional important warrant for the provision of a public water supply system is provided.

The fire insurance rating system in use within Wisconsin was devised by the Fire Insurance Rating Bureau, a private nonprofit association of fire insurance companies licensed to operate within the state. The system is intended to rate the ability of municipalities to prevent and to fight fires and is based primarily upon analyses of the adequacy of the municipal fire department, the water supply system, and the potential fire hazard, as determined by existing structural conditions in high-value districts. Under this system municipalities are assigned "points of deficiency" for inadequacies noted with respect to the following six items: water supply, fire department, fire

TABLE 99

CRITERIA FOR THE ESTABLISHMENT OF PUBLIC SANITARY SEWERAGE AND WATER SUPPLY SYSTEMS

POPULATION DENSITY PERSCNS PER SQUARE MILE (GROSS AREA)	EQUIVALENT LOT SIZES	PUBLIC WATER SUPPLY SYSTEM	PUBLIC SANITARY SEWERAGE SYSTEM
5,000 AND OVER	LESS THAN 1/2 ACRE	JUSTIFIED	JUSTIFIED
2,500 - 5,000	1/2-TO-1 ACRE	JUSTIFIED	NORMALLY JUSTIFIED
1,000 - 2,5C0	1-TO-2 ACRES	NORMALLY JUSTIFIED	NOT NORMALLY JUSTIFIED
500 - 1,000	2-TO-4 ACRES	NOT NCRMALLY JUSTIFIED	RARELY JUSTIFIED
5C0 AND UNDER	OVER 4 ACRES	RARELY JUSTIFIED	RARELY JUSTIFIED

SCURCE- U.S. PUBLIC HEALTH SERVICE.

alarm system, fire prevention efforts, building inspection, and structural conditions. In determining the number of "points of deficiency" in a category, such as water supply, a large number of items, such as reliability of supply, pumping equipment, and hydrant distribution, are considered. The total number of "points of deficiency" against a municipality determines its classification. The classes range from Class 1, with zero to 500 points of deficiency, to Class 10, with over 4,500 points of deficiency. As noted above, all but one of the urban communities in the watershed that do not presently provide water supply services have a fire insurance rating of Class 9, indicating a range of 4,000 to 4,500 points of deficiency. The single exception is the Village of Jackson, which has been assigned a rating of Class 7 because of the existence of a single-purpose fire protection water supply system. In comparison, those communities in the watershed having public water supply systems are rated in Classes 2 through 6, thus providing substantial savings in fire insurance premiums to their residents.

Effects of Regional Development

The ground water supply in the sandstone aquifer underlying the Milwaukee River watershed is affected by deep well pumpage throughout all of southeastern Wisconsin and, in addition, by such pumpage in the Chicago region. The changes in artesian pressure produced by such pumpage have been both pronounced and widespread. Since the first well was drilled into this aquifer approximately 100 years ago, water levels have declined nearly 700 feet at Chicago and more than 300 feet at Milwaukee. North of Milwaukee, however, these declines are much less pronounced, and the water level decline in the northwestern part of the watershed is estimated at less than 25 feet. Additional pumpage from the sandstone aquifer in any locality will increase the rate of decline in the water level while a reduction of pumpage will decrease the rate of decline.

Hydrographs of water levels in observation wells in the deep sandstone aquifer (see Figures 56 and 57) illustrate the water level changes in this aquifer as it underlies the watershed in the Milwaukee area. The hydrograph of Well ML-36 shows the long-term declining trend of water levels in the Milwaukee area. The hydrograph of Well ML-431 for a more recent period shows a very steep rate of water level decline. This steep decline is probably the result of a local increase in pumpage and therefore does not represent a regional trend in the watershed.

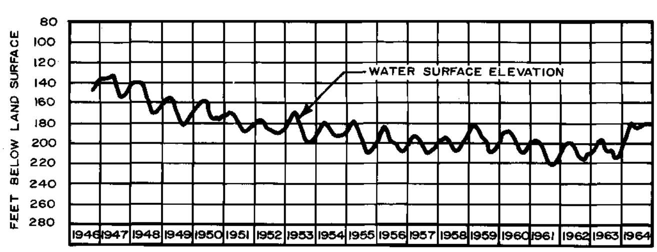
Heavy pumping of the dolomite aquifer will not produce major regional declines comparable to those in the sandstone aquifer because of differing hydraulic conditions and the local recharge available to this shallow aquifer. The observable affects of large-scale pumping of the aquifer at a particular site are normally limited to a 10-mile radius or less. Hydrographs of observation wells in the shallow dolomite aquifer (see Figures 58, 59, and 60) show an irregular fluctuation of water levels with no long-term trend apparent. The different wells reflect differing local conditions affecting the aquifer and differing rates of pumpage from the aquifer.

Because the sand and gravel aquifer occurs in more or less local discontinuous bands interconnected with the shallow dolomite aquifer and, like the latter aquifer, is recharged locally, no regional pumpage effects are possible. Increased local pumpage may, however, cause drastic declines in the local ground water levels and serious water supply problems.

Regional development has no measurable quantitative effect on Lake Michigan as a source of water, because all water pumped from the lake must be eventually returned to the lake by way of sewage treatment plants discharging directly to the lake or to streams which flow into the lake. The only

Figure 56

HYDROGRAPH OF WELL TAPPING THE DEEP AQUIFER IN THE CITY OF MILWAUKEE 1946-1964



MILWAUKEE CO., Well-36

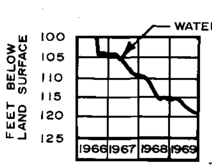
M1-7/21/12-36

A. O. Smith Corp. NE¼SE¼ Section 12, T. 7N., R. 21 E. Drilled unused artesian well in St. Peter sandstone, diam 14 inches reported depth 1,091 ft., cased to 774. Lsd 673 ft. above msl. MP top of flange, 3.00 ft., above lsd. Discontinued 1965.

Source: SEWRPC.

Figure 57

HYDROGRAPH OF WELL TAPPING THE DEEP AQUIFER IN THE VILLAGE OF BROWN DEER 1966-1969



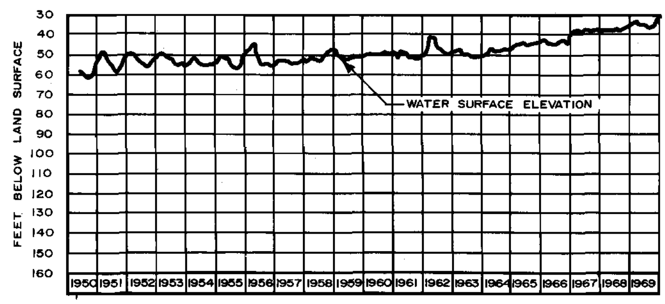
MILWAUKEE CO., Well-431 *M1-8/21/11-4.31*

Badger Meter Mfg. Co. NE¼NE¼. Section 11 T. 8 N., R. 21 E. Drilled industrial artesian well in sandstone of Cambrian age and St. Peter Sandstone of Middle Ordovician age, diam. 10 inches, reported depth 1,246 ft., cased to 757. Lsd 675 ft. above msl. MP hole in pump base, 7.00 ft. below lsd.

Source: SEWRPC.

Figure 58

HYDROGRAPH OF WELL TAPPING THE SHALLOW AQUIFER IN THE CITY OF MILWAUKEE 1950-1969



MILWAUKEE CO., Well-45

M1-7/22/29-45

Milwaukee Journal. NW¼NE¼, Section 29, T. 7 N., R. 22 E. Drilled unused artesian well in Niagara Dolomite, diam 8 to 5 inches, depth 1,015 ft., cased to 1,015 ft., ruptured 146-505. Lsd 591 ft. above msl. MP top of casing, 8.50 ft. below lsd. Recording gage. Lowest monthly plotted.

Source: U.S. Geological Survey.

Figure 59

HYDROGRAPH OF WELL TAPPING THE SHALLOW AQUIFER IN THE CITY OF MILWAUKEE 1946-1969

MILWAUKEE CO., Well-118

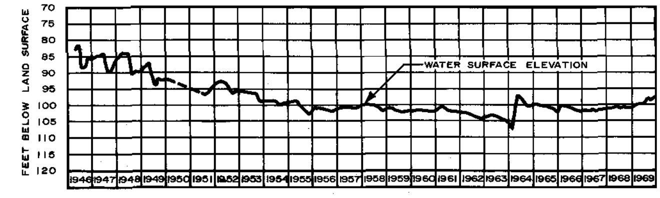
M1-8/21/35-118

A. Schaefer. NE¼NW¼ section 35, T. 8 N., R. 21 E. Drilled domestic artesian well in Niagara Dolomite, diam 6 inches depth 135 ft. Lsd 679.25 ft. above msl. MP top of casing, 0.60 ft. above lsd. Measured monthly. All plotted.

Source: U.S. Geological Survey.

Figure 60

HYDROGRAPH OF WELL TAPPING THE SHALLOW AQUIFER IN THE CITY OF MILWAUKEE 1946-1969



MILWAUKEE CO., Well-120 *M1-7/22/17-120*

Nunn-Bush Shoe Co. SE¼NW¼ section 17, T. 7 N., R. 22 E. Drilled unused artesian well in Niagara Dolomite of Middle Silurian age, diam 10 inches, reported depth 400 ft., cased to 104. Lsd 685 ft. above msl. MP top of concrete, 8.75 ft., below lsd. Affected by regional pumping. Measured monthly. All plotted.

Source: U.S. Geological Survey.

problem foreseen for the continued use of Lake Michigan as a major source of water supply is that which may be brought about by the continued decline in lake water quality through pollution of the lake both by the discharge of improperly treated sewage and by continued soil erosion in the tributary drainage area causing polluted sediments to enter the lake.

Effects of Local Development

Where pumping wells are spaced too closely for the hydraulic conditions in an aquifer, a mutual interference of the cones of depression surrounding the wells and a concomitant increased drawdown of water levels may result. This increased drawdown in turn causes increased pumping costs and, in some cases, reduced well and aquifer yields. The response of each aquifer to pumping differs because the hydraulic properties and recharge rates of the aquifers differ.

A specific example of how concentrated local pumpage may adversely affect an aquifer may be indicated by the experiences of the Village of Brown Deer. Until 1965 the Village of Brown Deer operated a municipal water system consisting of 16 subdivision wells, with each well serving only the immediate subdivision area and with no interconnection between the individual systems. With the increased concentrated population experienced by Brown Deer during the late 1950's and early 1960's, a greatly increased demand for water was placed upon this fragmented system of subdivision wells, resulting in a rapid decline in ground water levels and the need to deepen the wells almost annually in order to meet the growing demand. The Village was eventually forced to abandon the individual shallow wells as a source of supply and in 1965 began purchasing water from the City of Milwaukee municipal water utility. This shift in the source of supply, while necessitated by the continued rapid decline in the ground water levels, also provided a higher quality and more stable supply.

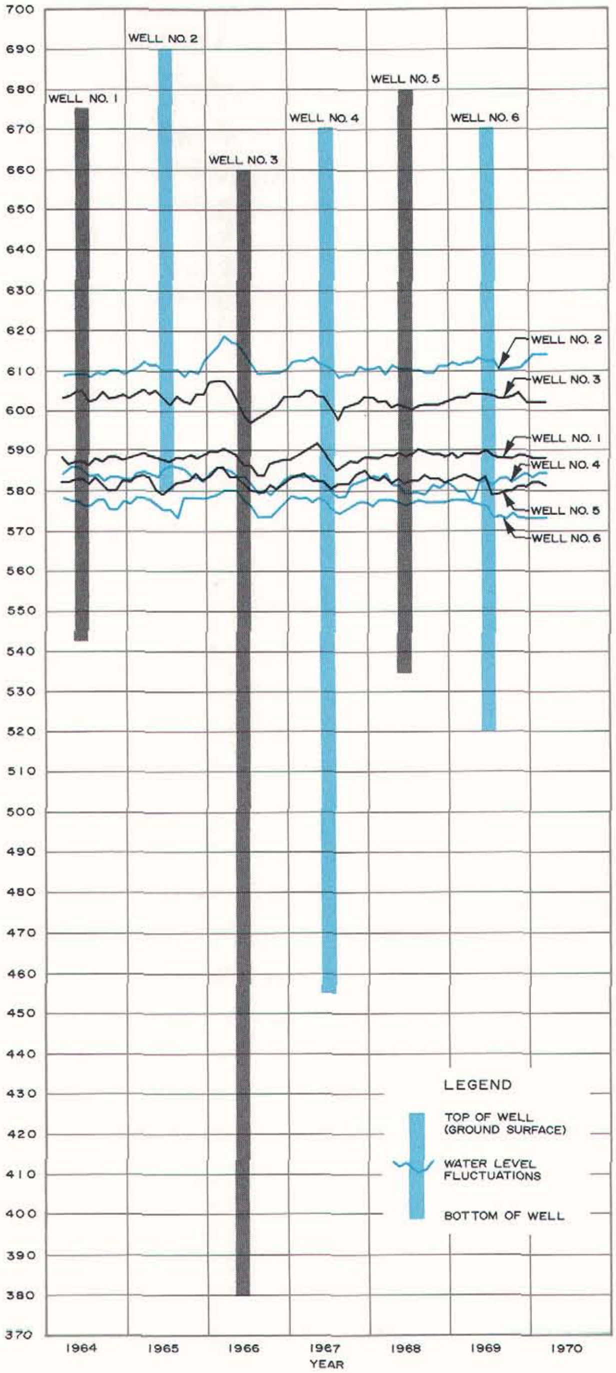
The Village of Bayside may face a similar situation as changes in land use development concentrate pumpage. Since April of 1964, the water levels in six wells within the Village have been monitored at approximately seven-day intervals. The results are shown in Figure 61 in terms of monthly average water levels. The locations of these observation wells, some of which lie outside the watershed, are shown on Map 56. Although no long-term trend in declining water levels is evident over the six years of record, all of the wells experienced drastic fluctuations in water level, some as much as almost 11 feet over a six-month period. This unreliability in water level creates a problem for the residential water users. In addition, water quality samples taken at other wells within the Village indicate a relatively high dissolved solids content, necessitating, in some instances, bottled water being brought to the home for domestic consumption and laundry being done outside the home in commercial laundromats. Thus, a potential water supply problem exists in the Village of Bayside, involving both quantitative and qualitative considerations. In the face of this problem, the Village administration wisely acted to institute the well-monitoring program and to sustain this program over the past six years. Also, within the past 15 years, the Village has engaged a consulting engineering firm to study various alternative public water supply systems, considering both ground and surface water as a source of supply and construction either by the Village alone or by the Village in cooperation with various adjacent communities. No action was, however, taken as a result of this engineering study, since all of the alternatives were rejected based upon financial considerations. In the final analysis, however, the ultimate decision may have to be based not only on the quality and quantity of the community water supply but also on whether or not a public water supply system becomes essential for the purpose of fire protection. Various development proposals advanced for the Village in recent years, if implemented, may make such a system essential.

The City of Mequon, which is experiencing rapid changes in land use as urban development continues in southern Ozaukee County, experienced a water supply problem during August 1970, when the water levels in many individual wells tapping the shallow dolomite aquifer declined below the pump intakes. Many homes were unable to obtain water until the water levels rose or until the pumps were lowered. This water supply problem, while temporary in nature due to a particularly long period of hot, dry weather, can be expected to increase in severity as development proceeds in Mequon and more and more individual wells tap the shallow aquifer.

The increases in ground water pumpage forecast for the Milwaukee River watershed may be expected to affect significantly water levels in

Figure 61

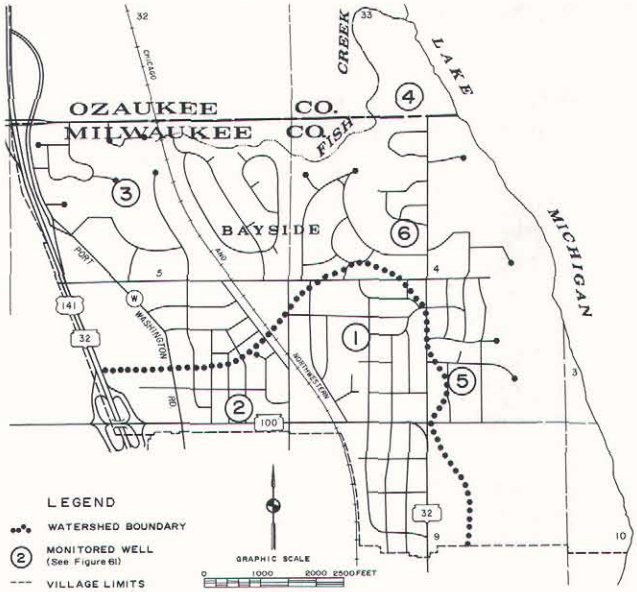
MONITORED WATER LEVELS IN SIX WELLS IN THE VILLAGE OF BAYSIDE, WISCONSIN 1964-1970



Source: Village of Bayside and SEWRPC.

Map 56

LOCATION OF MONITORED WELLS IN THE VILLAGE OF BAYSIDE, WISCONSIN 1964 - 1970



Since April of 1964, the Village of Bayside has conducted a weekly monitoring program of the water levels in six wells located throughout the Village. The program has revealed varying degrees of water level fluctuation, with the maximum fluctuation occurring in Well Number 3, where a difference in water levels of nearly 11 feet over a six-month period was found to have occurred.

Source: Village of Bayside and SEWRPC.

both the sandstone aquifer and the dolomite aquifer. In order to quantify these effects, the theoretical relationships between pumpage and drawdown for varying distances and times have been computed and the resulting curves and graphs are presented in Chapter VI, Volume 2, of this report. These curves can be used to estimate the response of each aquifer to most pumping situations. With the aid of these curves, well spacings can be effected that will minimize the adverse effects of interference for each pumping situation. Well drilling costs and pumping costs also may be estimated with the information provided by the curves.

Of major concern to owners and operators of wells in the sandstone aquifer underlying the watershed are the declines in water levels which have caused significant increases in well-operating expenses. As water levels decline, well yields are reduced; and the wells have to be operated for longer periods of time under greater pumping heads to produce the same quantity of water. The cost of electric power to operate the pumping equipment is the largest direct operating expense, and some operators feel that increased power costs may some day make pumping from the sandstone aquifer prohibitive in cost. The example given below demonstrates a method of estimating the direct costs of operating electrical pumping equipment for a typical high-capacity well and, moreover, illustrates the level of additional operating cost which is involved in pumping from a relatively high-capacity well in the face of declining water levels. In the example, if ground water levels are assumed to be declining at a rate of five feet per year, the additional annual expense to operate a well pumping at a continuous rate of 1 mgd can be calculated by the formula:

$$C_a = \frac{1.65\ Q\ H\ C_e}{E}$$

where:

C_a = annual cost of additional electricity in dollars.

Q = discharge rate in gpm.

H = head decline in feet.

C_e = cost of electricity per KWH in dollars, assumed to be \$0.015.

E = wire-to-water efficiency, assumed to be 0.6.

substituting:

$$C_a = \frac{1.65(695)(5)(0.015)}{0.6},$$

or \$143 per year increase in direct operating expense of the well.

SUMMARY

Rapid urbanization is occurring within the Milwaukee River watershed and is increasing the demands on municipal, industrial, and domestic water supplies. A comprehensive approach to the water resource problems of the watershed, therefore, requires that the major uses of the present water supply be assessed and the needs and potential availability or supply of water for the plan design year of 1990 be forecast. The water use inventories conducted under the Milwaukee River watershed study indicate that, except for the Mequon-Thiensville area, ground water is and may be expected to remain the principal source of domestic, municipal, agricultural, and industrial water supply in that portion of the Milwaukee River watershed lying above the Milwaukee County line. Within the Milwaukee County portion of the watershed, the principal source of water supply is and may be expected to remain Lake Michigan. Water use within the basin in 1967 totaled 24.4 billion gallons for all uses, 82 percent of which was obtained from surface water sources, mainly Lake Michigan. A total population of about 544,000 persons was supplied, and the total quantity of water used in the basin averaged 123 gallons per capita per day. This average utilization varied within the basin from a high of 293 gallons per capita per average day in the Village of Random Lake to a low of 81 gallons per capita per day in the Village of Brown Deer.

Water users were subdivided for analytical purposes into three major groups: municipal and privately owned public water utilities; self-supplied domestic and agricultural users; and self-supplied commercial and industrial users. The average daily use by these groups was, respectively: 59.18 mgd, or about 88 percent of the total use; 4.30 mgd, or about 6 percent of the total use; and 3.40 mgd, or about 6 percent of the total use. About 6 percent of the total municipal and private utility supply was obtained from the shallow aquifer, about 4 percent from the deep aquifer, and about 90 percent from surface water sources. These three sources may be expected to provide an adequate supply for municipal and private utility use to the plan design year of 1990, provided that an adequate water resources management program, specifically including a shift from ground to surface water as the principal source of supply in the Mequon, Thiensville, River Hills, Bayside area of the watershed and the proper location and spacing of wells in the remainder of the watershed, is affected. Lake Michigan water inlets for the new surface supplies will also have to be located on a coordinated basis, properly related to each other and to shoreline discharges of pollutants.

Approximately 26 percent of the self-supplied commercial and industrial use was obtained from the deep aquifer and 27 percent was pumped from the shallow aquifers of the watershed, with 47 percent being obtained from surface water sources. To date, self-supplied commercial and industrial users have no known problems anywhere within the watershed with respect to current or future supply. The required water resources management program within the basin, however, must include these major users.

The self-supplied domestic and agricultural water uses differ from the other two major uses, with most of the supply, slightly more than 99 percent, being derived from the shallow aquifers and less than 1 percent being obtained from surface water, while no water was obtained from the deep aquifer. The major water management problems of the rural portions of the Milwaukee River watershed are more related to agricultural practices, such as irrigation or drainage, than to domestic and livestock watering needs. Agricultural irrigation is presently not extensively practiced within the watershed; and only 2,000 acres, or 0.5 percent of the total area of the watershed, are under agricultural irrigation. The number of acres irrigated has increased rapidly in recent years, however; and, if current trends continue, the number of acres irrigated in 1990 could reach five times the present amount. Detailed soils maps of the watershed indicated that approximately 129,000 acres are covered by soils having characteristics that make them potentially irrigable. If in the future additional acreage is brought under irrigation, the demand for water will, because of potential use conflicts over surface waters, most probably have to be supplied almost entirely by the shallow ground water aquifer. An estimated four to six inches of water are applied to most irrigated crops in years having an average amount and normal seasonal distribution of precipitation. This withdrawal or application rate is higher than the estimated two inches per year average recharge rate of the shallow aquifer and, if not carefully managed, could result in local water use and supply conflicts and problems.

Soils maps indicate that approximately 124,400 acres in the watershed are covered by soils with restricted natural drainage. Eight agricultural drainage districts, one of which remains active, have been organized and four group enterprise projects established in order to implement agricultural drainage practices. To date, drainage improvements have been carried out on about 13,200 acres within the watershed.

Total water use may be expected to increase by 51 percent in the watershed by 1990, reaching an approximate total pumping rate of 103 million gallons per day, or 37.6 billion gallons per year. Municipal ground water use may be expected to comprise approximately 11 percent of this total water use, totaling 4.2 billion gallons per year. This forecasted total represents a 98 percent increase over the 1967 water use and represents a change in per capita consumption from 168 gallons per day in 1967 to 199 gallons per day in 1990. Municipal surface water may be expected to comprise 74 percent of this total water use, totaling 27.9 billion gallons per year. This forecasted total represents a 42 percent increase over the 1967 water use and represents a change in per capita consumption from 117 in 1967 to 143 in 1990.

The deep aquifer is a very complicated water supply, extending far beyond the surface boundaries of the watershed. Water levels (potentiometric surface) in this aquifer have, and will continue to show a decline within the Milwaukee River watershed, especially in areas of concentrated pumping. This decline, coupled with increasing water quality problems due to saline intrusion, is significant with respect to the total amount of water which is being used daily within the watershed, especially in the lower reaches of the watershed. As the level of the deep aquifer declines, the cost of pumping from the deep aquifer, as well as the cost of water treatment, may be expected to increase and to become major factors in determining future municipal and industrial water supply sources.

A ground water resource management program will have to be effected within the basin that considers both regional and local effects on the ground water system if local conflicts and shortages, as well as excessive costs of deep aquifer production, are to be avoided. An important aspect of such a program would be the identification of future well locations so as to produce a properly spaced network of wells, thereby avoiding the undesirable effect of well interference.

Chapter XII

RIVER PERFORMANCE SIMULATION

INTRODUCTION

One of the eight basic principles upon which the SEWRPC comprehensive watershed planning process is based as set forth in Chapter II, Volume 1, of this report, is:

> The capacity of each water control facility in the integrated watershed system must be carefully fitted to the present and probable future hydraulic loads, and the hydraulic performance and hydrologic feasibility of the proposed facilities must be determined and evaluated.

This principle is an extremely important one because, unless water control facility system plans are subject to quantitative test and evaluation, involving analysis of the hydraulic loading which the system must carry, the adequacy of the plans must remain in doubt from an engineering standpoint. Plans not subjected to such quantitative test and evaluation cannot provide a sound basis for project design or capital investment, nor can such plans provide sound, long-range solutions to water resource problems.

Quantitative hydraulic analysis, involving the preparation of forecasts and analyses of the amount of water to be passed or regulated by the existing and proposed water control facilities, is a fundamental requirement of any comprehensive watershed planning effort. A similar forecast and analysis of the pollution loading to be carried by the stream system is also an essential part of any comprehensive planning effort for large and complex watersheds, such as the Milwaukee River watershed. New engineering techniques make it possible to calculate future hydraulic and pollution loadings quantitatively as a function of watershed development patterns. These techniques involve the formulation and application of mathematical models which permit the present and probable future relationships existing within the watershed to be simulated and which permit qualitative and quantitative changes that may be expected to be induced upon the performance of the river system through changing land use and water control facility development to be forecast and analyzed.

This chapter describes the techniques used in the Milwaukee River watershed study for simulating the present and probable future hydrologic relationships existing within the watershed and the performance of the river system. Since the amount of water and the pollution loading to be carried by the river system had to be simulated separately, the models developed and applied in the study are presented in two sections. The first section, entitled "Flood Simulation," describes the mathematical model used to simulate the flood flow characteristics of the river system. The second section, entitled "Stream Water Quality Simulation," describes the mathematical model used to simulate water quality conditions in the river system.

FLOOD SIMULATION

As already noted, the watershed planning process requires definitive knowledge of both the present and the probable future flow behavior of the river system, particularly with respect to flood flows. The best means of obtaining information on the behavior of a river system is to measure the flow directly. To be of value for planning and engineering purposes, however, such direct measurements must extend over a long enough period of time to permit statistically valid conclusions concerning the probability of occurrence of various stream flows to be drawn from the records.

In the Milwaukee River watershed, river stage and discharge records have been obtained on the main stem at Milwaukee for a period of 54 years and on Cedar Creek at Cedarburg for a period of 38 years. These two gaging station records extend over long enough periods of time to be extremely useful to the hydrologic and hydraulic analyses required in the watershed planning effort. Four new streamflow gaging stations were established in the Milwaukee River watershed in 1968 as part of the watershed planning program: two on the main stem of the Milwaukee River at Kewaskum and Waubeka, one on the East Branch of the Milwaukee River at New Fane, and one on the North Branch of the Milwaukee River at Fillmore. The periods of record for these new gaging stations were too short to be useful in the watershed planning effort. The gages should, however, be maintained so that more complete data on the flow regimen of the watershed will become available over time. The records from the new gages will be particularly valuable in watershed plan implementation.

Although the direct flow measurements available from the existing gaging stations are extremely valuable to any sound analysis of the behavior of the river system, these measurements, even from the oldest gaging station in the watershed,have not been obtained over a long enough period of time to represent more than a very small sample of the possible ranges of hydrologic and hydraulic conditions within the watershed or to indicate any trends in the behavior of the stream system resulting from changes in land use development within tributary watershed areas. Moreover, the stream gaging records, regardless of duration, do not provide direct information in river discharge and water levels for stream reaches between or beyond the gaging station locations. Sound watershed planning, however, requires knowledge of the river system behavior along the entire length of the principal stream channels. Such information can be practically provided only through flow simulation studies.

The term "flood-flow simulation," as used in this report, means the representation of the surface water hydrologic and hydraulic system of the watershed by mathematical means in order to synthesize flood flows and concomitant high water surface elevations. In such simulation a mathematical model of the watershed and its stream system is constructed by assigning numerical values to various physical characteristics of the watershed and combining these values by means of established hydrologic and hydraulic relationships. Inputs to the model include data on the climate, topography, soils, and land use of the watershed and on the slope, cross section, and physical characteristics of the various stream channel reaches. Outputs include flood hydrographs, runoff volumes, peak flood discharges, and accompanying high water surface elevations. The ability of the model to simulate actual flood flows is verified by comparing the model outputs to available data on actual river performance, such as historic discharge records and high water marks.

Since all pertinent watershed characteristics are used in the development of the model, it becomes possible, by varying model inputs, to analyze the effects of changing land use and water control facility development on river system performance. Thus, the model not only provides definitive data concerning the existing and probable future behavior of the river system but also contributes to the attainment of a basic understanding of the specific hydrologic relationships existing within the watershed.

The complete flood-flow simulation model developed for, and utilized in, the watershed planning effort consists of two submodels. The first, or "backwater," submodel is used to determine the flood stages accompanying predetermined discharges for all dams, bridges, and culverts within the watershed and for selected representative channel cross sections working in an upstream direction from the watershed outlet. In addition, the output from this submodel provides the basis for determining whether channel routing or reservoir routing procedures are to be applied to each channel reach in the computation of flood inflows and outflows by the second, or flood-routing, submodel. The latter submodel is used to determine peak flood discharge through simulation of the runoff and movement of floodwaters as this runoff and movement occur in nature from the head of the watershed to the outlet. In addition, the flood-routing submodel, utilizing the stage-discharge relationships obtained from the backwater model, determines the final stages accompanying the flood discharges. These two models used in sequence provide the definitive data on flood flows—flood stage and discharge—necessary not only for sound watershed planning but also for the sound regulation of land use development in the riverine areas of the watershed. Figure 62 summarizes the essential features of the flood-flow simulation model.

In the complete flood-flow simulation process, the backwater simulation model is used first to develop inputs to the flood-routing submodel by calculation of stage-discharge-volume tables for impoundment-controlled channel reaches and stage-discharge-area tables for channel and overbank flow-controlled channel reaches. The classification of the river reaches as being impounded or non-impounded is made through an examination of the water surface profiles implied by the stage-discharge relationships developed by application of the backwater submodel. The flood-routing submodel, utilizing the inputs from the backwater submodel, as well as additional inputs relating to the hydrologic and hydraulic characteristics of the watershed, was then used to determine the watershed-wide distribution of flood flows and river stages for floods of specific recurrence intervals.

Figure 62

Flood-Flow Simulation Model

<table>
<tr><td colspan="2">

I - Input

</td></tr>
<tr><td>

Natural Resource Base Data

1. Topography
2. Soil and Vegetal Characteristics
3. Channel—Overbank Conditions
4. Precipitation

</td><td>

Cultural Data

1. Land Use
2. Water Control Structures
3. Channel Alterations

</td></tr>
<tr><td colspan="2">

II - Backwater Submodel

1. Compute stage-discharge relationships at structures and other critical points.
2. Define impounded and non-impounded river reaches.

</td></tr>
<tr><td colspan="2">

III - Flood-Routing Submodel

1. Convert rainfall volume to runoff volume for each sub-basin.
2. Establish time distribution of sub-basin runoff.
3. Synthesize streamflow by combining sub-basin contributions.
4. Modify streamflow to reflect channel and impoundment storage effects. (Note: this process utilizes hydraulic characteristics as determined by the backwater submodel.)
5. Summarize runoff volume, peak discharge, and corresponding stage at structures and other critical points.

</td></tr>
<tr><td colspan="2">

IV - Calibration

Compare simulated results to flood volumes, discharges, and stages as measured during an actual historical flood event.

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<tr><td colspan="2">

V - Application

Calculate flood volume, discharge, and stage throughout the river system for:
1. Different flood return periods and levels of urbanization.
2. Different flood return periods and channel-reservoir modifications.

</td></tr>
</table>

Source: Harza Engineering Company and SEWRPC.

Backwater Submodel

In order to establish floodwater surface profiles along a river system, flood discharges must be related to high water surface elevation (stages) at channel obstructions, such as bridges; in storage areas behind dams or other water control structures; and in all intervening reaches of the channel. Each of these types of stage-discharge relationships is established in a slightly different manner. Since it is not practicable to establish by measurement actual stage-discharge relationships along an entire river system, these relationships must be established by use of analytical procedures.

Water levels in a river system are a function of discharge; channel, floodway, and floodplain size, shape, slope, and hydraulic friction; man-made obstructions; and downstream water levels. Therefore, the determination of stage-discharge relationships at various locations along a river system requires an evaluation of the physical characteristics of the channel system and an engineering procedure for calculating water surface elevations that accounts for both physical characteristics and downstream water levels.

Method of Computation: Stage-discharge relationships were established at 694 locations in the 216 miles of channel length studied. This number includes the relationships developed for the upstream and downstream sides of 243 dams, bridges, and culvert installations and 208 representative channel and floodplain sections. The necessary computations were performed using an IBM-1130 electronic computer. In addition to performing stage-discharge computations, the program calculates flow areas at each cross section and determines the number of acres inundated and the volume of storage between cross sections for each specified discharge. Cross-sectional flow areas and volume of storage thus derived were used in the flood-routing procedure.

The U. S. Army Corps of Engineers computer program, "Backwater—Any Cross Section,"[1] was used to compute water surface elevations corresponding to specified flow rates at selected locations along the river channel. The effects of various hydraulic structures, such as bridges, culverts, weirs, embankments, and dams, were considered in the computation. River conditions, such as variable channel and overbank roughness, islands, bends, and junctions of streams, were also considered.

The computational procedure, known as the "standard step method," applies Bernoulli's theorem for the total energy at each cross section and Manning's formula for the friction head loss between cross sections. Energy losses resulting from expansion or contraction of flow due to changes in cross sections and from bridge or culvert losses are also computed.

Program inputs include river cross sections, distances between sections, roughness coefficients, flow rates, and changes in flow rates. Structure data, such as the bridge waterway opening, top of roadway and low chord elevations, and pier head loss coefficients, are also entered as inputs. Computations proceed upstream from a known or computed water surface elevation at a selected downstream cross section. The Bernoulli equation is used to balance the total energy at any two consecutive locations. Since the water surface elevation is known at the initial cross section, the water surface elevation at the next upstream section can be computed from the energy balance.

Energy losses caused by structures, such as bridges and culverts, are computed in two steps. First, the losses due to expansion and contraction of the cross section on the upstream and downstream sides of the structure are computed. Second, the loss caused by the structure itself is determined.

Bridge and culvert losses are computed for open channel flow, pressure flow, and weir flow or for any combination of these types of flow. Open channel flow occurs when the water surface elevation is below the low chord of the bridge, and head losses are caused by contraction and expansion of the flow through the waterway opening and around pier obstructions. Pressure flow occurs when the water surface elevation is above the low chord of the bridge but below the surface of the roadway. An orifice flow equation is used for pressure flow. Weir flow over the roadway and pressure flow through the bridge opening occur when the water surface elevation overtops the roadway.

Determination of Channel and Floodplain Characteristics: Channel, floodway, and floodplain size and shape were obtained from cross-sectional drawings of the riverine area. Channel cross sections were obtained for 53 locations from data gathered by the U. S. Army Corps of Engineers in a 1960 survey of the main stem of the Milwaukee River between Waubeka and Milwaukee. Additional channel sections were surveyed at 75 locations throughout the Milwaukee River system by the Commission and Harza Engineering Company staff. Corresponding overbank sections were determined from U. S. Geological Survey 7 1/2-

[1] *Hydrologic Engineering Center Computer Program 22-J2-L212, U. S. Army Engineer District, Sacramento, California, October 1966.*

minute and 15-minute topographic maps, from 1" = 100' scale, 2-foot contour interval, topographic maps available from the Villages of Brown Deer and River Hills, and from 1" = 200' scale, 2-foot-4-foot contour interval, topographic maps available from the Commission.

The physical characteristics of road and railway embankments, bridges, culverts, and water control structures were obtained from engineering drawings of each structure prepared by the Commission. The drawings were developed from field surveys made of each structure by the firm of Alster & Associates, Inc., photogrammetric and control survey engineers, under contract to the Commission. All elevations were referenced to Mean Sea Level Datum, 1929 Adjustment, as established by the U. S. Coast and Geodetic Survey; and second order bench marks were set on or near each structure surveyed.

Channel slopes were estimated using elevations of the channel bottom determined as part of the field survey of the channel and structure cross sections, and distances between the cross sections, measured on 1" = 400' scale aerial photographs. It was generally assumed that a constant channel slope existed between the cross sections, except where topographic maps indicated a pronounced break in slope between the cross sections.

Hydraulic friction is a relative measure of the ability of the channel, floodway, and floodplain to pass or retard flow. Channel, floodway, and floodplain retardance, as represented by the "n" value in the Manning formula, was estimated on the basis of field observation of channel, floodway, and floodplain characteristics at each cross-section location. Values were estimated as the sum of the amounts attributable to various factors, as summarized in Table 100. Separate estimates of "n" were made for the channel and the overbank sections. Values of "n" used in this study were based on summer, or growing season, conditions.

Determination of Water Surface Elevations: As already noted, the procedure used to develop the relation between water surface elevation and discharge combines the hydraulic relationships established in the Manning formula with the Bernoulli theorem or conservation of energy principle. In this combination, Manning's formula is used to estimate the loss of energy between two points along the channel; and the conservation of energy principle is used to determine the depth of flow. The actual determination of water surface elevations requires a trial and error solution utilizing cumbersome mathematical equations and will not be discussed here.[2]

In order to evaluate the effects of downstream water levels on upstream elevations, backwater computations were initiated at the North Avenue dam and carried systematically upstream from one cross section to the next. When structures that raise water levels above natural flow elevations were encountered, the computations were terminated; and a new set of computations, based upon a stage-discharge relationship which was established at the structure, was begun.

Stage-Discharge Relationships-Channel Sections: At all cross sections, a water surface elevation was determined for each of five selected discharges. These five discharges were selected so as to well define the rating curve for each cross section, with no particular regard for flood frequency occurrence, except that an attempt was made to define the rating curve beyond the anticipated 100-year flood level and below the 10-year flood level. In order to reflect the variation in discharge that occurs between locations of two cross sections, discharge values were assumed to be proportional to the 0.6 power of the ratio of the drainage area upstream from the section to the total drainage area. This means that, when a water surface elevation was established at a cross section, a higher discharge was assumed to be occurring at the same instant at downstream cross sections. Stage-discharge relationships were developed using the five established points for each cross section. Figure 63 shows a typical stage-discharge curve for a cross section of the channel and overbank section.

Stage-Discharge Relationships-Water Control Structures: Figure 64 shows the stage-discharge curve developed by standard weir formulas and measured structural characteristics for the North Avenue Dam in Milwaukee. This curve is typical of discharge rating curves developed for water control structures in the watershed. These curves were used to establish starting elevations for stage-discharge computations. Fifteen structures have water control facilities, such as gates or flashboards, that can be manually operated to adjust stage-discharge relationships. In this

[2] *Ibid, footnote 1.*

TABLE 100

CHANNEL FRICTION COMPONENTS FOR USE IN EVALUATION OF CHANNEL AND OVERBANK ROUGHNESS COEFFICIENTS UTILIZED IN THE MANNING FORMULA

COMPONENT	PARTIAL 'N' VALUE
CHARACTER OF CHANNEL	
CHANNELS IN EARTH..................................	0.020
CHANNELS CUT IN ROCK...............................	0.025
CHANNELS IN FINE GRAVEL............................	0.024
CHANNELS IN COARSE GRAVEL..........................	0.028
DEGREE OF SURFACE IRREGULARITY	
SMOOTH...	0.000
MINOR..	0.005
MODERATE...	0.010
SEVERE...	0.020
VARIATION OF CROSS-SECTION SIZE AND SHAPE	
GRADUAL..	0.000
OCCASIONAL...	0.005
FREQUENT...	0.010-0.015
OBSTRUCTIONS (STUMPS, BOULDERS, FENCES, LOGS)	
NEGLIGIBLE...	0.000
MINOR..	0.015
APPRECIABLE..	0.030
SEVERE...	0.060
EFFECT OF VEGETATION	
LOW..	0.005-0.010
MEDIUM...	0.010-0.025
HIGH...	0.025-0.050
VERY HIGH..	0.050-0.100

ADJUSTMENT IN FRICTION FACTOR FOR CHANNEL MEANDERING

DEGREE OF MEANDERING	RATIO OF MEANDER LENGTH[a] TO STRAIGHT LENGTH	FACTOR[b] TO BE APPLIED TO TOTAL 'N'
MINOR.......	1.0 - 1.2	1.00
APPRECIABLE.	1.2 - 1.5	1.15
SEVERE......	OVER 1.5	1.30

[a]EQUIVALENT STRAIGHT LINE LENGTH MEASURED ALONG THREAD OF CHANNEL.

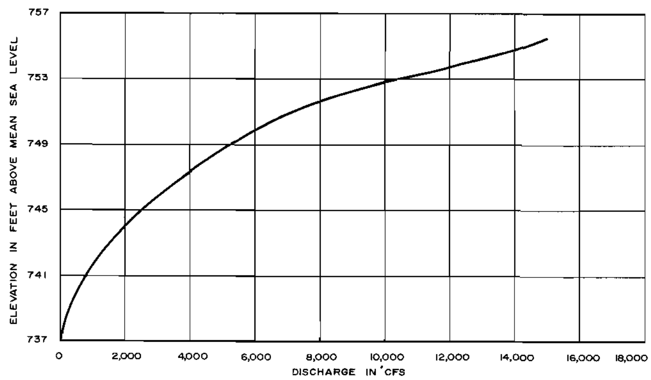
[b]THIS FACTOR IS USED TO MULTIPLY TOTAL 'N' VALUE DERIVED BY ADDING PARTIAL VALUES.

SOURCE- SUPPLEMENT B, U.S. SOIL CONSERVATION SERVICE ENGINEERING HANDBOOK, SECTION 5, 'HYDRAULICS.'

study it was assumed that, where operable, gates would be completely opened and flashboards removed when water levels rose to within one foot of the top of the dam.

Stage-Discharge Relationships-Bridges and Culverts: Bridge and culvert installations raise upstream water levels above downstream water levels by an amount approximately equal to the loss of energy that occurs as water passes through the structure. The change in water surface elevation at bridges and culverts was calculated using a procedure developed by the U. S. Army Corps of Engineers. This procedure estimates the total change in water surface elevation between cross sections immediately upstream and downstream

Figure 63
STAGE-DISCHARGE CURVE
MILWAUKEE RIVER MAIN STEM
NEAR SAUKVILLE (RM 35.84)



Source: Harza Engineering Company.

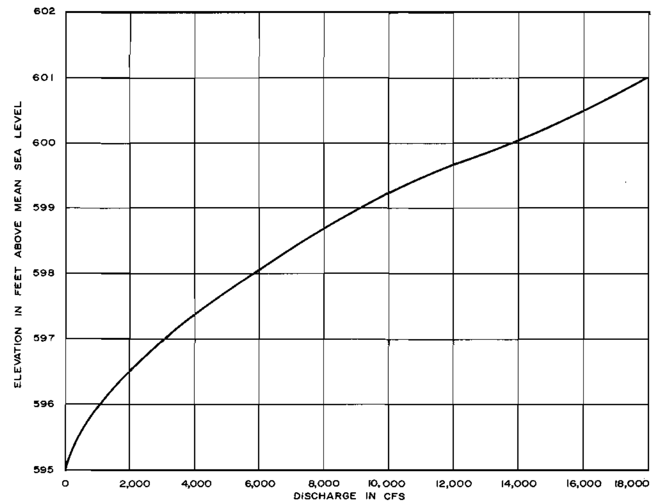
from the structure as the sum of the head losses attributable to flow contraction, friction, and obstructions in the opening. Circular culverts were converted to equivalent rectangular shapes having equal flow areas and treated in the same manner as bridges. Flows over road or railway embankments are computed using standard broad-crested weir formulas.

Flood-Routing Submodel

The factors that determine the characteristics of the flood flows in a watershed can be separated into three principal groups. One group of factors relates to the amount of runoff that occurs within the watershed and thus can be used to establish the total volume of the flood flows. The second group relates to the time distribution of the runoff and thus can be used to establish the manner in which the runoff will be distributed over time. The third group relates to the hydraulic performance of the river system itself and thus can be used to establish the extent to which the flood flow will be modified as it progresses through the river system and to establish the resulting high water elevations. Flood simulation, accordingly, involves three basic steps: 1) estimation of the amount of runoff, 2) development of the time distribution of runoff, and 3) determination of how the runoff moves through the river system and how the flood flows are modified by that system.

The flood-routing submodel developed for, and applied in, the Milwaukee River watershed study follows the three steps described above. This submodel, developed by the U. S. Soil Conservation Service and entitled, "Project Formulation Hydrology," is essentially the same model used by the Commission in all of its watershed studies to

Figure 64
STAGE-DISCHARGE CURVE
MILWAUKEE RIVER MAIN STEM
NORTH AVENUE DAM (RM 3.10)



Source: Harza Engineering Company.

date.[3] The complete hydrologic simulation model applied in the Root River watershed study differed somewhat from the models used in the Fox and Milwaukee River watershed studies in that: 1) in the Root River study, the stage-discharge-volume relationships were developed by application of the "normal depth" method of computation rather than by the "backwater" method of computation; 2) in the Root River study, only the storage-indication method of flood routing was used; and 3) in the Root River study, the model was programmed for an IBM Model 1620 computer instead of for an IBM Model 1130 and a UNIVAC Model 1108 computer.

Method of Computation: The flood-routing submodel is based on established mathematical relationships between physical characteristics of the watershed and surface water runoff. The submodel considers soil type, land use and treatment, the amount of precipitation, and antecedent moisture condition to be the factors that determine the amount of runoff; watershed size, shape, slope, overall hydraulic efficiency, and the pattern of precipitation as the main determinants of the pattern of runoff; and channel size, shape, slope, hydraulic friction, and man-made obstruction as the variables that affect the movement of flood flows through the stream system. The flood-routing submodel, as applied to the Milwaukee River wa-

[3] *U. S. Soil Conservation Service, Engineering Division, Technical Release No. 20, Computer Program for Project Formulation-Hydrology, May 1965.*

tershed, was used to simulate floods of selected frequency under both present and future land use development within the watershed and to evaluate the effect of various proposed water control facilities on flood levels and discharges in the river system.

The submodel was programmed for use on a UNIVAC 1108 computer. The complete Fortran computer program used to perform the calculations in the model is on file in the Commission offices. The computer program was used to simulate mathematically conditions along the principal channels of the watershed (see Table 101 and Map 57), consisting of the main stem of the Milwaukee River, the North, East, and West branches of the Milwaukee River, and four tributaries—Lincoln Creek, Cedar Creek, Silver Creek, which passes through the City of West Bend, and Silver Creek, which passes through the Village of Random Lake—and the outlet channel from Crooked Lake.

The basic relationships used in the flood-routing submodel for determining the movement of flood runoff through the waterways are the convex method of routing in channels and the storage indication method of routing where pondage occurs. Simulation is begun with the calculation of the amount of runoff caused by rainfall or snowmelt or a combination of both. Rainfall or snowmelt depth, duration, and intensity and antecedent soil moisture conditions are entered into the model, which calculates discharge hydrographs at the outlets of each of a number of rationally delineated sub-basins. At each sub-basin input point to the channel system over which the flood routing is being simulated, the flow is increased for the tributary input. The effects of channel and impoundment storage at various locations between the sub-basin input points are computed, and the discharge accordingly adjusted. The resulting discharge values are used as inputs to the calculations for the succeeding reach.

TABLE 101

PORTIONS OF THE MILWAUKEE RIVER WATERSHED STREAM SYSTEM INCORPORATED IN THE FLOOD-FLOW SIMULATION MODEL

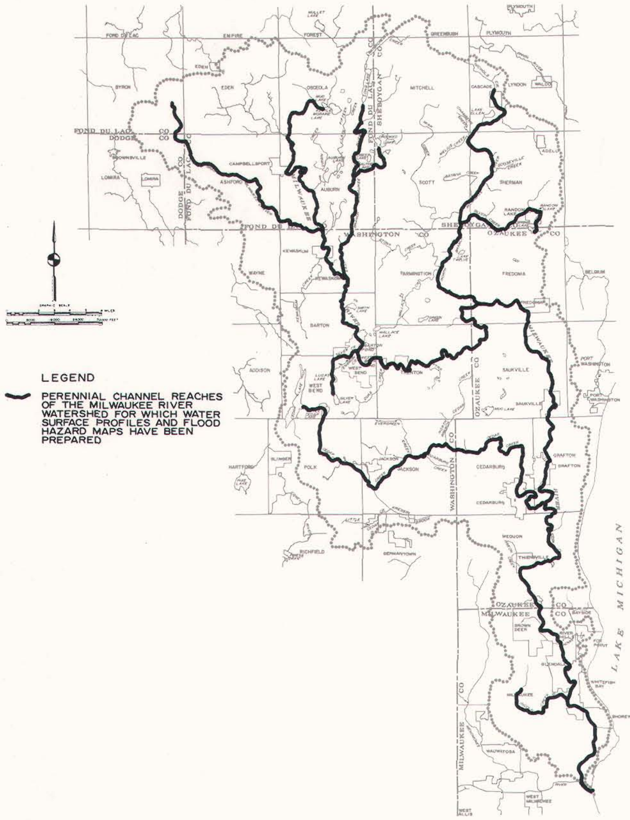
CHANNEL NAME	FROM (RIVER MILES)[a]	TO (RIVER MILES)[a]	LENGTH (MILES)
MILWAUKEE RIVER (MAIN STEM)	RM 96.88 AT THE OUTLET OF MUD LAKE	RM 0.00 IN THE HARBOR AT THE LAKE MICHIGAN SHORELINE	96.88
WEST BRANCH	RM 100.36 THIRTEEN MILES UPSTREAM FROM ELMORE	RM 79.49 AT THE CONFLUENCE WITH THE MILWAUKEE RIVER	20.87
EAST BRANCH	RM 92.24 AT THE OUTLET OF LONG LAKE	RM 74.27 AT THE CONFLUENCE WITH THE MILWAUKEE RIVER	17.97
CROOKED LAKE CREEK	RM 90.06 AT THE OUTLET OF CROOKED LAKE	RM 84.93 AT THE CONFLUENCE WITH THE EAST BRANCH	5.13
NORTH BRANCH	RM 70.56 ONE-HALF MILE UPSTREAM FROM CASCADE	RM 47.90 AT THE CONFLUENCE WITH THE MILWAUKEE RIVER	22.66
SILVER CREEK (SHERMAN TOWNSHIP)	RM 66.94 ONE-HALF MILE UPSTREAM FROM THE VILLAGE OF RANDOM LAKE	RM 57.34 AT THE CONFLUENCE WITH THE NORTH BRANCH	9.60
SILVER CREEK (WEST BEND TOWNSHIP)	RM 71.93 AT THE OUTLET OF SILVER LAKE	RM 67.31 AT THE CONFLUENCE WITH THE MILWAUKEE RIVER	4.62
CEDAR CREEK	RM 60.29 AT THE OUTLET OF BIG CEDAR LAKE	RM 27.57 AT THE CONFLUENCE WITH THE MILWAUKEE RIVER	32.72
LINCOLN CREEK	RM 13.61 AT SILVER SPRING DRIVE	RM 7.86 AT THE CONFLUENCE WITH THE MILWAUKEE RIVER	5.75
		TOTAL	216.20

[a]RIVER MILES ON THE MAIN STEM OF THE MILWAUKEE RIVER ARE MEASURED IN AN UPSTREAM DIRECTION BEGINNING WITH RM 0.00 IN THE HARBOR AT THE LAKE MICHIGAN SHORELINE. RIVER MILE STATIONING ON ALL STREAMS TRIBUTARY TO THE MILWAUKEE RIVER, OR ONE OF ITS TRIBUTARIES, IS ALSO REFERENCED TO STATION 0.00 AT THE LAKE MICHIGAN SHORELINE. THEREFORE, THE RIVER MILE STATION OF ANY POINT IN THE CHANNEL SYSTEM INDICATES THE LINEAL DISTANCE, MEASURED ALONG THE PRINCIPAL CHANNELS, BETWEEN THAT POINT AND STATION 0.00 AT THE LAKE MICHIGAN SHORELINE.

SOURCE- HARZA ENGINEERING COMPANY AND SEWRPC.

Map 57

CHANNEL REACHES FOR WHICH WATER SURFACE PROFILES HAVE BEEN PREPARED IN THE MILWAUKEE RIVER WATERSHED



The flood-flow simulation model developed in the watershed study was used to prepare 10- and 100-year recurrence interval flood high-water surface profiles along 216 miles of stream channel within the watershed. Included in this total are the entire main stem of the Milwaukee River; the North, East, and West Branches of the Milwaukee River; and four major tributaries--Lincoln Creek, Cedar Creek, Silver Creek (Sheboygan County), and the outlet channel from Crooked Lake.

Source: SEWRPC.

This procedure is repeated for all reaches in the stream system to the stream outlet. Reaches are established between points of the stream system at which significant changes occur in channel and related floodplain section and slope; channel and floodplain "roughness"; at dams, bridges, and culverts; and at major tributary points.

Delineation of Hydrologic Sub-Basins: In order to provide a manageable basis for the identification and analysis of topography, soil type, and land use and treatment, the entire Milwaukee River watershed was divided into 63 hydrologic sub-basins, ranging from 2.4 to 21.4 square miles in size. The sub-basins are shown on Map 58, together with the hydrologic soil group predominant in each sub-basin. Most of the 63 sub-basins also provided the geographic basis for the development of hydrographs; that is, graphs showing the changes in the discharge of a stream over time. It was determined, however, that, in order to best represent the progressive contribution of runoff water along the entire length of the river system, two of the 63 sub-basins should be further subdivided. Thus, hydrographs were developed for 66 individual sub-basins. These additional sub-basins are also shown on Map 58. The 66 hydrographs representing the runoff characteristics of the individual sub-basins were generated by computer, utilizing, as input to the computer program, sub-basin area, time of concentration, weighted hydrologic curve number, precipitation, and a dimentionless or generalized hydrograph. In the operation of the flood-routing submodel, the individual sub-basin hydrographs were transformed into composite hydrographs representing the runoff characteristics of the watershed at critical points along the stream channel system. This transformation was accomplished by a process of cumulative addition of the hydrographs. The shape of the hydrograph is changed between the selected critical points along the stream channel to reflect the effects of channel storage.

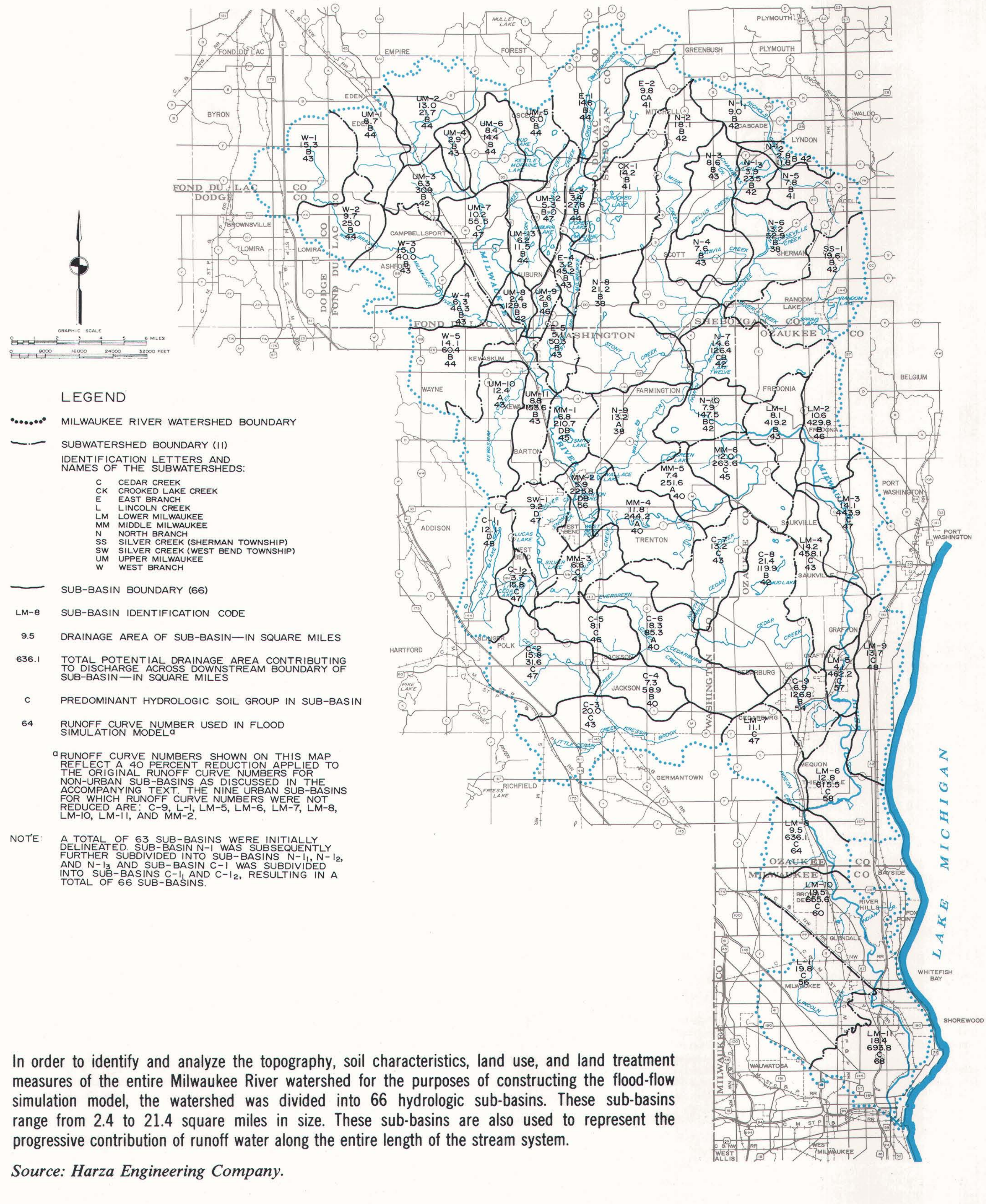
Estimation of Runoff: Soil properties influence the process of runoff generation and must be considered in runoff estimation. When runoff from individual storms is the major concern, as in simulation of floods due to rainfall, the soil properties can be represented by a hydrologic parameter taken as the minimum rate of infiltration obtained for the bare soil after prolonged wetting. The influences on runoff of both the surface and the various sub-surface horizons of a soil are thereby considered. The influence of ground cover is treated independently, as described below. The hydrologic parameter, indicating the runoff potential of a soil, is the basis for classification of all soils into four hydrologic soil groups:

1. Group A—representing soils having a low runoff potential due to high infiltration rates. These soils consist primarily of deep, well-drained sands and gravels.

2. Group B—representing soils having a moderately low runoff potential due to moderate infiltration rates. These soils consist primarily of moderately deep to deep and moderately well to well-drained soils, with moderately fine to moderately coarse textures.

Map 58

HYDROLOGIC SUB-BASINS OF THE MILWAUKEE RIVER WATERSHED



In order to identify and analyze the topography, soil characteristics, land use, and land treatment measures of the entire Milwaukee River watershed for the purposes of constructing the flood-flow simulation model, the watershed was divided into 66 hydrologic sub-basins. These sub-basins range from 2.4 to 21.4 square miles in size. These sub-basins are also used to represent the progressive contribution of runoff water along the entire length of the stream system.

Source: Harza Engineering Company.

3. Group C—representing soils having a moderately high runoff potential due to slow infiltration rates. These soils consist primarily of soils in which a layer exists near the surface that impedes the downward movement of water or soils with moderately fine to fine texture.

4. Group D—representing soils having a high runoff potential due to very slow infiltration rates. These soils consist primarily of clays with high swelling potential, soils with permanently high water tables, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious parent material.

Detailed soils maps of the entire watershed prepared for the Commission by the U. S. Department of Agriculture, Soil Conservation Service (SCS), were used to identify the predominant soil types in each sub-basin. All soil types occurring in the Milwaukee River watershed were classified into one of the four hydrologic soil groups, as indicated in Appendix C of SEWRPC Planning Guide No. 6, Soils Development Guide, August 1969. This classification was made as an integral part of the soil interpretations accompanying the regional soil survey.

In view of the availability of detailed soils data for the entire watershed, the SCS Runoff-Curve-Number system was used for calculating the runoff resulting from a given depth and duration of rainfall. This method assigns runoff curve numbers to a range of hydrologic, soil, and surface condition complexes comprised of varying combinations of hydrologic soil groups and agricultural land uses, as shown in Table 102. The method thus incorporates the effects of surface conditions on runoff as indicated by the type of land use or cover and the treatment or practice existing or anticipated within each hydrologic sub-basin. Land use and cover in this context refer to such surface conditions as the presence or absence of vegetation, litter, bare soil, water surfaces, and impervious surfaces, such as pavements and roofs, while land treatment refers to certain agricultural practices, such as contouring, terracing, grazing control, and crop rotation. The term "hydrologic condition," used as a column heading in Table 102, refers to the infiltration and retention characteristics accompanying the method of land use. In the case of row crops, small grain, and legumes or rotation meadow, hydrologic condition is based on the sequence of crop rotation, ranging from good, when the rotation includes legumes or grasses, to poor, when a row crop is planted year after year. In the case of pasture or range, heavily grazed pasture would be classified as fair and lightly grazed as good (having 75 percent or more vegetative cover). In the case of woodland, heavily grazed or burned areas would be classified as poor, while those that are ungrazed would be classified as excellent.

The Runoff-Curve numbers also vary with the antecedent soil moisture condition, defined as the amount of rainfall occurring in a selected period preceding a given storm. In general, the greater the antecedent rainfall, the more direct runoff there is from a given storm. A five-day period is used as the basis for estimating antecedent moisture conditions. Soil moisture conditions also vary during a storm. Heavy rain falling on a dry soil can change the soil moisture condition from dry to average to wet during the period of the storm. Table 103 lists the rainfall groups for estimating antecedent soil moisture conditions.

Weighted average runoff curve numbers were calculated at the normal antecedent soil moisture condition for sub-basins having mixed land uses or treatment practices. The proportion of each hydrologic sub-basin occupied by various land uses was obtained from the SEWRPC 1967 land use inventory for present conditions and from the SEWRPC adopted regional land use plan for future conditions. Estimates of the proportion of each hydrologic sub-basin under various land treatment practices were obtained from the publication "Assessor Farm Statistics," Wisconsin Statistical Reporting Service, 1967.

Urban areas were represented by weighted average runoff curve numbers calculated by assuming the area to consist of lawns or open space (pervious) and paved or roofed (impervious) areas. The proportions of impervious area assumed for each of the major urban land use categories are summarized in Table 104. A runoff curve number of 96 was assigned to paved and roofed areas. Urban lawns and open space were considered comparable to good agricultural pasture.

Empirical curves relating runoff to rainfall for various runoff curve numbers are shown in Figure 65. These curves were prepared by the SCS

TABLE 102

RUNOFF CURVE NUMBERS FOR HYDROLOGIC SOIL COVER COMPLEXES[a]
(FOR WATERSHED MOISTURE CONDITION II)[b]

LAND USE OR COVER	TREATMENT OR PRACTICE	HYDROLOGIC CONDITION[c]	RUNOFF CURVE NUMBERS BY HYDROLOGIC SOIL GROUP A	B	C	D
FALLOW	STRAIGHT ROW	--	77	86	91	94
ROW CROPS	STRAIGHT ROW	POOR	72	81	88	91
	STRAIGHT ROW	GOOD	67	78	85	89
	CONTOURED	POOR	70	79	84	88
	CONTOURED	GOOD	65	75	82	86
	CONTOURED & TERRACED	POOR	66	74	80	82
	CONTOURED & TERRACED	GOOD	62	71	78	81
SMALL GRAIN	STRAIGHT ROW	POOR	65	76	84	88
	STRAIGHT ROW	GOOD	63	75	83	87
	CONTOURED	POOR	63	74	82	85
	CONTOURED	GOOD	61	73	81	84
	CONTOURED & TERRACED	POOR	61	72	79	82
	CONTOURED & TERRACED	GOOD	59	70	78	81
CLOSE-SEATED LEGUMES[d] OR ROTATION MEADOWS	STRAIGHT ROW	POOR	66	77	85	89
	STRAIGHT ROW	GOOD	58	72	81	85
	CONTOURED	POOR	64	75	83	85
	CONTOURED	GOOD	55	69	78	83
	CONTOURED & TERRACED	POOR	63	73	80	83
	CONTOURED & TERRACED	GOOD	51	67	76	80
PASTURE OR RANGE		POOR	68	79	86	89
		FAIR	49	69	79	84
		GOOD	39	61	74	80
	CONTOURED	POOR	47	67	81	88
	CONTOURED	FAIR	25	59	75	83
	CONTOURED	GOOD	6	35	70	79
MEADOW (PERMANENT)		GOOD	30	58	71	78
WOODS (FARM WOODLOTS)		POOR	45	66	77	83
		FAIR	36	60	73	79
		GOOD	25	55	70	77
FARMSTEADS		--	59	74	82	86
ROADS[e] (DIRT)		--	72	82	87	89
(HARD SURFACE)		--	74	84	90	92

[a]ENGINEERING HANDBOOK, SECTION 4, 'HYDROLOGY,' U.S. DEPARTMENT OF AGRICULTURE, SOIL CONSERVATION SERVICE, 1957.

[b]MOISTURE CONDITION II IS DEFINED AS 1.4 TO 2.1 INCHES OF RAINFALL IN THE PRECEDING FIVE DAYS.

[c]HYDROLOGIC CONDITION IS DEFINED AS THE RAINFALL RETENTION CHARACTERISTICS OF THE LAND USE OR COVER AND THE TREATMENT OR PRACTICE.

[d]CLOSE-DRILLED OR BROADCAST.

[e]INCLUDING RIGHT-OF-WAY.

SOURCE- U.S. DEPARTMENT OF AGRICULTURE, SOIL CONSERVATION SERVICE.

TABLE 103

RAINFALL GROUPS FOR ANTECEDENT SOIL MOISTURE CONDITIONS DURING GROWING SEASON

ANTECEDENT CONDITION	CONDITION DESCRIPTION	FIVE-DAY ANTECEDENT RAINFALL (INCHES)
I	AN OPTIMUM CONDITION OF WATERSHED SOILS, WHERE SOILS ARE DRY BUT NOT TO THE WILTING POINT, AND WHEN SATISFACTORY PLOWING OR CULTIVATION TAKES PLACE.	<1.4
II	THE AVERAGE CASE FOR ANNUAL FLOODS.	1.4-2.1
III	WHEN A HEAVY RAINFALL, OR LIGHT RAINFALL AND LOW TEMPERATURES, HAVE OCCURRED DURING THE FIVE DAYS PREVIOUS TO A GIVEN STORM.	>2.1

SOURCE- U.S. SOIL CONSERVATION SERVICE.

TABLE 104

URBAN LAND USE IMPERVIOUS AREA RATIOS

LAND USE	NET LOT AREA PER DWELLING UNIT	DWELLING UNITS PER NET[a] RESIDENTIAL ACRE	PERSONS PER NET[a] RESIDENTIAL ACRE	PERSONS PER GROSS[b] SQUARE MILE	RATIO OF IMPERVIOUS AREA TO TOTAL AREA
LOW-DENSITY RESIDENTIAL......	20,000 SQ. FT. & OVER	0.2- 1.6	0.6- 5.5	350- 3,499	15%
MEDIUM-DENSITY RESIDENTIAL...	6,000-19,999 SQ. FT.	1.6- 4.6	5.5-15.6	3,500- 9,999	30%
HIGH-DENSITY RESIDENTIAL.....	UNDER 6,000 SQ. FT.	4.6-11.4	15.6-39.1	10,000-25,000	60%
COMMERCIAL-INDUSTRIAL........	--	--	--	--	92%

[a]NET RESIDENTIAL AREA IS DEFINED AS THE AREA OF LAND ACTUALLY DEVOTED TO RESIDENTIAL USE WITHIN SITE BOUNDARIES AND INCLUDES THE BUILDING GROUND AREA COVERAGE, TOGETHER WITH THE NECESSARY ON-SITE YARDS AND OPEN SPACES.

[b]GROSS RESIDENTIAL AREA IS DEFINED AS THE NET AREA DEVOTED TO A GIVEN USE PLUS THE AREA DEVOTED TO SUPPORTING LAND USES, SUCH AS STREETS, PARKS, SCHOOLS, CHURCHES, AND NEIGHBORHOOD SHOPPING CENTERS.

SOURCE- SEWRPC.

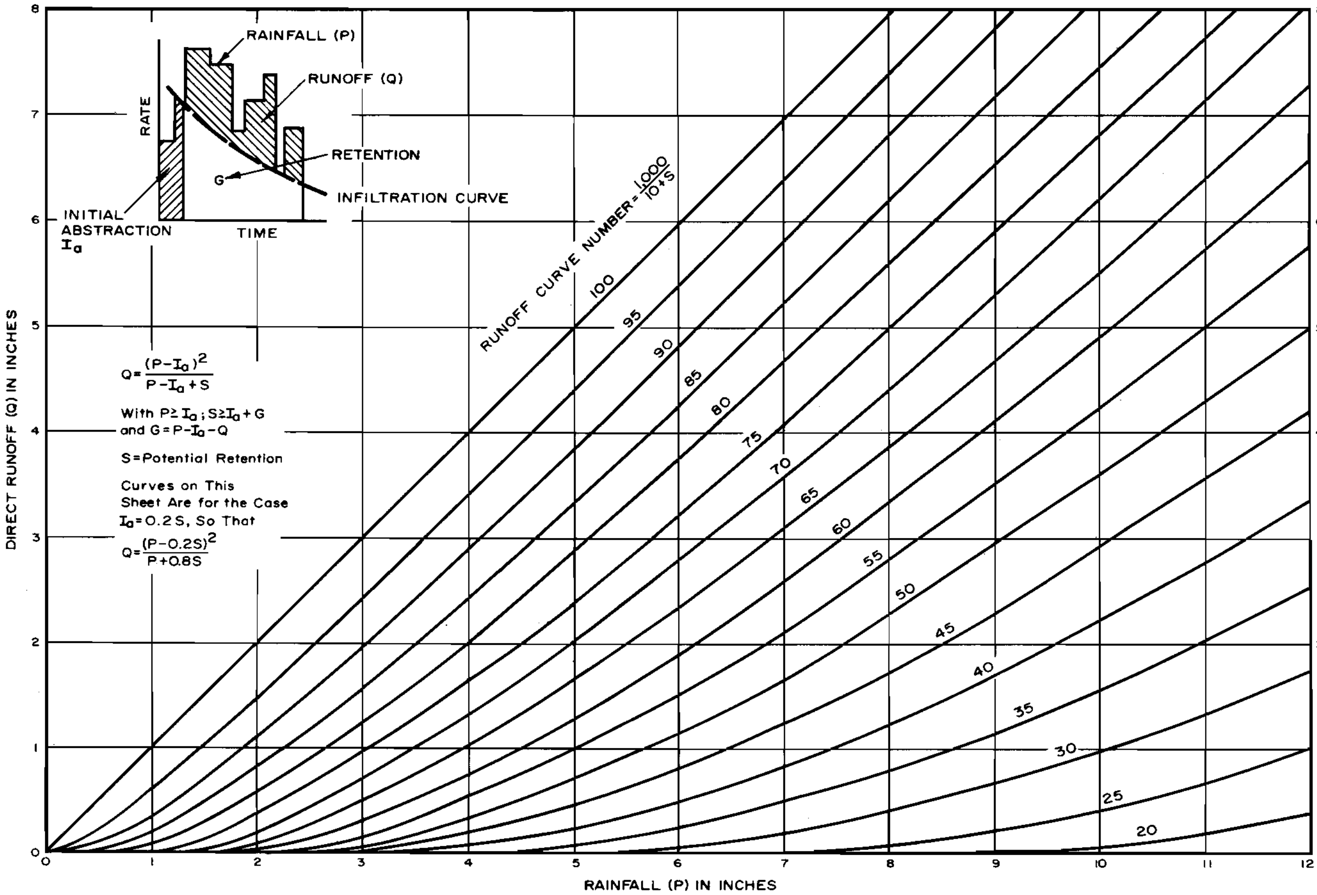
using data from gaged watersheds with known soils and cover and generally represent small catchment areas of one square mile or less in extent. The curves indicate the runoff which may be expected to result from rainfall of 24-hour duration or less on unfrozen ground and served as a basis for estimating the amount of runoff produced by selected rainfalls.

The weighted average runoff curve numbers were then checked by calculating the runoff volumes for the June 1940 flood and comparing these calculated volumes to the corresponding volumes as actually measured at the Cedar Creek and Milwaukee River stream gages. Runoff volumes computed by using the SCS generalized procedure were found to be somewhat larger than the actual recorded event. Analysis of the differences indicated that the numerous lake wetlands and kettle moraine areas within the Milwaukee River watershed provide more floodwater storage than that indicated by the generalized runoff curve numbers prepared for more typical agricultural watersheds. Based upon further analyses of the 1924 and 1940 rainfall floods in the watershed, a 40 percent reduction, at the normal antecedent condition, was applied to the runoff curve numbers for nonurban sub-basins of the watershed to account for the retarding influence on runoff of the large areas of the watershed covered by lakes, wetlands, and kettles. The revised runoff curve numbers are shown on Map 58 and were found to reproduce the 1940 measured flood event.

Time Distribution of Runoff: A major objective of the hydrologic and hydraulic studies is to determine the distribution of flood flows and water levels throughout the entire channel system. Since only two long-term gaging stations existed within the watershed, both in downstream areas, it was necessary to synthesize the flood flows in the remainder of the watershed. This is done by gen-

Figure 65

RAINFALL-RUNOFF RELATIONSHIPS FOR HYDROLOGIC SOIL-COVER COMPLEX RUNOFF CURVE NUMBERS



Source: U.S. Soil Conservation Service.

erating a simple natural hydrograph[4] for each of the 66 individual sub-basins in the watershed. Figure 66 shows a typical simple natural hydrograph, together with the rainfall and the effects of antecedent soil moisture conditions on infiltration rates resulting in the runoff.

Characteristics of the simple natural hydrograph vary with the size, shape, and slope of the tributary drainage area. The most significant characteristics are the "basin lag," which may be defined as the time from the center of mass of rainfall excess to the hydrograph peak, and the "peak discharge" for a given rainfall. Steep slopes, compact shape, and an efficient channel network tend to make lag time short and peaks high, while flat slopes, elongated shape, and an inefficient channel network tend to make lag times long and peaks low.

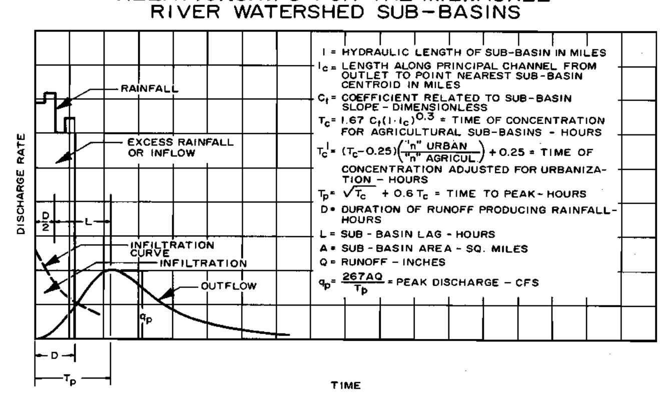
[4] *A "simple natural hydrograph" is a graph showing, for a given point on a stream, the discharge with respect to time occurring as the result of a discreet meteorological-hydrological event.*

Basin lag, (L), measured in hours, and time of concentration, (T_c), measured in hours, are related by the empirical equation:

$$L = 0.6\ T_c \qquad \text{(a)}$$

Figure 66

SIMPLE OUTFLOW HYDROGRAPH AND EMPIRICAL RELATIONSHIPS FOR THE MILWAUKEE RIVER WATERSHED SUB-BASINS



Source: U.S. Soil Conservation Service and Harza Engineering Company.

The time of concentration, (T_c), is defined as the time required for a particle of water to travel from the hydraulically most distant point of a drainage area to its outlet.

Lag was determined by using the equation:

$$L = C_t\ (l \cdot l_c)^{0.3} \qquad \text{(b)}$$

where:

l = distance from sub-basin outlet to hydraulically most remote point of sub-basin or length of main stream from the sub-basin inlet to outlet in miles.

l_c = distance from the point on the watercourse nearest the sub-basin centroid to the outlet in miles.

C_t = a dimensionless coefficient related to sub-basin slope.

The following equation for time of concentration was determined by combining equations a and b above:

$$T_c = 1.67\ C_t\ (l \cdot l_c)^{0.3} \qquad \text{(c)}$$

Values of C_t were calculated by Harza for the Knapp Creek watershed near Bloomingdale, Wisconsin, and the Mount Vernon Creek watershed near Mount Vernon, Wisconsin, watersheds having gaged outlets, utilizing Equation b above. These watersheds have drainage areas of 8.5 square miles and 16.1 square miles, respectively, and are topographically similar to many of the sub-basins of the Milwaukee River watershed. The C_t values so obtained were then used to calculate C_t values for each of the 66 sub-basins in the Milwaukee River watershed upon the assumption that C_t varied with slope according to the following relationship:

$$C_t = K\ (h/l)^{-0.385} \qquad \text{(d)}$$

where:

h = rim-to-mouth elevation difference in feet.

l = principal channel length in miles.

K = dimensionless coefficient of proportionality.

This equation is based upon the relationship derived by Kirpich[5] for small agricultural watersheds. The Kirpich equation was not used directly to determine times of concentration (T_c), as analses made during the SEWRPC studies of the Root and Fox River watersheds indicated that use of the equation to determine T_c produced attenuated hydrographs with too high a peak and too short a time base.

Equation c above is applicable to small rural watersheds in southeastern Wisconsin. Urban watersheds exhibit shorter concentration times because of higher flow velocities over paved areas and in storm sewers. Adjustments for increased velocities in urban areas were made by reducing the calculated time of concentration in direct proportion to the ratio of assumed hydraulic frictions of the drainage systems in urban and rural areas. Hydraulic friction was represented by Manning "n" values of 0.075 for agricultural areas, 0.050 for partially storm-sewered urban areas, and 0.025 for fully storm-sewered urban areas.

In the calculation of the time of concentration for urban areas (T_c'), it was recognized that runoff from the most remote portions of the basin will occur first as overland flow. A portion of the time of concentration in urban areas is, therefore, similar to that of agricultural areas. Fifteen minutes was selected as a reasonable allowance for overland flow for sub-basins of the size used in the study. The remainder of T_c was adjusted for effects of urbanized drainage to obtain T_c'.

The unit storm duration, D, represents the duration of runoff producing rainfall used in the construction of synthetic hydrographs. The relationships shown in Figure 66 indicate that the selected value of D should be smaller than the time of concentration, T_c, since the synthetic hydrograph relations are derived for situations wherein peak discharge occurs after the end of the runoff-producing rainfall. D must also be chosen small enough so that the varying rates of rainfall which actually occur during the unit storm duration can be closely approximated by an average rate. A unit storm duration equal to one hour was selected for use throughout the study.

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[5] *Z. P. Kirpich, "Time of Concentration for Small Agricultural Watersheds," Civil Engineering, June 1940.*

The pattern of tributary inflow from each of the 66 individual sub-basins was represented by a dimensionless hydrograph. A dimensionless hydrograph is derived from a simple natural hydrograph by taking the time to peak (T_p) and peak discharge rate (q_p) as units and plotting t/T_p against q/q_p, where t is a given time and q is the flow rate at the given time.

An average curvilinear dimensionless hydrograph was developed by the SCS from analyses of many natural hydrographs.[6] This curvilinear shape, along with its representative triangular hydrograph, is shown in Figure 67. A dimensionless hydrograph in combination with T_c, computed from Equation c above and incorporating the relationships shown in Figures 66 and 67, was used, as already noted, within the flood-routing submodel to synthesize a unique simple hydrograph for each of the 66 sub-basins. Initial application of this general hydrograph in the simulation of historic flood events in the Milwaukee River watershed produced flood hydrographs that were too high in peak, too steep in the recession limb, and too short in time base. Evaluation of the historic Milwaukee River floods indicated that a broader dimensionless hydrograph should be used. Figure 67 shows the revised dimensionless hydrograph used and its representative triangular shape.

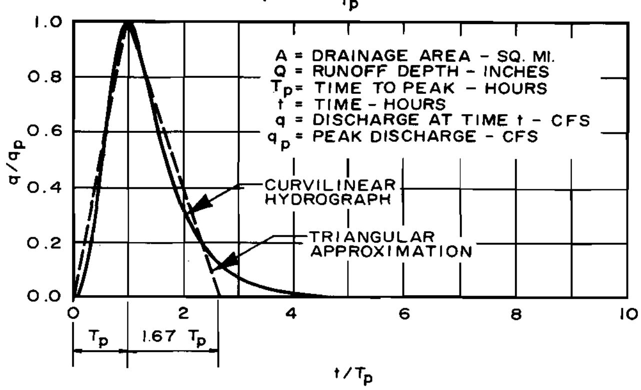
[6] *U. S. Soil Conservation Service, <u>National Engineering Handbook</u>, Section 4, "Hydrology."*

Figure 67

DIMENSIONLESS HYDROGRAPHS

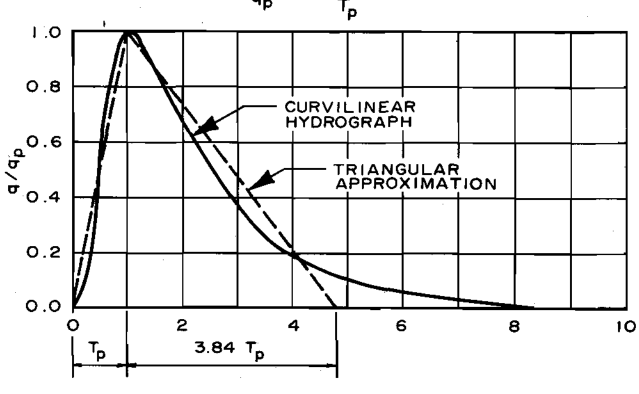
SCS AVERAGE DIMENSIONLESS HYDROGRAPH

$$q_p = \frac{484AQ}{T_p}$$



DIMENSIONLESS HYDROGRAPH FOR THE MILWAUKEE RIVER WATERSHED SUB-BASINS

$$q_p = \frac{267AQ}{T_p}$$



Source: U.S. Soil Conservation Service and Harza Engineering Company.

<u>Flood Movement:</u> Flood routing is the mathematical process of simulating the movement of flood waves through a river system. As a flood wave moves through a portion of the river, the peak rate of flow is usually reduced and the duration of flow increased. These alterations result from the ability of the river system to function as a reservoir; that is, to store water temporarily while flows are increasing and release the storage when flows decrease.

Many methods of flood routing have been developed, and each method has certain inherent advantages and disadvantages. The "convex method of flood routing" was selected as the most suitable for use in those portions of the Milwaukee River system not subject to impoundment. The submodel routing equation used is derived from inflow-outflow hydrograph relationships and follows the mathematical theory of convex sets:

$$O_2 = (1-C)\,O_1 + CI_1$$

where:

I_1 = inflow in cfs at the upstream end of the portion of the river under consideration (reach length) at time, T_1.

O_1 = outflow in cfs at the lower end of the reach at time, T_1.

O_2 = outflow in cfs at the lower end of the reach at time, T_2.

C = a dimensionless routing coefficient that reflects the physical characteristics of the channel.

$T_2 - T_1$ = the time increment in hours for which the outflow will be determined.

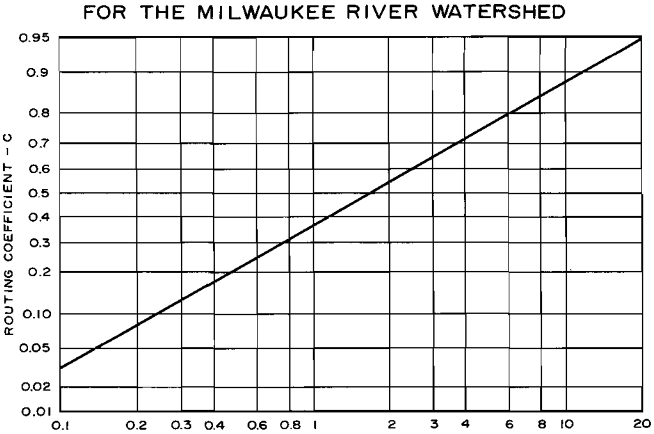
The ability of a portion of the river to modify flood flows varies with the size, shape, slope, and hydraulic friction of both the natural channel and its man-made obstructions. The convex routing method makes use of these same characteristics to determine the flow velocity from which a routing coefficient may be determined. The empirical relationship between velocity and the routing coefficient, as shown in Figure 68, was developed by SCS from gaged watersheds. An average velocity is determined for the portion of the flood hydrograph in excess of one-half the peak discharge. This average velocity is used to determine the routing coefficient.

Velocities and corresponding routing coefficients were determined for 311 locations from the stage-area-discharge curves that had been prepared as described above. Each of the 311 coefficients represents the characteristics of a portion of the river system. The coefficients derived from the stage-area-discharge curves developed at locations directly upstream from bridges and culverts reflect the ability of these obstructions to modify flood flows. Coefficients derived from stage-area-discharge relationships at locations other than directly upstream from man-made obstructions indicate the influence of channel characteristics on flood flows.

In addition to the alterations caused by artificial obstructions, such as bridges and culverts, and the physical characteristics of the channel itself, flood waves are also modified by man-made water control structures, such as dams. The ability of such a structure and its impoundment to modify flood flows is dependent upon the hydraulic capacity of the structure outlet and the storage capacity of the impoundment area directly upstream from the structure. The process of determining the modifications made upon a flood wave as it passes through a structure and impoundment is called reservoir routing. Reservoir-routing operations were performed at 30 structure locations in the watershed[7] by the "storage-indication" method of flood routing. The general-routing equation may be given as:

Figure 68

EMPIRICAL FLOOD ROUTING COEFFICIENT - FLOW VELOCITY RELATIONSHIP FOR THE MILWAUKEE RIVER WATERSHED



Source: U.S. Soil Conservation Service.

$$\overline{O} = \overline{I} + \frac{S}{t}$$

where:

$\overline{O}$ = average rate of outflow in cfs during the time interval t;

$\overline{I}$ = average rate of inflow in cfs during the time interval t;

S = change in volume of storage during the time interval t, expressed as cfs-hours; and

t = a time interval in hours.

Stage-discharge-storage relationships at structure locations were derived as described above.

Sequence of Operation of the Flood-Flow Simulation Model

Hydraulic and topographic data, along with hydraulic capacity information about bridges, culverts, and dams, were entered into the backwater submodel; and computations were performed on an IBM-1130 computer. Output from these backwater computations was interpreted so as to identify impounded and non-impounded reaches of the river system. Stage-discharge-volume tables were manually assembled for the former, while stage-discharge-area tables were prepared for the latter.

These tables, in combination with additional data describing the hydrology of the sub-basins and the selected flood event, were introduced into the flood-routing submodel. The program was executed on a UNIVAC-1108 computer. Hydrographs,

[7] *Although there are 38 dams on that portion of the stream channel system of the watershed to which the flood-flow simulation model was applied, reservoir-routing operations were applicable to only those 30 dams which were not submerged at flood flows.*

runoff volumes, and peak discharges with corresponding stages were produced by the flood-routing submodel for all cross sections located on the non-impounded reaches of the river system; and the same information was also provided at dams that formed impoundments.

Flood simulation model computations, as described above, were extensive and repetitive; but the two computer programs executed them in the same systematic manner that might be used for manual calculations. Therefore, consistent additional computations can be made manually, or with the assistance of a computer, at any time.

Calibration of the Flood-Flow Simulation Model

Since theoretical and general empirical relationships were used to construct the submodel, it was necessary to calibrate the model to the specific characteristics of the Milwaukee River watershed. A number of suitable calibration standards were fortunately available within the watershed for this purpose. Measured stage-discharge relationships were available from the records of the stream gages located on the main stem of the Milwaukee River at Milwaukee and on Cedar Creek at Cedarburg. In addition, measured high water elevations were available for various locations along the main stem for the 1924, 1959, and 1960 flood events.

In order to provide the best possible basis for model calibration, an actual flood event should be used for such calibration and should meet the following criteria:

1. The precipitation causing the flood event should be fairly uniform throughout the basin.
2. The runoff distribution should be nearly the same throughout the basin.
3. The actual rates and distribution of precipitation should be known.
4. A continuous record of discharge rates and volumes should be available in at least one location in the watershed.
5. A number of high water marks and other documented flood data should be available throughout the watershed.
6. The magnitude of flooding should be of an infrequent nature, preferably in excess of 10 years, and have a runoff volume equivalent to at least one inch of rainfall excess over the entire watershed.

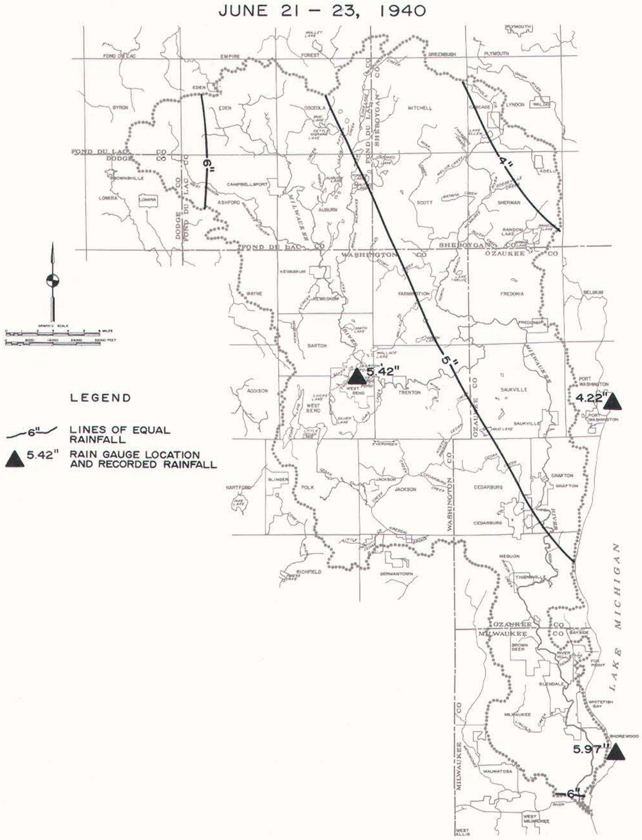
If an actual flood of record existed that fully met all of the above criteria, and assuming that enough hydraulic information was available to define precisely the physical characteristics of the drainage network, it would then be theoretically possible to duplicate exactly the historic flood event simply by adjusting the variable hydrologic inputs to the simulation model. Once this was accomplished, the model would be fully calibrated and could be used with a very high degree of confidence to synthesize possible future flood events of any desired magnitude. Such a calibration would provide checks on hydrograph shape, base time, and discharge peaks at points where actual discharge records existed, as well as checks on high water marks and rainfall-runoff relationships which were applicable to the entire drainage network.

The flood of June 1940 was selected as the historic event for calibration of the hydrologic submodel. The rainfall causing this flood was fairly uniform throughout the basin, and discreet discharge hydrographs relating only to the one event were recorded at the gaging stations. The peak discharge of 6,600 cfs at Milwaukee corresponds to an event with a four-year recurrence interval, and the peak discharge of approximately 3,200 cfs on Cedar Creek at Cedarburg corresponds to an event with a 10-year recurrence interval. Map 59 shows the rainfall isohyetals for the significant period of the storm, from 9:00 p. m. on June 21, 1940, to 12:00 a. m. on June 23, 1940; and the sequence of rainfall accumulation is shown in Figure 69 for three recording rain gages located in and around the watershed. The total volume of runoff was equal to 1.61 inches over the drainage area upstream from the gaging station at Estabrook Park in Milwaukee. Historic high water marks were not available for the 1940 flood.

In the model calibration, the hydraulic inputs to the backwater submodel, including stream cross-section and structure data, based on field survey data, were assumed to define adequately the physical characteristics of the channel system and adjacent floodways and floodplains and were held constant. Hydrologic inputs to the flood-routing submodel, including tributary drainage area, time of concentration, runoff curve number, and precipitation pattern, were then determined from analysis of topographic, soils, and land use maps and of weather records. Stream gaging records

Map 59

ISOHYETAL MAP OVER THE MILWAUKEE RIVER WATERSHED
JUNE 21 – 23, 1940

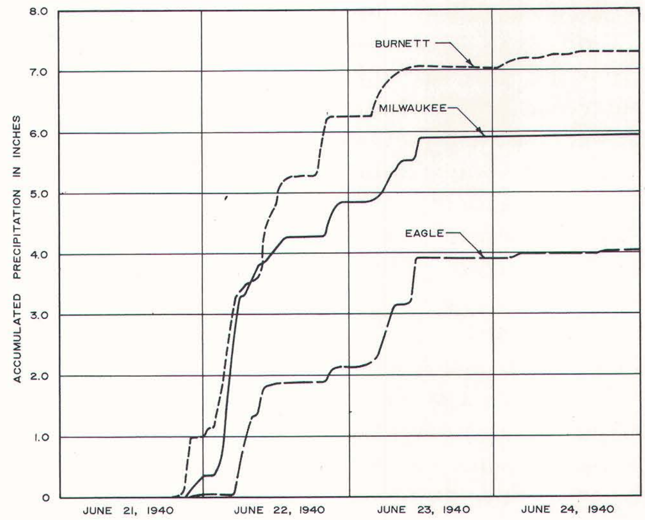


The flood of June 1940 was utilized in the watershed study as an actual historic rainfall event for calibration of the hydrologic submodel. The rainfall causing this historic flood was fairly uniform throughout the river basin. In addition, very discreet discharge hydrographs relating only to the flood event produced by this rainfall were recorded at the Cedarburg and Milwaukee stream gaging stations.

Source: Harza Engineering Company.

Figure 69

ACCUMULATED RAINFALL AS MEASURED AT THREE RECORDING RAIN-GAGING STATIONS DURING STORM OF JUNE 21-23, 1940 MILWAUKEE RIVER WATERSHED AND ENVIRONS



Source: Harza Engineering Company.

for the two long-term stream gaging stations in the watershed provided the principal calibration standards. A trial model run was then made to attempt to duplicate the June 1940 flood event for model calibration purposes.

Calibration of the submodel was performed initially for the 121-square mile area of Cedar Creek which is gaged. The flood could be simulated for this smaller area with one continuous run of the computer; and the problems concerning evaluation of effects of urbanization, structures, natural storage areas, tributary inflow, and channel characteristics were, therefore, less formidable than for the river system as a whole. A series of flood routings were performed for Cedar Creek by which the relative sensitivity of the output of the model to various input parameters was evaluated. Following this initial calibration work, the model was then calibrated to the entire watershed.

The results of the initial model runs were found to reproduce the timing of the actual measured flood peaks reasonably well. Generally, however, the synthetic hydrograph bases were found to be too short and the discharge peaks too high. Both triangular and curvilinear dimensionless hydrographs, as shown in Figure 67, were used. Even though the resulting flood hydrographs closely approximated the same slope, the curvilinear hydrograph was selected for use in the model, as it more nearly resembles a natural hydrograph. Due to the fact that the Milwaukee River watershed lies in a glaciated area with only a moderately well-developed surface drainage system, it was necessary to make significant overall reductions in the generalized runoff curve number developed by the U. S. Soil Conservation Service, as described earlier in this chapter, and to increase times of concentration initially selected for some sub-basins. The relative weightings of sub-basin characteristics, as determined by soil type and land use, were maintained.

Hydrograph Shape: As noted above, historic hydrographs, which provide one of the best model calibration standards available, were on record. With a well-conceived and constructed model, hydrograph shape, as defined by the surface runoff base time, time to peak, and the ratio of peak discharge to volume, as well as by the geometry of the rising and receding limbs of the hydrograph, can be duplicated in the calibration process. The shape of a streamflow hydrograph at any point in a river system is determined by the sum of the elemental hydrographs from all the contributing subareas, modified by the effect of transit time through the basin, and storage in the stream channels. Since the physical characteristics of basin shape, size, slope, infiltration, and channel geometry are essentially constant, the shape of hydrographs from different flood events caused by similar hydrologic conditions is also similar. This is the essence of the unit hydrograph theory and is the fundamental basis for the flood simulation technique used in the Milwaukee River watershed study. Once the typical hydrograph for a particular flood event has been simulated at one location in the basin, the model may then be considered calibrated; and synthesized hydrographs at other locations should also be representative. The model can then be programmed to develop a new set of hydrographs by varying the hydrologic characteristics which caused the flooding to be simulated.

Actual hydrograph shapes always vary somewhat from one flood to another, owing to differences in the conditions which cause the flooding, such as runoff duration, time distribution, areal distribution, and runoff amount. Fortunately, hydrograph shape is not extremely sensitive to any one of these factors, changing only slightly over a wide range of these factors, especially for extreme flood events.

Comparisons of the final adjusted synthesized hydrographs to recorded streamflow hydrographs at U. S. Geological Survey stream gaging stations are shown in Figures 70 and 71. The comparisons between the recorded and the synthesized streamflow hydrographs indicate that the model simulated the stream behavior very well.

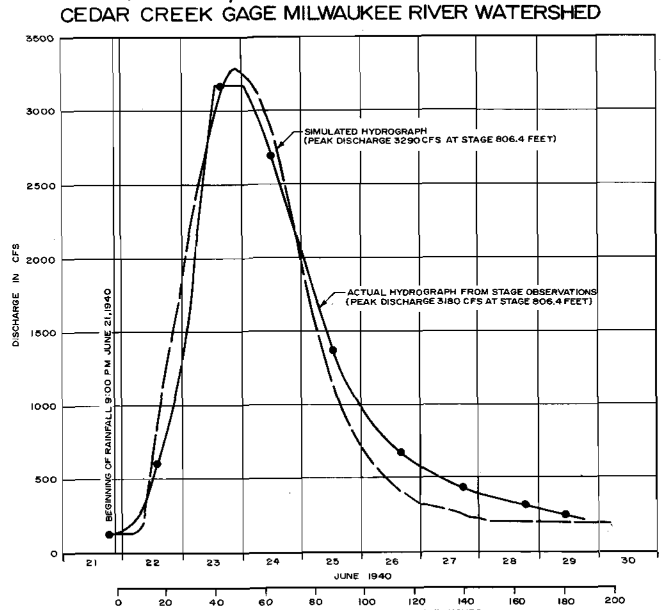
Rainfall-Runoff Relationship: In order to synthesize flood events resulting from excess rainfall, the flood simulation model must include some means of determining what portion of total rainfall will contribute to surface runoff. As already noted, empirical runoff curves have been developed by the U. S. Soil Conservation Service for this purpose, based on soil type, soil cover, land treatment, and antecedent precipitation. These curves were evaluated and adjusted during the calibration procedure, based on the June 1940 rainfall event. The adjusted runoff curve numbers may be used to determine runoff volumes for synthesized rainfall events. For the climatic and hydrologic conditions that prevail in the Milwaukee River watershed, these runoff curve numbers are significant primarily for simulating summer events. Since the majority of flood events with recurrence intervals greater than 10 years result from snowmelt or snowmelt and rainfall, however, it may be assumed that the ground is frozen or essentially saturated during major floods. Thus, runoff would be nearly uniform in depth over the watershed; and differences identified by runoff curve numbers would be eliminated. The most direct method of determining runoff volume of major flood events is from streamflow records. Volume-frequency analyses were made for the Milwaukee River and Cedar Creek, as described in Chapter VI of this volume, entitled "Hydrology." From these analyses it is possible to assign a frequency of occurrence to a specific runoff volume. The analyses also show that runoff from a major flood occurs over a period of seven days on Cedar Creek at Cedarburg and over a period of 12 days on the Milwaukee River at Estabrook Park.

Development of Synthetic Floods

After the flood simulation model was calibrated to duplicate measured flow characteristics of the

Figure 70

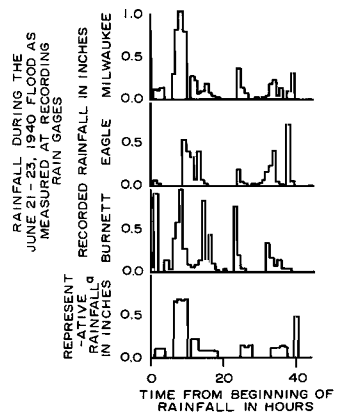
CALIBRATION OF FLOOD SIMULATION MODEL
JUNE 21-23, 1940 FLOOD HYDROGRAPH AT
CEDAR CREEK GAGE MILWAUKEE RIVER WATERSHED



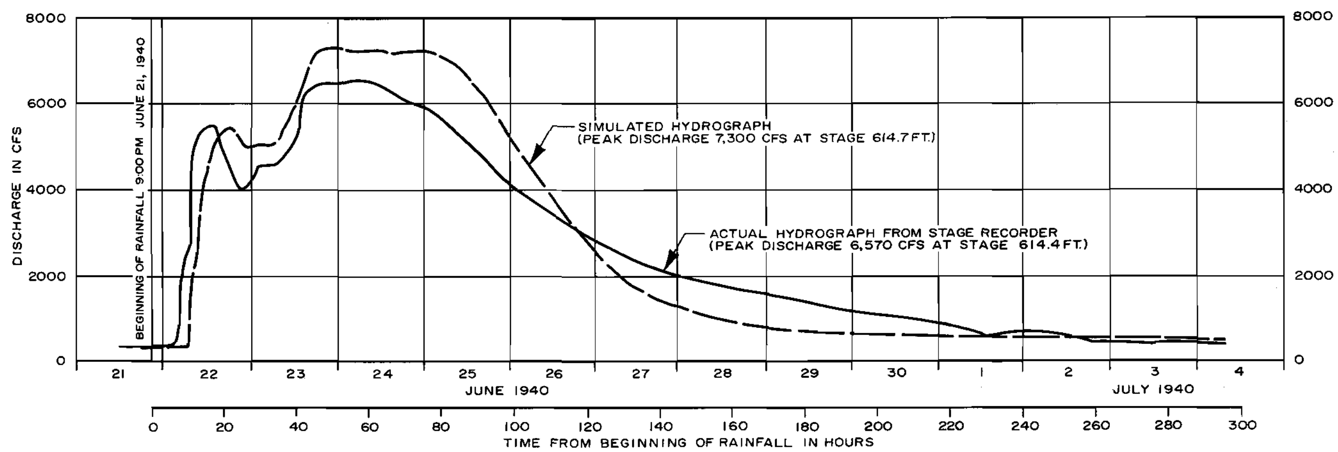
Source: Harza Engineering Company.

Figure 71

CALIBRATION OF FLOOD SIMULATION MODEL
JUNE 21-23, 1940 FLOOD HYDROGRAPH AT
ESTABROOK PARK GAGE MILWAUKEE RIVER WATERSHED



[a] FOR LOWER PORTION OF WATERSHED A TOTAL OF SIX REPRESENTATIVE RAINFALL DISTRIBUTIONS, BASED PRIMARILY ON DATA FROM THE THREE RECORDING GAGES, WERE USED TO SIMULATE THE SPATIAL VARIATION OF THE ACTUAL RAINFALL RESPONSIBLE FOR THE JUNE 21 - 23, 1940 FLOOD.



Source: Harza Engineering Company.

watershed, it then was used to develop synthetic flood hydrographs for the 10-year and 100-year flood recurrence intervals. These synthesized floods became the basis for the evaluation of the adequacy of existing water control facility structures within the watershed, for the preliminary design and evaluation of proposed water control facility structures and management practices, and for the preparation of flood hazard maps for the application of land use controls.

Synthesis of Snowmelt and Snowmelt-Rainfall Floods (Major Subwatersheds): The characteristics and magnitude of floods generated by melting snow vary with the physical properties of the watershed, the condition of the soil beneath the snow cover, the rate of snowmelt, and the volume of runoff produced by the snow cover. The influence that the physical features of the watershed have on flood flows was described earlier in this chapter. The treatment of the other variables in the flood simulation is described below. Soils were assumed to be saturated or frozen during the snowmelt period, and all hydrologic subareas were assigned a runoff curve number of 100 (impervious soils) to adjust the model to these conditions. Historic spring flood events and weather records were investigated to determine a reasonable melt period and rate of snowmelt runoff. Melt potentials were established from data on the historic snowpack accumulations and temperature data for late March and early April by use of the following equation:

$$M = KD$$

where

M = Potential snowmelt in inches of water.

K = A constant expressed in inches of snowmelt per degree-day that varies with watershed and climatic conditions. A value of 0.08 was used for runoff events that were assumed to originate entirely from snowmelt.

D = The number of degree-days. A degree-day is defined as an increment of one degree Farenheit in the range above 32°F for a 24-hour period during which the average temperature is above 32°F.

Maximum potential snowmelts were determined by a systematic search of the historic temperature records for the period from 1950 through 1968 in order to determine the number of degree-days that might be expected to occur within the watershed in a series of several days between March 15 and April 15 preceded by average temperatures below 32°F. About one-half of these years contained 105-hour periods with the total of 48 degree-days required to melt snow with a water equivalent of 3.8 inches as required for the 100-year recurrence interval watershed flood event. There is, therefore, based on this analysis, an approximately 50 percent probability in any year of having a 105-hour period between March 15 and April 15 with the potential to melt snow in a quantity equivalent to the 100-year recurrence interval flood.

U. S. Weather Bureau data[8] were used to assess the likelihood of having sufficient snowpack in the watershed preceding and during the prime melt period. Historical snowpack data indicate that, from March 1 through March 31, there is a probability of about 2 percent in any year that there will be a snow accumulation on the ground within the watershed with a water equivalent of 4.0 inches.

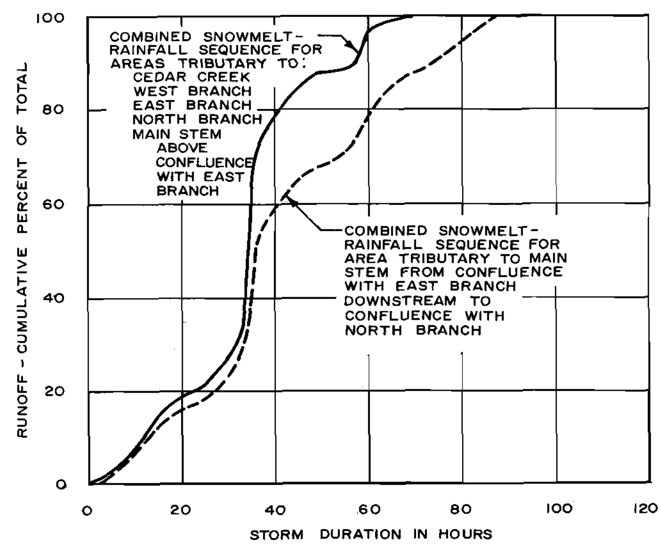
Based on the above individual probabilities of sufficient snowmelt potential and adequate snowpack, the combined, or joint, probability of the simultaneous occurrence of snowmelt potential and snowpack equivalent to the 100-year recurrence interval flood volume is about 1 percent. This analysis demonstrates, therefore, that the 100-year recurrence interval flood for the total Milwaukee River watershed could be entirely a snowmelt event.

The 100-year flood on the Cedar Creek subwatershed was synthesized by using combined snowmelt and rainfall distribution similar to those that occurred in 1959 and 1960. The runoff distributions used to simulate the spring flood events are shown in Figures 72 and 73. The 10-year and 100-year runoff distributions for the remaining major subwatersheds were derived by using the Cedar Creek distribution adjusted for the desired runoff volume. The distribution of runoff in the central reaches of the Milwaukee River from the East to the North Branches was assumed to be the average of the distributions for the total watershed and for Cedar Creek.

Assignment of Flood Frequency: Frequency analyses using the U. S. Geological Survey gaging records were made to determine the percent

Figure 72

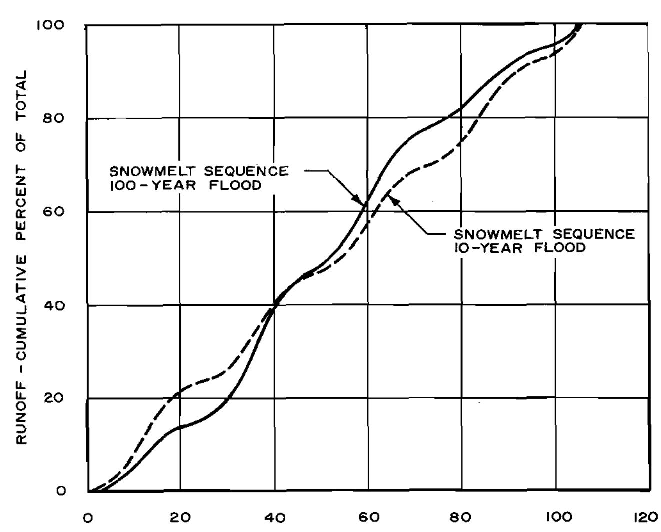
RUNOFF DISTRIBUTIONS FOR THE 10-YEAR AND 100-YEAR SNOWMELT – RAINFALL RUNOFF EVENTS FOR MAJOR SUBWATERSHEDS OF THE MILWAUKEE RIVER WATERSHED



Source: Harza Engineering Company.

Figure 73

RUNOFF DISTRIBUTIONS FOR THE 10-YEAR AND 100-YEAR SNOWMELT RUNOFF EVENT FOR THE TOTAL MILWAUKEE RIVER WATERSHED



Source: Harza Engineering Company.

[8] *U. S. Department of Commerce, Weather Bureau, Technical Paper No. 50, Frequency of Maximum Water Equivalent of March Snow Cover in North Central United States, Washington, D. C., 1964.*

chance of occurrence of instantaneous peak discharges and flood volumes for the Milwaukee River at Milwaukee and for Cedar Creek at Cedarburg.[9] Results of these studies indicated that the flood data could be analyzed on an annual basis, since the spring and summer flood events were similar in both peak and volume. Also, it was concluded that the results of the independent analyses of peak-stage frequency and flow-volume frequency could be used jointly for determining the magnitude of a specific major flood event. The depths of runoff for the 100-year event were determined to be 3.8 inches for the Milwaukee River at Milwaukee and 5.3 inches for Cedar Creek at Cedarburg. These values were used as a guide in calculating the volume of runoff to be used in synthesizing floods from the other major drainage areas of the watershed.

Depths of runoff and the drainage areas used in synthesizing floods with recurrence intervals of 100 years for subwatersheds of the Milwaukee River watershed are listed in Table 105 and shown in Figure 74. The 10-year flood volume was found to be 2.6 inches per unit area for both the Milwaukee River and the Cedar Creek gage records. This 10-year volume of 2.6 inches was used to simulate the 10-year flood for all major subwatersheds.

Runoff intensities and durations were developed for the gaged Cedar Creek subwatershed and the gaged Milwaukee River watershed, based upon both volume and peak frequency analyses. The resulting simulated flood hydrographs had peak discharges nearly equal to the peak discharges expected from the discharge frequency analyses. Similar runoff-intensity and -duration patterns were used for the ungaged major subwatersheds. The appropriate 10-year and 100-year runoff volume and the appropriate 10-year and 100-year peak discharges on the ungaged major subwatersheds were defined by the flood simulation model using the appropriate runoff-intensity and -duration pattern.

Discussion of the 10-Year and 100-Year Flood Simulation: The results obtained by synthesizing the 10-year and 100-year recurrence interval floods for the total Milwaukee River watershed compared very well with measured historic flood hydrographs and recorded high water marks for floods of similar frequencies. Comparison of the results of the flood simulation and the expected values based on frequency analyses[10] is shown in Table 106. The simulated hydrographs for these events are shown in Figures 75 and 76. Historic and simulated flood stages for the 10-year recurrence interval total watershed flood are compared in Table 107. High water marks for the 1924 flood, a 77-year recurrence interval event, were used to assess the accuracy of the simulated stages for the 100-year event, as summarized in Table 108.

Simulation of the 100-year flood event for the Cedar Creek subwatershed proved more difficult than was the case for the entire Milwaukee River

[9] *See Chapter VI, Volume 1, of this report.*

[10] *Ibid, footnote 9.*

TABLE 105

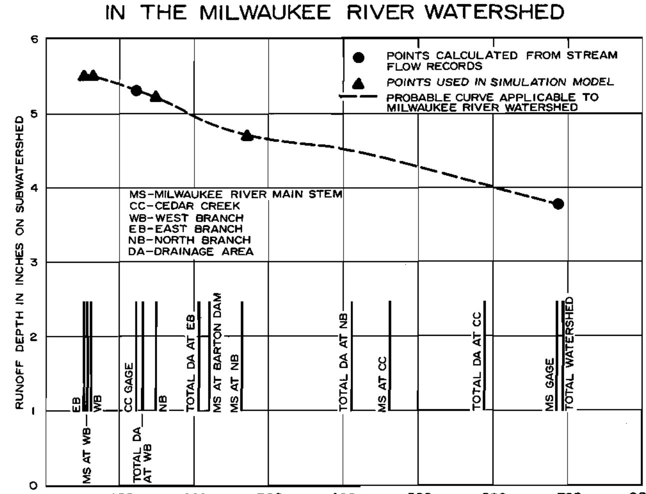
100-YEAR RECURRENCE INTERVAL FLOOD VOLUMES PER UNIT AREA IN THE MILWAUKEE RIVER WATERSHED

SUBWATERSHED	DRAINAGE AREA (SQ. MI.)	100- YEAR DEPTH OF RUNOFF (INCHES)
EAST BRANCH	50.3	5.5
WEST BRANCH	60.4	5.5
CEDAR CREEK	126.8	5.3
NORTH BRANCH	147.5	5.2
MILWAUKEE RIVER AT CONFLUENCE WITH NORTH BRANCH	263.6	4.7
MILWAUKEE RIVER AT NORTH AVENUE DAM	690.0	3.8

SOURCE- HARZA ENGINEERING COMPANY.

Figure 74

100-YEAR RECURRENCE INTERVAL RUNOFF DEPTHS FOR MAJOR SUBWATERSHEDS IN THE MILWAUKEE RIVER WATERSHED



Source: Harza Engineering Company.

watershed. Statistical frequency analyses, using a 35-year period of record, indicated a 100-year recurrence interval peak rate of discharge of 7,200 cfs and a flood volume of 5.3 inches at the Cedar Creek gage. Several attempts were made to synthesize a 100-year discharge of 7,200 cfs. It was found that this discharge value could not be duplicated even by assuming a severe combined snowmelt and rainfall distribution. After several trials were made to simulate the 100-year event, it was determined that the storage available in Jackson Marsh limited the peak-discharge values downstream. The most reasonable peak discharge simulated at the Cedar Creek gage was 6,310 cfs.

TABLE 106

SIMULATED 10- AND 100-YEAR TOTAL MILWAUKEE RIVER WATERSHED RUNOFF VOLUME AND PEAK DISCHARGE COMPARED TO FREQUENCY ANALYSIS VALUES

RECURRENCE INTERVAL	FREQUENCY ANALYSES		FLOOD SIMULATION	
	PEAK DISCHARGE AT ESTABROOK PARK GAGE (CFS)	12-DAY RUNOFF VOLUME (INCHES)	PEAK DISCHARGE AT ESTABROOK PARK GAGE (CFS)	12-DAY RUNOFF VOLUME (INCHES)
100-YEAR	16,000	3.80	16,460	3.84
10-YEAR	9,200	2.60	10,140	2.58

SOURCE- HARZA ENGINEERING COMPANY.

This discharge is considered to be acceptable as the 100-year flood peak for the following reasons:

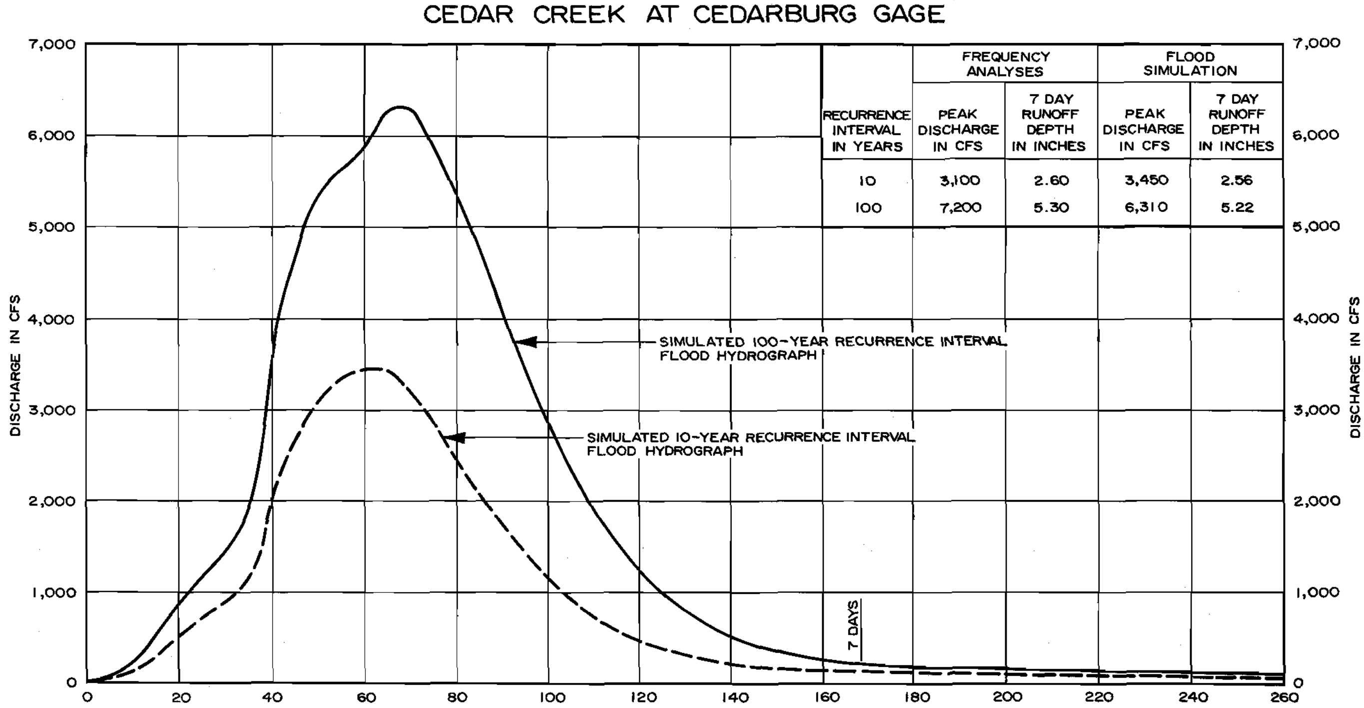
1. The peak-frequency analysis is based on a 35-year record, but the largest discharge of record, 3,600 cfs on March 30, 1960, represents a flood with an indicated recurrence interval of only 14 years. Thus, considerable extrapolation is required to define an event with a recurrence interval of 100 years.

2. The statistical analysis for peak discharge does not reflect the reduction of peak in the Jackson Marsh for floods greater than 3,600 cfs, a 14-year recurrence interval flood.

3. The difference between water surface elevations at the gage for the synthesized event and for the event estimated by frequency analysis is acceptable. The water surface elevation, corresponding to the simulated 100-year flood peak of 6,310 cfs, is 808.7 feet above mean sea level. The water surface elevation for a discharge of 7,200 cfs is 809.2 feet, a difference of only 0.5 foot.

Figure 75

10-YEAR AND 100-YEAR RECURRENCE INTERVAL SNOWMELT FLOOD SIMULATION CEDAR CREEK AT CEDARBURG GAGE

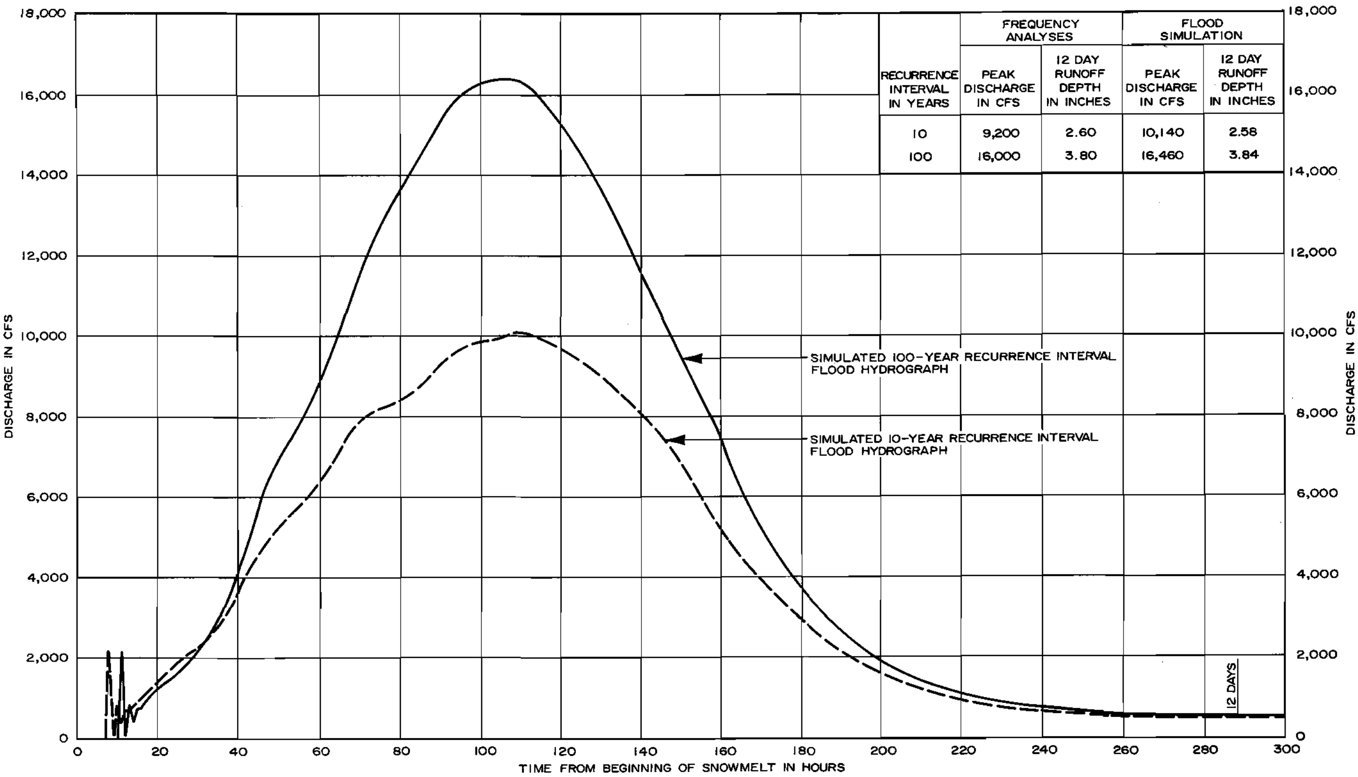


RECURRENCE INTERVAL IN YEARS	FREQUENCY ANALYSES		FLOOD SIMULATION	
	PEAK DISCHARGE IN CFS	7 DAY RUNOFF DEPTH IN INCHES	PEAK DISCHARGE IN CFS	7 DAY RUNOFF DEPTH IN INCHES
10	3,100	2.60	3,450	2.56
100	7,200	5.30	6,310	5.22

Source: Harza Engineering Company.

Figure 76

10-YEAR AND 100-YEAR RECURRENCE INTERVAL SNOWMELT FLOOD SIMULATION
MILWAUKEE RIVER AT ESTABROOK PARK GAGE



Source: Harza Engineering Company.

The simulated 10-year flood for the Cedar Creek subwatershed resulted in a peak discharge of 3,450 cfs and a seven-day flood volume of 2.56 inches at the gage. These values compare favorably to those expected from the frequency analyses, with a peak discharge of 3,100 cfs and a flood volume of 2.60 inches.

Synthesis of Floods Produced by Rainfall (Minor Subwatersheds): Floods produced by rainfall were critical for the following minor subwatersheds: Silver Creek (West Bend Township), Silver Creek (Sherman Township), Lincoln Creek, and for the outlet channel from Crooked Lake. These floods were synthesized by using the 24-hour rainstorm distribution shown in Figure 77.

Each of the four minor tributaries for which water surface profiles were determined was treated as an individual sub-basin in the overall watershed flood-flow simulation model. Generalized runoff hydrographs were computed for the watershed model, but there was no distribution of runoff within the sub-basin. It was necessary to make a flow distribution within each of the four minor tributary drainage areas before calculations of water surface levels were made. Because it was not intended that a large number of downstream routings be made on these small tributaries, however, it was considered impractical to computerize the downstream routing. Therefore, flood-routing studies were made manually for each of the four sub-basins. The resulting peak outflow and runoff distribution were used in the computerized backwater program to calculate the peak water surface profiles.

Runoff Determination and Flood Routing: The runoff generated by rainfall was determined based on the following assumptions and procedures:

1. The 100-year runoff would result from a rainfall or series of rainfall bursts that would occur within one 24-hour period of a one- to two-day storm. Thus, a 24-hour pattern of rainfall could be determined based on information published in Technical Publication 40 of the U. S. Weather

TABLE 107

COMPARISON OF HISTORIC 1960 FLOOD STAGES AND SIMULATED 10-YEAR RECURRENCE INTERVAL FLOOD STAGES

BRIDGE ON THE LOWER MILWAUKEE RIVER	LOCATION (RIVER MILE)	1960 FLOOD STAGE[a] (FT. ABOVE MSL)	10-YEAR RECURRENCE INTERVAL SIMULATED STAGE[b] (FT. ABOVE MSL)	SIMULATED STAGE MINUS HISTORIC STAGE (FT.)
C. & N.W. RR BRIDGE..............	8.12	618.6	619.6	1.0
SILVER SPRING DRIVE BRIDGE......	8.49	622.6	622.2	-0.4
BENDER ROAD BRIDGE..............	9.79	627.9	628.1	0.2
C. & N.W. RR BRIDGE..............	9.97	628.4	628.9	0.5
GREEN TREE ROAD BRIDGE..........	11.29	635.4	633.5	-1.9
RANGE LINE ROAD BRIDGE..........	13.82	646.8	647.0	0.2
BROWN DEER ROAD BRIDGE..........	14.99	648.4	647.4	-1.0
STH 167 BRIDGE..................	18.83	656.5	655.3	-1.2
CTH M BRIDGE (OZAUKEE COUNTY)...	23.15	662.5	661.9	-0.6
CTH C BRIDGE (OZAUKEE COUNTY)...	26.25	668.2	667.8	-0.4
GRAFTON DAM SPILLWAY............	30.76	737.8	738.8	1.0
STH 57 BRIDGE..................	30.84	738.8	739.2	0.4
CTH I BRIDGE (OZAUKEE COUNTY)...	45.50	782.9	783.7	0.8

[a] THE 1960 FLOOD PEAK DISCHARGE OF 9,300 CFS, AS MEASURED AT THE MILWAUKEE GAGE, IS A 10-YEAR RECURRENCE INTERVAL FLOOD. HIGH WATER MARKS FOR THE MARCH 29 TO APRIL 10, 1960 FLOOD WERE PAINTED ON 21 BRIDGES OVER THE MAIN STEM OF THE MILWAUKEE RIVER BETWEEN MILWAUKEE AND FREDONIA ON APRIL 7, 1960 BY PERSONNEL OF THE CHICAGO DISTRICT OFFICE OF THE U. S. ARMY CORPS OF ENGINEERS. HARZA AND SEWRPC PERSONNEL WERE ABLE TO RELOCATE THE 13 HISTORIC HIGH WATER MARKS APPEARING IN THE TABLE AND DETERMINED THEIR ELEVATION REFERRED TO MEAN SEA LEVEL DATUM.

THERE IS A POSSIBILITY THAT SOME RECORDED HISTORIC HIGH WATER MARKS ARE LOWER THAN THE PEAK FLOOD STAGES THAT ACTUALLY OCCURRED BECAUSE THE FOUR CORPS OF ENGINEERS FIELD OBSERVERS COULD NOT SIMULTANEOUSLY MONITOR THE CHANGING WATER SURFACE ELEVATIONS AT ALL 21 ORIGINAL OBSERVATION STATIONS AND, THEREFORE, MAY HAVE MISSED THE PEAK STAGE.

HISTORIC 1960 FLOOD STAGES MAY REFLECT THE BACKWATER EFFECT OF TEMPORARY ACCUMULATIONS OF ICE AND OTHER DEBRIS AT POINTS OF CHANNEL CONSTRICTIONS, PARTICULARLY BRIDGES. THIS BLOCKAGE, COMMON IN LATE WINTER-EARLY SPRING FLOODS, IS NOT, BECAUSE OF ITS UNPREDICTABLE NATURE, INCORPORATED INTO THE FLOOD FLOW SIMULATION MODEL AND ITS ABSENCE MAY EXPLAIN SOME OF THE DIFFERENCES BETWEEN HISTORIC AND SIMULATED FLOOD STAGES.

[b] 10-YEAR RECURRENCE INTERVAL FLOOD STAGE AS COMPUTED WITH THE FLOOD-FLOW SIMULATION MODEL.

SOURCE- HARZA ENGINEERING COMPANY, U. S. ARMY CORPS OF ENGINEERS, AND SEWRPC.

TABLE 108

COMPARISON OF HISTORIC 1924 FLOOD STAGES AND SIMULATED 100-YEAR RECURRENCE INTERVAL FLOOD STAGES

BRIDGE OR OTHER LOCATION ON THE LOWER MILWAUKEE RIVER	LOCATION (RIVER MILE)	1924 FLOOD STAGE[a] (FT. ABOVE MSL)	100-YEAR RECURRENCE INTERVAL SIMULATED STAGE[b] (FT. ABOVE MSL)	SIMULATED STAGE MINUS HISTORIC STAGE (FT.)
PORT WASHINGTON ROAD BRIDGE	6.91	622.0	618.8	-3.2[c]
C. & N.W. RR BRIDGE	8.12	626.9	621.9	-5.0[c]
SILVER SPRING DRIVE BRIDGE	8.49	627.9	625.0	-2.8[c]
RIVER BEND NEAR THE INTERSECTION OF RIVERVIEW DRIVE AND RIVER FOREST DRIVE IN THE CITY OF GLENDALE	9.03	629.0	627.7	-1.3[c]
BENDER ROAD BRIDGE	9.79	629.9	630.1	0.2
IMMEDIATE VICINITY OF KLETZSCH PARK DAM	10.09	630.8	631.3	0.5
OZAUKEE COUNTY - MILWAUKEE COUNTY LINE	16.15	653	652.9	-0.1
SOUTH BOUNDARY OF SECTION 26, T9N, R21E	17.60	655	655.0	0.0
STH 167 BRIDGE	18.83	658	658.1	0.1
SOUTH BOUNDARY OF SECTION 13, T9N, R21E	21.11	663	663.4	0.4
CTH M (OZAUKEE COUNTY)	23.15	663	664.5	1.5
SOUTH BOUNDARY OF SECTION 1, T9N, R21E	24.36	665	665.4	0.4
CTH T (OZAUKEE COUNTY)	28.01	681	681.5	0.5
SOUTH BOUNDARY OF SECTION 13, T10N, R21E	31.15	740	741.7	1.7
SOUTH BOUNDARY OF SECTION 12, T10N, R21E	32.35	747	746.5	-0.5
SOUTH BOUNDARY OF SECTION 35, T11N, R21E	35.26	753	753.3	0.3
STH 33	36.79	755	757.1	2.1
SOUTH BOUNDARY OF SECTION 24, T11N, R21E	38.00	759	760.3	1.3
SOUTH BOUNDARY OF SECTION 14, T11N, R21E	39.10	763	762.1	-0.9
SOUTH BOUNDARY OF SECTION 11, T11N, R21E	40.42	766	765.1	-0.9
SOUTH BOUNDARY OF SECTION 3, T11N, R21E	41.92	772	768.8	-3.2
SOUTH BOUNDARY OF SECTION 34, T12N, R21E	43.02	777	773.2	-3.8

[a]THE AUGUST 6, 1924 FLOOD PEAK DISCHARGE OF 15,100 CFS AS MEASURED AT THE MILWAUKEE GAGE, IS A 77-YEAR RECURRENCE INTERVAL FLOOD. THIS HISTORIC FLOOD, ALTHOUGH NOT EQUAL IN RECURRENCE INTERVAL, IS THE BEST AVAILABLE CRITERION FOR EVALUATION OF THE ACCURACY OF THE SIMULATED STAGES FOR THE 100-YEAR RECURRENCE INTERVAL FLOOD. THERE IS GENERALLY VERY LITTLE DIFFERENCE IN PEAK STAGES ASSOCIATED WITH FLOODS AS RARE AS THE 77- AND 100-YEAR EVENTS, SINCE SUCH FLOODS OCCUPY THE FLOODPLAIN, A WIDE FLOW PATH IN WHICH SIGNIFICANT ADDITIONAL DISCHARGE IS TYPICALLY ACCOMMODATED WITH VERY LITTLE STAGE INCREASE. THIS EFFECT IS ILLUSTRATED BY THE STAGE-DISCHARGE CURVES FOR A TYPICAL CHANNEL-FLOODPLAIN CROSS-SECTION AND FOR THE NORTH AVENUE DAM, SHOWN RESPECTIVELY IN FIGURES 63 AND 64, WHICH SHOW STAGE DIFFERENCES OF LESS THAN 0.2 FEET BETWEEN THE 77- AND 100-YEAR RECURRENCE INTERVAL PEAK FLOOD DISCHARGES.

HISTORIC PEAK FLOOD STAGES FOR THE LOWER MILWAUKEE RIVER FROM RIVER MILE 6.91 THROUGH 10.09 WERE EXTRACTED FROM RECORDS OF THE CITY OF MILWAUKEE, BUREAU OF ENGINEERING. THAT BUREAU, UNDER SPECIAL PROJECT 133, ESTABLISHED STAFF GAGES IN THE MILWAUKEE RIVER DURING THE WINTER OF 1923-1924 AND SUBSEQUENTLY MADE DETAILED STAGE OBSERVATIONS OVER A TWELVE-DAY PERIOD DURING THE AUGUST 1924 FLOOD.

THE REMAINING HISTORIC FLOOD STAGES, ALL LOCATED IN OZAUKEE COUNTY, WERE ASSEMBLED FOR A WPA PROJECT SPONSORED BY THE WISCONSIN PUBLIC SERVICE COMMISSION BY MEANS OF RESIDENT INTERVIEWS CONDUCTED BY PROJECT WORKERS IN COMBINATION WITH AGRICULTURAL ADJUSTMENT ADMINISTRATION AERIAL PHOTOGRAPHS, AND HOUSE COUNTS AND ELEVATIONS FROM WISCONSIN PUBLIC SERVICE COMMISSION MAPS AND REPORTED IN THE MILWAUKEE RIVER BASIN, WISCONSIN STATE PLANNING BOARD, BULLETIN NO. 10, JUNE 1940. THESE OZAUKEE COUNTY FLOOD STAGES ARE REFERRED TO IN THE WISCONSIN STATE PLANNING BOARD REPORT AS 'HIGH WATER MARKS' AND, ALTHOUGH NOT EXPLICITLY STATED THEREIN, ARE PRESUMED TO BE ASSOCIATED WITH THE TWO LARGEST FLOODS OF RECORD, THE AUGUST 1924 FLOOD OR THE MARCH 1918 FLOOD, THE LATTER ALSO BEING A 77-YEAR EVENT.

HISTORIC PEAK FLOOD STAGES FOR THAT PORTION OF THE MILWAUKEE RIVER IN OZAUKEE COUNTY ARE NOT AS RELIABLE AS THOSE DERIVED FROM THE THOROUGH CITY OF MILWAUKEE BUREAU OF ENGINEERING STUDY BECAUSE THE FORMER ARE BASED IN PART ON THE RECOLLECTIONS OF AREA RESIDENTS AND ARE REPORTED ONLY TO THE NEAREST FOOT.

[b]100-YEAR RECURRENCE INTERVAL FLOOD STAGE AS COMPUTED WITH THE FLOOD-FLOW SIMULATION MODEL.

[c]THE LARGE DEVIATION BETWEEN HISTORIC AND SIMULATED FLOOD STAGES AT THE PORT WASHINGTON ROAD BRIDGE (RIVER MILE 6.91) AND THE C. & N.W. RR BRIDGE (RIVER MILE 8.12) REFLECTS THE EXTENSIVE CHANNEL MODIFICATION UNDERTAKEN BY THE CITY OF MILWAUKEE SINCE THE 1924 FLOOD IN A 7,000 FOOT REACH PORTION OF THE LOWER MILWAUKEE RIVER THROUGH LINCOLN PARK DOWNSTREAM OF THE C. & N.W. RR BRIDGE AS REPORTED IN WISCONSIN STATE PLANNING BOARD, BULLETIN NO. 10. THESE CHANNEL MODIFICATIONS CONSISTED OF A 1935 WPA PROJECT DURING WHICH THAT PORTION OFF THE CHANNEL PASSING OVER A LIMESTONE RIDGE WAS DEEPENED AND A PROJECT INITIATED IN 1937 DURING WHICH A NEW CHANNEL REACH WAS CUT WITHIN LINCOLN PARK SO AS TO BYPASS THE BULK OF FLOOD FLOW PAST TWO OX-BOW BENDS.

ACCORDING TO THE AFOREMENTIONED BULLETIN, THE CITY OF MILWAUKEE ENGINEER'S OFFICE PREDICTED THAT IF THE 1924 FLOOD DISCHARGE OCCURRED IN THE DEEPENED AND STRAIGHTENED CHANNEL, THE CORRESPONDING PEAK STAGE WOULD BE ABOUT FIVE FEET BELOW THE 1924 PEAK STAGE THROUGH THE IMPROVED CHANNEL, WHICH APPROXIMATES THE DIFFERENCES APPEARING IN THE TABLE FOR THE C. & N.W. RR AND PORT WASHINGTON ROAD BRIDGES. BECAUSE OF THE BACKWATER EFFECT, CHANNEL MODIFICATION IN LINCOLN PARK MAY PRODUCE A REDUCTION IN FLOOD STAGES UPSTREAM OF THE C. & N.W. RR BRIDGE, PARTICULARLY AT SILVER SPRING DRIVE AND THE DOWNSTREAM RIVER BEND DESCRIBED IN THE TABLE, AND THUS ACCOUNT FOR THE FACT THAT SIMULATED PEAK FLOOD STAGES AT THOSE TWO LOCATIONS ARE, RESPECTIVELY, 2.8 AND 1.3 FEET BELOW THE 1924 PEAK FLOOD STAGES.

SOURCE- WISCONSIN STATE PLANNING BOARD; CITY OF MILWAUKEE, BUREAU OF ENGINEERING; HARZA ENGINEERING COMPANY; AND SEWRPC.

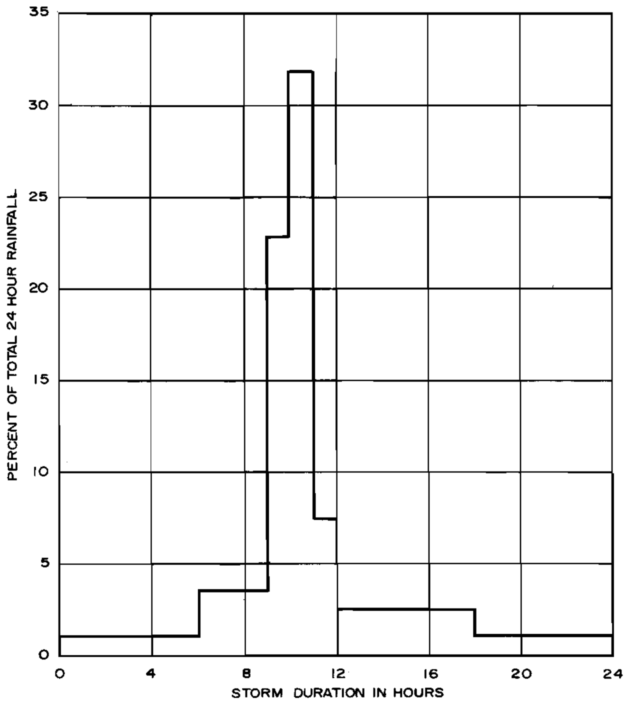
Bureau[11] and on hourly rainfall patterns observed during major storms in the vicinity of the City of Milwaukee.

2. The portion of the 24-hour rainfall which effectively would contribute to the peak runoff would be a three-hour burst of 3.5 inches which would occur during the tenth to thirteenth hours of the storm; about 0.60 inch would contribute to initial infiltration requirements and the remainder would occur following the peak rainfall burst (see Figure 77).

[11] *U. S. Department of Commerce, Weather Bureau, Technical Paper No. 40, Rainfall Frequency Atlas of the United States, Washington, D. C., 1961.*

Figure 77

RAINFALL DISTRIBUTION FOR 10-YEAR AND 100-YEAR RECURRENCE INTERVAL FLOOD EVENTS FOR MINOR TRIBUTARIES OF THE MILWAUKEE RIVER WATERSHED[a]



[a] LINCOLN CREEK, SILVER CREEK (WEST BEND TOWNSHIP), SILVER CREEK (SHERMAN TOWNSHIP), AND OUTLET CHANNEL FROM CROOKED LAKE.

Source: Harza Engineering Company.

3. Frequency could be assigned to the flood on the basis of the rainfall used to synthesize the flood; that is, the 1 percent chance rainfall flood could be synthesized by assuming that 5.4 inches of rain would fall in 24 hours (1 percent chance, 24-hour rainfall amount), and the 10 percent chance rainfall flood could be synthesized by assuming that 3.82 inches of rain would fall in 24 hours (10 percent chance, 24-hour rainfall amount). These values, which are point rainfall amounts, would not be adjusted for reductions of rainfall intensities that accompany increases in the areal extent of storms producing rainfall but, since the areas are small, would cover the entire area of the subwatersheds.

4. The subwatersheds would be divided into subareas for which unit hydrographs would be prepared.

5. Hourly excess rainfall amounts would be applied to one hour unit hydrographs to prepare subarea runoff hydrographs.

6. Levels for all lakes would be one foot above the invert or crest elevation of their outlet control structures, when the last 24 hours of rainfall commenced.

7. The storage-indication procedure would be used to route the runoff hydrographs through lakes and ponds at structures.

8. Storage along non-impounded reaches of the stream system would be insignificant because of relatively steep channel slopes. Hydrographs corresponding to the upstream and downstream ends of such reaches would, therefore, be identical in shape, but with the downstream hydrograph shifted in time by an increment related to the length of the channel reach and to estimated channel velocities.

Calculation of Water Surface Profiles: The routed runoff values were entered into the backwater program to determine water surface profiles. Backwater profiles were calculated beginning with 10-year and 100-year flood levels in the streams to which the small subwatersheds are tributary. Channel sections were determined from information shown on sketches of structures prepared by the Commission and Alster & Associates; from drawings provided by the Office of the City Engineer of the City of Milwaukee; and from U. S. Geological Survey, Villages of Brown Deer and River Hills, and SEWRPC topographic maps.

Determination of flood flows and water levels for a given frequency flood using rainfall-frequency information is an uncertain process because of the many assumptions, such as time distribution of rainfall and antecedent moisture conditions, which must be made. The assumptions made, however, appeared to yield runoffs that were reasonable, as shown in Table 109. For example, the calculated 100-year recurrence interval runoff for the Silver Creek subwatershed at West Bend is 3.6 inches, or 67 percent of the 24-hour rainfall of 5.4 inches. This yield indicated a soil complex curve number of about 83. As indicated in the original list of soil complexes and runoff curve numbers (see Table 102), a runoff curve number of 83 is reasonable for the soils of sub-basin M-13 with the assumed antecedent moisture condition. Runoff records for the Milwaukee River watershed and Cedar Creek show that the 100-year recurrence interval flood yields about four and five inches of

TABLE 109

DEPTH OF RUNOFF FOR SELECTED MINOR TRIBUTARIES OF THE MILWAUKEE RIVER FOR THE 10- AND 100- YEAR RECURRENCE INTERVAL FLOODS

MINOR TRIBUTARY	10-YEAR FLOOD		100-YEAR FLOOD	
	RUNOFF DEPTH	PERCENT OF PRECIPITATION	RUNOFF DEPTH	PERCENT OF PRECIPITATION
CROOKED LAKE CREEK......	2.07	56	3.44	66
SILVER CREEK (WEST BEND TOWNSHIP)...	2.25	59	3.60	67
SILVER CREEK (SHERMAN TOWNSHIP).....	2.31	63	3.62	70
LINCOLN CREEK...........	2.79	74	4.27	80

SOURCE- HARZA ENGINEERING COMPANY.

runoff, respectively. These floods are of much longer duration and include floods originating from snowmelt.

The calculated peak runoff for Silver Creek (West Bend Township) was 1,135 cfs, or 123 cfs per square mile (drainage area 9.2 square miles). These appear to be reasonable values, considering the large storage capacity in this small drainage area. It was estimated, based on peak-flow-frequency analyses, that the 100-year peak flows are 24 cfs per square mile for the Milwaukee River at Estabrook Park (drainage area 686 square miles) and 60 cfs per square mile at the Cedar Creek stream gage (drainage area 121 square miles). Without the storage effects of the lakes and channel ponds and the effect of a small, late, contributing drainage area, the unit runoff from the Silver Creek-West Bend drainage area probably would fall between 150 and 200 cfs per square mile.

Regional Analysis

One of the primary purposes of the hydrologic model is the generation of peak flood-discharge-frequency relationships at dams, bridges, and other critical points throughout the entire stream system of the Milwaukee River watershed. Because these discharge-frequency relationships are so important to the sound preparation of a comprehensive watershed plan, a significant effort was devoted in the watershed study to the development of the flood-flow simulation model described in this chapter. The model was carefully calibrated to simulate flood conditions actually experienced during major historic floods, and peak flood-flow values developed by application of the model are considered to be reliable for recurrence intervals ranging from 10 to 100 years.

The peak flood flows derived through application of the flood-flow simulation model were compared with similar flows derived through application of a regional flood estimation technique developed by the U. S. Geological Survey.[12] This comparison was considered particularly important because both the Wisconsin Department of Transportation and the Wisconsin Department of Natural Resources make use of the regional flood analysis technique to determine flood frequency and discharge values for bridge and culvert design and for floodplain management purposes.

The regional estimation technique was developed by the U. S. Geological Survey from analyses of actual stream discharge measurements from many stream gaging stations in Wisconsin. The data from these stations were analyzed and composite flood-frequency curves developed, which relate floods of various recurrence intervals to the mean annual flood. In addition, multiple correlation techniques were applied to the data in order to obtain a mathematical equation relating selected physical characteristics of a watershed to the mean annual flood flow. The watershed characteristics to which the mean annual flood flow was correlated included tributary drainage area, main channel slopes, and lake and reservoir surface area within the tributary watershed. By utilizing the composite flood-frequency curves and the mean annual flood-flow formula so derived, the peak flood discharges for various recurrence intervals can be estimated for drainage basins having an area of over 20 square miles in extent. The method is not intended to be applicable to the main stems of larger river systems, to highly regulated streams, or to urban watersheds.

The mean annual flood formula applicable to the Milwaukee River watershed, as derived by the U. S. Geological Survey, is:

$$Q = 17.3A^{0.8}S^{0.4}L^{-0.5}G$$

where

Q = mean annual flood flow (recurrence interval 2.33 years) in cubic feet per second.

A = drainage area in square miles.

[12] *A detailed description of the method is given in the USGS publication, Floods in Wisconsin-Magnitude and Frequency, by D. W. Ericson, prepared in cooperation with the State Highway Commission of Wisconsin. (Open-file report, Madison, Wisconsin, 1961.)*

S = slope in feet per mile for channel reach located between 10 and 85 percent of the river mile distance from site under consideration to basin divide.

L = lake and reservoir surface area as percent of total drainage area + 0.50.

G = dimensionless geographic factor which varies with location within southeastern Wisconsin from 0.90 to 1.2.

The mean annual flood, as computed from the foregoing equation, is then related to a flood flow of specified recurrence interval by a composite flood-frequency curve, with appropriate adjustment for the size of the drainage area.

The results of the comparisons of the application of the flood-flow simulation model and the regional flood analysis technique at 16 locations throughout the watershed are summarized in Appendix I of this report. The peak discharge-frequency line, designated "Simulation Model" on the comparative curves in Appendix I, was obtained by application of the flood simulation model, while the line designated "USGS" was obtained by application of the regional flood analysis method. In nearly every case, the latter values were found to be significantly lower than the hydrologic model would indicate, over a recurrence interval range of 10 to 50 years. In addition, the line on the comparative curves in Appendix I designated "log-Pearson" shows the results of discharge-frequency analyses made from measured streamflow data. These values were statistically computed using a log-Pearson Type III distribution for 51 years of record at the stream gage on the Milwaukee River at Estabrook Park in Milwaukee and for 35 years of record at the stream gage on Cedar Creek at Cedarburg.

Significant differences between the flood-flow values derived from application of the simulation model and the regional flood analysis are indicated for certain subwatersheds, including the Cedar Creek subwatershed. These differences are due in part to the physical characteristics peculiar to each of these individual subwatersheds; and these peculiarities cannot be reflected in the relatively broad generalizations which must be made in application of the regional analyses but which can be reflected in the simulation model.

The referenced U. S. Geological Survey report describing the derivation and application of the regional flood estimation technique lists the Cedar Creek mean annual flood, as derived from an analysis of the stream gaging records, as 1,420 cfs. Calculation of the mean annual flood by the basin factors, however, yields a discharge of 1,120 cfs, or 79 percent of the gaged value. Use of the basin factors listed for the Milwaukee River at Estabrook Park yields a discharge for the mean annual flood of 4,600 cfs, essentially the same as the mean annual flood derived from the gaging records. Thus, flood-flow values developed by application to regional flood analysis can be used with more confidence to estimate flood flows in the lower reaches of the Milwaukee River watershed, with peak flows calculated by the regional flood analysis method ranging from 15 to 30 percent below the values derived from application of the flood-flow simulation model. For other river reaches of the watershed, including Cedar Creek, the North Branch of the Milwaukee River, and the main stem of the Milwaukee River in the Campbellsport area and between West Bend and Newburg, application of the regional flood analysis method may be expected to yield peak flood flows which are as much as 50 percent below the values derived from application of the flood-flow simulation model. The simulation model permits consideration to be given to the effects on flood flows of more factors than do the regional flood analysis techniques, including variations in the capacity of channel reaches, soils, and land use.

Effect of Human Activities on Runoff

The flood-flow simulation model was constructed and calibrated on the basis of present hydrologic conditions in the watershed. One of its principal functions, however, was to permit portrayal of the changes in river system performance which may be expected to occur with changing land use and water control facility development within the watershed. For this purpose components of the model were modified to reflect the land use development expected or the water control facility development proposed.

Hydrologic Effects of Urbanization: A substantial increase in urban development in portions of the watershed is expected by 1990, the watershed plan design target date. An analysis of the effects of this urbanization on the performance of the river system of the watershed was made, utilizing the flood-flow simulation model and inputs derived from the adopted regional land use plan. The conversion of land from rural to urban use has two major effects on the hydrologic regimen. The rainfall-runoff relationship is modified as a result of an increased amount of impervious area and a change in land use in the remaining pervious area. The time of concentration of the drainage area is modified as a result of decreased hydraulic friction and improved drainage facilities.

There are four areas in the watershed which are presently devoted to primarily rural land uses and which may be expected to be devoted to primarily urban land uses by 1990: the upper reaches of Lincoln Creek, the Mequon area, the Cedarburg-Grafton Area, and the West Bend area. Even though the changes expected in these areas are large in terms of the amount of land to be converted from rural to urban use and in terms of the concomitant increases in these areas, the changes were found to hardly affect the flood flows and river stages of the Milwaukee River.

The effects of urbanization on spring floods, as determined by analyses, were most pronounced in small drainage areas, as represented by sub-basin inflow hydrographs. As shown in Table 110, peak discharges for hydrologic sub-basins were found to increase by almost 25 percent; however, most increases were in the range of 0 to 5 percent for the 14 sub-basins undergoing the most rapid urbanization. Significant increases in runoff were found only for sub-basins MM-2, LM-6, LM-8, and LM-10, which are located in the Mequon and West Bend areas of the watershed.

The peak discharge of floods on the main stem of the Milwaukee River and Cedar Creek were essentially unaffected by changes in runoff from spring floods in urbanizing areas. This absence of effect results because flood flows are large in the river system at the points of urbanization; and, therefore, changes in flow from sub-basins are minor in comparison to total streamflow. Also, since the urbanizing areas are located primarily in the downstream reaches of the watershed, urbanization tends to contribute to early peaks in the downstream areas which precede the arrival of peak flows from upstream. Thus, in the Milwaukee River, the present and projected location and pattern of urbanization tends actually to reduce flood flows in the lower Milwaukee River by a small amount.

For summer rainfall events, the change in rainfall-runoff relationships accompanying urbanization was represented by changes in the runoff curve number assigned to the hydrologic sub-basins. The change was made to reflect both the anticipated increase in impervious area and the greater retention capability of soils under lawn cover, as compared to agricultural uses. These two adjustments are, to some degree, compensating; but, in general, the net effect is to increase the volume of runoff from a given summer rainfall event. In the case of spring snowmelt and snowmelt-rainfall events, the ground was assumed to be frozen or saturated; and, therefore, a runoff curve number of 100 was used for all sub-basins.

The change in drainage hydraulics accompanying urbanization was represented by a reduction in the time of concentration of the affected sub-basins. Time of concentration values were reduced in direct proportion to the ratio of assumed hydraulic friction of the drainage systems in urban and rural areas, as described earlier herein. The reduction in concentration time has the effect of shortening the time of tributary outflow and increasing peak discharge amounts from the tributaries for both spring and summer events.

Floods for future (1990) land use conditions were synthesized for snowmelt and snowmelt-rainfall events using the same rainfall amounts and snowmelt volumes that were used to develop flood flows for present land use conditions. The effects of urbanization on snowmelt and snowmelt-rainfall floods in the Milwaukee River were calculated to be minimal. Watershed-wide analyses were not made for summer events, as the 100-year summer rainfall resulted in a flood peak with an indicated recurrence interval of only about 20 to 25 years on Cedar Creek.

Effects of Structural Flood Control Facilities: Alternative structural water control facilities considered in the watershed plan design included dams and diversion channels. The effects of these works of improvement were determined by operating the hydrologic model with the assumed plan element in place. Results of these studies are described and discussed in Chapter IV, Volume 2, of this report.

STREAM WATER QUALITY SIMULATION

As already noted, the comprehensive watershed planning process required definitive knowledge of present and probable future surface water quality conditions, as well as of streamflows. The exist-

TABLE 110

EFFECTS OF URBANIZATION ON
RUNOFF FOR THE 100-YEAR TOTAL WATERSHED FLOOD EVENT[a]

LOCATION		SUB-BASIN RUNOFF[b]			STREAM FLOW[b]		
		PEAK DISCHARGE (CFS)		PERCENT CHANGE	PEAK DISCHARGE (CFS)		PERCENT CHANGE
AREA	SUB-BASIN	1970 CONDITIONS	1990 CONDITIONS		1970 CONDITIONS	1990 CONDITIONS	
MILWAUKEE....	LM-11	595	595	0.0	16,683	16,492	-1.1
MILWAUKEE....	L-1	807	807	0.0	16,452	16,271	-1.1
GLENDALE, RIVER HILLS & BROWN DEER.	LM-10	734	906	23.4	16,141	15,979	-1.0
MEQUON.......	LM-8	348	429	23.2	15,823	15,633	-1.2
MEQUON.......	LM-6	487	560	15.0	16,762	15,605	-1.0
MEQUON.......	LM-7	407	408	0.0	15,669	15,520	-1.0
CEDARBURG....	C-9	289	270	-0.7	3,621	3,638	0.5
GRAFTON......	LM-5	192	202	5.2	11,893	11,858	-0.3
SAUKVILLE....	LM-4	482	475	-0.1	11,850	11,818	-0.3
SAUKVILLE....	LM-3	536	538	0.0	11,616	11,573	-0.4
FREDONIA.....	MM-2	385	388	0.1	11,302	11,249	-0.5
WEST BEND....	MM-2	210	260	23.8	6,043	6,023	-0.3
WEST BEND....	SW-1	320	328	2.5	5,890	5,875	-0.3
KEWASKUM.....	UM-11	315	322	2.2	4,633	4,611	-0.5

[a]THE CAUSATIVE PHENOMENON UTILIZED IN THE FLOOD FLOW SIMULATION MODEL TO GENERATE THE 100-YEAR RECURRENCE INTERVAL TOTAL WATERSHED FLOOD EVENT WAS SNOWMELT. SUCH A FLOOD COULD ALSO BE PRODUCED BY AN EQUIVALENT COMBINATION OF SNOWMELT AND RAINFALL COMMON IN LATE WINTER-EARLY SPRING FLOODING, OR BY AN EQUIVALENT RAINFALL ALONE AS LONG AS THE GROUND WAS EITHER FROZEN OR SATURATED. CONCEIVABLY, AN EVEN GREATER RAINFALL COULD PRODUCE SUCH A FLOOD IN THE ABSENCE OF FROZEN OR SATURATED GROUND CONDITIONS. THE COMPARISONS IN THE TABLE, HOWEVER, DO NOT REFLECT FLOODING FROM SUCH AN EVENT SINCE CONDITIONS OF SATURATED OR FROZEN GROUND WERE ASSUMED IN THE MODEL APPLICATION, THAT IS, ALL RUNOFF CURVE NUMBERS WERE SET AT 100.

[b]ALL STREAM FLOWS, EXCEPT THOSE FOR SUB-BASIN C-9, ARE FOR THE MAIN STEM OF THE MILWAUKEE RIVER AT THE POINT OF SUB-BASIN INFLOW. THE STREAM FLOWS SHOWN FOR SUB-BASIN C-9 ARE FOR CEDAR CREEK. DISCHARGES APPEARING IN THIS TABLE ARE THE PEAK VALUES THAT WERE COMPUTED FOR THE VARIOUS LOCATIONS DURING SIMULATION OF THE 100-YEAR RECURRENCE INTERVAL TOTAL WATERSHED FLOOD EVENT, THAT IS, THE SNOWMELT EVENT THAT PRODUCES A PEAK DISCHARGE AT THE MILWAUKEE GAGE APPROXIMATELY EQUAL TO THE EXPECTED 100-YEAR DISCHARGE BASED ON A FREQUENCY ANALYSIS OF HISTORICAL GAGE DATA.

THE 1970 AND 1990 PEAK STREAM FLOWS SHOWN IN THIS TABLE FOR CEDARBURG, WEST BEND, AND KEWASKUM ARE LESS THAN THE 100-YEAR RECURRENCE INTERVAL DISCHARGES AT THESE POINTS, SINCE THE LATTER WERE OBTAINED BY SIMULATING FLOOD EVENTS ENCOMPASSING ONLY PORTIONS OF THE TOTAL WATERSHED, RATHER THAN THE TOTAL WATERSHED ITSELF. SIMILARLY, THE 1970 AND 1990 RUNOFF DISCHARGES FOR SUB-BASINS L-1, C-9, MM-2, SW-1 AND UM-11 ARE LESS THAN THE 100-YEAR RECURRENCE INTERVAL VALUES AT THESE POINTS, SINCE THE DISCHARGES APPEARING IN THE TABLE CORRESPOND TO A TOTAL WATERSHED EVENT WHILE THE 100-YEAR VALUES FOR THESE SUB-BASINS WERE OBTAINED BY SIMULATING AREAS SMALLER THAN THE TOTAL WATERSHED.

SOURCE- HARZA ENGINEERING COMPANY AND SEWRPC.

ing water quality conditions within the Milwaukee River watershed are described in Chapter IX of this volume entitled, "Surface Water Quality and Pollution." Future water quality conditions can be expected to differ significantly from present conditions as a result of either the adverse effect that continued urban development within the watershed will have on water quality or the desirable effect that implementation of a sound water quality management and pollution abatement plan may have on water quality. Therefore, it was necessary to develop a method for forecasting probable future water quality conditions which considered the location, quantity, and quality of treated waste water effluent discharges to the stream under future land use and water quality control facility development conditions, as well as the natural waste assimilation capacities of the streams. Ideally, it would be desirable to observe the actual performance of the river system under various conditions of waste loading, flow, and temperature variation. Since this is not possible, a mathematical model must be used to simulate river performance.

Description of the Organic Pollution Model for the Milwaukee Stream System

A mathematical model was accordingly developed to simulate the ability of the streams in the Milwaukee River watershed to assimilate waste discharges under various types and degrees of waste treatment and various locations of waste discharges. The major parameters selected for use in the model to describe water quality conditions were dissolved oxygen (DO), biochemical oxygen demand (BOD), and temperature. These parameters describe well the overall level of the water quality and permit this quality to be related to the water use objectives and standards formulated as part of the watershed planning process. The mathematical model was constructed using established relationships between these parameters and physical conditions in the stream channel system. The input to the model is actual water quality conditions in the river system, as determined by field surveys. The model was programmed for use on an IBM-1130 computer. A general flow diagram of the model is shown in Figure 78. The complete Fortran computer program used to perform the calculations in the model is described in SEWRPC Milwaukee River Watershed Study Planning Memorandum No. 4[13] and is on file with the Commission. The computer program was used for modeling conditions along the main stem of the Milwaukee River from Campbellsport to West Bend and from West Bend to the North Avenue Dam; along Cedar Creek from Jackson to the confluence with the main stem of the Milwaukee River; along Silver Creek from Random Lake to its confluence with the North Branch of the Milwaukee River; and along the unnamed tributary from Adell to its confluence with the North Branch of the Milwaukee River.

The basic relationship used in the model for determining the dissolved oxygen concentrations in a given stream reach is the Streeter-Phelps[14] equation, as modified by Camp,[15] Dobbins,[16] and O'Connor.[17] The Streeter-Phelps equation has long been a standard analytical aid in water pollution studies. The modified equation incorporates several additional factors that permit a better evaluation of the actual performance of the river system with regard to water quality conditions. The modified equation used in the model may be written as follows:

$$(1)\ D = B(x)\, D_o\, e^{-J_a Z(x)} + F_1 \left(e^{-J_r Z(x)} - e^{-J_a Z(x)}\right) + F_n \left(e^{-J_n Z(x)} - e^{-J_a Z(x)}\right) + \left(\frac{K_d L_a}{K_a K_r}\right) \left(1 - e^{-J_a Z(x)}\right)$$

where:

$$F_1 = \frac{B(x)\, K_d\, (L_o - L_a/K_r)}{K_a - K_r}$$

$$F_n = \frac{B(x)\, K_n N_o}{K_a - K_n}$$

$$J_{r,n,a} = \frac{K_{r,n,a}}{U_o}$$

$B(x) = 1$ for constant flow in a reach.

$B(x) = (1 + qx)^{-1}$ for linearly increasing flow in a reach.

$Z(x) = x$ for constant flow and constant cross-sectional area.

[13] *See Milwaukee River Watershed Study Planning Memorandum No. 4, Surface Water Quality Simulation, prepared by Harza Engineering Company for the Southeastern Wisconsin Regional Planning Commission, June 1969.*

[14] *H. W. Streeter and E. B. Phelps, U. S. Public Health Service Bulletin 146, A Study of the Pollution and Natural Purification of the Ohio River, Part III, 1925.*

[15] *T. R. Camp, Water and Its Impurities, Reinhold Publishing Company, New York, New York, 1963.*

[16] *W. E. Dobbins, "BOD and Oxygen Relationships in Streams," Journal of the Sanitary Engineering Division, American Society of Civil Engineers, Vol. 90, No. SA3, June 1964.*

[17] *D. J. O'Connor, "The Temporal and Spatial Distribution of Dissolved Oxygen in Streams," Water Resources Research, Vol. 3, No. 1, 1967.*

$$Z(x) = \frac{x^2 - x_o^2}{2x_o}$$

for constant flow and linearly increasing cross-sectional area.

$$Z(x) = \frac{\ln(1 + qx)}{q}$$

for linearly increasing flow and constant cross-sectional area.

$$Z(x) = \frac{1}{x_o} \left(\frac{x}{q} - \frac{1}{q^2}\right) (\ln \ (1 + qx))$$

for linearly increasing flow and linearly increasing cross-sectional area.

and where:

D = dissolved oxygen deficit at a location x distance downstream from the start of a reach in mg/l.

D_o = dissolved oxygen deficit at the beginning of a reach in mg/l.

e = natural logarithm base.

K_a = reaeration rate constant in days^{-1}.

K_d = deoxygenation rate constant due to carbonaceous BOD in days^{-1}.

K_n = rate constant for nitrogenous oxygen demand in days^{-1}.

K_r = total rate constant for carbonaceous BOD removal in days^{-1}.

L_a = rate of addition of BOD from nonpoint sources in mg/l/day.

L_o = BOD concentration at the beginning of a reach in mg/l.

N_o = Nitrogenous oxygen-demand concentration at the beginning of a reach in mg/l.

q = coefficient characteristic of the shape and size of the drainage area in miles^{-1}.

U = average velocity in a stream reach in miles per day.

U_o = velocity at the beginning of a reach in miles per day.

x = distance downstream from the beginning of a reach in miles.

x_o = distance from a hypothetical origin to the beginning of a reach in miles.

These equations are used in the model to calculate the dissolved oxygen deficit at any point in the stream system, exclusive of the effects of photosynthesis and plant respiration, at any time of the day. The carbonaceous and nitrogenous oxygen demands in each reach were computed using the following equations:

$$(2)\ L = B(x)\ \left(L_o - \frac{L_a}{K_r}\right) e^{-J_r Z(x)} + \frac{L_a}{K_r}$$

$$(3)\ N = B(x)\ \ N_o\ e^{-J_n Z(x)}$$

in which L and N are, respectively, the carbonaceous and nitrogenous oxygen demands expressed in mg/l, at x distance downstream from the beginning of the reach; and all other factors and terms are as defined above.

In application, the water quality simulation is begun just upstream from a major waste discharge to the stream. The upstream conditions, including streamflow, dissolved oxygen content (DO), carbonaceous and nitrogenous biochemical oxygen demand (BOD), and temperature, are entered into the model. The initial conditions for the beginning of the reach are determined in the model by adding the DO, BOD, and flow of the waste input at the beginning to the amounts already present in the stream. The DO and BOD levels at various locations throughout the reach are then computed in the model by application of the equations previously described. At the end of the reach, a check is made to determine whether or not the reach ends at a dam. If there is a dam, the DO on the downstream side of the dam is adjusted to reflect the effects of flow over the dam. If there is no dam, no adjustment is made. The starting values of DO, BOD, and flow are then computed for the next reach by adding any DO, BOD, and flow from a waste discharge or tributary stream to the amounts present in the stream, as computed from the previous reach. These new values then serve as the initial conditions for computing DO and BOD levels throughout

Figure 78

GENERALIZED FLOW DIAGRAM FOR WATER QUALITY MODEL

Begin

Define variables

Collect and analyze physical stream data

Read initial conditions, reach constants, and tributary input data

Set time

Compute starting values of Biochemical Oxygen Demand, Nitrogenous Oxygen Demand, and Dissolved Oxygen; saturation Dissolved Oxygen; Discharge and velocity; reach length

Adjust rate constants to stream temperature

Move to a location x distance downstream

Calculate $Z(x)$, $B(x)$, area, discharge, velocity, F_l, and F_n at present location

Calculate DO deficit and DO

Repeat calculations for each x distance to the end of the reach

At end of reach, check for dam. Adjust DO if reach ends at a dam

Calculate BOD and NOD at end of reach

Repeat calculations for all reaches in the system

End

Source: Harza Engineering Company.

this reach. The same procedure is followed for all reaches in the stream system. Reaches are established between carefully selected points on the stream system, such as points of significant change in slope or cross-sectional area, and points of major waste or tributary flow inputs.

Calibration of the Model

Since general theoretical and general empirical relationships were used to develop the water quality model, it was necessary to calibrate the model to the specific characteristics of the Milwaukee River system. This involved the determination of the constants in the equations previously described from stream water quality data obtained by the Commission, the Harza Engineering Company, the Milwaukee-Metropolitan Sewerage Commissions, and the Wisconsin Department of Natural Resources in field surveys. The field surveys are described in greater detail in SEWRPC Milwaukee

River Watershed Study Memorandum No. 1.[18] Data collected during these surveys included information on the physical characteristics of the stream channels, dissolved oxygen, biochemical oxygen demand, and temperature conditions in the river system during the critical summer period and on streamflow conditions in the system. Data on major waste sources within the watershed were obtained from records of the Wisconsin Department of Natural Resources.

The value of the carbonaceous biochemical oxygen demand degradation rate constant, K_1, was determined from an analysis of the results of long-term biochemical oxygen demand tests, with suppression of nitrification, that were conducted for river water samples obtained at three locations along the river system. The analysis was performed by the graphical method.[19] The value of the deoxygenation rate constant due to carbonaceous BOD, K_d, was set equal to the BOD degradation rate, K_1. The rate constant for degradation of nitrogenous oxygen demand, K_n, was determined in a similar fashion by analysis of the results of long-term BOD tests without suppression of nitrification. The K_n values determined by this method were checked by an independent determination of K_n using nitrogen data obtained during the water quality sampling surveys. A plot was made of the ammonia nitrogen loading at several points in the stream system versus the time of travel between these points. The slope of the line of best fit was taken as the rate constant, K_n. A similar procedure was used to determine the carbonaceous BOD removal rate, K_r. The BOD loading at various points along the stream was plotted versus the time of travel between these points. The slope of the line of best fit was taken as the rate constant, K_r. The BOD removal due to sedimentation and/or volatilization, K_3, was determined from the difference between K_r and K_1 wherever K_r was greater than K_1.

The value of the reaeration rate, K_a, was determined from O'Connor's empirical equation relating the reaeration constant to stream velocity and stream depth:

(4) $$K_a = \frac{12.9\, U^{1/2}}{H^{3/2}}$$

where:

K_a = Reaeration constant at 20°C in days^{-1}.

U = average stream velocity in feet per second.

H = average stream depth in feet.

The average stream velocity for each reach in the river system was determined by the use of Manning's equation. This equation was solved utilizing slope and cross-sectional information obtained from the Commission and the U. S. Army Corps of Engineers, supplemented by additional cross-section information, estimates of channel friction factor, and flow information obtained by the Harza Engineering Company. Average stream depths in each reach were estimated from the cross-sectional data. Average stream velocity and depth data were then used in the equation described above to solve for the reaeration constant, K_a. The coefficient, q, for the characteristic shape and size of the drainage area, was determined from a plot of drainage area versus distance along the stream system. The slope of the line of best fit, divided by the initial drainage area at the beginning of each reach, was taken as the coefficient, q, for the reach. Utilizing the values determined for the constants described above and the BOD data available from the stream water quality surveys, equation (2) was solved for the rate of addition of BOD from nonpoint sources, L_a. For any reaches in which K_r was greater than K_1, L_a was set equal to zero.

An additional factor that is not present in any of the preceding equations but which was used in calibrating the model is an adjustment in the dissolved oxygen content due to flow over a dam. The change in dissolved oxygen content due to flow over a dam was modeled according to the equation:

$$D_d = C_{1,2}\, D_u$$

where:

D_d = dissolved oxygen deficit downstream from the dam in mg/l.

D_u = dissolved oxygen deficit upstream from the dam in mg/l.

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[18] *See Milwaukee River Watershed Study Planning Memorandum No. 1, Evaluation of a Water Quality Field Survey Conducted on the Milwaukee River During 1968, prepared by Harza Engineering Company for the Southeastern Wisconsin Regional Planning Commission, January 1969.*

[19] *H. A. Thomas, Jr., "Graphical Determination of BOD Curve Constants," Water and Sewage Works, Vol. 97, 1950.*

C_1 = coefficient of adjustment if D_u is negative.

C_2 = coefficient of adjustment if D_u is positive.

The value of the coefficient C was determined by solving the above equation using field measurements of DO taken above and below six dams in the watershed at three-hour intervals during the 1968 water quality sampling program. These values are used in the model for those reaches that ended at a dam. For reaches not ending at a dam, the value of $C_{1,2}$ was set equal to 1.00.

The procedures described above resulted in the determination of a set of constants that describe the performance of the river system with regard to water quality conditions. The values of all of the temperature-dependent input constants to the mathematical model were adjusted to 20°C (68°F). The temperature-dependent variables were adjusted in the computer program if temperatures other than 20°C were assumed for conditions of study. The final input values used in the water quality model are presented in Table 111. The solid lines in Figures 79 and 80 indicate the results of final calibration of the model for two of the sections of the main stem of the Milwaukee River in which diurnal dissolved oxygen data were available. The lower dashed line in each figure represents the measured DO for the early morning hours, which is generally the time of lowest DO, and the upper dashed line represents measured DO for the mid-afternoon hours, which is the time of highest DO. The points plotted on these figures are the actual DO concentrations for the early morning and mid-afternoon hours, as measured over a period of three days during the 1968 summer sampling pro-

TABLE 111

CONSTANTS USED IN THE WATER QUALITY MODEL FOR THE MILWAUKEE RIVER WATERSHED[a]

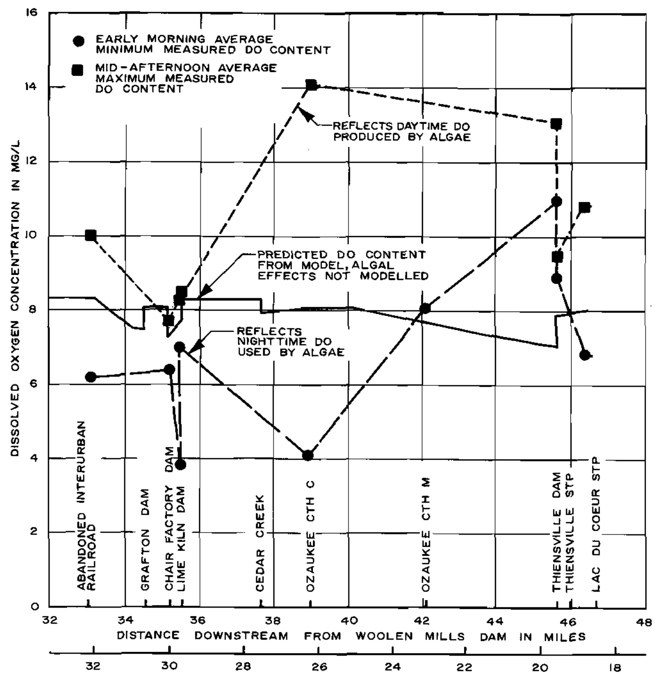
REACH	K_a	K_d	K_n	K_r	K_3	L_a	q	C_1	C_2
MILWAUKEE RIVER									
WEST BEND STP TO NEWBURG BACKWATER.....	3.80	0.26	0.70	0.26	0.00	0.00	0.00854	1.00	1.00
NEWBURG BACKWATER TO NEWBURG DAM.......	0.52	0.26	0.70	0.26	0.00	0.00	0.00800	0.40	0.70
NEWBURG DAM TO NEWBURG STP.............	14.00	0.26	0.10	0.26	0.00	0.00	0.00795	1.00	1.00
NEWBURG STP TO NORTH BRANCH............	4.30	0.26	0.10	0.26	0.00	0.00	0.00794	1.00	1.00
NORTH BRANCH TO WAUBEKA BACKWATER......	4.00	0.21	0.10	0.21	0.00	0.00	0.00810	1.00	1.00
WAUBEKA BACKWATER TO WAUBEKA DAM.......	0.58	0.21	0.10	0.21	0.00	0.00	0.00805	0.10	0.25
WAUBEKA DAM TO FREDONIA STP............	0.73	0.10	0.10	0.10	0.00	0.25	0.00798	1.00	1.00
FREDONIA STP TO SAUKVILLE STP..........	9.00	0.10	0.10	0.10	0.00	1.00	0.00789	1.00	1.00
SAUKVILLE STP TO GRAFTON BACKWATER.....	5.10	0.10	0.10	0.10	0.00	1.00	0.00845	1.00	1.00
GRAFTON BACKWATER TO GRAFTON DAM.......	0.64	0.10	0.10	0.10	0.00	0.25	0.00022	0.20	0.40
GRAFTON DAM TO CHAIR FACTORY DAM.......	0.55	0.10	0.10	0.10	0.00	0.25	0.00022	0.20	0.40
CHAIR FACTORY DAM TO LIME KILN DAM.....	1.20	0.10	0.70	0.10	0.00	0.25	0.00022	0.20	0.20
LIME KILN DAM TO CEDAR CREEK...........	6.80	0.10	0.10	0.10	0.00	1.00	0.00022	1.00	1.00
CEDAR CREEK TO THIENSVILLE BACKWATER...	5.10	0.10	0.10	0.10	0.00	1.00	0.00309	1.00	1.00
THIENSVILLE IMPOUNDMENT................	0.53	0.10	0.10	0.10	0.00	0.25	0.00329	0.20	0.40
THIENSVILLE DAM TO THIENSVILLE STP.....	4.60	0.10	0.10	0.10	0.00	1.00	0.00435	1.00	1.00
THIENSVILLE STP TO LAC DU COEUR STP....	4.70	0.10	0.70	0.10	0.00	1.60	0.00435	1.00	1.00
LAC DU COEUR STP TO KLETZSCH PARK DAM..	3.40	0.10	0.10	0.10	0.00	1.60	0.00079	1.00	1.00
KLETZSCH PARK DAM TO LINCOLN CREEK.....	4.90	0.10	0.10	0.10	0.00	1.60	0.00077	1.00	1.00
LINCOLN CREEK TO ESTABROOK PARK DAM....	0.55	0.10	0.10	0.10	0.00	0.50	0.00062	0.10	0.25
ESTABROOK PARK DAM TO CAPITOL DRIVE....	3.70	0.10	0.10	0.10	0.00	0.50	0.00062	1.00	1.00
CAPITOL DRIVE TO NORTH AVENUE DAM......	0.34	0.10	0.10	0.10	0.00	0.10	0.00071	1.00	1.00
UPPER MILWAUKEE RIVER									
CAMPBELLSPORT STP TO LAKE 15 CREEK.....	3.50	0.26	0.70	0.26	0.00	0.00	0.02410	1.00	1.00
LAKE 15 CREEK TO WEST BRANCH...........	5.00	0.26	0.70	0.26	0.00	0.00	0.01040	1.00	1.00
WEST BRANCH TO KEWASKUM STP............	2.00	0.26	0.70	0.26	0.00	0.00	0.01590	1.00	1.00
KEWASKUM STP TO EAST BRANCH............	2.30	0.26	0.70	0.26	0.00	0.00	0.05310	1.00	1.00
EAST BRANCH TO YOUNG AMERICA DAM.......	1.70	0.26	0.70	0.26	0.00	0.00	0.00680	1.00	1.00
CEDAR CREEK									
JACKSON STP TO HORNS CORNERS...........	2.70	0.26	0.70	0.26	0.00	0.00	0.11000	1.00	1.00
CEDARBURG STP TO HAMILTON DAM..........	2.80	0.26	0.70	0.26	0.00	0.00	0.01340	0.25	0.50
HAMILTON DAM TO MILWAUKEE RIVER........	7.60	0.26	0.70	0.26	0.00	0.00	0.00960	1.00	1.00
ADELL TRIBUTARY									
ADELL STP TO NORTH BRANCH..............	5.80	0.26	0.70	0.26	0.00	0.00	0.52500	1.00	1.00
SILVER CREEK (SHERMAN TOWNSHIP)									
RANDOM LAKE STP TO NORTH BRANCH........	4.40	0.20	0.70	0.26	0.00	0.00	0.11700	1.00	1.00

[a] ALL VALUES WERE DETERMINED FOR LOW FLOW CONDITIONS STANDARDIZED TO 20°C.

SOURCE- HARZA ENGINEERING COMPANY.

Figure 79

CALIBRATION OF STREAM WATER QUALITY SIMULATION MODEL - DISSOLVED OXYGEN PROFILE GRAFTON - THIENSVILLE REACH OF THE MILWAUKEE RIVER SUMMER 1968

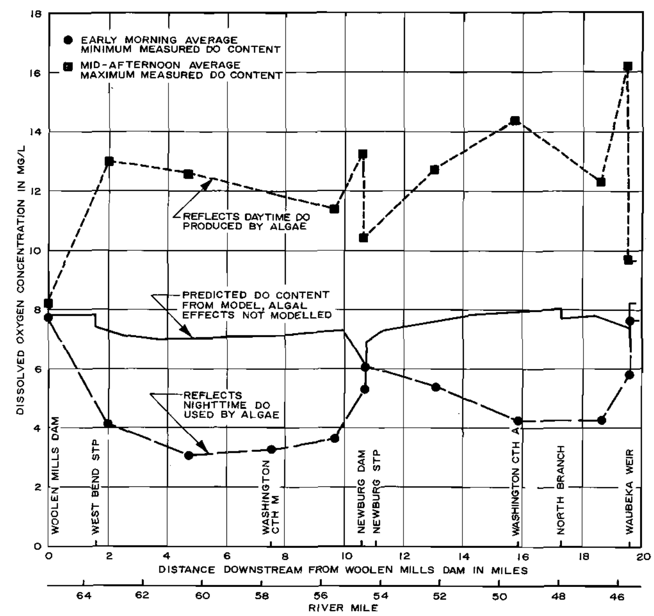


NOTE: AVERAGE RIVER TEMPERATURE 23° C. (73° F.); CORRESPONDING DO SATURATION LEVEL 8.7 MG/L.

Source: Harza Engineering Company.

Figure 80

CALIBRATION OF STREAM WATER QUALITY SIMULATION MODEL - DISSOLVED OXYGEN PROFILE WEST BEND - WAUBEKA REACH OF THE MILWAUKEE RIVER SUMMER 1968



NOTE: AVERAGE RIVER TEMPERATURE 23° C. (73° F.), CORRESPONDING DO SATURATION LEVEL 8.7 MG/L.

Source: Harza Engineering Company.

gram. Figures 79 and 80 show the large diurnal fluctuation of DO due to algal activity. Algal effects were not included in the mathematical model since future algal activity cannot be quantitatively forecast with reliability. The computed DO levels from the model check reasonably well with the measured values downstream from dams. The fall over the dam reduces the algal effect by increasing the DO level during periods of algal respiration or reducing the DO level during periods when the process of photosynthesis is taking place.

The values of the constants obtained by the above procedures, as shown in Table 111, are based on the water quality data and measurements available for the Milwaukee River system and reflect the actual purification performance of the streams to the extent that the available data accurately describe this performance. The model, as presently calibrated, is applicable to summer and fall low-flow conditions which are of primary concern for future oxygen demand forecasting. The model would have to be modified to be used for winter ice-covered conditions or high-flow conditions, such as occur during the spring runoff or during summer flood events. As stream sampling surveys are carried out in future years, the data obtained can be used to further refine the values used in the model to determine future low flow conditions.

Development of Synthesized Profiles

Input: In order to use the water quality model, it is necessary to provide certain input data to the computer program. These data consist of the initial stream conditions at the beginning of the first reach, the quality and quantity of all tributary inflows and waste discharges, the location of the beginning and end of each reach and the cross-sectional area in each reach, the location of all dams within the stream section being modeled, and the calibration constants for each reach.

Initial Conditions: Water quality conditions at the beginning of the first reach and for all tributary stream inflows were determined from data collected during water quality surveys conducted within the Milwaukee River watershed. Streamflows in each reach were based on tributary drainage areas and on a seven-day low flow, as determined from an analysis of the most recent 10 years (1958-1967) of streamflow records for the Milwaukee River at Estabrook Park in Milwaukee. This analysis was performed using low-flow data only for the months of July and August since critical conditions with respect to the dissolved oxygen content of the streams normally occur during these two months. Estimates of the seven-day low flow at various locations in the Milwaukee River system are shown in Table 112.

TABLE 112

DESIGN LOW STREAM FLOW AT SELECTED LOCATIONS IN THE MILWAUKEE RIVER WATERSHED[a]

LOCATION	FLOW (CFS)
MILWAUKEE RIVER	
AT CAMPBELLSPORT	1.8
AT KEWASKUM	5.3
AT WEST BEND	8.4
AT NEWBURG	9.0
AT FREDONIA	15.2
AT SAUKVILLE	15.8
AT GRAFTON	16.6
AT THIENSVILLE	22.4
AT ESTABROOK PARK	24.5
EAST BRANCH AT MILWAUKEE RIVER	1.8
NORTH BRANCH AT MILWAUKEE RIVER	5.3
CEDAR CREEK	
AT JACKSON	1.9
AT STH 60 UPSTREAM FROM CEDARBURG	4.3
AT CEDARBURG STP	4.4
AT MILWAUKEE RIVER	4.7
LINCOLN CREEK AT MILWAUKEE RIVER	0.7

[a]BASED ON THE LOWEST AVERAGE FLOW OCCURRING DURING A SEVEN CONSECUTIVE DAY PERIOD IN THE LAST TEN YEARS (1960-1969), EXCLUSIVE OF ALL SEWAGE TREATMENT PLANT OR INDUSTRIAL WASTE WATER FLOWS. THIS FLOW MUST BE USED IN EVALUATING COMPLIANCE WITH STATE-ESTABLISHED WATER QUALITY STANDARDS. FLOW INPUTS AT WASTE WATER DISCHARGE POINTS MUST BE ACCOUNTED FOR IN OPERATING THE MODEL.

SOURCE- HARZA ENGINEERING COMPANY.

Waste Discharges: Information on the quantity and quality of wastes discharged to surface waters in the Milwaukee River watershed was obtained from the Commission, the Wisconsin Department of Natural Resources, and the Federal Water Pollution Control Administration. This information consisted of average sewage flows and estimates of the biochemical oxygen demand loading discharged to the stream. Variable assumptions were made as to the average dissolved oxygen concentration and the nitrogenous oxygen demand of the effluents. This information, together with sewage flows and biochemical oxygen demand loadings developed for future conditions in the watershed, was utilized in the water quality model as the basic source of data for forecasting the effects of the major waste discharges on water quality.

The location of the beginning and end of each reach, in terms of distance from a preselected point, and the locations of all dams in each stream section were determined utilizing 1" = 400' scale aerial photographs of the watershed. The average area of flow in each reach was determined from measured channel sections. The values of the calibration constants for each reach were determined as described previously.

Output from the Model: The output from the water quality model consists of the forecast water quality conditions in the Milwaukee River system corresponding to the input conditions in terms of the quantity, quality, and location of waste discharges. The output includes the dissolved oxygen concentrations at various locations in each reach, the carbonaceous and nitrogenous biochemical oxygen demand concentrations at the beginning and end of each reach, the initial streamflow and the amount of tributary flow added, and the amount of biochemical oxygen demand added in the tributary flow.

Data entered into the model to determine probable water quality conditions of streams during low flow for conditions expected to prevail in the year 1990, with unplanned urban development and 90 percent biochemical oxygen demand removal at all sewage treatment plants, are described in a section of Chapter IX of this volume. Results of some of these computations are shown in Figures 37 and 42 (see Chapter IX).

SUMMARY

The preparation of sound, long-range, comprehensive watershed development plans requires information on the range of river performance that may be expected over time and under differing land use and water control facility development conditions. In order to provide this information with respect to both flood flow and water quality, two mathematical simulation models were developed under the Milwaukee River Watershed Study. These models are based upon well-established mathematical relationships drawn from the sciences of hydrology, hydraulics, and water chemistry and upon measurements of certain pertinent physical characteristics of the watershed and its stream system. Both models are adapted for use with electronic computers. Prior to application as predictive tools, the models were carefully calibrated to known measured historic conditions within the watershed.

The flood simulation model, which involved the sequential use of a backwater submodel and a flood-routing submodel, was designed to simulate the flood-flow performance of the watershed under both present and anticipated future conditions of land use and water control facility development. The backwater submodel was used to define the hydraulic characteristics, that is, the stage-discharge relationships, of the channel-floodplain cross sections. Such cross sections were located immediately upstream and downstream of 243 dams, bridges, and culverts and 208 additional locations, so as to be representative of the channel and floodplain conditions of the 216 miles of channel length studied. Impounded and non-impounded channel reaches were identified by examination of these hydraulic characteristics, and stage-discharge-volume and stage-discharge area tables prepared. These tables, along with hydrologic data for 66 sub-basins, were used as inputs to the flood-routing submodel to simulate the movement of floodwaters through the watershed as this flow actually occurs from the head of the watershed to the outlet, thereby providing definitive data on the amount and rate of flood flow throughout the channel system, as well as to develop the high water surface profiles accompanying the simulated flood flows.

The flood simulation model was calibrated to the watershed by duplication of a flood resulting from a discreet historic storm event which occurred from June 21 to June 23, 1940. Following this calibration, the model was further checked by comparing a simulated 10-year recurrence interval flood event against the high water marks actually observed for the 1960 flood within the watershed, which was a 10-year event. Similar information available for the 1924 flood event was used to check the ability of the model to simulate the 100-year recurrence interval flood event.

After satisfactory calibration was achieved, the model was used to develop flood flows and to establish flood frequencies as required for plan design. Three types of floods, ranging from those produced entirely by melting snow to those produced entirely by rainfall were synthesized to produce flood profiles. Discharges were developed for small drainage areas at various locations in the watershed for the 10-year and 100-year recurrence interval rainfall flood events; for the downstream reaches of the Milwaukee River for the 10-year and 100-year recurrence interval snowmelt flood events; and for intermediate-sized drainage areas for the 10-year and 100-year recurrence interval combined rainfall-snowmelt events. The frequency, or recurrence, interval of the summer floods was assigned on the basis of the rainfall used to synthesize the event. The frequency, or recurrence, interval of spring floods caused by snowmelt or snowmelt and rainfall was assigned on the basis of the volume and peak of flood flow. Results of the simulation of the three types of events were then combined to produce a composite, synthesized 10- and 100-year recurrence interval flood high water surface profiles along the 216 miles of stream channel studied and discharge-frequency curves for 16 selected locations on these stream channels. Except for the Estabrook Park gage site and the Cedar Creek gage site, where discharge-frequency relationships were developed from gage data, all the discharge-frequency relationships were developed by application of the model. The model as developed can be readily modified to represent the effects on the performance of the river system of any alternative structural flood control measures which may be proposed during watershed plan design.

Comparison of the results of the flood simulation model with measured data from the Estabrook Park stream gage indicates that the model accurately simulates flood flows in the river system. The discharge of the 100-year recurrence interval flood, as obtained from application of the flood simulation model, was approximately 16,500 cfs at the Estabrook Park gage, while the measured data determined by frequency analyses of the long-term gage records was 16,000 cfs. Similar excellent results were obtained for the 10-year recurrence interval flood discharge. The high water surface elevation for the 10-year flood event produced by application of the flood simulation model was generally found to be within 0.5 foot of the high water surface elevations recorded during an actual 10-year recurrence interval flood.

Application of the flood simulation model indicates that urbanization within the watershed may be expected to have only relatively minor effects on major floods. Major floods on the main stem of the Milwaukee River may be expected to remain essentially unchanged as urbanization progresses, primarily because the areas subject to intensive urbanization are located mainly in the downstream reaches of the watershed. This pattern of urbanization contributes to the early occurrence of flood peaks in the downstream areas of the watershed, so that these peaks precede the arrival of peak flows from upstream areas of the watershed. In certain sub-basins, however, peak flood flows have been and will continue to be increased by the effects of urbanization. Peak flood flows from some of the sub-basins may be expected to increase by as much as 25 percent due to the effects of urbanization within the watershed.

The water quality simulation model was designed to simulate the ability of the stream system of the Milwaukee River watershed to assimilate organic waste loadings under both present and anticipated future land use and water control facility development in the watershed. The model was constructed using well-established relationships between dissolved oxygen, biochemical oxygen demand, temperature, and the physical characteristics of the river system. The effects of the process of photosynthesis and plant respiration on the dissolved oxygen content of the streams, while not incorporated directly into the structure of the model, were accounted for by appropriate adjustments to the computed values for each stream reach based on field survey data.

The water quality simulation model was calibrated to the specific characteristics of the Milwaukee River system. This involved the determination of the constants in the equations for dissolved oxygen content, carbonaceous and nitrogenous oxygen demands, and reaeration in the streams and at dams. These constants were derived, and the model was calibrated based on measurements of actual water quality conditions made during extensive field surveys of the watershed.

The model in general produced dissolved oxygen levels ranging from six to eight parts per million, while the measured daily fluctuations ranged from three to 16 parts per million for the specific reaches used to check the model. The values of dissolved oxygen simulated by the model represent an average of the daily high and low measurements, exclusive of the effects of the processes of plant photosynthesis and respiration. The measured dissolved oxygen levels were very closely duplicated at dam locations where passage of water over the structure increased or decreased the dissolved oxygen content to approximately the saturation level, thus eliminating the effects of photosynthesis and respiration.

The stream water quality model described in this chapter provides the basis for the evaluation of the effects of alternative pollution abatement measures on the level of stream water quality existing within the watershed and permitted an evaluation to be made of the feasibility of attaining the established water use objectives and standards. In the application of the model to plan evaluation, the model inputs can be modified to represent the effects of continued urbanization within the watershed, together with the effects of proposed water quality control facility and management alternatives.

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Chapter XIII

NATURAL RESOURCE AND RECREATION-RELATED PROBLEMS

INTRODUCTION

The Milwaukee River watershed constitutes an area of valuable natural resources and related open-space within the rapidly urbanizing Southeastern Wisconsin Region. The watershed is particularly rich in resource base elements—such as lakes, streams, wetlands, woodlands, and wildlife habitat—important to recreational pursuits and to the maintenance of a healthy ecological balance within the Region. Rapid population growth and urbanization within the Region and the watershed are increasing the importance of these elements, while at the same time impairing their quality and reducing their quantity. Problems relating to these resources and their recreational uses in the watershed are of two distinct, but often interrelated, kinds: 1) those relating to the continuing deterioration of the resources induced or aggravated by human activity within the watershed, and 2) those relating to inadequacies inherent in the natural characteristics of the resources themselves, as related to qualitative or quantitative requirements for specific forms of recreational and other uses.

This chapter identifies the major temporal and spatial aspects of these two kinds of problems associated with the conservation of these natural resources and related recreation values. Because knowledge of the existing condition of the natural resources is necessary in order to understand recreation-related resource problems, this chapter also includes, as necessary, a brief description of each of the recreation-related resources within the watershed. It should be noted that, in addition to the summary data on the major lakes of the watershed presented within this chapter, individual lake use reports have been prepared for the 21 major lakes located within the watershed.[1] Each of these reports includes, for each lake covered, discussions of the physical characteristics of the lake concerned and its tributary watershed, present lake water quality, the natural resource base, present lake use, existing land use in proximity to the lake, and recreation and resource-related problems. The reports also recommend resource protection and enhancement measures required to maintain or restore the recreational values of the lake.

[1] *Individual lake plans may be obtained on a limited basis from the Southeastern Wisconsin Regional Planning Commission or the Wisconsin Department of Natural Resources.*

LAKES AND STREAMS

Description of the Resource

Lakes and streams are particularly complex ecological systems. An understanding of their existing conditions, as these conditions may affect their recreational value, requires knowledge of such phenomenon as thermal stratification and of such factors as dissolved oxygen content, concentration of certain chemicals and nutrients, aquatic plant life, bottom fauna and fish life, basin morphology, and shoreline modifications, both those made by man or created by natural processes.

Thermal Stratification

Many of the deeper lakes of southeastern Wisconsin exhibit the phenomenon known as thermal stratification, which may influence the natural resource and related recreational values of a lake in many subtle ways. Immediately following the melting of the ice cover in early spring, lakes in the Region become nearly uniform in temperature from top to bottom, at or near the temperature of maximum water density ($4^{\circ}C$ or $39^{\circ}F$). Wind-generated currents set in; and the whole water mass generally undergoes thorough intermixing, known as spring turnover. The duration of this turnover period is relatively short and is dependent upon weather conditions. Intermixing is rapid at the beginning of the turnover period because of low and more uniform water temperatures; but, as temperatures increase near, and at, the surface, the intermixing of the lower waters with the upper waters slows. Finally, mixing ceases as temperature (density) differences become too great; and, as the wind-driven water currents no longer can affect the lower depths of waters, thermal stratification occurs.

The extent to which the warm circulating surface water of the stratified lake reaches downward is dependent upon several factors, including the fetch, or length over which the wind can blow unimpeded on the lake surface, and the water density gradient that produces a resistance to mixing. With larger lakes the length of space over which wind can blow unimpeded is greater and results in a mixing by water currents deeper into the lake. In the smaller or more sheltered lakes, the warm-water stratum is a shallower and thinner layer. This upper, warm, circulating layer of water is known as the epilimnion. Immediately below the warm epilimnion lies a region of rapid decrease in temperature with increased depth, known as the thermocline, which varies in thickness and range of temperatures. Below the thermocline lies the deep, cold, and now undisturbed region of water known as the hypolimnion. Hypolimnion conditions may remain similar to those encountered in winter, or the waters may be oxygenated early in the stratification period, depending upon the amount of mixing that took place during the spring turnover. The decay of organic material, however, usually depletes the oxygen from the hypolimnion early in the summer; and it enters the state of summer stagnation.

In the fall surface cooling causes the epilimnion to deepen by convective mixing, resulting in another period of turnover. As cooling continues, the entire water mass eventually reaches the temperature of maximum density. Further cooling produces a temperature gradient in a thin surface layer, which permits freezing of the colder, less dense surface water of the lake. Temperatures immediately below the ice will be near $0^{o}C$ ($32^{o}F$), while the bulk of the water mass will be near $4^{o}C$. In the spring temperatures under the ice layer may rise a few degrees above $4^{o}C$ without disturbing the stable density gradient below. Once the ice has left, however, mixing usually occurs regularly as winds disturb and move the surface water.

During the spring and fall mixing periods, atmospheric pressure and microscopic plant life determine, through photosynthesis, the dissolved oxygen content of the surface layers which will approach saturation levels; and the vertical circulation will disperse this oxygen content throughout the water body, although saturation levels are not always reached in the deeper layers.

The thermal stratification exhibits the sharpest delineations during late July and August, provided the lake is deep enough to stratify. This is the most critical period in the survival of cold-water fish that might inhabit a lake having waters cool enough for such survival only in the thermocline and hypolimnion layers. Oxygenation normally must be a continual process for fish to survive in these deeper and colder layers, and light must penetrate in order to provide for photosynthesis. Light does not penetrate deeply in waters which are turbid, have dark coloration, or have dense algal blooms at the surface. As a result the deeper waters become deoxygenated. Since nearly all larger organisms require dissolved oxygen for life, the well-oxygenated surface layer becomes the zone of life within the lake in midsummer.

In deep, fertile lakes, large masses of water may remain throughout the summer without sufficient oxygen to support most forms of aquatic life. The proportion of the total volume of each major lake within the Milwaukee River watershed which may be expected to contain more than 2 mg/l of dissolved oxygen, considered to be the lower level at which most forms of aquatic life may be sustained in midsummer, is set forth in Table 113.

As the water temperatures cool and again become uniform in the fall, another mixing period sets in, known as the fall turnover. The water column again becomes well oxygenated. The lake surface then freezes; oxygen replenishment is negligible even near the surface; and chemical and biological oxygen demands will then determine the dissolved oxygen concentrations when thick ice and heavy snow cover prevent photosynthesis.

Of the 21 major lakes studied intensively within the Milwaukee River watershed, 13 were found to stratify thermally every year. The midsummer thermal characteristics of 20 of these lakes are illustrated in Figure 81. Shallow Mud Lake in Ozaukee County has a maximum depth of only four feet; does not stratify; and, therefore, maintains a nearly uniform temperature throughout the summer. The larger lakes have deeper thermoclines due to the influence of greater wind fetch turbulence. In some lakes the lower thermocline depth is not a distinct feature. The thermocline fades into the hypolimnion in Ellen Lake, Sheboygan County. Later, during the summer, stratification disappears completely. The classic temperature profile is shown by such lakes as Crooked Lake in Sheboygan County. The mean surface temperature exhibited in the profiles in Figure 81 was $24.5^{o}C$ ($76^{o}F$). The mean bottom temperature was $22.0^{o}C$ ($71.8^{o}F$) in unstratified lakes and $13.0^{o}C$ ($55.5^{o}F$) in stratified lakes. The maximum

TABLE 113

SELECTED DATA FOR THE MAJOR LAKES IN THE MILWAUKEE RIVER WATERSHED- 1968

LAKE NAME	COUNTY	ACREAGE	VOLUME (ACRE-FEET)	PERCENT OF AREA <3 FEET	PERCENT OF VOLUME <3 FEET	PERCENT OF AREA >20 FEET	PERCENT OF VOLUME >20 FEET	DEPTH (FEET) MAXIMUM	DEPTH (FEET) MEAN[a]	DEPTH TO THERMOCLINE (FEET)	RATIC OF AREA (SQ.MI.) TO SHORE LENGTH (MILES)
BIG CEDAR.......	WASHINGTON	932	31,983	7	8	47	62	105	34	24	0.132
LCNG............	FOND DU LAC	427	7,209	11	15	41	28	47	17	26	C.097
LITTLE CEDAR....	WASHINGTON	246	3,153	17	33	37	24	56	13	19	0.089
MUD.............	OZAUKEE	245	645	45	88	0	0	4	2.5	--[b]	0.100
KETTLE MORAINE..	FCND DU LAC	227	1,340	20	56	1	1	30	6	17	0.118
RANDOM..........	SHEBOYGAN	209	1,280	14	53	4	1	21	6	--[b]	C.091
ELLEN...........	SHEBOYGAN	121	1,890	15	18	37	26	42	16	13	0.100
SILVER..........	WASHINGTON	118	2,306	12	14	56	38	47	20	17	0.067
AUBURN..........	FCND DU LAC	107	1,474	14	27	32	5	29	14	12	0.070
CRCOKED.........	SHEBOYGAN AND FOND DU LAC	91	1,100	17	38	30	5	32	12	14	C.064
SMITH...........	WASHINGTON	86	252	45	79	0	0	5	3	--[b]	C.074
MAUTHE..........	FCND DU LAC	78	961	9	29	25	4	23	12	7	C.079
LUCAS...........	WASHINGTON	78	461	81	67	0	0	15	6	--[b]	C.051
GREEN...........	WASHINGTCN	71	1,195	11	17	38	18	37	17	11	C.062
BARTON POND.....	WASHINGTON	67	189	52	72	0	0	5	3	--[b]	C.035
WEST BEND POND..	WASHINGTON	67	427	12	44	0	0	14	6	--[b]	C.038
SPRING..........	OZAUKEE AND SHEBOYGAN	57	415	21	36	1	1	22	7	--[b]	0.055
MUD.............	FOND DU LAC	55	452	11	35	0	0	17	8	--[b]	C.061
TWELVE..........	WASHINGTON	53	341	34	39	0	0	20	7	10	C.063
WALLACE.........	WASHINGTON	52	558	16	26	17	16	35	11	11	C.054
FOREST..........	FOND DU LAC	51	552	12	29	18	8	32	11	5	C.060

LAKE NAME	PERCENT OF TOTAL VOLUME WITH> 2 MG/L DO	NUISANCE HAZARD BASED ON CL[c]	FERTILITY BASED ON SPRING PO_4[d]	FERTILITY BASED ON ALKALINITY	FERTILITY BASED ON PLANT TISSUE PO_4/CL	USE PROBLEMS[e] WINTER KILL	POLLU-TION	STUNTED PANFISH	CARP	WEEDS	ALGAE	HIGH FISHING PRESSURE[f]	RECREATIONAL RATING[g]
BIG CEDAR.......	44	LOW 0.8	HIGH	MODERATE	EXCESSIVE			X		X		X	54
LCNG............	81	LOW 0.8	LOW	MODERATE	MODERATE							X	61
LITTLE CEDAR....	78	LOW 0.6	HIGH	MODERATE	EXCESSIVE			X	X				60
MUD.............	100	LOW 0.8	LOW	MODERATE	MODERATE	X							39
KETTLE MORAINE..	98	LOW 0.4	LOW	MODERATE	EXCESSIVE	X		X		X			44
RANDOM..........	99	MEDIUM 1.7	LOW	MODERATE	EXCESSIVE	X	X	X		X	X		46
ELLEN...........	80	MEDIUM 1.3	LOW	VERY FERTILE	EXCESSIVE						X	X	49
SILVER..........	85	LOW 0.5	LOW	VERY FERTILE	LIMITING			X				X	59
AUBURN..........	82	LOW 0.5	LOW	VERY FERTILE	LIMITING							X	52
CRCOKED.........	82	LOW 0.6	LOW	VERY FERTILE	MODERATE			X		X		X	45
SMITH...........	99	LOW 0.4	LOW	MODERATE	EXCESSIVE	X			X		X		37
MAUTHE..........	73	LOW 0.7	LOW	MODERATE	MODERATE						X	X	48
LUCAS...........	99	LOW 0.5	LOW	MODERATE	LIMITING					X			54
GREEN...........	79	LOW 0.8	LOW	MODERATE	MODERATE			X	X			X	49
BARTCN POND.....	100	MEDIUM 1.5	HIGH	VERY FERTILE	EXCESSIVE		X		X	X	X		36
WEST BEND POND..	99	MEDIUM 1.7	HIGH	VERY FERTILE	EXCESSIVE		X		X	X	X		40
SPRING..........	99	LOW 0.6	LOW	MODERATE	MODERATE			X				X	56
MUD.............	93	LOW 0.7	MEDIUM	VERY FERTILE	MODERATE	X					X		37
TWELVE..........	99	LOW 0.4	LOW	VERY FERTILE	MODERATE			X	X		X	X	40
WALLACE.........	78	HIGH 2.3	LOW	MODERATE	EXCESSIVE			X				X	48
FOREST..........	85	LOW 0.4	MEDIUM	MODERATE	MODERATE	X					X	X	48

[a]VCLUME/AREA EQUALS MEAN DEPTH.

[b]NO THERMOCLINE MEASURED BECAUSE LAKE IS TOO SHALLOW TO STRATIFY.

[c]PCLLUTION HAZARD RATING-

INDEX BASED ON RATIO BETWEEN MEAN CHLORIDE CONTENT (8.5 MG/1) AND ACTUAL MEASUREMENT SHOWN IN TABLE 115.

LOW = 0-1
MEDIUM = 1-2
HIGH = 2+

[d]SPRING PHOSPHATE FERTILITY RATING-

LOW = LESS THAN 0.06 MG/1
MEDIUM = 0.06 - 0.15 MG/1
HIGH = MORE THAN 0.15 MG/1

[e]AN X INDICATES PROBLEM AREAS.

[f]OVER 100 HOURS PER ACRE ANNUALLY.

[g]RECREATIONAL RATING- HIGHEST POSSIBLE SCORE IS 72, SEE INDIVIDUAL LAKE USE PLANS FOR RATING SUMMARY.

SOURCE- WISCONSIN DEPARTMENT OF NATURAL RESOURCES.

rate of temperature decrease in the thermocline was found to be about 1.3^{O}C decrease per foot increase in depth. The average depth to the surface of the thermocline was found to be 14.3 feet, with a range from 5 to 26 feet.

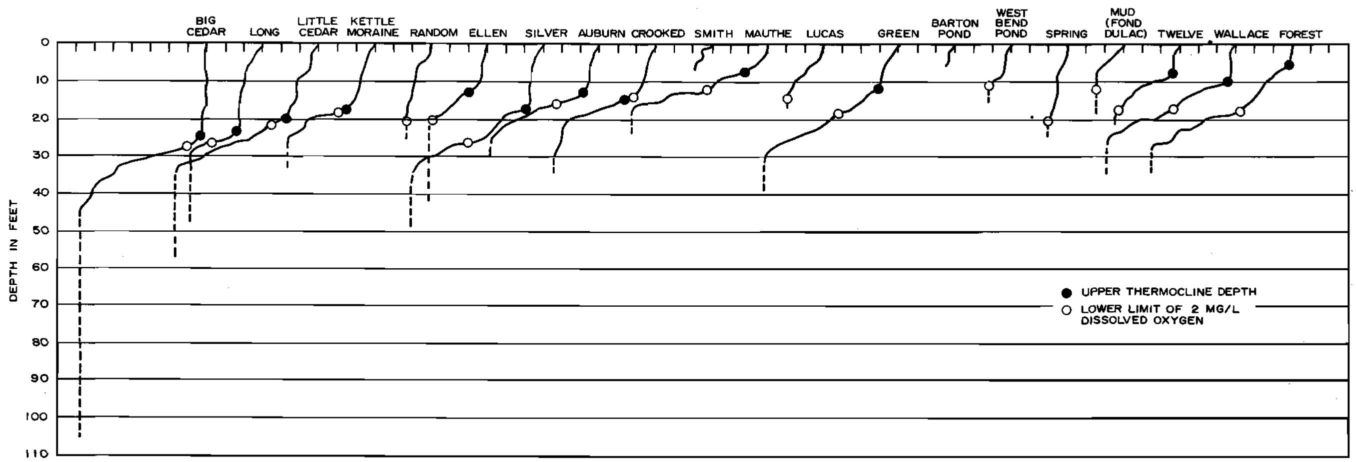
Oxygen Content

Since oxygen concentrations in midsummer determine the depths to which fish are found, oxygen profiles were prepared showing the depth to which dissolved oxygen (2 mg/l or parts per million) is adequate for the support of fish life. These profiles are illustrated in Figure 82 for 20 of the 21 major lakes within the watershed. Table 113 lists the percent of total water volume within each of these 20 lakes with more than 2 mg/l dissolved oxygen content in midsummer. The larger lakes with deeper thermoclines usually have greater concentrations of dissolved oxygen through the thermoclines. In most of the 13 stratified lakes of the watershed, an oxygen deficiency occurs in the lower thermocline; and in all the lakes with hypolimnions, dissolved oxygen was absent in this lowest thermal layer. The average oxygen concentration one foot below the surface for the lakes shown in Figure 82 was found to be 7.5 mg/l, with a range from 4.7 to 9.8 mg/l. The average bottom oxygen concentration encountered was less than 0.1 mg/l, with 18 of the 21 lakes found to

Figure 81

SUMMER TEMPERATURE PROFILES FOR SELECTED LAKES IN THE MILWAUKEE RIVER WATERSHED, WISCONSIN 1968[a]

TEMPERATURE IN TWO-DEGREE INCREMENTS, CENTIGRADE



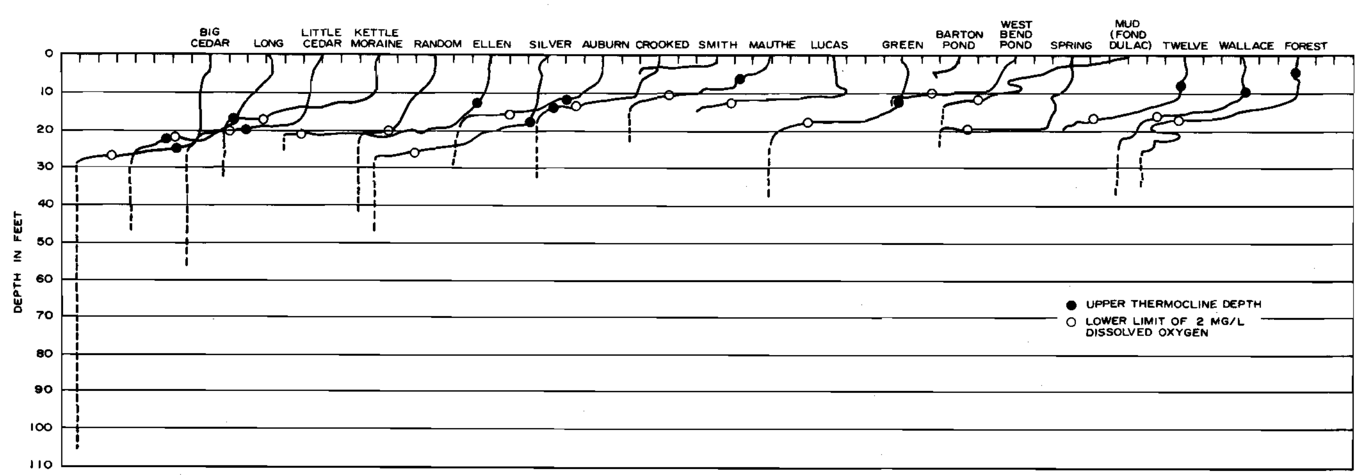
[a] INDIVIDUAL LAKE TEMPERATURE PROFILES HAVE BEEN PREPARED AND PUBLISHED IN A SERIES OF LAKE USE REPORTS AVAILABLE UPON REQUEST FROM THE SEWRPC.

Source: Wisconsin Department of Natural Resources.

Figure 82

SUMMER OXYGEN PROFILES FOR SELECTED LAKES IN THE MILWAUKEE RIVER WATERSHED, WISCONSIN 1968[a]

OXYGEN CONCENTRATIONS IN ONE MG/L UNITS



[a] INDIVIDUAL LAKE OXYGEN PROFILES HAVE BEEN PREPARED AND PUBLISHED IN A SERIES OF LAKE USE REPORTS AVAILABLE UPON REQUEST FROM THE SEWRPC.

Source: Wisconsin Department of Natural Resources.

have no measurable oxygen content near the bottom. The mean depth at which dissolved oxygen content was found to decrease to less than 2 mg/l was 17 feet, with a range from 10 feet (West Bend Pond in Washington County) to 27 feet (Big Cedar Lake in Washington County). The highest dissolved oxygen content was recorded at Mud Lake in Fond du Lac County at 9.8 mg/l.

Chemical Factors

Total alkalinity, expressed as milligrams per liter of calcium carbonate, is a basic measure of the amount of calcium, magnesium, and bicarbonate ions present in lake water. Lakes with high alkalinities are fertile and support greater plant growths. Photosynthesis indirectly decreases alkalinity by producing oxygen, which combines with calcium bicarbonate to form calcium carbonate, which, in turn, tends to precipitate out of solution. The reverse occurs when aquatic vegetation decomposes. Here, alkalinity increases as carbonates are brought back into solution as calcium bicarbonate. In midsummer the upper layers of lakes within the watershed, therefore, may be expected to have lower alkalinities, while the deeper waters, which must accommodate the decomposition of materials produced and settled from above, may be expected to have higher alkalinities. Lakes are classified as fairly fertile if their waters contain 40 mg/l or more of total alkalinity (see Table 114). By this definition all lakes of the Milwaukee River watershed are moderate to very fertile and productive. The mean total alkalinity of the 21 lakes studied within the Milwaukee River watershed during the spring mixing period was found to be 190 mg/l, with a range from 126 mg/l to 216 mg/l (see Table 115). In late summer under stratified conditions, the upper layers were found to average 184 mg/l total alkalinity.

TABLE 114

GENERAL LAKE WATER FERTILITY RATING BASED ON TOTAL ALKALINITY MEASURED

TOTAL ALKALINITY MEASURED (MG/L AS $CaCO_3$)	RELATIVE FERTILITY RATING FOR AQUATIC PLANT PRODUCTION	
0.0 TO 20.0	LOW	INFERTILE
21.0 TO 40.0	LOW-MEDIUM	INFERTILE
41.0 TO 99.0	MEDIUM-HIGH	INFERTILE TO FAIRLY FERTILE
100.0 TO 199.0	HIGH	MODERATELY FERTILE
200.0 OR MORE	HIGH	VERY FERTILE

SOURCE- WISCONSIN DEPARTMENT OF NATURAL RESOURCES.

The pH value (negative logarithm of the hydrogen ion concentration expressed in gram equivalents) determines the relative proportions of the components of total alkalinity. At pH values ranging between 4.5 and 8.2, alkalinity is nearly all bicarbonate. At pH values above 8.2, alkalinity is nearly all carbonate. Fish are commonly found in waters of a pH range of 5 to 9. More tolerant species can survive at higher or lower pH values, but such values may be considered generally hazardous to fish life. The mean pH value of the 21 lakes studied within the Milwaukee River watershed during spring mixing was 7.9, with a range of 7.3 to 8.6. In late summer upper waters averaged 8.6 and ranged from 7.9 to 9.5, while deep waters averaged 7.9 and ranged from 7.2 to 9.5 (see Table 115). Extreme values were encountered in Kettle Moraine, Lucas, Smith, and Wallace Lakes and were associated with algal blooms.

Chlorides in concentrations of more than 500 mg/l may adversely affect desirable forms of aquatic life. Chlorides are contributed to lake waters primarily from sewage, industrial wastes, and surface runoff, although other sources, such as animal excretia associated with heavy lake use by waterfowl, may also contribute. Little significant variation was found in the vertical distribution of chlorides. The mean chloride content of the 21 lakes studied within the Milwaukee River watershed was found to be 7.5 mg/l, with a range from 3.1 mg/l to 19.3 mg/l (see Table 115). Chloride concentrations higher than twice the mean are indicative of potential pollution problems. Lakes with such chloride concentrations within the watershed include Ellen, Random, and Wallace Lakes and Barton and West Bend Ponds.

Nutrients

Nutrients may be defined as those chemical elements necessary for the growth of plant life. Low concentrations of nutrients may be limiting to plant growth, while high concentrations may be toxic or inhibitory. Many different nutrients are essential to plant growth. Some, termed micronutrients, must be present in only very small, or trace, quantities. These include iron, manganese, copper, zinc, molybdenum, vanadium, boron, chlorine, cobalt, and silicon. Others, termed macronutrients, must be present in larger amounts and include phosphorus, nitrogen, carbon, hydrogen, oxygen, potassium, magnesium, calcium, and sulphur.

TABLE 115

SUMMARY OF DETAILED WATER ANALYSES OF MAJOR LAKES IN THE MILWAUKEE RIVER WATERSHED- 1961-1968

LAKE NAME	ACREAGE	DATE OF SAMPLE	SPECIFIC CONDUCTANCE (MICROMHOS/CM AT 25°C)	PH (UNITS)	TOTAL ALKALINITY (MG/1 AS CA CO_3)	NITRATE AS NITROGEN (MG/1)	TOTAL PHOSPHATES (MG/1)	DISSOLVED PHOSPHATES (MG/1)	CHLORIDES (MG/1)
BIG CEDAR.......	932	4- 2-68	303	7.5	161	0.06	0.13	0.06	03.0
		4- 3-68	346	7.9	183	0.01	0.56	0.52	07.0
		4- 3-68	357	7.8	183	0.01	0.56	0.47	07.0
		4- 3-68	310	7.8	183	0.01	0.77	0.52	07.5
		8- 6-68	293	8.9	154	--	0.56	--	08.5
		8- 6-68	302	7.8	158	--	0.64	--	06.3
LONG............	427	5- 3-65	--	8.2	194	0.24	0.08	0.08	05.3
		4- 3-68	362	7.8	200	0.02	0.11	0.03	08.5
		4- 3-68	386	7.7	199	0.01	--	0.03	08.5
		4- 3-68	379	7.7	200	0.01	0.27	0.03	08.0
		7-29-68	326	8.3	190	--	0.48	0.28	06.8
		7-29-68	326	7.8	210	--	0.11	0.12	06.5
LITTLE CEDAR....	246	7- 8-63	332	8.9	168	0.01	--	0.32	03.4
		7- 8-63	336	8.7	168	0.01	--	0.26	03.5
		4- 3-68	337	7.8	178	0.01	0.58	0.36	06.5
		7-31-68	321	8.5	174	--	0.52	0.50	06.3
		7-31-68	321	7.5	185	--	0.52	0.35	05.5
MUD (OZAUKEE)...	245	5- 1-68	277	7.9	154	0.10	0.08	0.03	06.5
KETTLE MORAINE..	227	4- 2-68	233	7.6	126	0.02	0.05	0.01	04.0
		7-29-68	197	9.2	118	--	0.12	0.12	03.8
		7-29-68	241	7.2	155	--	--	--	03.7
RANDOM..........	209	4- 4-68	400	7.9	172	--	0.01	0.01	16.3
		8- 7-68	390	7.7	171	--	0.06	0.03	12.8
		8- 7-68	329	8.5	158	--	0.17	0.01	13.3
ELLEN...........	121	4-26-61	510	8.1	225	2.20	--	--	10.2
		4-23-63	612	8.1	226	--	--	0.43	08.4
		4- 4-68	404	7.7	212	0.03	0.01	0.01	11.5
		7-29-68	412	8.4	198	--	0.99	0.09	13.0
		7-29-68	410	8.5	205	--	0.80	1.50	12.8
SILVER..........	118	4- 3-68	391	8.1	214	0.01	0.10	0.03	04.0
		7-31-68	354	8.2	212	--	0.10	0.10	03.3
		7-31-68	331	8.6	193	--	0.07	0.03	03.0
AUBURN..........	107	4-30-68	376	8.1	210	0.24	0.08	0.01	04.3
		8- 7-68	382	7.9	217	--	0.06	0.01	04.8
		8- 7-68	351	7.5	212	--	0.05	0.05	05.0
CROOKED.........	91	5- 3-65	--	8.3	190	0.07	0.16	0.13	04.7
		4- 2-68	379	7.4	204	0.05	0.13	0.02	06.8
		7-31-68	432	8.5	206	--	0.15	0.04	05.8
		7-31-68	354	7.6	217	--	0.16	0.17	06.5
SMITH...........	86	4-29-68	340	8.4	192	0.08	0.12	0.01	03.5
		8- 6-68	270	9.0	140	--	0.06	--	03.3
MAUTHE..........	78	5- 3-65	--	8.3	191	0.08	0.08	0.01	04.7
		5- 2-68	360	7.6	189	0.08	0.15	0.04	05.8
		8- 6-68	387	8.2	199	--	0.36	0.13	06.3
		8- 6-68	380	7.4	197	--	2.30	2.00	05.8
LUCAS...........	78	5- 1-68	340	8.3	191	0.03	0.05	0.02	04.5
		7-31-68	263	9.5	152	--	0.08	0.04	03.5
		7-31-68	256	9.5	153	--	0.08	0.03	03.8
GREEN...........	71	4-29-68	351	8.1	185	0.05	0.07	0.01	06.3
		8- 7-68	329	8.4	170	--	0.66	0.33	07.3
		8- 7-68	351	7.9	177	--	0.34	0.04	06.5
BARTON POND.....	67	4- 4-68	490	7.6	200	0.05	0.42	0.50	10.5
		8- 7-68	501	8.0	279	--	1.18	0.54	15.8
		8- 7-68	469	7.4	251	--	1.40	0.52	15.8
WEST BEND POND..	67	4-29-68	439	8.1	213	0.12	0.28	0.22	09.5
		8- 7-68	421	8.1	270	--	0.73	0.53	19.0
		8- 7-68	479	7.4	255	--	0.80	0.65	19.3
SPRING..........	57	5- 3-65	--	8.5	189	0.06	0.03	0.01	04.8
		4- 4-68	354	7.8	175	0.01	0.03	0.01	04.5
		8- 7-68	345	7.8	218	--	0.10	0.08	05.3
MUD............. (FOND DU LAC)	55	4- 2-68	382	7.4	191	0.06	0.23	0.10	07.3
		7-31-68	342	7.8	220	0.78	--	--	04.5
		7-31-68	331	8.4	221	--	0.18	0.08	05.0
TWELVE..........	53	4-29-68	376	8.1	216	0.14	0.12	0.05	03.0
		8- 7-68	363	8.4	222	--	0.13	0.11	03.5
		8- 7-68	376	7.9	218	--	0.18	0.11	03.0
WALLACE.........	52	4-29-68	354	8.6	184	0.04	0.07	0.01	18.8
		8- 6-68	311	9.2	135	--	0.08	0.04	20.0
		8-66-68	354	8.3	153	--	0.08	0.06	19.5
FOREST..........	51	4- 2-68	261	7.3	140	0.01	0.12	0.12	04.0
		7-31-68	256	7.9	156	--	0.17	0.13	02.3
		7-31-68	204	8.8	134	--	0.14	0.12	02.3

SOURCE- WISCONSIN DEPARTMENT OF NATURAL RESOURCES.

Phosphorus compounds are important in energy transformation, especially photosynthesis. Algae are dependent upon phosphorus for growth; and, therefore, the production of this food chain base for all aquatic life may be limited by the phosphorus supply. Growth of algae is inhibited when available dissolved phosphate concentrations are less than 0.03 mg/l. At concentrations higher than 0.05 mg/l, nuisance algal blooms can be anticipated. In lakes which stratify, a measurable increase in phosphorus content may occur in the lower hypolimnion in late summer. Under bloom conditions high total phosphate levels are frequently associated with very low dissolved phosphate levels. In early spring, preceding algal blooms, the average total phosphate and dissolved phosphate concentrations in the surface waters of the 21 lakes studied were found to be 0.16 mg/l and 0.10 mg/l, respectively (see Table 115). The range of these average levels for total phosphates varied from 0.01 mg/l to 0.63 mg/l and for dissolved phosphates, from 0.10 mg/l to 0.50 mg/l. During the summer the average total phosphate and dissolved phosphate levels in the surface layers were 0.35 mg/l and 0.28 mg/l, increasing considerably from previous spring levels. Deeper samples taken in midsummer indicated an even higher level than in the surface layers, with total phosphate content averaging 0.46 mg/l and dissolved phosphate, 0.31 mg/l.

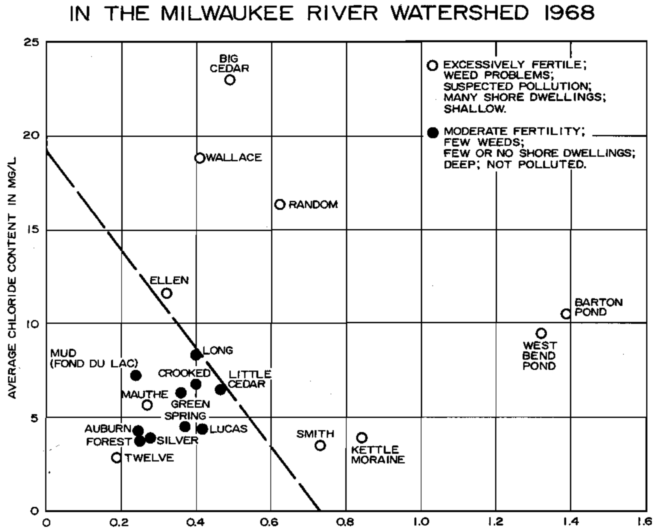
Of the 21 major lakes within the watershed, four had high concentrations of dissolved phosphate (over 0.15 mg/l) during both the spring and summer sampling periods. These were Big Cedar and Little Cedar Lakes and Barton and West Bend Ponds, all in Washington County. Two lakes were within the medium range of 0.06 to 0.15 mg/l dissolved phosphate during the same periods. Both lakes, Forest and Mud in Fond du Lac County, exhibited prominent algal blooms. Only three lakes—Silver and Lucas in Washington County and Auburn in Fond du Lac County—appear to have truly limiting phosphate levels throughout the year. All the remaining 12 lakes studied exhibited low concentrations of dissolved phosphates during the spring, but these levels increased during the summer months, and most achieved considerable growths of rooted aquatic vegetation or algal blooms. The causes of these increased dissolved phosphate levels may be attributed to diffusion from the hypolimnion or inflow of nutrients from the surrounding watershed. A general distinction between excessively fertile lakes and moderately fertile lakes is possible by relating the percent phosphorus in plant tissue to average chloride concentration of the lake water. Chloride is a reliable indicator of external enrichment, and phosphate consumed in excess of plant requirements by the rooted aquatic vegetation will usually indicate excessive water fertility stemming from such enrichment. The results of this correlation are presented in Figure 83.

Aquatic Plants

Most of the lakes studied within the Milwaukee River watershed displayed moderate-to-abundant growths of aquatic plant vegetation extending from the shorelines to depths as great as 20 feet. Generally, lakes with combinations of extensive shallow water areas, clear water, and muck bottoms produce more vegetation per acre than the lakes that have limited shallow water areas; turbid or brown-stained water; and marl, sand, gravel, or suspended ooze bottoms. A continuum of vegetative growths was found to exist, ranging from Ellen Lake, with relatively little plant life, to Crooked Lake, which displayed an abundance of plant growth. Two of the lakes surveyed, Crooked Lake and West Bend Pond, had unusually rank aquatic growth or excessive algal blooms, indicating pollution through unnatural enrichment. This type of enrichment can be caused by drainage from fertilized agricultural lands, storm water runoff from urban areas, and domestic and industrial liquid waste disposal.

Figure 83

PERCENT PHOSPHORUS IN ROOTED AQUATIC PLANTS AS RELATED TO AVERAGE CHLORIDE CONTENT OF LAKE WATER SAMPLES FOR SELECTED MAJOR LAKES IN THE MILWAUKEE RIVER WATERSHED 1968



Source: Wisconsin Department of Natural Resources.

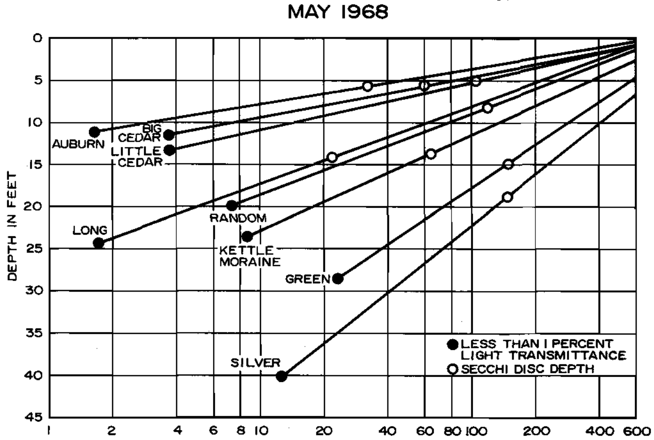
Within the Milwaukee River watershed, the distribution and abundance of aquatic plants varied with certain lake characteristics. Definite relationships were apparent between the occurrence of aquatic vegetation and water fertility, human weed control activities, water transparency, and type of bottom sediments. Lakes with excessive aquatic vegetational growth and algal blooms that reach problematic and nuisance proportions are indicated in Table 113.

A definite correlation was also found between the maximum depth at which the vegetation occurred and the relative transparency of the lake water as measured by Secchi disc. In Figure 84 the depth to which light penetrates to 1 percent of its surface intensity is plotted, along with Secchi disc depth readings. When samples from moderately deep lakes with varying degrees of coloration and turbidity were compared, the ratio of transparency depth readings of the Secchi disc to maximum depth of plant growth was found to be about 0.55 to 1. In other words, plants were generally found to grow to a depth of 1.82 times the transparency depth measured.

Fish Life

Of the 21 major lakes in the Milwaukee River watershed, all but Mud Lake, Ozaukee County, were found to support fisheries comprised of largemouth bass, bluegills, yellow perch, and bullheads (see Figure 85). Northern pike and black crappies are common in 18 of these same lakes. Over 75 percent of the lakes contain populations of rough fish, including white suckers, golden shiners, and carp, the latter species being

Figure 84
DEPTH OF LIGHT PENETRATION IN SELECTED MAJOR LAKES IN THE MILWAUKEE RIVER WATERSHED
MAY 1968

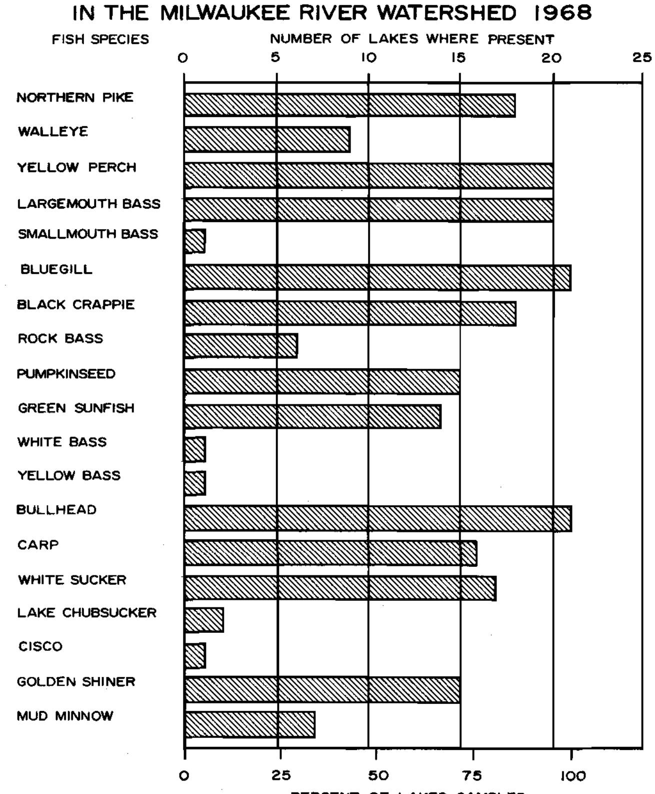


Source: Wisconsin Department of Natural Resources.

the most dominant. In six lakes rough fish occurred in such abundance as to be considered detrimental to the other, more desirable forms of fish life. The various fishery problems encountered within the lakes of the watershed are summarized in Table 113. Lakes with large rough fish populations were found to be generally shallow, with soft bottom materials, and are located either on, or drain into, a main surface stream. Nine lakes have populations of walleyes; five of these support good, fishable walleye populations—Little Cedar, Long, Mauthe, Silver, and Random Lakes. Big Cedar Lake supports a population of cisco; however, an occasional summerkill of this cold-water species occurs because of an extreme seasonal decrease of oxygen at the depths of desirable cool-water temperatures.

Of the 21 major lakes within the watershed, one, Mud Lake in Ozaukee County, is considered incapable of supporting significant fish populations. Five other lakes experience periodic winterkills but sustain a limited fishery nearly every year.

Figure 85
FREQUENCY OF OCCURRENCE OF VARIOUS SPECIES OF FISH IN MAJOR LAKES IN THE MILWAUKEE RIVER WATERSHED 1968



Source: Wisconsin Department of Natural Resources.

The remaining lakes sustain a moderate fishery and must support the major proportion of the heavy fishing demand that is evident on this watershed.

Stream fisheries of any consequence are limited in the watershed. Only five major streams—the Milwaukee River; its tributaries, including the East, North, and West Branches, and Cedar Creek—support a moderate fishery. These streams mainly support fisheries of white suckers but also include smallmouth bass, northern pike, bullheads, and carp. White suckers and carp, or the rough fish, are abundant or dominate the pools in these streams, as well as in other streams of smaller size within the watershed. Small populations of bluegills, black crappies, and walleyes are also present in limited size and quantity in the major streams. Cedar Creek has small populations of walleyes, panfish, and smallmouth bass. The major streams have additional northern pike populations during the spring spawning migration period.

The minor streams of the watershed support high populations of forage minnows and crayfish, with the exception of Water Cress Creek, Melius Creek, and the extreme upper portion of the North Branch of the Milwaukee River above Cascade Pond. Water Cress Creek has a good population of brook trout, while the North Branch of the Milwaukee River (Nichols Creek) has limited numbers of brown and rainbow trout. Melius Creek is periodically stocked with brown trout but is considered to be marginal trout water. Melius Creek, Nichols Creek, and Water Cress Creek, as well as Gooseville Creek in Sheboygan County and Lake Fifteen Creek in Fond du Lac County, are designated as official trout streams pursuant to Section 30.18 of the Wisconsin Statutes. Determinants of fish species distribution and abundance in the watershed are overenrichment by nutrients, insufficient and unstable spring flows, silty bottom conditions, eroding bank cover, and presence of dams. Map 60 shows the existing (1967) lake and stream fisheries in the Milwaukee River watershed.

Lake Basin Morphology

Certain aspects of lake basin morphology are particularly important to a critical assessment of the recreational value of a lake. The size of the lake, together with the area of open water available per unit of shoreline, is a measure of the potential water space available for recreational use. Size and orientation, with respect to prevailing winds, dictate the characteristics of the shoreline and, therefore, its value for such recreational uses as swimming, fishing, and wildlife observation. Volume, as related to area and depth, reflects the total life zone in the lake; the extent to which rooted vegetation may influence the basin; and in drainage lakes the extent to which influent waters will alter lake conditions.

Selected aspects of lake basin morphology are set forth in Table 113 for the lakes studied in the Milwaukee River watershed. Of the 21 major lakes studied within the Milwaukee River watershed, two are considered to be impoundments. These impoundments, the Barton and West Bend Ponds, are characterized as having irregular shorelines, elongated basins, predominantly silt bottoms, and extensive areas of shallow waters in the upstream portion of the basin. The remaining 19 natural lakes have been further categorized by size and basin morphology, as shown in Table 113.

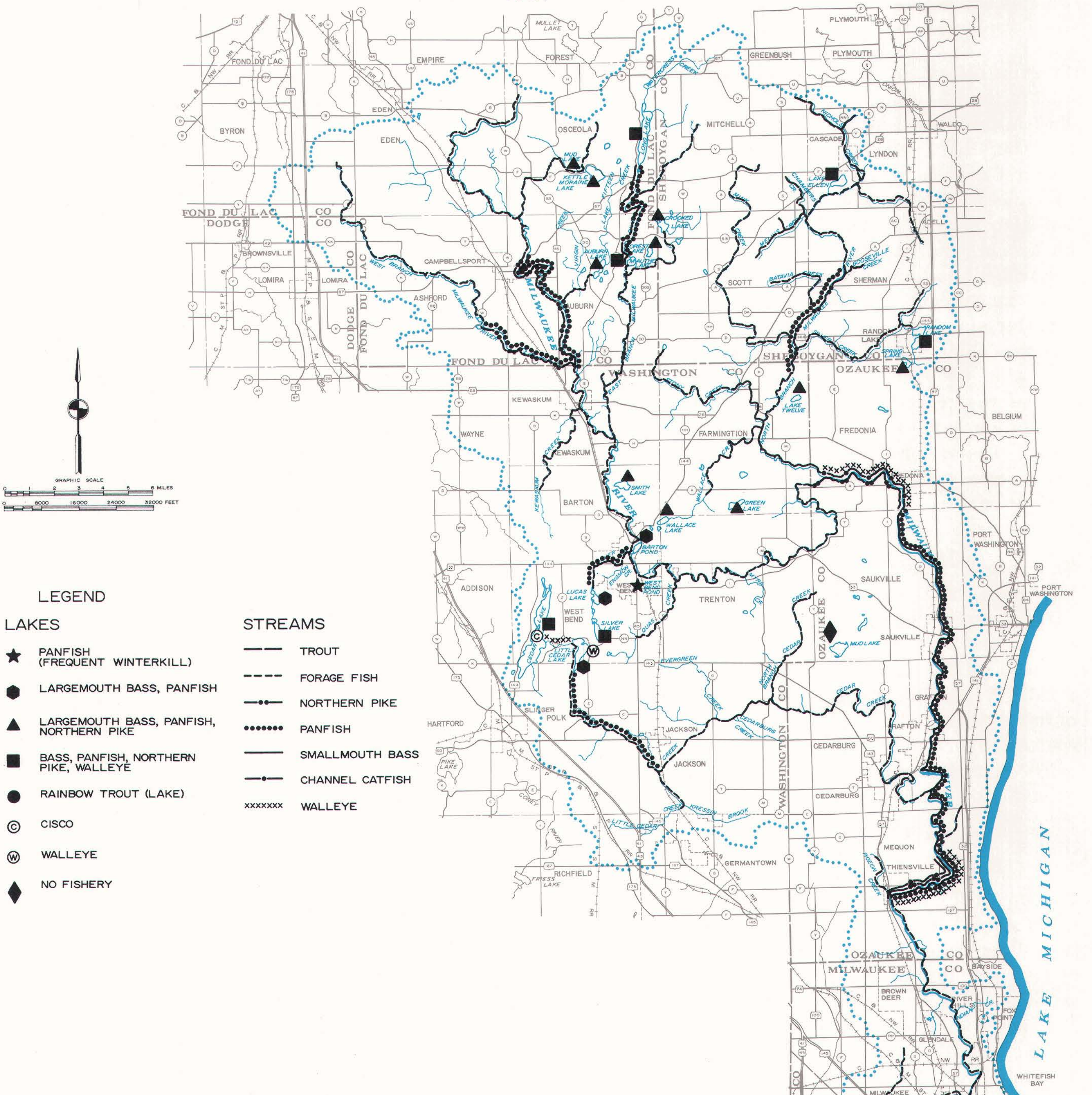
The area of open water per unit of shoreline varies in response to the irregularity of the shoreline and is expressed by the shore development factor, defined as the ratio of shoreline length to the circumference of a circle having an area equal to that of the lake in question. Figure 86 indicates the relationship of lake area to shoreline length and the shore development factor for the major lakes in the watershed.

The shorelines of lakes having a surface area of less than 100 acres are seldom affected by wind-induced wave-sorting of sedimentary material. Because of the direction of the prevailing winds within the Region, the shorelines of lakes ranging in size from 100 to 500 acres in area commonly have sand or gravel wave-washed shorelines along their east, north, and south shores and silt-covered west shorelines, the latter frequently well vegetated. Lakes larger than 500 acres in area experience some sorting on all shorelines except for bay areas protected from the wind.

Examination of the volumetric characteristics, as presented in Table 113, indicates that, in general, the major lakes of the watershed are shallow enough so that a large percentage of their total water volume is sufficiently oxygenated to support

Map 60

EXISTING LAKE AND STREAM FISHERIES IN THE MILWAUKEE RIVER WATERSHED 1967

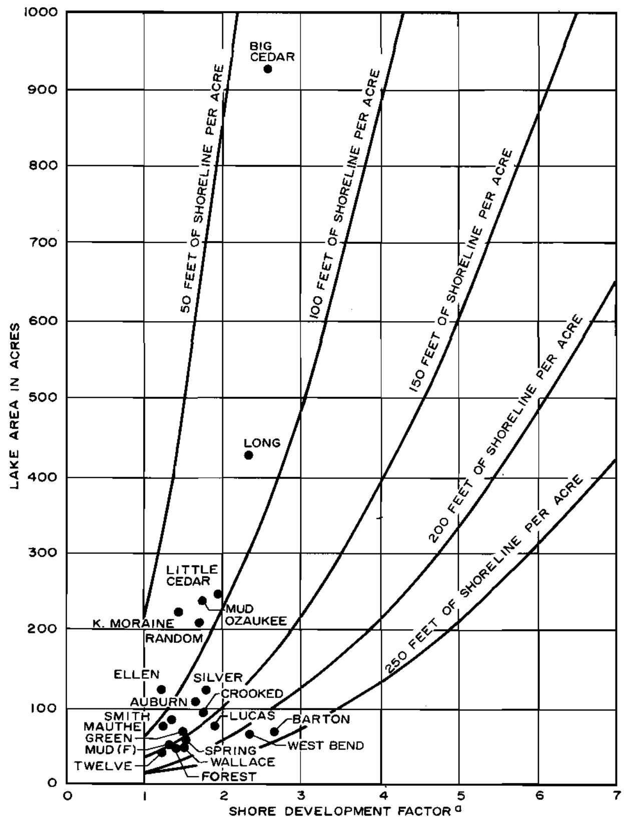


The maintenance and, in some cases, enhancement of stream and lake water quality throughout the watershed are essential if the fisheries of the watershed, which comprise an important recreational asset, are to be preserved and improved. Only five major streams within the watershed--the Milwaukee River, the East Branch, the North Branch, the West Branch, and Cedar Creek--presently support a moderate fishery. All but one of the 21 major lakes within the watershed--Mud Lake in Ozaukee County--also support a moderate fishery. Nutrients and oxygen-demanding organic materials are the major pollutional causes of fish management problems in the watershed.

Source: Wisconsin Department of Natural Resources.

Figure 86

LAKE AREA RELATED TO FEET OF SHORELINE PER ACRE OF WATER AND SHORE DEVELOPMENT FACTOR



a SEE ACCOMPANYING TEXT FOR DEFINITION.

Source: Wisconsin Department of Natural Resources.

fish life in summer. Six of the major lakes have no water areas greater than 20 feet in depth, however, and may be expected to occasionally lack sufficient oxygen for winter survival of fish life. Emergent rooted aquatic vegetation is limited to water less than three feet deep. Such shallow waters constitute 17.7 percent of the major lake acreage and 17.6 percent of the major lake volume.

Problems Related to Lakes and Streams

Inadequate Water Depth: A major recreational inadequacy in many of the lakes within the Milwaukee River watershed is the lack of sufficient depth. An examination of Table 113 indicates that the small lakes are not always the shallowest and that more than 20 percent of the total area of several of the larger lakes is covered by water less than three feet deep. Moreover, the depth of many of the lakes within the watershed can be expected to be reduced substantially with time, the principal causes of increasing shallowness of lakes within the watershed being vegetal aging and sedimentation.

The fertile lakes of the watershed produce great quantities of organic matter, and rich organic deposits accumulate rapidly. On leeward shores and in protected bays, emergent and eventually terrestrial vegetation develops readily and may progressively develop into a marsh area, replacing open water. Drainage lakes commonly have deltas produced where streams entering the lake release the materials carried in suspension. The development of these deltas is aggravated by soil erosion within the tributary watersheds and may be associated with both urban and rural land use activities not conducted in accordance with good soil and water conservation practice. Urbanization of lake watersheds may produce particularly heavy silt loads, which are deposited on the lake beds.

The recreational value of shallow lakes is limited for several reasons (see Table 113). Shallow water permits rooted aquatic vegetation to grow in profusion and interfere with use for boating and swimming. Such vegetation is a major problem on seven of the 21 lakes studied in the Milwaukee River watershed. Shallow lakes are subject to winterkill by the loss of fish due to an inadequate oxygen supply. This is a major problem on six of the 21 lakes studied within the Milwaukee River watershed. Boating is impaired on shallow lakes both by the existence of the shallow flats themselves and by the presence of rooted aquatic vegetation. The minimum desirable depth for boating is approximately five feet. Three of the lakes studied were found to have a mean depth of less than five feet, and seven additional lakes were found to have a mean depth of less than 10 feet. Finally, nutrient recycling occurs continually during the summer months in shallow lakes, since thermal stratification is either not attained or does not persist throughout the summer, when in deeper lakes hypolimnion stagnation is achieved. The continual summer turnover of shallow lakes, with the accompaniment of nutrient replenishment derived from plant decay and bottom muds, is further accelerated by wind-driven and inlet water currents, along with the rooting habits of carp. The accelerated nutrient enrichment then impairs the recreational value by causing excessive algal and aquatic plant growth. Eight of the lakes studied were found to have no definite thermocline and, therefore, no apparent barrier to recycling of nutrients.

Inadequate Lake Size or Streamflow: Lake size or streamflow is another major factor in determining the recreational potential of a lake or stream.

Small lakes, with a surface area of less than 50 acres, may be considered unsuited to the use of motor-powered boats. Fifty such small lakes exist within the watershed; and these were, because of their size and limited recreational value, excluded from more detailed consideration in the watershed study. Of the 21 major lakes studied, 15 were found to have a surface area ranging from 50 to 200 acres, the size for which the imposition of speed limitations on motor-powered boats is generally recommended. Such lakes can become highly congested and develop dangerous water use conflicts as, for example, between water skiing and fishing or swimming. There are six lakes within the Milwaukee River watershed having a surface area ranging from 200 to 1,000 acres. Although these lakes are relatively large, they may require spatial or temporal separation of recreational activities if serious use conflicts are to be avoided. Only on lakes of more than 1,000 acres of surface area can all recreational activities be permitted with a minimum of limitations. No such lakes exist within the watershed. Although larger lakes can accommodate more different uses and more users than smaller lakes, each lake, regardless of size, has a limited ability to meet the various recreational demands. For this reason the Wisconsin Department of Natural Resources has adopted lake use classification standards that are intended to assist in determining proper recreational uses of lakes. These standards are set forth in Appendix J of this volume.

The fisheries of the smaller lakes may be subject to excessive use when angling reaches the 100 man-hour per acre per year level; although under a good management program, the fisheries of some lakes can tolerate 100 to 200 man-hours of angling per acre per year. Of the major lakes studied within the watershed, 12 now receive more than 100 man-hours of fishing use per acre per year (see Table 113); and seven of these 12 have a surface area of less than 100 acres. Intensive conservation management measures are needed if high populations of desirable fish species are to be maintained in these lakes.

Streams with insufficient flow have physical limitations with respect to the movement and harboring of desirable forms of fish life and may have water temperatures higher than tolerable by coldwater species. Streams with low or intermittent flows thus can provide only a very limited fishery and cannot provide swimming, boating, or canoeing opportunities. Such streams may, however, provide an important source of water for wildlife and may have a significant aesthetic value. Intermittency of flow is a problem of nearly all minor tributaries within the Milwaukee River watershed, and low summer flows are also a problem of most major tributaries.

Lake Level Instability

Lake level instability is not a major problem within the Milwaukee River watershed except during extreme climatic conditions. Increases in lake levels normally occur in the spring and are the result of heavy surface runoff from snowmelt and rainfall, discharge from the ground water reservoir, or increases in ground water table elevations. Decreases in lake levels normally occur in the summer and are the result of evaporation, transpiration, discharge to outlet streams, discharge to the ground water reservoir, or decreases in ground water table elevations. Lakes and wetlands within the watershed may be expected to lose water through evapotranspiration in an amount approximately equal to the average annual rainfall on the surface of the lakes and wetlands; and, therefore, only extreme climatic conditions, such as prolonged droughts, will produce fluctuations sufficient to impair recreational use activities.

All but four of the 21 lakes studied within the Milwaukee River watershed have fluctuations in water levels of less than one foot per year and, therefore, may be considered stable. Two of the exceptions are Wallace and Forest Lakes, which are seepage type lakes, with "blind" watersheds having no outlets. Therefore, fluctuations in ground water levels may have a particularly adverse effect upon the levels of these two lakes. The other two exceptions are the Barton and West Bend impoundments on the Milwaukee River. As small impoundments, the levels of these lakes reflect the seasonal instabilities of flow in the Milwaukee River. Eight other natural lakes in the watershed—Ellen, Silver, Cedar, Little Cedar, Lucas, Mauthe, Random, and Long Lakes—have water level control structures on their outlets which control the outflow of water and thus tend to stabilize the lake levels. The nine remaining lakes—Mud (Fond du Lac), Kettle Moraine, Lake Fifteen, Crooked, Green, Smith, Spring, Mud (Ozaukee), and Twelve—although having uncontrolled outlets, exhibit relatively small fluctuations in water levels. Generally, lakes with small tributary watersheds and those highly perched in the ground water system may be expected to exhibit greater fluctuation in lake levels than lakes with large tributary watersheds.

All of the aforementioned causes of unstable lake levels may be intensified by ground water withdrawals for urban and rural use. Ground water pumpage from within tributary watersheds and subsequent discharge through sewerage or drainage systems to disposal points below lake outlets will tend to lower ground water and interconnected lake levels. The inventories, however, revealed that there are presently no sewered lake communities within the watershed where such water loss could occur.

Eutrophication: A term of recent popularity, eutrophication, has acquired additional meaning in discussions relative to the recreational use of lakes. Eutrophic, as originally defined, identified lakes exhibiting an extreme reduction in oxygen concentration with depth. The more recent and popular definition states that eutrophic waters have a good supply of nutrients and may support rich organic production, such as algal blooms. The eutrophication process may be accelerated by the intentional or unintentional nutrient enrichment of waters. Eutrophication is then the process of maturation of lakes, leading ultimately to their extinction through deposition of both inorganic and organic materials. The rate at which eutrophication occurs naturally at present defies quantitative measurement; but its acceleration by human activities is clearly discernible, if not measurable. Accelerated eutrophication is marked by extensive growth of aquatic vegetation and a high incidence of problems relating to the consumption of oxygen and decomposing vegetation. A characteristic problem is summerkill, a major fish mortality resulting from the excessive consumption of oxygen by decomposing algae and other vegetation on calm, dark summer days. Many of the conditions detrimental to recreational use which occur in lakes are by-products of eutrophication, as the term is currently used.

Excess fertility is indicated by certain water quality indicators, including phosphate concentrations in the spring of the year, total alkalinity, and the content of phosphorus in plant tissue versus the mean chloride content of the water. The average ionic composition of lake waters within the Milwaukee River watershed is set forth in Table 116, which is based upon an analysis of 72 water samples collected from lakes within the watershed. Individual lakes are evaluated with respect to water quality and fertility in several ways in Table 113. While considerable variation occurs between fertility ratings for the water quality characteristics, generally 18 of the 21 lakes studied showed nutrients to be present in excess of the amounts necessary to support aquatic vegetation in problem proportions. Of the 21 major lakes surveyed in the Milwaukee River watershed, four were found to be high in spring phosphate content; eight were very fertile, as measured by total alkalinity; and nine were excessively fertile, as measured by plant tissue content.

Animal Pests Affecting Recreational Water Use: Midges (Chironomidae), or blind mosquitoes, are common around the lakes and streams of the watershed and inhabit the bottom muds over winter. Adult midges emerge and swarm with the warming of the water in the spring and early summer, with massive occurrences common in late afternoon or early evening. Midges create nuisances by flying against the eyes and noses of people, discoloring painted surfaces, reducing visibility, and accumulating on lighting fixtures. While mosquitoes (Culicidae) are common pests around lakes and streams, they are generally produced in areas covered by shallow, temporarily standing water. Open-water surfaces are required for emergence; and hence the presence of extremely dense vegetation does not imply severe mosquito problems.

TABLE 116

AVERAGE IONIC COMPOSITION OF ALL LAKE WATERS IN THE MILWAUKEE RIVER WATERSHED- 1968

PARAMETER	AVERAGE FOR THE WATERSHED[a]
SPECIFIC CONDUCTANCE (MMHOS)....	351.00
PH..............................	8.13
TOTAL ALKALINITY (MG/1 $CACO_3$)...	187.23[b]
CALCIUM.........................	28.61
MAGNESIUM.......................	29.77
SODIUM..........................	4.76
POTASSIUM.......................	1.65
IRON............................	0.06[b]
AMONIA-NITROGEN.................	0.34
NITRATE-NITROGEN................	0.06[b]
TOTAL PHOSPHATE.................	0.32
DISSOLVED PHOSPHATE.............	0.23
CHLORIDE........................	7.5
SULPHATE........................	26.29

[a]EXPRESSED IN MG/1 UNLESS OTHERWISE SPECIFIED.

[b]BASED ON SPRING MEASUREMENTS ONLY.

SOURCE- WISCONSIN DEPARTMENT OF NATURAL RESOURCES.

Leeches (Hirudinea) abound in still, shallow waters of the watershed where a suitable substrata of plants, stones, or debris exist. The American Medical Leech (Macrobdella decora) is the principal nuisance in this group. It is most active at high water temperatures. It is a strong swimmer and will attach itself rapidly to hosts.

Larval trematodes (Schistosome cercariae) are the cause of "swimmer's itch" and are common in several lakes of the watershed. The adults are parasites of birds or mammals. Snails provide an intermedial host to an immature stage; and, thus, its larva may be expected to abound where birds and snails are found in large numbers. The stage which penetrates the skin of bathers cannot survive in the human host but does produce inflammation and severe itching in some individuals.

The level of insect pest problems can be reduced by the use of various pesticides, but such pesticides must always be applied with great care. Leeches may be controlled by the use of powdered lime and copper sulphate, but such control measures have not as yet been undertaken on any of the lakes within the Milwaukee River watershed. "Swimmer's itch" may also be controlled by the use of powdered lime and copper sulphate and by the use of copper carbonate, all of which serve to control the snail host. To date, such snail control measures have been undertaken on a modest scale on two of the lakes within the Milwaukee River watershed—Long and Mauthe Lakes. Several other lakes in the watershed, including Ellen and Random, are also affected by "swimmer's itch."

Aquatic Plants Affecting Recreational Water Use: Overabundant aquatic plant growth interferes with swimming, fishing, boating, and associated recreational activities and greatly reduces the aesthetic value of lakes and streams. Different recreation users place different and often conflicting values on rooted aquatic plant growths; for example, fishermen consider weed beds desirable, while swimmers consider such beds objectionable. Excessive algae growths, however, are objectionable to most recreational uses.

The excessive growth of rooted aquatic vegetation was found to be a problem in seven of the 21 major lakes studied within the watershed: Big Cedar, Crooked, Kettle Moraine, Long, Lucas, Seven, and West Bend Pond. In addition, excessive algae growths were found to exist in nine lakes: Barton Pond, Ellen, Forest, Mauthe, Mud (Fond du Lac County), Random, Smith, Twelve, and West Bend Pond. These 16 lakes have weed or algae problems or both sufficiently serious to warrant expenditures for control measures.

A listing of the relative abundance and presence of aquatic plants found in the Milwaukee River watershed is presented in Table 117. Species of stonewort, pondweed, and water milfoil are the most abundant species found in those lakes that exhibit excessive vegetational growths. Though efforts have been made to control aquatic vegetation, quite frequently less desirable species replaced those which were destroyed. Large-leaved pondweeds are commonly replaced by fine-leaved forms which can grow in even greater profusion.

Algal blooms become more frequent as a result of overfertilization, particularly in lakes inhabited by carp; and these blooms are marked by characteristic shifts in distribution and composition of the algal community. The "blue-green" species of algae (Anabaena, Aphanizomenon, Microcystis) tends to dominate the green species of algae, and fewer species, but many more individuals, are found. The layer in which photosynthesis can occur under surface masses of algae is thinner due to the shading effect of the masses of algae. Under such conditions fishing quality generally deteriorates. Except for walleyes, the larger predators, which are commonly sight feeders, become ineffective under reduced visibility. Bottom feeders, such as carp, maintain their effectiveness and persist in greater numbers. Rich organic sediments, which accumulate in the overly fertile environment, are unsuited to the spawning of more desired species. The rough fish problem encountered in six of the major lakes studied, including Barton, Green, Little Cedar, Smith, Twelve, and West Bend, is associated with excessive fertility.

Fish Management Problems: The most serious fishery-related problems result from human activity in the watershed. Lake- and stream-bed alterations have resulted in the loss of considerable habitat. The deposition of sedimentary materials directly on the beds of lakes has resulted in destruction of spawning areas, with serious destruction on Big Cedar and Wallace Lakes, lakes which had only limited desirable fish-spawning habitat to begin with. Lakeshore

TABLE 117

AQUATIC PLANT TYPES IN 24 LAKES IN THE MILWAUKEE RIVER WATERSHED- 1968[a]

AQUATIC PLANT TYPE		TYPE OF AQUATIC VEGETATION	LAKES WHERE FOUND	
SCIENTIFIC NAME	COMMON NAME		NUMBER	PERCENT
ACORUS CALAMUS...........	SWEET FLAG	EMERGENT	1	4
ANACHARIS CANADENSIS.....	WATERWEED	SUBMERGENT	16	66
ASCLEPIAS INCARNATA......	SWAMP MILKWEED	EMERGENT	10	42
BRASENIA SCHREBERI.......	WATER SHIELD	FLOATING	2	8
CALTHA PALUSTRIS.........	MARSH MARIGOLD	EMERGENT	1	4
CAREX COMOSA.............	SEDGE	EMERGENT	13	55
CERATOPHYLLUM DEMERSUM...	COONTAIL	SUBMERGENT	16	66
CHARA....................	STONEWART OR MUSKGRASS	SUBMERGENT	22	92
CYPERUS SPP..............	SEDGE	EMERGENT	14	58
DECONDON VERTICILLATUS...	SWAMP LOOSESTRIFE	EMERGENT	7	27
ELEOCHARIS SPP...........	SPIKE RUSH	EMERGENT	17	70
EQUISETUM SPP............	HORSETAIL	EMERGENT	2	8
EUPATORIUM PURPUREUM.....	JOE-PYE-WEED	EMERGENT	3	12
HETERANTHERA DUBIA.......	WATER STAR GRASS	EMERGENT	11	46
IRIS SPP.................	IRIS	EMERGENT	3	12
JUNCUS SPP...............	RUSH	EMERGENT	1	4
LEMNA....................	DUCKWEED	FLOATING	16	66
L. MINOR................	LESSER DUCKWEED	FLOATING	11	46
L. TRISULCA............	STAR DUCKWEED	FLOATING	2	8
LYTHRUM ALATUM...........	SPIKED LOOSESTRIFE	EMERGENT	1	4
MYRIOPHYLUM..............	WATER MILFOIL	SUBMERGENT	21	88
M. EXCELBESCENS........	WATER MILFOIL	EMERGENT	15	62
NAJAS....................	BUSHY PONDWEED	SUBMERGENT	16	66
N. FLEXILIS............	BUSHY PONDWEED	EMERGENT	14	58
N. MARINA.............	BUSHY PONDWEED	EMERGENT	3	12
NASTURTIUM OFFICINALE....	WATER CRESS, NASTURTIUM	EMERGENT	1	4
NUPHAR SPP...............	YELLOW WATER LILLY, SPATTERDOCK	FLOATING	22	92
NYMPHAEA.................	WHITE WATER LILLY	FLOATING	24	100
N. TUBEROSA............	WHITE WATER LILLY	EMERGENT	23	96
PHRAGMITES SPP...........	REED GRASS	EMERGENT	1	4
POLYGONUM NATANS.........	WATER SMARTWEED OR AMPHIBIOUS SMARTWEED	EMERGENT-FLOATING	3	12
PONTEDERIA CORDATA.......	PICKERELWEED	EMERGENT	6	25
POTAMOGETON..............	PONDWEEDS	SUBMERGENT	24	100
P. AMPLIFOLIUS.........	LARGELEAF PONDWEED, MUSKY WEED, OR BASS WEED	SUBMERGENT-FLOATING	19	79
P. CRISPUS.............	CURLYLEAF PONDWEED	SUBMERGENT	3	12
P. FRIESII.............	FRIE'S PONDWEED	SUBMERGENT	15	62
P. GRAMINEUS...........	VARIABLE PONDWEED	SUBMERGENT-FLOATING	13	55
P. NATANS..............	FLOATING-LEAF PONDWEED	FLOATING	21	88
P. NODOSUS.............	AMERICAN PONDWEED	SUBMERGENT-FLOATING	16	66
P. PECTINATUS..........	SAGO PONDWEED	SUBMERGENT	23	96
P. RICHARDSONII........	RICHARDSON PONDWEED, CLASPING LEAF PONDWEED	SUBMERGENT	4	17
P. ROBBINSII...........	ROBBINS' PONDWEED	SUBMERGENT	2	8
P. STRICTIFOLIUS.......	--	SUBMERGENT	3	12
P. ZOSTERIFORMIS.......	FLAT-STEMMED PONDWEED	SUBMERGENT	19	79
RANUNCULUS LONGIROSTRIS..	BUTTERCUP, CROWFOOT	EMERGENT	8	33
RUPPIA MARITIMA..........	WIGEON GRASS	EMERGENT	1	4
SAGITTARIA LATIFOLIA.....	ARROWHEAD, WAPATO	EMERGENT	18	75
SCIRPUS..................	BULRUSH	EMERGENT	24	100
S. AMERICANUS..........	THREE-SQUARE BULRUSH	EMERGENT	4	17
S. ATROVIRENS..........	--	EMERGENT	6	25
S. SUBTERMINALIS.......	WATER BULRUSH	EMERGENT	5	21
S. VALIDUS.............	SOFTSTEM BULRUSH, GREAT BULRUSH	EMERGENT	21	88
SPARGANIUM...............	BUR REED	EMERGENT	13	55
S. EURYCARPUM..........	BUR REED	EMERGENT	10	42
SIUM SUAVE...............	WATER PARSNIP	EMERGENT	2	8
TYPHA SPP................	CATTAIL	EMERGENT	23	96
UTRICULARIA..............	BLADDERWORT	SUBMERGENT-FLOATING	11	46
U. GEMINISCAPA.........	BLADDERWORT	SUBMERGENT	1	4
U. VULGARIS............	COMMON BLADDERWORT	SUBMERGENT	2	8
VALLISNERIA AMERICANA....	WILD CELERY OR EEL GRASS	SUBMERGENT	10	42
VERONICA SPP.............	SPEEDWELL	EMERGENT	1	4
WOLFFIA COLUMBIANA.......	WATERMEAL	FLOATING	2	8
ZIZANIA AQUATICA.........	WILD RICE	EMERGENT	3	12

[a] THE 24 LAKES INVENTORIED INCLUDE THE 21 MAJOR LAKES IN THE MILWAUKEE RIVER WATERSHED PLUS ERLER LAKE, GILBERT LAKE, AND LAKE SEVEN.

SOURCE- WISCONSIN DEPARTMENT OF NATURAL RESOURCES.

improvement and the creation of a few open waterways through wetland areas bordering lakes have created additional areas of shallow water and increased the plant productivity of certain lakes. Soil erosion, resulting both from poor agricultural soil conservation and water management practices and from urban development, has served to increase problems associated with sedimentation and the attendant destruction of spawning areas.

One of the more serious fish management problems within the watershed is the abundance of rough fish. Introduced into the watershed by man, carp have flourished to the detriment of other, more desirable, species of fish life and have afflicted streams, as well as lakes. Most of the lakes draining directly into the Milwaukee River stream system have carp populations, although not always of a problem proportion. In fertile shallow lakes, the presence of carp may be disastrous to other forms of fish life.

Intense fishing pressure within the watershed has resulted in a heavy harvest of northern pike and largemouth bass, especially from the smaller lakes. Although panfish are harvested extensively, crowding has led to stunting or slow growth rates in at least 10 of the 21 major lakes studied within the watershed. While a practical control method of the stunted panfish problem is yet to be developed, the loss of large predators, protection from sight feeders offered by turbid water, and an overabundance of nursery areas due to extensive weed growths all contribute to this problem.

Disease-induced mortalities are a minor fishery problem on some of the shallower lakes. Fish mortalities resulting from oxygen depletion occur in both summer and winter; however, the mortalities occurring in the winter are considered to be, in most instances, natural phenomena abetted by human activity within the watershed. The frequency of fishery species is summarized in Figure 85 for the major lakes of the Milwaukee River watershed, and fishery locations for all streams within the watershed are shown on Map 60.

WETLANDS

Description

Wetlands comprise a prominent feature of the natural environment. As such, they function not only as an integral part of the hydrological system but also have topographical, biological, agricultural, and aesthetic relationships and values. Wetlands are also important recreation-related resources, having not only recreational value as hunting preserves and wildlife habitat areas but also scientific value as natural laboratories and aesthetic value as highly visible parts of the natural landscape. Although the identification of wetlands involves consideration of a number of physical and vegetative conditions, the working definition of the term "wetland," adopted for use in this study, is: any natural area where the water table either intersects and lies above the surface of the earth or lies so close to the surface of the earth that the raising of a cultivated crop is usually not possible. Wetlands may be classified into seven types: pothole, fresh meadow, shallow marsh, deep marsh, shrub swamp, timber swamp, and bog. The definitions of these seven types are set forth in Appendix K of this report.

All of the wetlands within the watershed, as identified by application of the above definition, and having a surface area of 50 acres or more were identified and mapped as complexes of the aforelisted seven basic types. Utilizing topographic maps, current Commission aerial photography, detailed operational soils maps, and piezometric maps, 199 wetland units, totaling 62 square miles in surface area, were identified and delineated within the watershed (see Map 21). The wetland units so inventoried were, as already noted, complexes of the seven basic wetland types. Although the units may have, in some cases, consisted of monotypes, typically the units consisted of a mixture of all or several types which could be grouped into four composite type categories: meadow, marsh, shrub swamp, and timber swamp. A determination of the composite type of each of the 199 wetland units was carried out by a point sampling method, with the results indicated in summary form in Table 118.

TABLE 118

TYPE AND COMPOSITION OF THE SIGNIFICANT WETLAND UNITS IN THE MILWAUKEE RIVER WATERSHED

COMPOSITE TYPE	COMPOSITION	PERCENT OF TOTAL WETLAND AREA MAPPED
MEADOW.........	FRESH MEADOW	26
MARSH.........	POTHOLE, SHALLOW MARSH, DEEP MARSH, BOG	4
SHRUB SWAMP...	SHRUB SWAMP	17
TIMBER SWAMP..	TIMBER SWAMP	53
TOTAL		100

SOURCE- WISCONSIN DEPARTMENT OF NATURAL RESOURCES.

An approximate breakdown of the marsh composite type, based upon the total of such marsh composite units mapped, was: 2 percent shallow marsh; 1 percent deep marsh; and less than 1 percent pothole and bog. The marsh composite type includes the usually wetter areas with some exposed surface water and totals only 4 percent of the total wetland area mapped. The remaining categories, constituting the drier types, comprise 96 percent of the total area mapped; but interspersed in the drier types is perhaps an additional 6 percent of very wet area, thus reducing the "drier" category to 90 percent and raising the "wet" area to 10 percent. Under many conditions a large, additional amount of timber swamp may also seasonally be very wet. A summary listing of the acreage, quality rating, and recommended game management practices with major game species is set forth in Appendix L of this report.

As is true of lakes, two general morphological conditions produce wetlands. The first is a basin, or seepage, situation (the seepage may occur in valley bottoms or on slopes); and the second, a drainage situation in connection with a watercourse. Both represent a surface exposure of the upper water table. Typically, the latter type has been ditched to some degree to facilitate surface runoff and to permit some cultivation of row crops in portions of the ditched wetland in dry years. The former situation, being a landlocked one, makes ditching less feasible; and a more constant water table level is likely to prevail. Within the Milwaukee River watershed, a basin, or landlocked, condition was found to exist for about 22 percent of the 199 identified wetland units, totaling about 12,000 acres; and a surface drainage condition through some outlet was found to exist for about 73 percent of the 199 identified wetland units, totaling about 26,000 acres, with many of these units lying in the floodplain of a stream or watercourse. The remaining 5 percent was found along lakeshores and could represent either situation.

Because the water table may vary greatly seasonally, as well as annually, the "wetness" of the wetlands will vary greatly. Unlike a lake, where water depths and bottom slopes are usually much greater, the typical wetland is either covered by very shallow water or consists of a vegetative mat or muck and peat soils near the water table. Therefore, any fluctuation in the water level has an immediate and readily apparent effect on the entire wetland surface. The drainage types of wetlands conform to the configuration of the valley floor in which they lie and hence are often long, sinuous, and branched, with the width depending on the broadness of the valley, as well as on the marginal use of the floodplain. Soils, in addition to the organic series, will commonly include alluvial types, bearing stratified outwash mineral residues. Springs may occur along their length, often changing to a wetland what would otherwise be just a periodic stream overflow area. The basin, or seepage, wetlands tend to an irregularly rounded form due to their glacial origin. Soils commonly include fine textured silts and undifferentiated till under muck and peat deposits.

Chemically, the wetlands of the watershed are basic, reflecting the bedrock geology of the watershed. The peat and muck soils occurring in the wetlands, as well as the poorly drained mineral types, are even less acid than the upland silt loams, probably because of the perfusion of these soils by lime-bearing waters. This is contrary to the usual condition of peat soils being highly acidic. The peat and mucks within the wetlands vary greatly in depth from a few feet to perhaps 20 feet and more. In addition to a high calcium content, the wetland soils are often low in phosphorus and potassium, as well as in minor elements; and, therefore, the general fertility of these wetland soil types is low.

The microclimate of the wetlands within the watershed tends to differ somewhat from that of the uplands, largely because of the low situation of the wetlands in the landscape. Cold air drainage into the wetlands results in a lower average temperature than in upland areas and in a shorter frost-free growing season. Excessive condensations, as indicated by fog formation, are also present; and the latent heat released may forestall greater drops in temperatures. As already noted, the net evapotranspiration rate for wetlands with emergent vegetation is generally believed to be little different from that for open water.

Loss of Wetlands

In the wetlands inventory of the Milwaukee River watershed, it was very apparent that many pasture lands and low fields under cultivation were derived from wetlands. This was evident from the presence of wetland soil types—peats, mucks, and poorly and very poorly drained mineral soils—which are not under cultivation. The analyses indicated that approximately 120 square miles, or 17 percent of the area of the Milwaukee River watershed, were originally covered by wetlands and that only 62 square miles, or about one-half of this original wetland area, remain. It is evident that a deterioration of the quality of the remaining wetlands has also taken place.

Problems Related to Wetlands

Some of the more important problems related to the wetlands of the watershed include recycling of nutrients, unstable water levels, odors, undesirable insects, undesirable or nuisance plant and animal species, undesirable natural water quality, conversion to agricultural use, conversion to urban use, and loss of environmental amenities. Each of these problems is discussed in the following sections.

Recycling of Nutrients and Water Quality: Wetlands adjacent to lakes and streams have great value as fish and wildlife habitat. The effect of wetlands on water quality is not well understood. Wetlands are sometimes considered to act as filters of waters flowing through them, trapping nutrients present in growing plants. After the plant material produced each season decomposes, however, the nutrient in the plant tissue very likely finds its way into any interconnected lakes and streams, thus contributing to the surface water fertility. In addition, drainage from marshes and bogs sometimes contributes water low in dissolved oxygen and high in iron, color, organic material, and other compounds. These undesirable water quality characteristics probably do not, in a natural state, offset the recreation and aesthetic values of wetlands. However, if wetlands are drained, tiled, plowed, or fertilized, the natural rate of decomposition is accelerated; and the contribution of undesirable nutrients and other materials may be greatly increased.

Nutrient relationships in undrained wetlands are not well understood or documented. It is known, however, that both chemical and microbial oxidation and reduction are related to nutrient production. In the waterlogged soil of a wetland, oxygen deficiency occurs; and, therefore, reduction of chemical compounds is accelerated. Iron, manganese, and phosphorus are soluble in such a reduced state, while they are nearly insoluble in a well-oxidized condition. These elements are leached out of permanently waterlogged soil layers. Iron and manganese may be redeposited in surface soil horizons if the water table fluctuates through this zone causing alternate oxidation and reduction. Only small deposits, indicated by soil mottling, may form; or fairly massive deposits may form, as in the case of iron pan, often found in wetlands (bog ore).

If the water table is always above the mineral soil surface, organic materials accumulate faster than they can be incorporated into the soil. If the accumulated material is below the water level, it undergoes very slow decomposition by anaerobic microorganisms. Anaerobic decomposition is relatively inefficient, and only the more easily decomposable materials are broken down. This leaves the structural materials, lignins and celluloses, relatively intact so that the plant species are still identifiable. This accumulated material is called peat. If the water level declines below the accumulated organic material for significant lengths of time, aerobic decomposition also takes place. Such decomposition is more efficient and hence more complete and results in the formation of muck. Often these two kinds of organic soils are found together, with the peat being covered by a layer of muck. The type of decomposition is important in wetland chemistry because, under normal anaerobic conditions, methane (marsh gas), sulfides, and ammonia are the end products of decomposition. These are odoriferous but are bound up or oxidized near the surface to carbon dioxide, water, sulfates, and nitrates. When the decomposing materials are exposed, either through drought, drainage, or disturbance, a temporary odor problem exists until an aerobic condition is reestablished at the new surface.

Ammonia is the chief nitrogenous compound produced in anaerobic decomposition. It appears that most of it is either held on the surface of the decomposing material by its base exchange capacity or is tied up in the bodies of the decomposing organisms. Drained organic soils are high in nitrogen, usually set free as nitrates by oxidizing bacteria; and drained wetlands are, therefore, contributors to lake eutrophication. Little nitrogen loss, however, seems to occur in undrained wetlands. Phosphorus is another element contributing to lake eutrophication found in large quantities in wetlands. It is soluble under reducing conditions and is washed out of waterlogged soils when drained. It can be expected to be present in higher concentration in waters with low dissolved oxygen content. Sulfides likewise may be released under these conditions. This release of phosphorus and sulfides may also occur under ice or at the time of breakup.

As already noted, wetlands have a high evaporation rate, approaching that of a free water surface. Probably the highest evaporation occurs in the pothole type of wetland, which receives ground water that has flowed through calcareous dolomitic till. This appears to be a one-way system, with many nutrients washed into the potholes and left there by evaporation. Other wetland types having water flowing through are also enriched by this evaporative process. Water flowing through drainage-type wetlands can be expected to have its dissolved oxygen content reduced and its phosphorus content increased with little effect upon its nitrogen content. In general, intake water, rate of flow, disturbance, and many other factors modify wetlands chemistry so that conditions need to be carefully specified.

Unstable Water Levels: Typically, wetlands lie in shallow basins with very gentle bottom gradients. This makes them extremely sensitive to any changes in water level. Whereas a one-foot decline in the water level of a steep-sided lake would hardly be noticeable, such a decline in a typical wetland might change it from an open sheet of water to an exposed mat of vegetation. Conversely, a slight increase in water level can extensively flood a wetland. Consequently, plants and animals must be hydrophytic or amphibious in nature to inhabit a wetland area. Adaptation by the permanent biota was achieved only through thousands of years of slow change under a wide spectrum of mechanisms. Occasionally the demands exceed the capacity to adjust; and changes in species may result. Thereupon a new series of plant and animal types may be induced into the area. The threat of such changes may be lessened or may be increased by human activities. If seasonal flooding is either prolonged or unduly restricted, changes in the characteristics of the wetlands may result. Excessive water depth, if prolonged, will kill cattail stands; in contrast, more rapid drainage of floodwaters will inhibit such undesirable species as the millets, smartweeds, and duck potato.

Fluctuation of the water level will contribute to the water transport of plant materials and debris. Soluble materials may be expected to move up and out of the wetlands during periods of rising water levels, while alluvial materials may be settled out during periods of declining water levels. Fluctuating water levels may also aggravate or create a mosquito problem as some species avail themselves of the temporary water conditions provided. Any permanent alterations of the water level would completely modify a wetland, either turning it into dry land or into a lake.

Odors: Odors from wetlands are produced in two ways. One is through anaerobic decomposition of organic deposits, which yields the gases methane, hydrogen sulfide, and ammonia. All of these have strong characteristic odors. Under normal circumstances, water bacteria oxidize these gases so that they do not escape into the air except during drought or after drainage. The second source of odors is algae, which may abound if the wetland receives excessive enrichment, as from field fertilizers. Typically, mid-to-late summer is the most obnoxious period for producing wetland odors due to high temperatures, lowered water levels, and accumulated vegetative growth. The drier types of wetlands are much less of a problem in this regard than are marsh types.

Undesirable Insects: The major undesirable group of insects associated with wetlands is the mosquito, although wetlands contribute less to the mosquito problem than is commonly believed. There are many species of mosquitoes, only some of which bite man; and mosquitoes may be produced in large numbers in areas other than wetlands. In addition to tin cans, eave troughs, and other containers, temporary stands of water in fields, woods, and tree cavities may "come to life" from previously deposited eggs after snowmelt or heavy rains. Some of the hardest biting species have life cycles of only a few days. Many of the larger wetland areas, if a well-diversified biota is present, generate relatively small numbers of mosquitoes. Locally, black flies and deer flies may also create nuisance situations.

Conversion to Agricultural Use: Conversion to agricultural use is a common cause of the loss of wetlands within the Milwaukee River watershed. The requirements for cultivation are good drainage and a cleared surface free of trees, brush, and sod. Therefore, the measures necessary to convert wetlands to agricultural use vary with the nature of the wetland. Drainage is usually accomplished by ditch construction, which serves to lower the water level by conducting ground and surface water to some larger surface drainage system. To increase the rate and effectiveness of drainage, drain tile may be installed to aid the flow of ground water to lateral ditches or canals. Surface material may be burned off or bulldozed and grubbed, then piled and burned. Sod in sedge meadows may be disced and plowed. All of these measures serve to destroy the original wetland.

Having once been converted to tillage, these areas undergo further changes. Muck soils become friable and powdery when dry and, due to their organic composition, also become very light in weight. Such soils are thus susceptible to wind erosion in the absence of ground cover and of such soil conservation practices as shelter belts. Their organic nature also makes such soils subject to oxidation over time. The muck and peat soils are highly compressible and subject to undesirable compaction when heavy farm equipment is used. These soils also have a large total surface area, a characteristic of soils having many fine particles and, therefore, have a high capability of adsorbing pesticides. Organic soils generally require considerably heavier applications of herbicides to achieve the same control as lesser application rates on normal mineral soils. The use of stable pesticides, which degrade only very slowly on such soils, may result in accumulations reaching very high levels with repeated applications. Subsequent transfer of the soil particles by wind or water erosion might transfer the pesticides into other areas, creating serious environmental pollution.

Undesirable Plant Communities: Disturbance of wetlands induces vegetational changes. Following the death of tamarack induced by sudden drainage, a shrub community of poison sumac and dogwood typically develops. Willow eventually replaces the sumac, instituting a shrub carr. Should the shrubs and tree stumps be grubbed out following demise of the tamarack, a sedge or grassy meadow develops. Grazing on both drained and undrained sedge meadows leads to a bluegrass-redtop grass pasture. Vervain and thistle invade as weeds if the grazing becomes severe. On drained peat lands redtop gives way to bluegrass as compaction or further drainage causes more drying of the site. In the absence of occasional burning or mowing, shrub carr will invade the pastured meadow as it does ungrazed meadows. Persisting stinging nettle may become a problem on drained and burned peat lands.

Conversion to Industrial and Urban Uses: The expansion of urban development within the Milwaukee River watershed has been well documented in other parts of this report. Initially, urban development takes place on the higher and drier sites; but rising land values often result in the development being expanded into adjacent, less desirable, lowland areas. Typically, the development of such lowland areas entails the filling of wetlands, often preceded by excavation of the organic surface soil layers, and is accompanied by urban drainage improvements. Not only does the urban development process destroy the immediate wetland involved, but remaining adjacent wetlands are also placed in jeopardy. The adjoining lowland is apt to suffer dumping of waste or scrap, polluting materials, and excessive fertilization from lawns or septic tanks. In such instances the remaining wetland may degenerate into a cesspool condition. Land fill for solid waste disposal, of course, obliterates the wetland.

The proximity of urban development to the wetland may lead to considerable disturbance of the larger and more conspicuous members of the fauna and flora. Dogs and cats roaming the area, as well as undirected children, may lead to both discouragement and direct loss of some species. Chemical treatments of various sorts for insects and aquatic weeds may further abuse the community structure of the remaining area. The end result often is a waste area that has lost much of its original diversity, interest, and resource value.

Wildlife: Wildlife preservation problems usually accompany the conversion of wetlands and adjacent areas to agricultural and urban uses. The wildlife may, in turn, create nuisance conditions for man in a number of ways. Such conditions may result from wildlife feeding habits resulting in browsing or girdling in gardens, orchards, or on other shrubs and trees by field mice, rabbits, and deer; from burrowing or tunneling of lawns or banks by muskrats or woodchucks; from break-ins by squirrels or raccoons; or from offensive odors created by skunks denning in foundations. The possibility of the transmission of diseases or parasites from wildlife to pets and humans exists, and actual known cases occur annually. Poultry is especially vulnerable to predation by foxes and raccoons.

Conversely, the activities of man may adversely affect wildlife. Some effects of human activities on wildlife may be indirect. Certain original endemic species, such as free-ranging bison, elk, and bear, disappeared early because of their space and forage requirements and their massiveness. Being highly adaptable and cunning, such species as the fox and skunk are able to profit from an association with man; and the species may actually grow in numbers with agricultural and even suburban development. The suppression of predators, such as hawks and owls, may permit rapid growth of field mice populations and also may permit rabbit and squirrel populations to become objectionably high.

Direct impact of man on wildlife comes through nest molestation or destruction, attrition by dogs and cats, indiscriminate hunting, by auto collision, and by entanglement or entrapment in fences. Direct or indirect poisoning may also occur. Nests of birds, such as the pheasant and Hungarian partridge, are destroyed in haying; and often rabbit nests are similarly destroyed.

Loss of Environmental Amenities: Wetlands lend contrast to the landscape, providing needed open space and a relief feature or backdrop to any monotony in the surroundings. If sheeted with water at times, an even more varied and interesting feature is provided. When any ruggedness exists in the topography, the wetlands form a base level for the landscape. Drainage and filling of wetlands for agricultural disposal or urban use will generally result in a lack of the visual amenity wetlands can provide in the total landscape. Much more subtle is the progressive loss of the biological complexity or diversity of a wetland through deterioration associated with development. The basic elements may remain; but a lackluster condition evolves, along with a degradation of the natural environment. With the addition of contaminating elements or foreign materials, a permanent alteration and attrition may develop.

Diversity in the biota is more than just a pleasant extra; it is a highly desirable state essential to maintaining an ecological balance. When a community is fully stocked, there are more organisms available to create a more balanced predator-prey relationship; and this condition helps prevent outbreaks or irruptions of pests or nuisances. Diversity is the original ecological control that must increasingly be returned to as a substitute for chemical control methods if the overall quality of the environment for life is to be preserved. When man forces biological simplification on the native biota, this reduction in diversity permits irruptive situations to develop. From a biological standpoint, the loss of diversity as wetlands are destroyed is probably the greatest loss of all the amenities. The loss is in the variety and numbers of interesting wild creatures which add to the aesthetic quality of the total landscape.

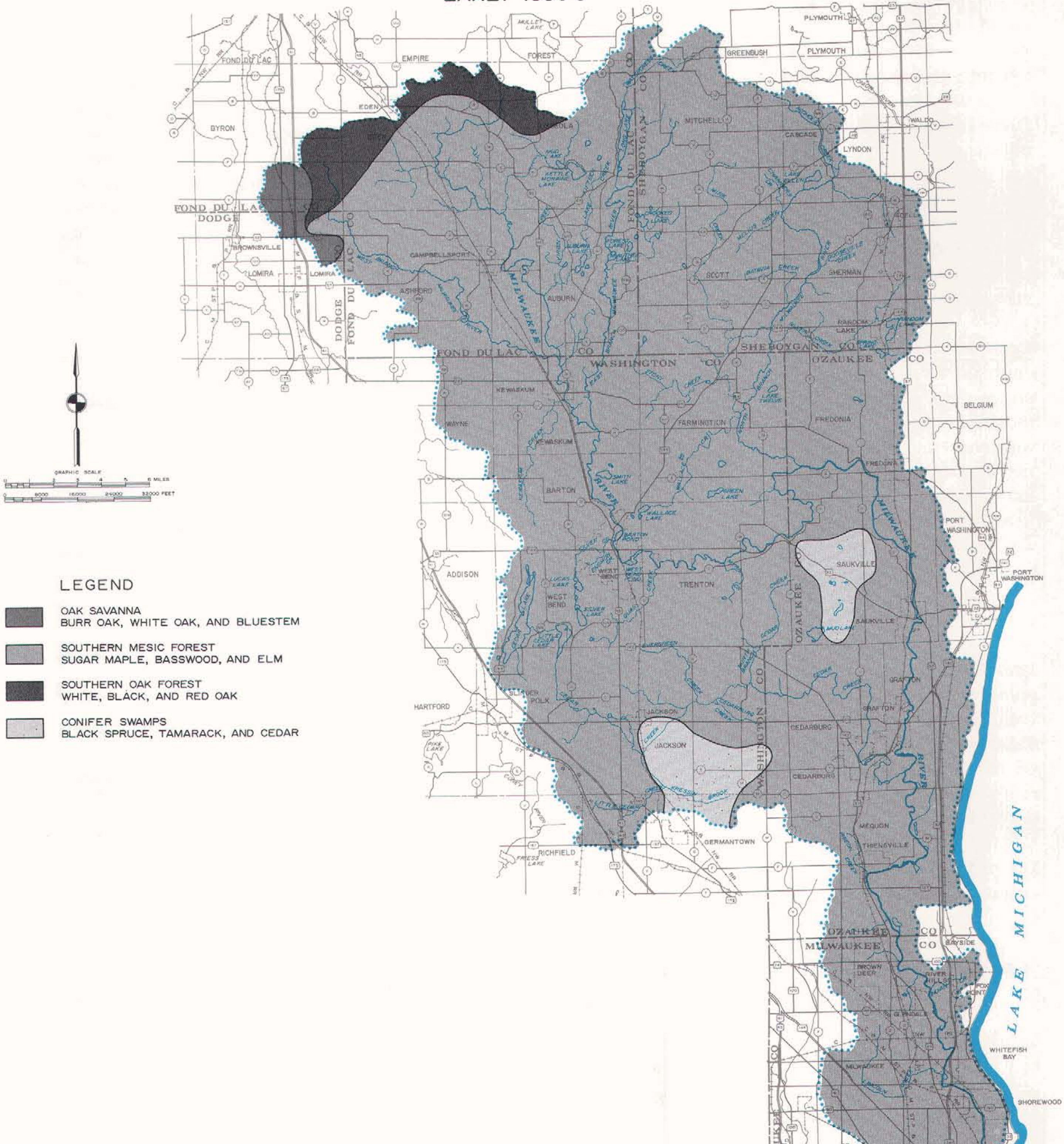
WOODLANDS

Description of the Recreational Resource

Woodlands are a resource with immense and varied value to a civilized society. When the first European settlers came to the Milwaukee River watershed, they encountered abundant woodlands of oak, maple, ash, basswood, cherry, walnut, elm, and other hardwood species (see Map 61). Based upon an analysis of the records of the U. S. Public Land Survey carried out within the watershed from 1832 to 1836, it is estimated that approximately 368,562 acres, or 83 percent of the total area of the watershed, was covered by woodlands. These woodlands were beautiful and their products essential for the development of the watershed and the Region. Extensive timber cutting over the years reduced the woodland area in both size and quality. Woodlands were cleared to grow wheat and corn and to raise cattle. Areas of steep land, infertile soil, and wetlands prevented the settlers from clearing all the land. Most of the areas left in woodland cover were and are still better suited to growing trees than agricultural crops.

Woodland inventories made as a part of the Milwaukee River Watershed Study, utilizing the Commission's 1967 aerial photographs, indicate that woodlands presently cover 70,885 acres, or approximately 16 percent of the total land area of the Milwaukee River watershed (see Map 20). Thus, only 19 percent of the original woodland cover remains. These woodlands constitute an invaluable natural resource. Trees brighten the landscape and soften the lines of lakeshores and streambanks. They represent the largest and oldest of living things in the Milwaukee River watershed. Woodlands maintain a unique natural relationship between plant and animal communities, reduce storm water runoff, provide a source of income to landowners, and provide a resource base for forest product industries. They reduce disquieting sounds of the countryside and the effects of solar radiation; they screen unsightly areas and limit the movement of wind, dust, and snow; and they protect watersheds and control erosion. In addition, trees and shrubs and wildlife associated with them provide daily reminders of man's relationship with nature. In short, here is a direct means of reinforcing human dignity and

Map 61
HISTORICAL VEGETATION OF THE MILWAUKEE RIVER WATERSHED EARLY 1800'S



Over 80 percent of the Milwaukee River watershed was covered by woodlands when the first European settlers entered the watershed in the early 1830's. About 17 percent of the watershed was covered by wetlands. Today, only about 19 percent of this woodland area and about 50 percent of this wetland area remain; and the destruction of the remaining woodlands and wetlands continues.

Source: Wisconsin Geological and Natural History Survey.

freeing human spirits now encircled by monotony, rigidity, pollution, and physical blight. Woodlands, through implementation of balanced use and sustained yield management, can produce repeated crops of wood products, as well as aesthetic beauty, and can simultaneously serve this combination of productive uses. A value rating of the remaining woodlands in the Milwaukee River watershed is set forth in Table 119 and shown on Map 20.

Most of the woodlands in the Milwaukee River watershed are established on moraines, stream bottom lands, and wetland areas, occupying more than one-half of these areas at some locations. Approximately 250,000 trees on some 250 acres of land are planted in the Milwaukee River watershed each year. It is estimated that the woodland acreage being destroyed for the construction of roads, buildings, and other purposes and by livestock grazing, land drainage, and neglect is approximately 400 acres per year, or 150 acres greater annually than that being planted to trees. This destruction of natural woodlands will accelerate unless proper management is practiced and a more intensive reforestation program applied.

Five identifiable woodland types are established in the Milwaukee River watershed: 1) oak, 2) central hardwoods, 3) northern hardwoods, 4) upland conifers, and 5) wetland conifer-hardwoods (see Table 120). The acreage of each type within the watershed was estimated by foresters of the Wisconsin Department of Natural Resources utilizing 1967 Commission aerial photographs, U. S. Geological Survey Maps, and their personal knowledge of the woodland areas of the Milwaukee River watershed, supplemented by field checks on almost all of the remaining woodland acreage within the watershed.

Central Hardwoods Type: The central hardwoods type is the most abundant forest type in the watershed, comprising 25,453 acres, or 36 percent of the total woodland cover. The dominant feature of this type, even before white settlement, was its diversity of composition. Two broad vegetative

TABLE 119

VALUE RATINGS OF WOODLANDS IN THE MILWAUKEE RIVER WATERSHED BY COUNTY- 1967

COUNTY	AESTHETIC WOODLANDS								COMMERCIAL WOODLANDS		TOTAL	
	HIGH VALUE		MEDIUM VALUE		LOW VALUE		TOTAL					
	ACRES	PERCENT OF TOTAL	ACRES	PERCENT OF TOTAL	ACRES	PERCENT OF TOTAL	ACRES	PERCENT OF TOTAL	ACRES	PERCENT OF TOTAL	ACRES	PERCENT OF TOTAL
DODGE.......	55	55	45	45	--	--	100	100	--	--	100	100
FOND DU LAC.	14,495	77	4,025	21	--	--	18,520	98	375	2	18,895	100
MILWAUKEE...	1,515	100	--	--	--	--	1,515	100	--	--	1,515	100
OZAUKEE.....	8,075	66	3,845	31	--	--	11,920	97	360	3	12,280	100
SHEBOYGAN...	12,915	80	2,465	15	--	--	15,380	95	670	5	16,050	100
WASHINGTON..	14,420	65	6,125	28	--	--	20,545	93	1,500	7	22,045	100
TOTAL	51,475	73	16,505	23	--	--	67,980	96	2,905	4	70,885	100.00

SOURCE- WISCONSIN DEPARTMENT OF NATURAL RESOURCES AND SEWRPC.

TABLE 120

WOODLANDS IN THE MILWAUKEE RIVER WATERSHED BY COUNTY BY FOREST TYPE- 1967

COUNTY	FOREST TYPE										TOTAL	
	OAK		CENTRAL HARDWOODS		NORTHERN HARDWOODS		UPLAND CONIFERS		WETLAND CONIFER-HARDWOODS			
	ACRES	PERCENT	ACRES	PERCENT	ACRES	PERCENT	ACRES	PERCENT	ACRES	PERCENT	ACRES	PERCENT
DODGE.......	--	--	48	48	52	52	--	--	--	--	100	100
FOND DU LAC.	1,233	7	6,384	34	4,058	21	1,586	8	5,634	30	18,895	100
MILWAUKEE...	310	20	918	61	198	13	89	6	--	--	1,515	100
OZAUKEE.....	223	2	4,904	40	3,475	28	290	2	3,388	28	12,280	100
SHEBOYGAN...	1,872	12	4,803	30	4,553	28	1,737	11	3,085	19	16,050	100
WASHINGTON..	1,895	9	8,396	38	5,462	25	1,275	6	5,017	22	22,045	100
TOTAL	5,533	8	25,453	36	17,798	25	4,977	7	17,124	24	70,885	100

SOURCE- WISCONSIN DEPARTMENT OF NATURAL RESOURCES AND SEWRPC.

associations are distinguishable, depending on site quality. On the drier sites, stands consist predominantly of oaks, while on the more moist sites, they contain a heterogeneous mixture of species, including red, white, and burr oak; sugar, red, and silver maple; basswood; white and green ash; bitternut and shagbark hickory; black cherry; beech; black walnut; and American and slippery elm. The present composition of a stand usually depends more on its past treatment than on-site quality. Thus, the trees present now are not necessarily the species best suited to the site; nor are they the ones considered most desirable. The species to favor and manage and to reintroduce, if necessary, are the most valuable and attractive species that had grown on the site originally, prior to its deterioration.

Lack of management and excessive grazing by livestock have made stands of this type of species deficient in reproduction and sapling-size trees. The central hardwoods type has a dependable reproduction potential if livestock are excluded, but it must be properly managed to be fully productive for sustained yield. Mature stands must be harvested in a way to regenerate preferred species in adequate amounts for the site. Understocked stands, and these are in the majority, or stands with undesirable species may need a reproduction cut prior to a harvest cut in order to quickly improve stand composition and achieve full utilization of the site. The central hardwoods type under management can furnish good timber for the commercial market and, equally important in this watershed, provides a suitable wildlife habitat and outstanding natural beauty to the countryside.

Northern Hardwoods Type: The northern hardwoods type comprises 17,798 acres, or 25 percent of the total woodland cover within the watershed. It is established primarily on comparatively deep soils with good moisture and fertility, conditions conducive to the production of quality timber if management is applied. The principal species are sugar and red maple, red and white oak, beech, basswood, and American elm. Frequently associated with the above species are white ash, black cherry, and rock elm. The Dutch Elm disease has killed many elms in this woodland type; but, through proper management, other tree species can close the openings and gradually return the woodlands to normal density and appearance.

This type of woodland within the watershed usually has appreciable amounts of residual old growth of mature trees that were either unmerchantable or not wanted by the buyer at the time of the last cut. Unmanaged stands also contain substantial amounts of defective and poorly formed trees in addition to unwanted species. The present composition of the stands usually is the result of their past neglect rather than on-site quality. As a consequence, the trees on a given site are not necessarily a dependable guide to the species best suited to the site. The species to favor and manage, or to reintroduce, should be selected from the most valuable and attractive species known or believed to have been present on the site originally.

Oak Type: The oak type comprises 5,533 acres, or 8 percent of the total woodland cover within the watershed. It occurs principally on dry uplands of glacial moraines, particularly on ridge tops and on south and southwest slopes. Primary species are black oak and shagbark hickory on the drier sites; and white oak on the better sites. Due to the lack of proper management, oak type woodlands have rapidly deteriorated over the years. An inherent characteristic of this type is its low reproduction potential. Heavy grazing by livestock, however, has been the chief contributing cause to its generally poor condition. Most oak type woodlands are understocked and noticeably deficient in reproduction and sapling-size trees. They often have a park-like appearance; and, because of this condition, as well as their location, they possess not only a significant aesthetic value but also a high value for urban-type residential development. Because woodlands of the oak type usually are established on ridge tops and upper slopes, the trees, often readily seen from a distance, contribute appreciable beauty to the countryside.

Virtually no management by private landowners is presently being applied to oak type woodlands. Without management the stands are grossly understocked, the trees are mature or nearly mature, and there is little or no reproduction taking place to perpetuate the stands. If this neglect continues, the acreage of the oak type is expected to decrease; and the woodlands will gradually disappear from the watershed.

Upland Conifer Type: The upland conifer type comprises 4,977 acres, or 7 percent of the total woodland cover within the watershed. It consists of plantations mostly of red and white pine and white and Norway spruce. Plantations on the Kettle Moraine State Forest also include other species, such as white cedar, black spruce, and jack pine. Plantations are even-aged in blocks, having been machine-planted on open land. Tree survival has been exceptional; therefore, many of the older plantations are overstocked and approaching the age where intermediate management practices, particularly thinning to optimum density and pruning of crop trees, are needed. This woodland type provides greenery to the countryside during every season of the year.

Wetland Conifer-Hardwoods Type: The wetland conifer-hardwoods type comprises 17,124 acres, or 24 percent of the woodland cover within the watershed. It is established principally on the poorly drained peat soils of the watershed. Tamarack—the only deciduous conifer native to Wisconsin and a species extremely susceptible to even minor changes in the water table level—is the most abundant conifer of this woodland type. Tamarack is the only tree species growing naturally within southeastern Wisconsin today that has survived from the original post-glacial forest.

White cedar or arbor vitae is found in small amounts along streams or in cool swamps where the water is not stagnant, usually mixed with hardwoods. It is one of the preferred species for deer browse; and, in this respect, it is exceedingly important in recreation areas. Various hardwood species, including swamp white oak, American and slippery elm, silver maple, black and green ash, and black willow, also occur in the wetland conifer-hardwoods type; but, while the trees display a certain natural beauty, they are seldom of adequate size and quality for commercial use. This woodland type is important as wetland cover, as well as a retreat and shelter for wildlife. Drainage of wetlands has had a serious, detrimental effect on this woodland type. In some instances the woodland cover has been completely destroyed.

Problems Related to Woodlands

Insects and Diseases: Adequate protection is an essential part of the management of woodlands valued for aesthetics, recreation, timber, wildlife, or homesites. Only when woodlands are protected from the various destructive agents can long-range plans for their development and use be carried out. Insect and disease enemies of woodlands are numerous and are constantly working to destroy the stands; and prompt action is required in dealing with these destructive agents in order to prevent not only wood product losses but also the loss of the other woodland values.

Healthy, vigorous, rapidly growing trees in a well-managed woodland are less likely to be damaged by insects or diseases than in an unmanaged woodland. Even these trees, however, are not immune to attack by pests. Trees subjected to livestock grazing, fire, too little or too much moisture, and overcrowding are most vulnerable and serve as breeding grounds for insects, which spread to healthy trees, sometimes killing large numbers of trees in the immediate vicinity. Fortunately, natural woodlands in the Milwaukee River watershed consist primarily of mixed tree species, which suffer severe losses less frequently than do woodlands of a single species.

Forest pests affect tree growth by interfering with rates and balances among internal physiological processes, especially food, hormone, and water relations. The aim of science in the continuing warfare against harmful insect pests is a cure that will destroy the pests but leave other forms of life untouched. Hormonal insecticides are a possibility. Such insecticides have strong support from conservationists. Most insects have a three-stage development—from larva to pupa to adult—which is precisely controlled by the secretion of three insect hormones. A brain hormone triggers two nearby glands into producing two different hormones. One of these, called ecdysone (molting hormone), stimulates growth and differentiation processes in larva, pupa, and adult. The other, a juvenile hormone secreted mainly during the larval stage, keeps the caterpillar in its immature stage until it is ready to change into a pupa and adult. The hormones must be secreted in the right amounts at the right time. Too much ecdysone in larvae speeds up development and differentiation, and the larvae die prematurely. If excess juvenile hormone is present in the pupa, development is deranged or halted. Thus, compounds that mimic the insect hormones can be turned into highly effective agents for disrupting the insect's life and, at the same time, contributing to its destruction. This concept provides a major breakthrough in pest control, in that substances may be used as insecticides that leave no damaging residue to interfere with wildlife or pollute water resources.

A very serious disease of trees in the Milwaukee River watershed at present is the Dutch Elm disease. The fungus is carried from diseased trees to healthy ones by elm bark beetles, but it may also spread by means of natural root grafts. Grafts are common in wooded wetlands where the roots are concentrated in a thin layer of soil above the water level. Disease symptoms vary; but usually the top leaves on one or more branches wilt, droop, turn yellow, then brown and become dry. A diagonal cut through a recently wilted branch usually reveals brown discoloration or streaking in the current or last year's wood. Laboratory diagnosis is necessary to be certain, however. Control of the Dutch Elm disease is possible, but only through united community action. It may be impractical to apply control measures in inaccessible areas. Control measures presently are being applied in greater or lesser degrees by a few communities; but, for the most part, the disease is left to run its course. Numerous dying and dead elms are conspicuously visible in rural woodlands where no control measures have been applied.

Another destructive disease of trees in the Milwaukee River watershed is oak wilt. All species of oak are susceptible to oak wilt, but the red and black oaks become infected more readily and wilt more rapidly than the white and bur oaks. The oak wilt disease develops from an extremely virulent fungus. It spreads in at least two ways: through natural underground root grafts locally and by various flying insects. Trees are most likely to become infected in woodlands where some trees had been cut during the active growing season. Any disturbances in oak areas should be restricted to the dormant season. Control is possible, but each situation presents its own peculiar problems for which one or a combination of control methods must be chosen. The premature cutting of oak trees because of the threat of oak wilt is unjustified, and well-managed woodlands seldom are severely damaged.

Another destructive disease of trees in the watershed is white pine blister rust. It spreads to white pines from nearby currant and gooseberry bushes by means of wind-borne spores. The fungus enters the needle, then grows into the bark and eventually kills the tree. The disease is deceptive, and usually infection on pines is not noticed until damage is apparent. The disease kills small white pines quickly but usually requires several years to kill large trees.

Control of white pine blister rust rests with the eradication of all currant and gooseberry bushes within 900 feet of the trees; but in a few situations where the microclimate is especially favorable, a greater distance is necessary. In the case of plantations, the bushes should be eradicated before the trees are planted. Six wild Ribes species have been found in the watershed: the pasture, Missouri, hair-stem gooseberries and the American black, swamp red, and prickly currants. Cultivated species, including the red currant and flowering currant, also can spread the disease. The highly susceptible cultivated European black currant is a special case and under favorable conditions can infect white pines as far as one mile away.

Scattered currant and gooseberry bushes may be uprooted by hand, but care must be taken to prevent sprouting by removing all the roots. In areas of numerous bushes, chemical control with 2,4,5,-T[2] is desirable. For the correct concentration, one must follow precisely the directions on the manufacturer's label. On high-value trees where infection already has started on an outer limb, pruning off the infected branch several inches below the visible canker prevents its growth into the tree trunk and thus saves the tree from eventual death. Early pruning also can reduce the incidence of infection; however, reinfection may occur on other branches of the tree if currant and gooseberry bushes have not been eradicated from infecting distance of the tree.

One of the most serious, potentially destructive agents to tree growth is air pollution. Air pollution damage to trees is increasing rapidly, particularly in the urban-suburban areas, but also in some rural communities where conifers, through needle dwarf and yellow color, show the effect of air pollution drift. Air pollution, supplemented or reinforced by drought, insects, diseases, and other adverse factors, is a prime suspect for declines and ailments of many tree species.

Ash dieback is established in the watershed but presently not in epidemic proportions. All ash species, white, green, blue, and black, appear to be susceptible. In the early stages of ash dieback, the leaves of diseased trees lose their normal dark green color and become pale greenish-

[2] *Trichlorothenoxyacetic acid acts as a herbicide to control broad-leaved plants and young grass seedlings but does not affect mature grass. It also serves as a bush killer.*

yellow. In the late stage, only a few live branches remain; and the trees appear to be near death. Certain symptoms of ash dieback are typical of virus diseases and suggest a virus as a possible causal agent. Studies indicate that, once the tree develops the disease, it will not recover; however, it may take from two to 10 years before it dies.

The box elder bug, a one-half inch long black-colored insect with red stripes, is present in a few localities, when mature, but only where female box elder trees (seed-bearing) grow. This insect lives on the flowers and seeds of box elder trees and, in rare instances, on maples. In late autumn the bugs seek a warm location and find their way indoors despite screened windows and doors. They are particularly annoying to housewives, partly because of their presence but more so because of their disagreeable odor. Control for the following years rests with elimination of the pistillate (female) seed-producing tree growing near the house. Staminate (male) box elders do not contribute to the life cycle of this insect and can be retained. If a replacement is desired for the tree removed, a choice species can be planted.

Heart rots, cankers, and root rots are other common diseases which damage trees. Bark beetles, aphids, weevils, borers, and a variety of leaf defoliators, including destructive sawflies, are the most common insects. Although the hickory bark beetle is present, it is of minor importance. The locust borer and other borers of deciduous and coniferous trees which destroy the cambium and penetrate the wood have been found. Aphids which are present oftentimes transmit virus diseases to trees.

Prevention is the ideal form of woodland protection. Periodic checks by owners of managed woodlands oftentimes enable the detection of outbreaks of insects or diseases in their early stages; and this permits proper remedial action before a minor problem becomes serious and, in extreme cases, catastrophic.

As trees become overmature, such as many of the natural hardwoods in the watershed, their physiological activity is reduced; and they become subject to widespread attack by destructive insects and diseases. It cannot be stressed too strongly that such a physiological change in a tree commonly is a prerequisite to attack. Such predisposing characteristics vary widely among tree species and may involve threshold levels of flowering, cambium activity, critical sapwood moisture content, and other changes.

Urban Encroachment: The Milwaukee River watershed has been subjected to rapid population growth and urbanization, and the economic forces underlying this growth and change are largely centered in the Milwaukee urbanized area. Woodlands, perhaps more than other rural lands, are affected by the conversion of land from rural to urban use; and wooded areas, especially those on ridges and slopes, are undergoing an accelerated conversion from rural to urban uses. Considerable urban sprawl, in the form of isolated residential development, also is beginning to occur in the as yet comparatively undisturbed rural areas of the watershed, away from established communities. In this connection it is important to note that, of the total of 70,885 acres of woodlands existing within the watershed, only 15,455 acres, or 21.8 percent, are in state ownership; 972 acres, or 1.4 percent, in county ownership; 64 acres, or 0.1 percent, in local municipal ownership; while the remaining 54,394 acres, or 76.7 percent, are in private ownership.

Unfortunately, altogether too few woodland owners, when considering the development of their lands, are interested in preserving the woodlands and associated scenic values by large lot or cluster subdivisions in which street and lot patterns can be fitted to the wooded terrain, all utility wires placed underground, and landscaping restrictions incorporated into the deeds which assure the preservation of the woodlands. Most homesites in new urban developments have lot areas which are too small for adaptation to wooded terrain. Thus, a disproportionate number of trees on each lot must be removed for buildings, driveways, and lawns. Unfortunately, also, the tendency where trees are saved is to try to retain all of the remaining large trees on the lot, even though they may be mature or overmature, and to destroy the reproduction and sapling-size trees in order to achieve park-like appearance. The mature and overmature trees gradually will die, and there will be no younger trees on the site to take their place. It should instead be understood that a wooded area is in a constant state of change; that trees become old and die and should be cut and utilized before this occurs; that those which die either from old age or disease and remain standing may become a safety hazard if left where people walk or congregate; that harvest cuts not only provide an income to the owner but, if properly managed, actually improve the stand by keeping it productive; and that a healthy woodland should consist of various-sized trees and age classes. Thus, management of a wooded area in a residential subdivision is as necessary as management of any other woodland. Harvest cuts, stand improvement, thinning, and tree planting are needed; but these must be designed to satisfy local situations. Local subdivision control ordinances should require woodland areas to be left in their natural state insofar as practicable in order to accentuate the beauty of the subdivision. Such provision will not only benefit the overall environment of the watershed and the Region but will also add value to the individual homesites and increase the monetary return to the developer.

The loss of trees and shrubs in the urban environment usually leads to the destruction of environmental values. The ameliorating effect on air temperatures, air pollution, and humidity; the softening of city noise; and the reduction of erosion and sedimentation are all affected by trees and associated plant communities within and around heavily populated areas. Although beautification in a formal manner is understood, the management of trees and associated plants for sylvan aesthetics, microclimate control, and a large number of related benefits is not well understood. It involves a combination of technical disciplines, careful planning, continued management, and strong community action. Without these in the right combination, public and private programs for planning and managing natural woodlands in an urban, or potential urban, area cannot be successful.

Property taxes on wooded land in some communities of the watershed are rising disproportionately even on land not in immediate demand for urban development. To protect wooded areas in the watershed and encourage good management, some type of tax adjustment is needed. A woodland once destroyed requires a lifetime to replace. An equitable tax on wooded areas, subject to protective management, is needed to encourage private owners to keep the land in woodland cover and preserve the accompanying environmental qualities.

Degradation of Woodlands from Livestock Grazing: Woodlands in the Milwaukee River watershed have been subjected to considerable damage from livestock grazing. The widespread practice of allowing livestock to graze woodlands can be attributed to several factors: privately owned woodlands in the watershed are composed almost entirely of hardwood species that provide young growth on which livestock feed; there is a large livestock population on farms with a corresponding pressure for more pasture; the timber value of woodlands is underrated while the forage value is overrated; and woodlands furnish shade to animals in hot weather. Livestock grazing eliminates wildlife food and habitat and limits tree reproduction. It is estimated that 45 percent of the privately owned woodlands in the watershed, exclusive of wooded wetlands, are being grazed. If land is to be devoted to either timber production or the maintenance of aesthetic woodlands, farm livestock must be fenced out. Usually the minor loss in forage value due to fencing a woodland can be more than compensated through improvement of pasture land on the same farm. If shade is needed, a fringe of woods can be fenced into the pasture.

Grazing woodlands is particularly injurious to reproduction and, in the long run, can become as damaging to wildlife. Livestock trampling and browsing kills the tree seedlings. Heavy trampling by cattle packs the forest soil and hampers soil aeration, thus reducing its water-holding capacity. Existing trees grow slowly and become increasingly poorer in quality, and grazed woodlands become understocked. There will be few seedlings or saplings to replace old trees, and the woodlands will eventually disappear.

Fire: Uncontrolled fire has been responsible for substantial losses of woodland in the Milwaukee River watershed since the days of early settlement by Europeans. Some woodlands over the years have burned several times, continuously destroying the young trees, as well as the litter and humus that protect the soil from erosion. Woodland fires, which once were common in the watershed, have occurred less frequently during the last two decades. Fire, however, remains a constant threat; and a reversal of the trend of the past two decades appears to be taking place, with the annual number of woodland fires increasing in the last few years as more and more people use the woodlands. Fortunately, as hardwood stands increase in stocking through management, they become less susceptible to serious fires. Open areas reforested to conifers, however, increase the threat of catastrophic fires. Slow-burning and foul-smelling peat fires sometimes occur in wooded wetlands that have been drained. Such fires may burn for months before being extinguished, and oftentimes drifting smoke from these fires obliterates visibility on highways and seriously endangers the lives of motorists. The disagreeable smell from burning peat also annoys many people and, in extreme cases, may cause illness.

Fire protection efforts have been intensified in recent years. Protection, however, does not keep fires from starting. Woodlands that burn today, as in the past, destroy needed reproduction for future timber crops; drive out wildlife and ruin the habitat; destroy the beauty of the natural environment; set back for a quarter of a century the ability of the vegetation and soil to retard water runoff and supply cool, clear water to streams; destroy new forest plantings and agricultural crops; and, in some instances, destroy buildings. About 1 percent of all fires in the watershed start from lightning; thus, approximately 99 percent are man-made. Virtually all man-made fires are caused through carelessness and, therefore, can be prevented. Smokers unintentionally set many fires. Uncontrolled debris burning causes many fires. Campers, hunters, and fishermen also cause destructive burns.

The actual number of fires varies considerably from year to year, depending largely upon weather conditions. Woodland cover, character, the amount of combustible material that is present, and its use are the chief factors which determine the distribution and concentration of forest fires. Since forest fires are approximately 99 percent man-caused, they tend to occur most frequently in the vicinity of roads, railroads, and settlements. They are most likely to start, however, where combustible material predominates and where there is no forest cover. Least subject to fire are areas of well-stocked timber, especially hardwoods. Before more organized fire protection, the accepted method of controlling fires was to direct them into green timber where they gradually extinguished themselves. Fire protection in the watershed is a cooperative effort between the Wisconsin Department of Natural Resources, local governmental agencies, and individuals.

Game Management: The wildlife resource within the woodlands of the Milwaukee River watershed is limited in numbers and variety but quite substantial for an urbanizing area. Because the woodlands are located within easy travel time of a large urban center, this wildlife resource assumes appreciable recreational importance. The opportunity to observe wild animals and birds in a wooded environment is a factor influencing some persons to establish homes in rural areas. Wildlife in the watershed has many values; and, although the value may be difficult to assess in monetary terms, it is, nevertheless, real. Management of woodlands is needed to develop and maintain a more favorable natural plant-animal community.

There is a definite need for more flora that provides food, as well as shelter, for wildlife. Oak, walnut, hickory, and other species which supply acorns and nuts are needed for an adequate squirrel population. Other trees and shrubs which provide edible fruit and berries are also required to sustain birdlife. Some sizable trees with decaying heartwood are needed for den trees. These trees should be located away from houses, roads, or trails, as they may constitute a safety hazard.

There also is need for a proper balance in the wildlife population of woodlands. Too many rabbits in some areas, particularly where hunting is restricted, girdle small trees and shrubs, thereby destroying the very food and habitat so necessary for their existence. Sport hunting of various wildlife species, including the fox and raccoon, when and where permitted, can avoid damage caused by an overpopulation of a given species. A sizable deer population is developing in some areas of the watershed; and, as a consequence, deer-browse damage to young hardwoods and conifers is increasing. A proper balance between animals and food is highly desirable.

Persons who live in wooded areas sometimes unknowingly are destroying wildlife habitat by either cutting or using herbicides to kill undesired young trees or shrubs which shelter the wildlife. Birds can be killed by the indiscriminate use of insecticides. Individually, the areas affected may be small; but collectively, the habitat and birdlife lost is sizable. A natural woodland is a distinctive plant-animal community which cannot be duplicated under artificial situations and which can become severely altered if natural conditions are modified to a significant degree.

Other Basic Woodland Resource Values: It is highly important that the total values of a fully managed woodland be understood. The woodlands compose an environment for a vast community of living organisms, all interacting to produce the highest benefits to both man and the various other species that inhabit the woodlands. The benefits from a fully managed woodland are equally as important to the adjacent areas as they are to the woodlands themselves. Soil organisms, pollinating insects, natural predators of undesirable insects, and a host of other species produced in the woodlands are all required to maintain a natural balance in the woodland and surrounding areas. It is also essential to recognize that woodlands in this part of Wisconsin cannot be reproduced in other parts of the state. The climate, soil type, geological history, and other characteristics are unique to this part of Wisconsin.

WILDLIFE

Mammals

A complete list of the mammals found in the Milwaukee River watershed is included in Appendix M to this report. A discussion of species of the greatest interest and importance in the watershed is presented below.

White-Tailed Deer: Greatest concentrations of deer occur in the more northerly portions of the watershed in Fond du Lac and Sheboygan Counties, where there are many larger swamps and other wetland areas and more forested area. Deer habitat is estimated to comprise about 8 percent of the total area of the watershed, excluding Milwaukee County, or about 32,700 acres. The deer habitat areas are the retreat areas from which the deer may forage over parts of adjacent agricultural land or open-space areas, such as marshes and meadows. The area of such foraging may cover as much as 30 percent of the total area of the watershed. Estimated deer harvests in watershed portions of the four major counties for the past five years are given in Table 121.

TABLE 121

ESTIMATED DEER HARVESTS IN THE MILWAUKEE RIVER WATERSHED BY COUNTY- 1964-1968

YEAR	ESTIMATED NUMBER OF DEER HARVESTED				WATERSHED TOTAL
	FOND DU LAC COUNTY	OZAUKEE COUNTY	SHEBOYGAN COUNTY	WASHINGTON COUNTY	
1964	36	22	43	176	277
1965	218	18	48	109	393
1966	202	95	110	125	532
1967	134	63	240	121	558
1968	125	78	182	116	501
FIVE-YEAR TOTAL	715	276	623	647	2,261

SOURCE- WISCONSIN DEPARTMENT OF NATURAL RESOURCES.

The average annual harvest for the past five years has been about 450 deer, plus a limited harvest with bow and arrow. There is considerable additional attrition of the herd through car collisions. This loss, based on reported car kills prorated for the watershed, is estimated to be about 200 animals in 1966. Other unreported collision losses are known to exist, as well as losses from occasional poaching, killing by dogs, and other accidents. These are estimated to approximate 100 deer annually, bringing the total estimated cropping of deer within the watershed to an estimated 750 deer per year.

Whether the deer herd has reached a degree of stability in the watershed is not known. The potential exists, however, for further expansion. While current gun season regulations permit taking of any deer, only shotguns using ball or slug loads are permitted; and season length has been three or four days. If there is sufficient hunting privilege granted to the public by landowners or enough participation by the resident landowners, the harvest level of deer could easily prevent any major irruption. On the other hand, tight restriction of admission for hunting, coupled with limited hunting by residents, could allow an irruptive situation to develop.

Fur Bearers: The fur bearers of the Milwaukee River watershed include the muskrat, mink, beaver, otter, weasel, raccoon, fox, skunk, and opossum. The first six named are generally associated with aquatic types of habitat; and the others, with uplands. Generally, all enjoy a great abundance in the watershed, with the exception of the beaver and otter. The watershed has the numerous lakes, creeks, marshes, and woodlands to permit such abundance in the foreseeable future. Population estimates indicate the number of muskrats within the watershed in the fall at about 25,000; the number of mink, at about 2,000; and the number of raccoon, at about 5,000. Foxes, both red and gray, are estimated to number approximately 2,000.

Muskrats are the most abundant and widely distributed of the fur bearers and bring the greatest economic return to trappers. Numbers may fluctuate widely from year to year, building up under favorable conditions and sometimes dropping to very low levels during adverse conditions. Drought, disease, and severe winter freezing are factors which may drastically reduce the muskrat population. Almost any water area may attract muskrats. Lakeshores, marshes, small ponds, rivers, small creeks, and drainage ditches may provide a homesite for muskrats. In marshes the familiar muskrat house possesses a visual amenity and contributes a certain amount of interest to the landscape. These houses are often used by other wildlife. Waterfowl make use of the houses as loafing areas and, to a lesser extent, for nesting. Mink and raccoon use muskrat houses as denning areas. Muskrats dig dens into the banks of water areas or into dikes where there is no marsh to provide shallow water to support a house. Inspection of Milwaukee River water areas in the fall of 1967 showed muskrats to be widely distributed, almost all suitable areas showing signs of muskrat occupancy. Even though isolated ponds and marshes may lose all their muskrats due to freezeout from low water and thick ice, muskrats will quickly repopulate these when favorable conditions return. While always taken by trapping, the effort varies with pelt values. This has been low for many years and barely enables trappers to cover their expenses. However, many trappers consider the effort as a recreational one, similar to hunting experiences. Most trapping is on a part-time basis, except that licensed fur farms run the activity as a business venture. The meat may be utilized in various ways and sometimes is a food item in other parts of the country.

Habitat suitable for muskrats is also likely to be used by mink. Mink are, however, great travelers; and they range much farther from watercourses as a normal way of life. Preservation and improvement of muskrat habitat will automatically benefit the mink. Mink provide an extra challenge to trappers because of their remarkable ability to detect and avoid traps. Pelt values suffer from the competition of ranch-raised mink. Wild pelts often show scar defects due to fighting.

Raccoons are often associated with woodlands, but many of their favorite foods are found in or near water so that they make much use of wetlands. Usually a tree cavity dweller, the raccoon also makes use of rock crevices or other substitute situations for denning. It is highly adaptable to changes in land use.

Both the red and gray fox occur commonly in the watershed area. The red is more characteristic of mixed habitat and farmland, while the gray occurs in hilly, wooded areas. Despite the classical concept of the rapacious ways of the fox, a more proper perspective would place them only in the nuisance category. Also, the fox consumes quantities of crop-damaging species, such as field mice, which may be a value outweighing its liabilities. Many people bear an attitude of tolerence toward the fox because of its aesthetic appeal, while others conceive of it only as a marauding threat to other wildlife. Fox hunting is a growing sport, despite the removal of state bounty payments.

Skunks and opossums are fur bearers whose pelts are presently of little value. They are largely nocturnal, slow moving, and very likely to be killed on the highways. Skunks consume large numbers of June bug grubs in sod. However, this may cause considerable consternation when the skunk rips up a lawn in the process. Skunks are the major carrier of rabies in Wisconsin. The opossum is largely harmless. Both use woodland areas bordering farmlands and venture onto the wetlands in search of food. Both skunk and opossum tend to become inactive in cold weather, although they are not true hibernators.

Other Mammals: Additional larger mammals include the woodchuck and perhaps an occasional badger. Of greatest abundance in terms of total numbers are the various small mammals. These include the spermophile, the chipmunk, and several species of mice and shrews. They occur in a variety of habitat types. Most of them are relatively innocuous and highly interesting. Of greatest total impact is probably the field mouse, which damages hayfield seedlings, orchard stock, and shrubbery.

Birds

A complete list of the birds found in the Milwaukee River watershed is included in Appendix N to this report. A discussion of species of the greatest interest and importance in the watershed is presented below.

Pheasants: The pheasant, while not a native, has the aesthetic appeal shared by all gallinaceous birds. It is highly prized by the hunter, and many sportsman's clubs and private shooting preserves have their programs largely based upon the pheasant. With average fall population within the Milwaukee River watershed estimated at 25,000 birds, or about 39 per square mile, the range of densities between areas of township size might vary from very low numbers to highs of 80 or more per square mile. These values are close to average for southern Wisconsin. Generally, the East Branch and Kettle Moraine area have lower numbers of birds. Of the total non-cropland game range within the watershed, the acreage estimated to be used by pheasants according to quality categories is shown in Table 122.

The pheasant enjoys the highest rate of occupancy of any game species in the watershed, with the possible exception of the cottontail rabbit. For, in addition to the above-indicated range quantities, the pheasant penetrates deeply into agricultural lands for nesting and feeding and thus may be expected almost anywhere except in some of the woodlands. The pheasant in this latitude requires winter protection when lesser cover becomes buried under snow. Cattail marshes, shrub swamps, and tamarack swamps fill this need. While corn is perhaps above all the favorite winter food of the pheasant, a wide variety of seeds, greens, and insect food is also taken. Corn is available in much of the area as waste in picked fields except where fall conditions permit late plowing. Annual weeds, such as smartweed, often found in cornfields, provide additional feed. The giant ragweed in peat areas is also a favorite winter food.

Secure nesting cover is often a premium item for the pheasant. The forage crops—alfalfa, clover, and grass mixtures—may be death traps when hens, as often happens, are drawn in by early vegetative growth and caught by high-speed harvest machinery prior to hatching of the clutch. Lowland areas of cover may be flooded during unusually heavy rainfall. Ideal cover is offered by abandoned fields, including Feed Grain and Soil Bank lands, or lightly pastured areas. Nesting losses are considered to be a major limiting factor on pheasant numbers.

TABLE 122

ESTIMATED PHEASANT RANGE ACREAGE IN THE MILWAUKEE RIVER WATERSHED
1967

RATING	NUMBER OF ACRES	PERCENT OF WATERSHED (EXCLUDING MILWAUKEE COUNTY)
GOOD....	21,300	5.2
FAIR....	18,900	4.6
POOR....	6,200	1.5
TOTAL	46,400	11.3

SOURCE- WISCONSIN DEPARTMENT OF NATURAL RESOURCES.

Waterfowl: Waterfowl are of universal appeal both on the water and in the air. The Milwaukee River watershed is a major pathway in the Mississippi Flyway. It is estimated that approximately 2 percent of the annual waterfowl take in the state occurs in the watershed. Provision of opportunity to hunt waterfowl is one of the major activities in the field of game management. Many private organization, as well as state, efforts are directed to this end; and it is the present major source of strength for high quality wetlands preservation. Average density observed for the watershed was three to four breeding ducks per square mile, as compared to a statewide average of 5 per square mile.

A much greater variety of species is encountered during spring or fall migration. Virtually any of the species using the Mississippi Flyway occur in the watershed, with the exception of a few of the Great Lakes ducks. This includes all the "puddle" ducks, divers, mergansers, and the swans and geese—in all, perhaps 25 species. The most common species occurring early in the fall season would be the blue-winged and green-winged teal, the mallard, black duck, wood-duck, and the ringneck. Later arrivals in numbers would be the scaup. Lesser and irregular numbers of other species occur. These include pintails, baldpates, shovelers, redheads, and canvasbacks. Among the geese the Canada goose and its subspecies are of regular occurrence in the spring and fall, while blue geese and snow geese may sometimes be found in good numbers but much more irregularly. Smaller groups of whistling swans may occur during spring migration.

Nesting waterfowl favor the smaller and shallower bodies of water in the watershed, including potholes and marshes as habitat. In migration the larger bodies of water are used. Due to the relatively limited marsh component of the wetlands in the watershed, however, and the presence of the Kettle Moraine area, the watershed rates below average for southeastern Wisconsin in the quality of waterfowl habitat. Of the total non-cropland game range, the acreage estimated to be used by waterfowl according to quality categories is shown in Table 123.

Waterfowl foods other than the aquatic plants include waste grain, especially corn, in harvested fields and occasionally acorns or other mast. Aquatic plant food favorites found in the watershed are muskgrass, Sago pondweed and other pond-

TABLE 123

ESTIMATED WATERFOWL ACREAGE IN THE MILWAUKEE RIVER WATERSHED-1967

RATING	NUMBER OF ACRES	PERCENT OF WATERSHED
GOOD....	4,200	1.0
FAIR....	3,200	0.8
POOR....	1,300	0.3
TOTAL	8,700	2.1

SOURCE- WISCONSIN DEPARTMENT OF NATURAL RESOURCES.

weeds, various smartweeds, bulrush, duckweed, wild celery, wild rice, naiads, and others of more occasional use. These include bur reed, arrowhead, coontail, sedges, milfoils, and spike rushes.

Hungarian Partridge: Of general occurrence with the pheasant is the Hungarian partridge, also an introduced bird of the farmlands. Of considerable lesser importance than the pheasant both locally and continentally, it still is abundant enough to be of interest to the public and to the sportsman. A coveying bird, it is often seen in flocks on snow-drifted fields.

Bobwhite Quail: This bird is extirpated or possibly of irregular, rare occurrence in the watershed. However, the range potential for this bird would seem to exist within the watershed. The quail makes use of the more brushy irregular lands in farming areas. The major limiting factor appears to be the discontinuity with other suitable occupied range. Larger populations of this bird are 75 to 100 miles away.

Ruffed Grouse: This game bird is distributed quite regularly throughout the watershed where larger wooded tracts are found. It utilizes both the upland forests and the lowland timber swamps.

Marsh, Shore, and Water Birds: Other water-associated birds are too numerous to discuss individually; but the major groups, as well as individual species of unusual interest, can be mentioned. The loon and cormorant occur in migration on the larger lakes and rivers; the smaller pied-billed grebe nests in or uses the watershed. Several herons occur, the great blue and the two species of bittern nesting, while the little blue and snowy egret are summer visitors. The jacksnipe and woodcock occur in migration commonly, the latter nesting to some extent. A wide gamut of sandpipers, plovers, gulls, terns, rails, and gallinules occur, some of which also nest. The larger species of these, such as the coot and rails, are hunted. A favorable study area for most of these species is the Jackson Marsh Wildlife Area, but many of the wetland units also provide these opportunities.

Other Birds: Because of the admixture of lowland and upland forest, meadows, and agricultural lands and favorable warm-season climate, the watershed abounds in all other bird types. These include the many perching birds, swallows, woodpeckers, hawks, and owls. Conspicuous single representatives, some from other groups, are the occasional eagle, turkey vulture, the mourning dove (abundant), whip-poor-will, and pileated woodpecker.

There are no known bird species present that are unique to the watershed. Pest species may be considered to include the imported English sparrow, the starling, and the common pigeon. The native redwing blackbird is very abundant and may damage sweet corn stands.

Other Wildlife

Much of the biological activity in the environment depends not on the more highly visible and attractive mammal and bird life, but on the myriads of lesser invertebrate organisms, ranging from viruses through the amoeba, zooplankton, free-living nematodes, annelids, molluscs, and into numerous insects. Many of these fulfill essential roles, in absence of which the natural world could not function. A similar panoply exists in the plant kingdom. Of greatest regard, however, is that these groups comprise a web of life that must be given recognition and perpetuation. Robust as this web is, it can be severely damaged on occasion. In southeastern Wisconsin, as in any highly urbanized areas, much of the natural environment has been destroyed; and the remaining amount has been severely disturbed. Every possible course of action must be taken, therefore, to protect the existing wetlands; the natural shoreline of lakes and streams, as well as the lakes and streams themselves; and the woodlands, for it is in these areas where the biological activity and life upon which man ultimately depends for his very existence begin and end.

The natural wildlife habitat areas remaining within the watershed, totaling about 42.3 square miles in area, or 6 percent of the total area of the watershed, are shown on Map 22 and are summarized by value rating in Table 16.

ENVIRONMENTAL CORRIDORS

In Chapter IV of this report, the concept of the environmental corridor was advanced and briefly discussed. Because of the importance of these corridors to the maintenance of both the ecological balance and natural beauty of the watershed, the corridors are discussed in somewhat greater detail here. Although comprising an integral system with a total area of about 157 square miles, or 23 percent of the total watershed area (see Map 25), the primary environmental corridor pattern within the watershed can be broken down into 12 distinct corridors, as shown on Map 25 and listed in Table 124. These corridors represent a refinement of the corridors originally delineated on the adopted regional land use plan. A detailed description of each corridor, together with a discussion of the man-made and natural problems affecting the resource elements contained within each corridor, is available in separate technical staff memoranda on file in the Commission offices.

The primary environmental corridors contain almost all of the remaining high-value elements of the natural resource base within the watershed.

TABLE 124

SUMMARY OF LAND USE AND NATURAL RESOURCES INVENTORIES WITHIN THE PRIMARY ENVIRONMENTAL CORRIDORS OF THE MILWAUKEE RIVER WATERSHED- 1967

			NET CORRIDOR LAND USE[a]											
			WATER		WETLAND		WOODLAND		AGRICULTURE AND RELATED		UNUSED LAND		NET CORRIDOR TOTAL	
CORRIDOR NUMBER	CORRIDOR NAME	LOCATION	ACRES	PERCENT OF CORRIDOR	ACRES	PERCENT OF CORRIDOR	ACRES	PERCENT OF CORRIDOR	ACRES	PERCENT OF CORRIDOR	ACRES	PERCENT OF CORRIDOR	ACRES	PERCENT OF CORRIDOR
1	MILWAUKEE	T 7N,R22E T 8N,R22E	203	48.31	69	16.45	12	2.92	4	1.09	131	31.23	419	100
2	CEDARBURG	T 9N,R21E T10N,R21E	1,287	8.60	7,772	51.90	2,421	16.17	3,150	21.04	343	2.29	14,973	100
3	WAUBEKA	T11N,R21E T12N,R21E	686	7.31	4,170	44.47	1,841	19.63	2,470	26.34	211	2.25	9,377	100
4	WEST BEND	T11N,R19E T12N,R19E	2,045	14.88	3,977	28.93	3,588	26.10	3,824	27.81	315	2.29	13,750	100
5	GERMANTOWN	T 9N,R20E T10N,R20E	0.37	0.02	57	3.71	692	44.93	789	51.23	2	0.11	1,541	100
6	WAYNE MARSH	T12N,R18E	--	--	1,433	76.83	63	3.40	341	18.28	28	1.49	1,866	100
7	CASCADE	T13N,R21E T14N,R21E	244	3.34	3,568	48.77	1,607	21.97	1,732	23.68	164	2.25	7,315	100
8	MINK CREEK	T13N,R20E	14	0.62	1,095	47.09	832	35.78	345	14.82	40	1.70	2,325	100
9	RANDOM LAKE	T13N,R21E	262	6.24	2,011	47.91	642	15.30	1,162	27.68	120	2.87	4,198	100
10	CAMPBELLSPORT	T14N,R18E	162	1.90	5,439	63.76	878	10.29	1,865	21.86	187	2.19	8,530	100
11	WEST BRANCH	T13N,R18E	174	3.34	2,721	52.28	913	17.55	1,318	25.33	78	1.50	5,204	100
12	KETTLE MORAINE	T13N,R19E T14N,R19E	1,476	4.79	12,849	41.75	7,285	23.67	6,933	22.53	2,232	7.25	30,774	100
TOTAL			6,554	6.54	45,160	45.04	20,774	20.72	23,934	23.87	3,851	3.84	100,272	100

			CORRIDOR NATURAL RESOURCE USE[b]									
			WETLAND		WOODLAND		WILDLIFE HABITAT		RECREATION			
									EXISTING		POTENTIAL	
CORRIDOR NUMBER	CORRIDOR NAME	LOCATION	ACRES	PERCENT OF CORRIDOR	ACRES	PERCENT OF CORRIDOR	ACRES	PERCENT OF CORRIDOR	ACRES	PERCENT OF CORRIDOR	ACRES	PERCENT OF CORRIDOR
1	MILWAUKEE	T 7N,R22E T 8N,R22E	72	17.18	24	5.72	179	42.24	304	72.55	--	--
2	CEDARBURG	T 9N,R21E T10N,R21E	8,068	53.88	7,360	49.15	7,179	47.93	3,860	25.77	3,401	22.71
3	WAUBEKA	T11N,R21E T12N,R21E	4,329	46.16	1,892	20.17	4,188	44.64	597	6.36	3,756	40.05
4	WEST BEND	T11N,R19E T12N,R19E	4,128	30.02	5,412	39.36	6,010	43.69	2,085	15.16	4,173	30.34
5	GERMANTOWN	T 9N,R20E T10N,R20E	59	3.82	776	50.35	468	30.24	--	--	34	2.20
6	WAYNE MARSH	T12N,R18E	1,487	79.68	640	34.29	935	50.00	80	4.28	--	--
7	CASCADE	T13N,R21E T14N,R21E	3,704	50.63	3,180	43.47	3,386	46.26	17	0.23	991	13.54
8	MINK CREEK	T13N,R20E	1,137	48.90	864	37.16	1,216	52.21	--	--	866	37.24
9	RANDOM LAKE	T13N,R21E	2,088	49.73	1,854	44.16	1,823	43.37	41	0.97	134	3.19
10	CAMPBELLSPORT	T14N,R18E	5,646	66.18	2,414	28.30	4,058	47.55	74	0.86	432	5.06
11	WEST BRANCH	T13N,R18E	2,824	54.26	1,790	34.39	2,382	45.71	58	1.11	102	1.96
12	KETTLE MORAINE	T13N,R19E T14N,R19E	13,342	43.35	18,745	60.91	13,509	43.89	17,562	57.06	678	2.20
TOTAL			46,884	46.75	44,951	44.82	45,333	45.18	24,678	24.51	14,467	14.42

[a]AS DETERMINED IN SEWRPC LAND USE INVENTORY. NET CORRIDOR IS DEFINED AS THAT PORTION OF THE ENVIRONMENTAL CORRIDORS CONSISTING OF WATER, WETLANDS, WOODLANDS, AGRICULTURAL LANDS, AND OTHER GENERALLY OPEN OR UNUSED LANDS, EXCEPT THOSE CONTAINED WITHIN THE MAJOR PARK LANDS.

[b]AS DETERMINED IN WATERSHED RESOURCE INVENTORIES.

SOURCE- WISCONSIN DEPARTMENT OF NATURAL RESOURCES AND SEWRPC.

More specifically, the 157 square miles of primary environmental corridor within the Milwaukee River watershed contain 52 lineal miles of lake shoreline, or 88 percent of the total lineal miles of shoreline on the 21 major lakes within the watershed. The environmental corridors also contain 282 lineal miles, or 85 percent of the 330 total lineal miles of perennial stream channel length within the watershed. Significantly, the lake shoreline and stream channel lengths encompassed by the environmental corridors are those remaining in predominantly rural and open use.

The environmental corridors contain 46,884 acres, or 68 percent of all the remaining wetlands within the watershed, including 35,628 acres, or 68 percent of the 199 significant wetland units, and 11,256 acres, or 32 percent of the minor wetland units. The corridors also contain 44,951 acres, or about 63 percent of the remaining 70,885 acres of woodland cover within the Milwaukee River watershed, including 35,257 acres, or 69 percent of the high-value aesthetic woodlands; 8,580 acres, or 52 percent of the medium-value aesthetic woodlands; and 1,114 acres, or 38 percent of the commercial woodlands remaining in the watershed. No low-value aesthetic woodlands were found to exist within the watershed. The environmental corridors also contain 45,333 acres, or 67 percent of the 67,662 acres of wildlife habitat areas within the watershed.

It is important to recognize that, in the watershed planning program, the detailed wetland and woodland natural resource inventories were conducted independently by natural resource specialists from a natural resource, rather than a land use, point of view, resulting in the multiple counting of certain acreage. For example, a given acre of timber swamp would have been inventoried and counted as both an acre of wetland and as an acre of woodland. Similarly, many acres of wetlands and woodlands would be included in the inventory of wildlife habitat areas.

In direct contrast, the existing land use inventories conducted under the regional planning program contain no such multiple countings. Therefore, the existing land uses within the primary environmental corridors of the watershed constitute mutually exclusive categories of land use. The results of both the land use inventories and the natural resource inventories for the primary environmental corridors in the Milwaukee River watershed are shown in Table 124.

The intrusion of urban land uses into the corridors will tend not only to destroy the very resources and related amenities sought by such urban development but will tend to create severe environmental problems having areawide effects within the watershed. Since these environmental corridors are endowed by nature and are truly irreplaceable by man, they must serve the watershed and the Region not only for today but for all time. Preservation and protection of these corridors in compatible open uses is, therefore, essential to the maintenance of a good environment for life within the watershed and to the preservation of its unique cultural and natural heritage, as well as its natural beauty.

SUMMARY

The Milwaukee River watershed constitutes an area of valuable natural resources and related open space within the rapidly urbanizing Southeastern Wisconsin Region. This chapter has described in some detail the physical characteristics of several major recreation and recreation-related natural resources of the watershed. This chapter has also described the major problems relating to the conservation and wise use of these resources, problems related to the natural characteristics of the resources themselves, as well as problems induced or aggravated by human activity within the watershed. The resources involved include the lakes and streams, the wetlands and woodlands, and the wildlife of the watershed.

There are 71 lakes within the Milwaukee River watershed, of which 21 have a surface area of 50 acres or more. The 71 lakes have a combined surface area of 6.5 square miles, or 1 percent of the total watershed area. The latter figure compares to 4 percent for the Fox River watershed in southeastern Wisconsin and 2 percent for the state as a whole. The 21 major lakes have a total surface area of 5.7 square miles, or 88 percent of the total lake surface area within the watershed, and a total shoreline length of 59 miles, or 70 percent of the total lake shoreline within the watershed. These lakes, together with the 330 miles of perennial streams within the watershed, constitute the major recreational resource, as well as one of the most important natural resources of the watershed. The lakes provide opportunities for swimming, boating, fishing, and other aquatic sports; serve as natural floodwater retention reservoirs, thereby reducing peak flood discharges within the watershed; and provide one of the most pleasing aesthetic elements of the landscape, enhancing adjacent property values.

Major problems of the lakes within the watershed in relation to public recreational demands concern insufficient depth, size, instability of water levels, and deteriorating water quality. Although some of these problems are related to the natural characteristics of the lakes themselves, the problem of water quality, which affects eutrophication rates, is by far the most serious, having been greatly intensified by human activity within the watershed. Accelerated eutrophication is evidenced by extensive growth of aquatic vegetation and a high incidence of problems related to the consumption of oxygen and decomposing vegetation. Thirteen of the 21 major lakes of the watershed already exhibit overabundant aquatic plant growths, which interfere with recreational uses, such as swimming, fishing, and boating, while connected streams continue an endless effort to carry away enough of the nutrient contributions to allow a balanced aquatic plant growth. The most pressing need in this respect is to reduce or eliminate nutrient contribution to the lakes from domestic sewage, farm, and urban runoff. Failure to reduce this nutrient contribution will eventually destroy the lakes within the watershed as a recreational asset and turn them into a severe public liability.

The problems of the lakes have been intensified by changes in the natural drainage pattern of the watershed through ditching and channel improvements and by poor agricultural and urban land development and use practices, which cause both accelerated eutrophication and sedimentation. In the latter process, sedimentary materials are deposited directly on the beds of the lakes, destroying valuable fish spawning areas and further reducing the depth of already shallow bodies of water. This soil erosion and consequent stream and lake sedimentation is one of the more serious immediate problems existing within the watershed. The overabundance of rough fish is another serious fish management problem, plaguing both the lakes and streams of the watershed by creating water conditions which favor undesirable plant, animal, and other aquatic life forms.

There are 199 wetland units having a surface area of 50 acres or more within the watershed. These wetlands have a combined surface area of 62.0 square miles, or 9.7 percent of the total area of the watershed. This latter figure compares to 8.5 percent for the Fox River watershed and 6.8 percent for the state as a whole. Almost one-half of the original wetlands existing within the watershed have been destroyed or greatly modified since settlement. Wetlands have great value as fish and wildlife habitat areas; act as natural filters to trap and store nutrients; like the lakes, constitute important natural floodwater storage reservoirs, thereby reducing peak flood discharges within the watershed; and contribute to the aesthetic character and overall quality of the environment within the watershed. Wetlands of the watershed are subject to pollution, siltation, and molestation of wildlife, as well as destruction through conversion to agricultural and urban land uses. Problems in wetland management arise from unstable water levels, which can create odors, undesirable insect populations, and occasional release of stored nutrients to downstream watercourses.

Woodlands are another important natural resource of the watershed. Originally, approximately 576 square miles, or 83 percent of the total area of the watershed, were covered by woodlands. This has been reduced to approximately 111 square miles, or about 16 percent of the total area of the watershed, so that over 81 percent of the original woodland cover has been destroyed. At the present time, the amount of woodland acreage being destroyed within the watershed, primarily for roads and agricultural and urban land use development, is estimated to be approximately 400 acres, or 150 acres more annually than is being planted to trees. Because of the type, quality, and age of the remaining woodland stands within the watershed, however, this rate of woodland destruction will accelerate as woodland neglect and urbanization proceed, unless a woodland management and an active reforestation program is instituted. Woodlands within the watershed not only constitute an economic asset of great value but provide wildlife habitat; assist in reducing storm water runoff; and constitute an important aesthetic feature of the landscape, greatly enhancing the value of land for urban uses, as well as contributing to the ecological balance of the watershed. Problems related to the preservation of woodlands include, in addition to their destruction through clearance for agricultural and urban use, insects and diseases, degradation by livestock grazing, and fire.

Almost 42.3 square miles, or 6 percent of the total watershed, form a natural wildlife habitat.

The most important species of wildlife now living within the watershed include white-tailed deer, beaver, otter, raccoon, fox, muskrat, weasel, skunk, opossum, woodchuck, and even an occasional badger, the symbol of the state. Small animals are naturally in more abundance than the large ones since they are generally better able to adapt to the conversion of land to agricultural and urban use. Birds are also abundant within the watershed, with pheasant, Hungarian partridge, and various waterfowl forming an important recreational asset.

The best remaining elements of the resource base of the watershed—the prime undeveloped stream and lakeshore areas, the best remaining woodlands and wetlands, and the best remaining wildlife habitat areas—form lineal patterns within the watershed termed primary environmental corridors. These corridors comprise a total area of about 157 square miles, or 23 percent of the total watershed area. These corridors, however, encompass 88 percent of the lake shorelines of the 21 major lakes within the watershed; 85 percent of the total lineal miles of major stream channel length within the watershed; 68 percent of all remaining wetlands; 63 percent of all remaining woodlands; and 67 percent of the remaining wildlife habitat. The protection and preservation of these corridors in compatible open uses is, therefore, essential to the maintenance of a healthy environment for life within the watershed; to the preservation of its wildlife; to its unique cultural and natural heritage; and to its natural beauty. Because these environmental corridors must serve the watershed and its residents for all time to come, the value of these corridors will grow as the watershed continues to urbanize.

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Chapter XIV

OUTDOOR RECREATION NEEDS

INTRODUCTION

Rapid population increase and urbanization, combined with rising income levels, are generating a rapidly increasing demand for outdoor recreation in southeastern Wisconsin. This demand is further intensified by the close proximity of the Southeastern Wisconsin Region with its nearly 1.8 million urban residents, to the northeastern Illinois metropolitan region, with its nearly 7 million urban residents, many of whom seek outdoor recreational opportunities in southeastern Wisconsin. The Milwaukee River watershed, with its many streams and lakes, varied topography, woodlands, wetlands, and wildlife habitat areas, comprises a relatively prime recreational resource; and its proximity to the Milwaukee, as well as to the Chicago, Kenosha, and Racine, urbanized areas serves to increase its potential recreational value. If this recreation potential is to be fully protected and developed to meet the growing demand for outdoor recreational opportunities, careful attention must be given in the comprehensive watershed planning effort to both a quantification of the existing and potential demand for outdoor recreation and to the means available to satisfy this demand through public and private investment in outdoor recreational facility development.

This chapter is primarily concerned with the determination of gross recreational land needs within the Milwaukee River watershed to the year 1990. It also presents in summary form the results of the inventory of existing public and nonpublic outdoor recreational land, of the analyses of existing and probable future participant demand, and of the forecast of overall recreational land and water area requirements needed to meet the probable future demand prepared as a part of the watershed planning effort.

EXISTING OUTDOOR RECREATIONAL LAND INVENTORY—1967

The results of the outdoor recreation and related open-space site inventory conducted in 1967 by the Wisconsin Department of Natural Resources, in cooperation with the Southeastern Wisconsin Regional Planning Commission (SEWRPC), revealed that there were 186 such public and nonpublic sites within the Milwaukee River watershed, encompassing a total of 29,065 acres, or 6.5 percent of the total watershed area. These 186 sites included 3,055 acres of water surface area, or about 45 percent of the total of 6,800 acres of water surface area existing within the watershed.[1] Publicly controlled lands owned or leased by a governmental body or agency account for 25,120 acres, or about 86 percent of the total acreage of recreation and related open-space sites within the watershed. Nonpublic ownership accounts for the remaining 3,945 acres, or about 14 percent (see Table 125). The status of public recreation and related land ownership in the five counties in which the watershed is located is summarized in Table 126 and shown on Map 23.

The total outdoor recreation and related open-space site area, while one measure of the potential supply of recreational space, does not reflect the area actually developed for specific recreational activities and, therefore, available for active recreational use. A more detailed analysis of the site area devoted to specific recreational activities, as shown in Table 125, indicates that only 11,187 acres, or approximately 38 percent of the publicly controlled recreational lands within the watershed, are available for the 16 major specific water- and land-based outdoor recreational activities listed in Table 125. Areas acquired and protected for their natural biotic values but open to public hunting comprise over 81 percent of these lands. Only 2,124 acres, or approximately 19 percent of the publicly controlled recreational lands, are available for other outdoor recreational activities.

Undeveloped outdoor recreation lands total 14,645 acres. Approximately 95 percent are in public ownership and may be divided, as shown in Table 127, into two categories:

1. Developable lands, or lands acquired for specific outdoor recreational activities.

[1] *See Chapter IV, Volume 1, of this report, Tables 17 and 18 and Map 23.*

TABLE 125

OUTDOOR RECREATION LANDS IN THE MILWAUKEE RIVER WATERSHED BY MAJOR RECREATIONAL ACTIVITY AND OWNERSHIP 1967

ACTIVITY[a]	PUBLIC ACRES				NONPUBLIC ACRES				TOTAL PUBLIC AND NONPUBLIC ACREAGE
	STATE	COUNTY	LOCAL	TOTAL	PRIVATE (RESTRICTED)	ORGANIZATIONAL	COMMERCIAL	TOTAL	
DEVELOPED RECREATION LANDS									
WATER-BASED									
SWIMMING	2	4	10	16	2	9	13	24	40
BOATING	3	2	2	7	--	6	3	9	16
FISHING[b]	--	--	--	--	--	--	--	--	--
CANOEING[b]	--	--	--	--	--	--	--	--	--
WATERSKIING[b]	--	--	--	--	--	--	--	--	--
SUBTOTAL	5	6	12	23	2	15	16	33	56
LAND-BASED									
SITE ACTIVITIES									
CAMPING	130	21	--	151	--	197	293	490	641
PICNICKING	46	350	195	591	7	22	41	70	661
GOLFING	--	438	--	438	1,046	40	279	1,365	1,803
HUNTING[c]	9,063	--	--	9,063	238	500	--	738	9,801
SKIING	--	20	--	20	--	20	26	46	66
ROAD ACTIVITIES									
SIGHTSEEING[b]	--	--	--	--	--	--	--	--	--
PLEASURE DRIVING[b]	--	--	--	--	--	--	--	--	--
BICYCLING[b]	--	--	--	--	--	--	--	--	--
TRAIL ACTIVITIES									
HIKING	--	--	--	--	--	--	--	--	--
NATURE WALKING	--	400	20	420	--	255	--	255	675
HORSEBACK RIDING	--	--	--	--	--	--	125	125	125
SUBTOTAL	9,239	1,229	215	10,683	1,291	1,034	764	3,089	13,772
OTHER MINOR LAND- OR WATER-BASED ACTIVITIES	4	327	150	481	4	100	7	111	592
TOTAL DEVELOPED RECREATION LANDS	9,248	1,562	377	11,187	1,297	1,149	787	3,233	14,420
TOTAL UNDEVELOPED RECREATION LANDS (UNUSED LAND AND OPEN SPACE LAND)[d]	13,154	634	145	13,933	88	368	256	712	14,645
TOTAL RECREATION LANDS	22,402	2,196	522	25,120	1,385	1,517	1,043	3,945	29,065

[a] ACTIVITIES LISTED AS WATER-BASED AND LAND-BASED ARE THE 16 ACTIVITIES WHICH HAVE THE HIGHEST PARTICIPATION RATE IN THE STATE OF WISCONSIN AS DETERMINED BY THE WISCONSIN DEPARTMENT OF NATURAL RESOURCES.

[b] NO LAND AREA INFORMATION AVAILABLE.

[c] AREAS ACQUIRED FOR NATURAL BIOTIC VALUES BUT OPEN TO HUNTING.

[d] UNDEVELOPED LANDS ARE FURTHER CLASSIFIED IN TABLE 127 .

SOURCE- WISCONSIN DEPARTMENT OF NATURAL RESOURCES AND SEWRPC.

TABLE 126

OUTDOOR RECREATION LAND IN THE MILWAUKEE RIVER WATERSHED BY COUNTY BY OWNERSHIP- 1967

COUNTY	PUBLIC (ACRES)				NONPUBLIC (ACRES)				TOTAL
	LOCAL	COUNTY	STATE	SUB-TOTAL	PRIVATE	ORGANI-ZATIONAL	COMMERCIAL	SUB-TOTAL	
DODGE	--	--	--	--	--	--	--	--	--
FOND DU LAC	16	--	8,805	8,821	116	390	156	662	9,483
MILWAUKEE	177	1,741	1	1,919	566	24	50	640	2,559
OZAUKEE	85	353	1,002	1,440	624	392	109	1,125	2,565
SHEBOYGAN	56	2	8,211	8,269	--	--	--	--	8,269
WASHINGTON	188	100	4,383	4,671	79	711	728	1,518	6,189
TOTAL	522	2,196	22,402	25,120	1,385	1,517	1,043	3,945	29,065

SOURCE- WISCONSIN DEPARTMENT OF NATURAL RESOURCES AND SEWRPC.

These lands total 708 acres, or about 4 percent of the total undeveloped outdoor recreation lands in the watershed.

2. Open-space lands, or lands acquired to provide open-space or undeveloped land adjacent to specific intensive outdoor recreational activity land and which, while essential to the protection and enhancement of the intensively used sites, are currently not intended for further development. These lands total 13,937 acres, or about 96 percent of the total undeveloped outdoor recreation land in the watershed. As shown in Table 128, certain of these open-space lands support lands developed for specific major intensive outdoor recreational activities.

TABLE 127

EXISTING UNDEVELOPED OUTDOOR RECREATION LANDS IN THE MILWAUKEE RIVER WATERSHED BY OWNERSHIP- 1967

OWNERSHIP	TOTAL UNDEVELOPED LAND (ACRES)	DEVELOPABLE LANDS		SUPPLEMENTARY LANDS[a]	
		ACRES	PERCENT OF TOTAL UNDEVELOPED LAND	ACRES	PERCENT OF TOTAL UNDEVELOPED LAND
PUBLIC					
LOCAL	145	37	25.5	108	74.5
COUNTY	634	110	17.4	524	82.6
STATE	13,154	200	1.5	12,954	98.5
SUBTOTAL	13,933	347	2.5	13,586	97.5
NONPUBLIC					
PRIVATE (RESTRICTED)	88	53	60.2	35	39.8
ORGANIZATIONAL	368	85	23.1	283	76.9
COMMERCIAL	256	223	87.1	33	12.9
SUBTOTAL	712	361	50.7	351	49.3
TOTAL	14,645	708	4.8	13,937	95.2

[a] SUPPLEMENTARY LANDS ARE THOSE LANDS LYING ADJACENT TO INTENSIVE RECREATION DEVELOPMENT WHICH PROVIDE RELATIVELY UNDEVELOPED OPEN SPACE OR NATURAL BUFFER AND ARE NOT INTENDED FOR INTENSIVE DEVELOPMENT.

SOURCE- WISCONSIN DEPARTMENT OF NATURAL RESOURCES AND SEWRPC.

TABLE 128

SUMMARY OF SUPPLEMENTARY LANDS FOR MAJOR RECREATIONAL ACTIVITIES BY OWNERSHIP- 1967

OWNERSHIP	TOTAL SUPPLEMENTARY LAND (ACRES)	ASSIGNABLE SUPPLEMENTARY LANDS (ACRES)				UNASSIGNABLE SUPPLEMENTARY LAND (ACRES)
		TOTAL	SWIMMING	PICNICKING	CAMPING	
PUBLIC						
LOCAL	108	19	9	10	--	89
COUNTY	524	430	67	323	40	94
STATE	12,954	2,838	8	360	2,470	10,116
SUBTOTAL	13,586	3,287	84	693	2,510	10,299
NONPUBLIC						
PRIVATE (RESTRICTED)	35	35	16	19	--	--
ORGANIZATIONAL	283	97	60	2	35	186
COMMERCIAL	33	12	--	12	--	21
SUBTOTAL	351	144	76	33	35	207
TOTAL	13,937	3,431	160	726	2,545	10,506

SOURCE- WISCONSIN DEPARTMENT OF NATURAL RESOURCES AND SEWRPC.

Privately owned outdoor recreation lands total 3,945 acres, or less than 1 percent of the watershed area; and of this total, 3,233 acres, or approximately 82 percent, were developed for active outdoor recreational use, and 712 acres, or approximately 18 percent, remain unused but potentially developable.

In addition to ownership, the existing developed outdoor recreation land area of the watershed was inventoried to determine the amount of land devoted to each of 16 major outdoor recreational activities (see Table 125). These 16 activities are consistent with the Wisconsin Department of Natural Resources outdoor recreation analysis categories and are divided into two major groups—five water-based activities and 11 land-based activities. All developed land not devoted to these 16 major activities, such as land for playfields, trapshoot areas, and skating areas, was also inventoried. The total developed acreage devoted to such minor land- and water-based activities is shown in a residual category in Table 125.

Water-Based Activities

Public Developed Lands Devoted to Water-Based Activities: The five major water-based activities—swimming, boating, fishing, canoeing, and water skiing—require land adjacent to a water body for access. Such lands include boat launching areas, swimming beaches, and fishing water-access areas. Publicly owned or controlled water-based recreational areas within the Milwaukee River watershed are limited to beach and boat water-access developments and are usually combined with a large multi-use public land-based outdoor recreation area. Lands in public ownership account for 41 percent of the total water-based outdoor recreational area in the watershed; however, at the present time, there are only 16 acres of public swimming beaches, having a combined shoreline frontage of 2,200 feet, and seven acres of public boat access, having a combined shoreline frontage of 300 feet, available in the watershed.

Publicly owned water-based recreational areas within the watershed are presently provided by three levels of government: local, county, and state. There are no federally owned lands developed for water-based recreational activities within the watershed. Of the total public land area devoted to water-based recreational activities, 50 percent is owned and operated by local units of government, about 25 percent is owned and operated by county units of government, with the remaining 25 percent owned and operated by the State of Wisconsin (see Table 125).

Nonpublic Developed Lands Devoted to Water-Based Activities: Nonpublicly owned land devoted to water-based activities may be classified as either private-restricted, organizational, or commercial. The organizational and private-restricted facilities, generally located on lake shorelines, are owned by private individuals or groups which restrict the use of the lands to members only. Swimming, sailing, canoeing, water skiing, and power boating are popular activities at private-restricted recreational developments. Most organizational developments devoted to water-based activities are group campgrounds, such as those used by the Boy Scouts, Girl Scouts, and church camps. Commercial water-based recreational activities, while privately owned, are open to the general public on a fee basis. Such commercial lands generally involve activities relating to boat rental, bait sale, and fishing access surrounding lake shorelines. Many of these areas provide the non-boat-owning public the opportunity to enjoy water activities by providing equipment on a rental basis, as well as access to a water body. Presently, there are a total of 24 acres of nonpublicly owned beaches, having a combined shoreline frontage of 3,275 feet, and nine acres of nonpublicly owned boat access areas, having a combined shoreline frontage of 507 feet, available within the watershed. Of this total, 13 acres of swimming beaches, having a shoreline frontage of 1,965 feet, and three acres of boat access, having a shoreline frontage of 167 feet, are in commercial use. The remaining areas are in private-restricted or organizational use. Some of the larger multi-use commercial recreation establishments provide swimming pools in addition to other recreational activities.

Land-Based Activities

Public Lands Devoted to Land-Based Activities: The 11 major land-based activities—camping, picnicking, golfing, hunting, skiing, sightseeing, pleasure driving, bicycling, hiking, nature walking, and horseback riding—are all recreational activities that are performed wholly on land. Publicly owned land-based recreational land areas within the watershed are presently provided by three levels of government: local, county, and state. There are no federally owned land-based recreational areas within the watershed. The local units of government presently provide most of the daily activity recreational areas in the form of neighborhood and community parks and playgrounds (see Table 125). Emphasis in the design and improvement of such land areas is placed on intensive use activities, such as ball fields and swimming pools; and such land areas are usually operated and maintained by local park and recreation departments.

County-owned recreational lands within the watershed generally are larger, multi-use park sites serving county and regional recreation needs, as well as meeting some local needs. Such county parks generally provide picnic areas, playfields, golfing, hiking, and camping areas (see Table 125). Milwaukee County currently has the largest and most completely developed county recreation lands in the watershed, totaling 1,741 acres, or about 80 percent of the total county-owned recreation lands within the watershed (see Table 126).

State-owned lands comprise the largest outdoor recreational land acreage within the watershed. Most of the state-owned lands are operated by the Forest and Fish and Game Management Bureaus of the Wisconsin Department of Natural Resources as state forests and wildlife habitat areas and are not developed or intended for intensive recreational use. These lands do, however, provide opportunities for sightseeing, pleasure driving, hiking, and hunting and are essential to the protection of essential biotic elements of the natural resource base. The only major intensively developed state outdoor recreational lands within the watershed are the Mauthe Lake and Long Lake recreational areas, both of which are located in the northern unit of the Kettle Moraine State Forest in Fond du Lac County. Camping, hiking, and picnic areas, as well as beach and boat launch areas, are provided at these parks. Additional intensively developed state recreation lands include special activities areas, such as wayside parks, which offer picnicking facilities (see Table 125).

Nonpublic Developed Lands Devoted to Land-Based Activities: Of the total land-based recreational area within the watershed, private-restricted lands presently account for approximately 9 percent. Primarily two types of recreational activities are provided by private operators: golf courses and hunting grounds. Other specialized recreational land-based activities provided for by private operators include picnic grounds, playfields, shooting ranges, and nature hiking areas (see Table 125). Although some of the private-restricted lands provide for several kinds of land-based recreational activities, the use of such lands is restricted by membership regulations and, therefore, is generally available only to a limited number of people. Generally heavily used only on summer weekends, these lands serve a valuable limited use open-space function throughout the entire year. Some private-restricted recreational establishments, however, are now beginning to provide for year-round recreational activities. Ozaukee County ranks first within the watershed in both acreage and in the number of activities provided for by private-restricted development (see Table 126).

Organizational group-owned lands presently account for approximately 7 percent of the total land-based recreational area within the watershed; and, like the private-restricted ownership lands, use is restricted to members of the sponsoring groups, such as fishing and hunting clubs, service clubs, and local scouting organizations. Typical recreational activities provided for on organizational-owned lands are group camping areas, picnic areas, trapshooting, hiking trails, and limited golf facilities (see Table 125). Some of the land areas owned and operated by organizational groups also provide ample opportunity for nature study and serve a valuable open-space function. Washington County ranks first in both acreage and the number of sites devoted to private organizational use within the watershed (see Table 126).

Many commercial recreational operations are located throughout the watershed, and these lands account for approximately 5 percent of the total land-based recreational areas within the watershed. Most commercial recreation operations are seasonal and range from single-use areas, such as horse rental stables, to multi-use areas, providing such activities as camping, horseback riding, golfing, and skiing. Such commercial operations constitute the largest amount of recreational land devoted to camping and skiing facilities in the watershed. Washington County currently ranks first in both acreage and the number of sites devoted to commercial recreational use within the watershed (see Table 126).

FACTORS AFFECTING THE EXISTING AND FUTURE DEMAND FOR OUTDOOR RECREATIONAL LANDS

The greatest use of outdoor recreational lands within the Milwaukee River watershed occurs during the summer vacation season, extending from Memorial Day weekend in May through the Labor Day weekend in September. This period of intensive use or high demand coincides with the warmest season of the year, the longest daylight hours, and the annual vacation times for the majority of persons having children affected by school-term residence requirements. Thus, the Milwaukee River watershed generally experiences its greatest recreational use pressures and largest number of users from the 4th of July through the first week of August.

As already noted, the Milwaukee River watershed is located within southeastern Wisconsin, one of the large urban regions of the United States. It is located, moreover, in close proximity to the northeastern Illinois metropolitan region, the third largest urban region in the United States. Both of these regions are experiencing rapid population growth and urbanization. By 1990, over 2.6 million people are expected to reside within the Southeastern Wisconsin Region; and over 9.5 million people, in the Northeastern Illinois Region (see Table 129). These forecast population levels constitute increases of approximately 800,000 people, or about 44 percent, and approximately 3 million people, or about 45 percent, respectively, over the 1967 population levels of these two regions. A greatly increased demand for outdoor recreation is certain to be generated by such rapid increase in population within these two urbanizing regions.

Urbanization within the watershed is already exerting a direct and rapidly increasing pressure on its recreational resources. By 1990 about 678,000 people are expected to reside within the watershed. This forecast of growth represents an increase of about 25 percent over the 1967 population of 544,000. This increase, while smaller in actual numbers than is expected in adjacent, more intensely urbanized areas, will have a more significant effect on the recreational facilities and resources of the watershed than the larger increases expected in the adjacent urbanized areas. Instead of only weekend and summer vacation use of the recreational resources of the watershed, daily year-round use is increasingly being made of these resources by watershed residents. This internal pressure on recreational watershed resources may be expected to increase as population growth increases within the watershed. Moreover, urban land development attendant to such population increase will not only result in greater pressures on recreation facilities but may also result in loss or irreparable damage to the recreation resource base itself.

Intensified pressure on recreational resources of the watershed is also being generated in the Southeastern Wisconsin Region outside the watershed by the rapidly increasing Kenosha, Milwaukee, and Racine urban populations. Reduction of travel time from urban centers to recreational areas in the watershed, especially by construction of new high speed, all-weather freeways, will make the recreational resources of the watershed more readily accessible to a larger urban population on a day-use basis. As population growth and transportation system improvement continues, the daily pressures on recreational resources are expected to increase; and additional daily, as well as additional weekend, demand will have to be met by existing and potential outdoor recreation areas within the watershed.

TABLE 129

EXISTING AND FORECAST POPULATION IN THE MILWAUKEE RIVER WATERSHED AND ADJACENT URBAN AREAS- 1967 AND 1990

AREA	POPULATION		PERCENT INCREASE
	1967	1990	
MILWAUKEE RIVER WATERSHED	543,790	677,650	24.6
SOUTHEASTERN WISCONSIN REGION	1,809,500	2,678,000	48.0
NORTHEASTERN ILLINOIS[a]	6,972,100[b]	9,537,500[c]	36.8

[a] INCLUDES ALL OF COOK, DUPAGE, KANE, LAKE, MCHENRY AND WILL COUNTIES IN NORTHEASTERN ILLINOIS.

[b] INTERPOLATED BY SEWRPC FROM 1965 AND 1975 POPULATION DATA COMPILED BY THE NORTHEASTERN ILLINOIS PLANNING COMMISSION (NIPC) AND REPORTED IN NIPC PLANNING PAPER NO. 10.

[c] INTERPOLATED BY SEWRPC FROM 1985 AND 1995 POPULATION FORECASTS PREPARED BY NIPC AND REPORTED IN NIPC PLANNING PAPER NO. 10.

SOURCE- SEWRPC.

The northeastern Illinois metropolitan region exerts an ever-increasing demand on nearby recreational areas, including the Milwaukee River watershed in Wisconsin. Data compiled by the Wisconsin Department of Natural Resources indicate that persons seeking day-use recreational activities will drive up to two hours from their residence to outdoor recreational activity facilities. This driving time places all of southeastern Wisconsin, nearly all of northeastern Illinois, as well as other large areas of southern Wisconsin and northern Illinois, within day-use range of recreational facilities in the watershed (see Map 62). About 7 million people reside within this day-use area. Unless potential recreation areas are acquired and developed, overuse and deterioration or destruction of existing recreation areas and the recreation resources base will result.

EXISTING OUTDOOR RECREATIONAL ACTIVITY DEMAND—1967

Outdoor recreation demand is measured in terms of individual participation in each of the 16 specific major outdoor recreational activities experiencing the highest participation on an average seasonal Sunday[2] in the State of Wisconsin, as determined by surveys of the Wisconsin Department of Natural Resources. Total participation in each of the 16 major outdoor recreational activities has been further subdivided into three major categories based on the residence of the participant; namely, residents of the watershed, residents of Wisconsin outside the watershed, and residents of other states (see Table 130).

Water-Based Activities

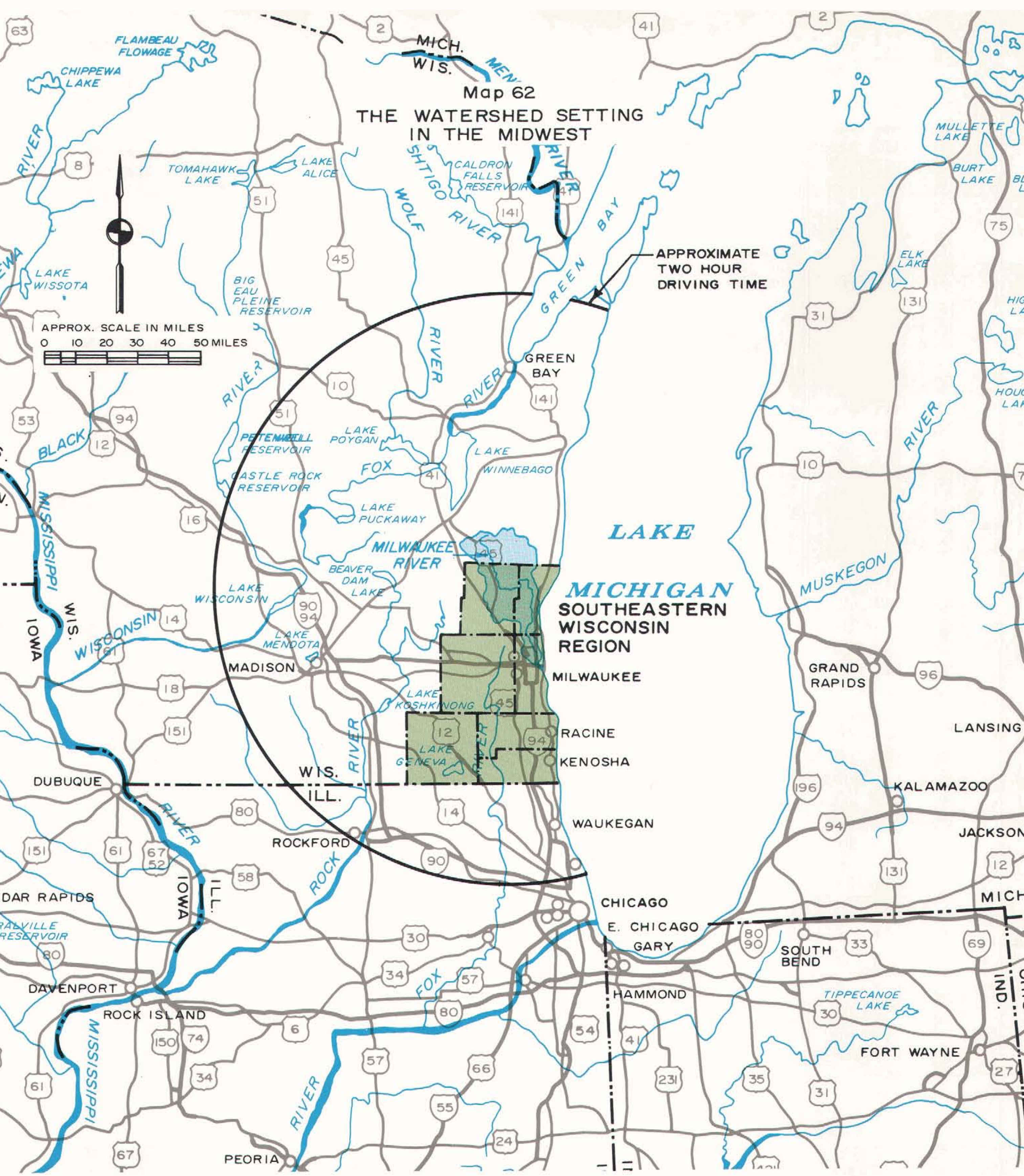
Water-based outdoor recreational activities, as previously indicated, are those activities which require access to a body of water (see Table 130). Demand for water-based activities in the watershed currently accounts for over 47 percent of the total outdoor recreation demand. Fifty-three percent of the total demand for water-based recreational activities in the watershed is generated by watershed residents, approximately 33 percent is generated from within the State of Wisconsin but outside the watershed, and the remaining 14.0 percent of total demand for water use is generated by out-of-state users.

As shown in Table 131, three of the seven highest ranked activities based on participation demand—swimming, boating, and fishing—require surface water. These three activities account for 30 percent of the outdoor recreation demand in the watershed. Despite this heavy demand, areas providing access to water bodies in the watershed total only 56 acres, or less than one percent of the total land area devoted to outdoor recreation. Seventeen acres, or 30 percent of the total developed water access points, are either in private-restricted ownership or organizational ownership and are not available for general public use. Because of this, therefore, the demand on public and commercially owned and operated water access areas is increased. At present, local units of government in the watershed provide 18 acres, or 32 percent of all lands developed for water access.

In view of the existing water-based activity demand, water surface area within the watershed is severely limited. Lake and stream surface area in the watershed totals approximately 6,800 acres, or less than 1.5 percent of the area of the watershed. Fortunately, the activity experiencing the highest participant demand—swimming—requires the least amount of water area. According to state promulgated standards for lake development, swimming should be allocated to the area extending 200 feet from the shoreline. In the Milwaukee River watershed, this swimming area allotment totals 2,206 acres, or about 32 percent of the total surface water area. It is anticipated that, if shoreline in the watershed is acquired and properly developed and if water quality levels in the lakes and streams are maintained to permit full-body-contact-recreational use, demands for swimming can be met within the watershed.

Demand for other water-based activities has, on the other hand, already reached critical levels. Surface water area available for all water-based recreational activities other than swimming totals only 4,594 acres. With a participant demand of 21,159 for water-based activities other than swimming on an average seasonal Sunday, only about

[2] The term "average seasonal Sunday" has been defined by the Wisconsin Department of Natural Resources for 14 of 16 major outdoor recreational activities as a summer Sunday not coinciding with a holiday weekend. An average seasonal Sunday for hunting and skiing activities is defined as a nonholiday weekend Sunday during the legal Wisconsin hunting season and a nonholiday weekend Sunday during the winter months, respectively. For the seven-county Southeastern Wisconsin Region, the rate of participant demand for an average seasonal Sunday has been calculated by the Wisconsin Department of Natural Resources in The Outdoor Recreation Plan, Wisconsin Development Series--1966, to be 2.3 times the average seasonal weekday participation demand.



The accessibility of the recreational resources of the Milwaukee River watershed, and in particular the upper watershed area in Wisconsin, to large concentrations of potential recreation users is graphically depicted on this map. A major portion of southern Wisconsin and northern Illinois lies within a day-use automobile drive from the watershed. The total population encompassed within that day-use radius presently exceeds 7 million persons and is expected to exceed 9 million persons by 1990.

Source: SEWRPC.

TABLE 130

EXISTING AVERAGE SEASONAL SUNDAY PARTICIPANT RECREATION DEMAND IN THE MILWAUKEE RIVER WATERSHED BY MAJOR RECREATIONAL ACTIVITY AND RESIDENCE OF PARTICIPANT- 1967

MAJOR RECREATIONAL ACTIVITY	TOTAL PARTICIPANTS	WATERSHED RESIDENTS		OUT-OF-WATERSHED WISCONSIN RESIDENTS		OUT-OF-STATE RESIDENTS	
		PARTICIPANTS	PERCENT OF TOTAL	PARTICIPANTS	PERCENT OF TOTAL	PARTICIPANTS	PERCENT OF TOTAL
WATER-BASED							
SWIMMING	44,027	23,286	52.9	14,778	33.6	5,963	13.5
BOATING	8,650	2,297	26.6	2,245	25.9	4,108	47.5
FISHING	10,837	5,082	46.9	3,242	29.9	2,513	23.2
CANOEING	423	105	24.8	158	37.4	160	37.8
WATERSKIING	1,249	419	33.5	508	40.7	322	25.8
SUBTOTAL	65,186	31,189	47.8	20,931	32.1	13,066	20.1
LAND-BASED							
SITE ACTIVITIES							
CAMPING	2,422	150	6.2	742	30.6	1,530	63.2
PICNICKING	17,408	11,621	66.7	4,614	26.5	1,173	6.8
GOLFING	16,097	11,865	73.7	2,348	14.6	1,884	11.7
HUNTING	3,084	850	27.6	2,154	69.8	80	2.6
SKIING	1,385	243	17.5	611	44.1	531	38.3
ROAD ACTIVITIES							
SIGHTSEEING	17,398	5,652	32.5	5,468	31.4	6,278	36.1
PLEASURE DRIVING	73,588	49,498	67.3	15,753	21.4	8,337	11.7
BICYCLING	7,054	6,817	96.6	237	3.4	--	--
TRAIL ACTIVITIES							
HIKING	1,442	824	57.1	314	21.8	304	21.1
NATURE WALKING	4,074	3 296	80.9	114	2.8	664	16.3
HORSEBACK RIDING	974	881	90.5	93	9.5	--	--
SUBTOTAL	144,926	91,697	63.3	32,448	22.4	20,781	14.3
TOTAL	210,112	122,886	58.5	53,379	25.4	33,847	16.1

SOURCE- WISCONSIN DEPARTMENT OF NATURAL RESOURCES AND SEWRPC.

TABLE 131

RANK ORDER OF EXISTING RECREATIONAL ACTIVITY DEMAND ON AN AVERAGE SEASONAL SUNDAY IN THE MILWAUKEE RIVER WATERSHED BY RESIDENCE OF PARTICIPANT- 1967

RANK ORDER OF ACTIVITY	WATERSHED RESIDENTS	OUT-OF-WATERSHED WISCONSIN RESIDENTS	OUT-OF-STATE RESIDENTS	TOTAL PARTICIPANTS
1	PLEASURE DRIVING (49,498)[a]	PLEASURE DRIVING (15,753)	PLEASURE DRIVING (8,337)	PLEASURE DRIVING (73,588)
2	SWIMMING (23,286)	SWIMMING (14,778)	SIGHTSEEING (6,278)	SWIMMING (44,027)
3	GOLFING (11,865)	SIGHTSEEING (5,468)	SWIMMING (5,963)	PICNICKING (17,408)
4	PICNICKING (11,621)	PICNICKING (4,614)	BOATING (4,108)	SIGHTSEEING (17,398)
5	BICYCLING (6,817)	FISHING (3,242)	FISHING (2,513)	GOLFING (16,097)
6	SIGHTSEEING (5,652)	GOLFING (2,348)	GOLFING (1,884)	FISHING (10,837)
7	FISHING (5,082)	BOATING (2,245)	CAMPING (1,530)	BOATING (8,650)
8	NATURE WALKING (3,296)	HUNTING (2,154)	PICNICKING (1,173)	BICYCLING (7,054)
9	BOATING (2,297)	CAMPING (742)	NATURE WALKING (664)	NATURE WALKING (4,074)
10	HORSEBACK RIDING (881)	SKIING (611)	SKIING (531)	HUNTING (3,084)
11	HUNTING (850)	WATERSKIING (508)	WATERSKIING (322)	CAMPING (2,422)
12	HIKING (824)	HIKING (314)	HIKING (304)	HIKING (1,442)
13	WATERSKIING (419)	BICYCLING (237)	CANOEING (160)	SKIING (1,385)
14	SKIING (243)	CANOEING (158)	HUNTING (80)	WATERSKIING (1,249)
15	CAMPING (150)	NATURE WALKING (114)	HORSEBACK RIDING --	HORSEBACK RIDING (974)
16	CANOEING (105)	HORSEBACK RIDING (93)	BICYCLING --	CANOEING (423)
TOTAL	(122,886)	(53,379)	(33,847)	(210,112)

[a] NUMBERS BELOW EACH ACTIVITY REPRESENT THE 1967 ESTIMATED PARTICIPATION DEMAND ON AN AVERAGE SEASONAL SUNDAY IN THE MILWAUKEE RIVER WATERSHED, EXPRESSED IN NUMBER OF PERSONS.

SOURCE- WISCONSIN DEPARTMENT OF NATURAL RESOURCES.

0.2 acre of available lake and stream and surface area could be allotted for each participant. If one-fifth of the total participants are on the water at any one time, this allocation would be increased to almost 1.0 acre per participant, only one-fifth the lake and stream water use standard of five acres per participant recommended for good water resource management by the Wisconsin Department of Natural Resources.

Land-Based Activities

Land-based outdoor recreational activity demand currently comprises over 45 percent of the total demand. Two activities—pleasure driving and sightseeing—account for over 63 percent of all land-based activity participation on an average seasonal Sunday. Neither of these recreational pursuits requires direct ownership of recreation land, but rather requires the provision of secondary highways as pleasure drives and the maintenance of the visual beauty of the countryside and the preservation of sites of scenic and historic interest. Therefore, while comprising the heaviest demand, these recreational pursuits are also the easiest to provide for in terms of land acquisition and development if the beauty of the landscape is maintained by well-planned urban and rural development and pollution control, assuring the continued availability of the landscape for aesthetic enjoyment.

Land developed within the watershed for land-based outdoor recreational activities is limited considering the rapidly increasing demand for such activities. While total outdoor recreation land acreage in the watershed appears large, that portion of the total actually developed and, therefore, available to the general public for intensive use is limited, particularly when related to participant demand. Of the 13,772 acres of land devoted to land-based recreational activities, only 3,971 acres, or less than 29 percent, are developed for active outdoor recreation purposes. Publicly owned land, totaling 1,620 acres, represents less than 41 percent of the total land devoted to active recreational use in the watershed. Private-restricted or organizational ownership totals 2,351 acres, or 59 percent of active recreational land in the watershed, but is not accessible to the general public. Of all publicly owned outdoor recreation land in the watershed, 9,801 acres are owned or leased primarily for protecting and enhancing the natural biotic values and secondarily for hunting purposes. These state-owned or controlled wildlife areas total 9,063 acres, or 92 percent. For these lands to achieve their primary purpose, they must be maintained in an essentially natural condition. Therefore, with the exception of such uses as hunting or sightseeing, they are generally not available for outdoor recreational activities.

FORECAST OUTDOOR RECREATIONAL ACTIVITY DEMAND—1990

As already indicated, large and rapid increases in population within the watershed, as well as in adjacent urbanizing regions, are expected to have a significant impact on the recreational facilities and the recreation resource base of the watershed. That expected impact can be expressed in terms of the participant demand forecast for each of the 16 major outdoor recreational activities in the watershed.

Water-Based Activities

By 1990 approximately 157,000 participants in water-based facilities are expected in the watershed, or 33 percent of the expected total participant demand for outdoor recreation. This is an increase of 92,000 water-based activity participants, or 141 percent of the 1967 demand levels, and an increase of 7 percent in the proportion which this participant demand comprises of the total demand. Thus, participant demand for water-based outdoor recreational activities in the watershed is not only expected to more than double in 20 years but is expected to become even more popular as a leisure-time activity than is now the case. As indicated in Table 132, participation in swimming is expected to increase 148 percent; and swimmers will remain the largest single-user group of water-based outdoor recreational facilities. Swimming will account for 76 percent of all water-based recreational activity participants and 29 percent of all major outdoor recreational activity participants. This significant increase in participant demand for swimming is indicated by the even more significant increase expected in out-of-state participant demand for swimming facilities. Out-of-state demand is forecast at 229 percent above the 1970 level, reflecting expected large population increases in northeastern Illinois, combined with more leisure time and improved transportation facilities.

Canoeing is expected to experience the largest percentage increase in water-based participant demand (222 percent) with 51 percent of the canoeing demand generated by out-of-state residents.

TABLE 132

FORECAST AVERAGE SEASONAL SUNDAY PARTICIPANT DEMAND IN THE MILWAUKEE RIVER WATERSHED BY MAJOR RECREATIONAL ACTIVITY AND RESIDENCE OF PARTICIPANT- 1990[a]

MAJOR RECREATIONAL ACTIVITY	TOTAL PARTICIPANTS	WATERSHED RESIDENTS		OUT-OF-WATERSHED WISCONSIN RESIDENTS		OUT-OF-STATE RESIDENTS		PERCENT INCREASE IN TOTAL PARTICIPANT DEMAND (1967-1990)
		PARTICIPANTS	PERCENT OF TOTAL	PARTICIPANTS	PERCENT OF TOTAL	PARTICIPANTS	PERCENT OF TOTAL	
WATER-BASED								
SWIMMING	119,169	61,323	51.5	38,221	32.1	19,625	16.4	148
BOATING	17,477	3,240	18.5	3,070	17.6	11,167	63.9	102
FISHING	16,144	7,084	43.9	4,386	27.2	4,674	28.9	49
CANOEING	1,161	233	20.1	340	29.3	588	50.6	222
WATERSKIING	2,928	874	29.8	1,031	35.2	1,023	35.0	134
SUBTOTAL	156,879	72,754	46.4	47,048	30.0	37,077	23.6	141
LAND-BASED								
SITE ACTIVITIES								
CAMPING	4,838	225	4.7	1,314	27.2	3,299	68.1	100
PICNICKING	24,749	16,018	64.7	6,347	25.7	2,384	9.6	42
GOLFING	22,294	16,077	72.1	3,157	14.2	3,060	13.7	38
HUNTING	4,406	1,210	27.5	3,007	68.2	189	4.3	43
SKIING	2,525	369	14.6	945	37.4	1,211	48.0	82
ROAD ACTIVITIES								
SIGHTSEEING	46,941	9,983	21.3	15,720	33.5	21,238	45.2	170
PLEASURE DRIVING	123,663	82,091	66.4	24,507	19.8	17,065	13.8	68
BICYCLING	10,290	9,939	96.6	351	3.4	--[b]	--[b]	46
TRAIL ACTIVITIES								
HIKING	3,620	942	26.0	1,651	45.6	1,027	28.4	151
NATURE WALKING	9,941	7,441	74.9	253	25.5	2,247	22.6	144
HORSEBACK RIDING	1,458	1,319	90.5	139	9.5	--[b]	--[b]	50
SUBTOTAL	254,725	145,614	57.2	57,391	22.5	*51,720	20.3	76
TOTAL	411,604	218,368	53.1	104,439	25.4	88,797	21.5	96

[a] INTERPOLATED BY SEWRPC FROM PARTICIPANT DEMAND DATA PROJECTED FOR THE YEARS 1980 AND 2000 BY THE WISCONSIN DEPARTMENT OF RESOURCE DEVELOPMENT AND PUBLISHED IN THE OUTDOOR RECREATION PLAN, WISCONSIN DEVELOPMENT SERIES-1966.

[b] DATA NOT AVAILABLE.

SOURCE- WISCONSIN DEPARTMENT OF NATURAL RESOURCES AND SEWRPC.

Forecast of participant demand for fishing will show the smallest increase during the period 1967 to 1990, an increase of 49 percent. This is large, however, considering the already intensive use of the surface waters in the watershed.

The forecast demand for water-based recreational activities in the watershed will exert great pressures on the water resources, which are already being used at a critical level with respect to the ability of these resources to sustain the use without an overall decline in quality. Meeting the expected intensified demand, therefore, will require the provision of additional water surface area in the watershed; stricter enforcement of use standards and regulations, thereby, in effect, limiting participation in water-based activities; or the lowering of use standards to allow a more intensive use of the resource. A combination of one or more of these or other measures may be the ultimate solution to meeting the expected high demands; but, in so doing, the ultimate destruction of the resource must not be permitted.

Land-Based Activities

Like water-based activities, land-based participant demand for major recreational activities in the watershed is expected to experience significant increases in the 20-year period, extending from 1970 to 1990. Participation in four of the 11 land-based activities may be expected to increase 100 percent or more in this period. Land-based activities may be expected in 1990 to account for 255,000 participants, or 62 percent of the total demand for outdoor recreation in the watershed. This is an increase in total participation of 110,000, or 76 percent over 1967.

Unless traffic congestion becomes intolerable, pleasure driving will remain the most popular land-based activity, with sightseeing second in popularity. These two activities will generate an average seasonal Sunday participation demand of 171,000, or 68 percent of all such demand for land-based activities. Activities, such as golfing, hunting, skiing, and horseback riding, are expected to generate modest increases in participation, as indicated in Table 132.

The relative popularity of the various recreational activities on an average seasonal Sunday in 1990 is expected to change only slightly from the 1967 ranking, as shown in Table 133. Sightseeing and boating are anticipated to move up in rank, while picnicking and hunting are anticipated to move down in rank. While hunting will remain an activity of relatively low rank, pressure on game species will increase because of continuing

TABLE 133

RANK ORDER OF FORECAST RECREATIONAL ACTIVITY DEMAND ON AN AVERAGE SEASONAL SUNDAY IN THE MILWAUKEE RIVER WATERSHED BY RESIDENCE OF PARTICIPANT- 1990[a]

RANK ORDER OF ACTIVITY	WATERSHED RESIDENTS	OUT-OF-WATERSHED WISCONSIN RESIDENTS	OUT-OF-STATE RESIDENTS	TOTAL PARTICIPANTS
1	PLEASURE DRIVING (82,091)[b]	SWIMMING (38,221)	SIGHTSEEING (21,238)	PLEASURE DRIVING (123,663)
2	SWIMMING (61,323)	PLEASURE DRIVING (24,507)	SWIMMING (19,625)	SWIMMING (119,169)
3	GOLFING (16,077)	SIGHTSEEING (15,720)	PLEASURE DRIVING (17,065)	SIGHTSEEING (46,941)
4	PICNICKING (16,018)	PICNICKING (6,347)	BOATING (11,167)	PICNICKING (24,749)
5	SIGHTSEEING (9,983)	FISHING (4,386)	FISHING (4,674)	GOLFING (22,294)
6	BICYCLING (9,939)	GOLFING (3,157)	CAMPING (3,299)	BOATING (17,477)
7	NATURE WALKING (7,441)	BOATING (3,070)	GOLFING (3,060)	FISHING (16,144)
8	FISHING (7,084)	HUNTING (3,007)	PICNICKING (2,384)	BICYCLING (10,290)
9	BOATING (3,240)	HIKING (1,651)	NATURE WALKING (2,247)	NATURE WALKING (9,941)
10	HORSEBACK RIDING (1,319)	CAMPING (1,314)	SKIING (1,211)	CAMPING (4,338)
11	HUNTING (1,210)	WATERSKIING (1,031)	HIKING (1,027)	HUNTING (4,406)
12	HIKING (942)	SKIING (945)	WATERSKIING (1,023)	HIKING (3,620)
13	WATERSKIING (874)	BICYCLING (351)	CANOEING (588)	WATERSKIING (2,928)
14	SKIING (369)	CANOEING (340)	HUNTING (189)	SKIING (2,525)
15	CANOEING (233)	NATURE WALKING (253)	HORSEBACK RIDING --[c]	HORSEBACK RIDING (1,458)
16	CAMPING (225)	HORSEBACK RIDING (139)	BICYCLING --[c]	CANOEING (1,161)
TOTAL	(218,368)	(104,439)	(88,797)	(411,604)

[a] INTERPOLATED BY SEWRPC FROM PARTICIPANT DEMAND DATA PROJECTED FOR THE YEARS 1980 AND 2000 BY THE WISCONSIN DEPARTMENT OF RESOURCE DEVELOPMENT AND PUBLISHED IN THE OUTDOOR RECREATION PLAN, WISCONSIN DEVELOPMENT SERIES, 1966.

[b] NUMBERS BELOW EACH ACTIVITY REPRESENT THE FORECAST 1990 PARTICIPATION DEMAND ON AN AVERAGE SEASONAL SUNDAY IN THE MILWAUKEE RIVER WATERSHED, EXPRESSED IN NUMBER OF PERSONS.

[c] DEMAND FIGURES NOT AVAILABLE.

SOURCE- WISCONSIN DEPARTMENT OF NATURAL RESOURCES AND SEWRPC.

changes in, and intensification of, land use development on areas adjacent to those specifically acquired for wildlife habitat values. In addition, wildlife areas are expected to provide significant values for such activities as sightseeing and hunting.

Land must be acquired and developed for intensive recreational use if the expected demand for outdoor recreational activity is to be accommodated in the watershed. If the acquisition and development of such land cannot be accomplished, other special, possibly severe, measures will be required to preserve the resource base in the face of expected intensive use. These measures may have to include limiting recreational use.

OUTDOOR RECREATION LAND AND WATER NEEDS—1990

Thus far, this chapter has presented a summary description of the existing and anticipated future demand for recreational activity within the Milwaukee River watershed. This section is concerned with the conversion of the forecast recreational activity demand to land and water needs in order that a complete assessment of the future outdoor recreation capabilities of the watershed can be made and alternate solutions for meeting the demand can be set forth, evaluated, and the best alternative recommended for implementation. In order to determine land and water needs for recreational purposes, participant demand for outdoor recreational activity must first be converted to land and water area demand by the application of minimum area-use standards. Subtracting the total lands presently owned or developed for land and water-based recreational activities from the results of this conversion will then provide a measure of the deficiencies of the presently available land and water area and thus of total needs. In such an analysis, it must be recognized that certain recreational activities require intensively developed recreational sites, while others do not. Consequently, as shown in Table 134, the 16 major outdoor recreational activities previously discussed in this chapter have been grouped into five classifications based on the types or degree of site development required in order to meet demands of participants in each activity. Only the activities in the first group actually require recreation sites per se. Activities in the other four groups can be partially accommodated on lands already being used for other public or nonpublic uses.

The five major outdoor recreational activities in the first group—swimming, picnicking, golfing, camping, and skiing—require specific intensive site development. Areas to be devoted to these uses can be delineated and, therefore, readily separated from other recreational use areas. The lone activity in the second group—hunting—can generally be accommodated on lands in private ownership, such as agricultural land or other open space; on public wildlife areas; or private shooting preserves and game farms which do not require intensive development, providing such lands exist in at least the present amount and proportions. The four activities in Group Three—boating, fishing, water skiing, and canoeing—require extensive areas of surface waters, with the only intensive development required being boat or canoe launching sites which can be included with other intensive water-based facility development. Unless the water surface areas in the watershed are increased appreciably, the existing and forecast heavy demand for water use activities cannot be met within the watershed; and measures will have to be taken to limit use of the surface waters in order to protect the resource base. It is anticipated that participant demand for the three activities in the fourth group—hiking, nature walking, and horseback riding—can be met through use of existing and future public recreation and open-space lands, as well as of lands in nonpublic agricultural or other open-space uses. As indicated earlier, participation in the three activities in the fifth group—pleasure driving, sightseeing, and bicycling—can be accommodated for the most part on existing secondary highway rights-of-way.

TABLE 134

SUGGESTED MINIMUM LAND AREA REQUIREMENTS[a] FOR MAJOR OUTDOOR RECREATIONAL ACTIVITY IN THE MILWAUKEE RIVER WATERSHED

MAJOR RECREATION GROUPS	MAJOR ACTIVITY	MINIMUM LAND AREA REQUIREMENT PER PARTICIPANT						DAILY PARTICIPANT TURNOVER RATES[d]	MINIMUM LAND AREA REQUIREMENT PER PARTICIPANT PER DAY					
		TOTAL AREA		PRINCIPAL DEVELOPMENT AREA[b]		BACKUP LAND OR SECONDARY DEVELOPMENT AREA[c]			TOTAL AREA		PRINCIPAL DEVELOPMENT AREA		BACKUP LAND OR SECONDARY DEVELOPMENT AREA	
		SQUARE FEET	ACRES	SQUARE FEET	ACRES	SQUARE FEET	ACRES		SQUARE FEET	ACRES	SQUARE FEET	ACRES	SQUARE FEET	ACRES
GROUP 1-REQUIRES LAND OWNERSHIP AND INTENSIVE DEVELOPMENT.	SWIMMING	588	0.0135	118	0.0027	470	0.0108	3.0	196	0.0045	39	0.0009	157	0.0036
	PICNICKING	8,712	0.2000	871	0.0200	7,841	0.1800	1.6	5,445	0.1250	545	0.0125	4,901	0.1125
	GOLFING	42,846	0.9836	42,846	0.9386	--	--	3.0	14,283	0.3279	14,283	0.3279	--	--
	CAMPING	58,079	1.3333	2,905	0.0667	55,173	1.2666	1.0	58,079	1.3333	2,905	0.0667	55,173	1.2666
	SKIING	4,840	0.1111	4,356	0.1000	484	0.0111	3.0	1,612	0.0370	1,451	0.0333	161	0.0037
GROUP 2-REQUIRES EXTENSIVE LAND OWNERSHIP.	HUNTING	THIS ACTIVITY CAN BE GENERALLY ACCOMMODATED ON EITHER PRIVATE OR PUBLIC LANDS NOT NECESSARILY ACQUIRED OR DEVELOPED FOR HUNTING BUT ONLY IF ADEQUATE FOOD, COVER, AND NATURAL AREAS ARE MAINTAINED.												
GROUP 3-REQUIRES EXTENSIVE WATER ACREAGE.	BOATING FISHING WATER-SKIING CANOEING	THESE ACTIVITIES REQUIRE LARGE AREAS OF WATER AND INTENSIVE WATER MANAGEMENT. REQUIRED LAND ACCESS FOR BOAT LAUNCHING AND INCIDENTAL PARKING CAN BE ACCOMMODATED IN CONJUNCTION WITH OTHER WATERFRONT RECREATION OR MULTI-USE DEVELOPMENT OR IN SMALL ISOLATED TRACTS READILY ACCESSIBLE BY MOTOR VEHICLE (NO SPECIFIC LAND AREA REQUIREMENT).												
GROUP 4-REQUIRES NO ADDITIONAL EXTENSIVE LAND OWNERSHIP OR DEVELOPMENT.	HIKING NATURE WALKING HORSEBACK RIDING	THESE ACTIVITIES CAN BE ACCOMMODATED ON LAND ACQUIRED AND DEVELOPED FOR OTHER MORE INTENSIVE MAJOR RECREATIONAL ACTIVITY OR ON POSTED PRIVATE PROPERTY NOT SPECIFICALLY DEVELOPED FOR RECREATIONAL PURPOSES (NO SPECIFIC LAND AREA REQUIREMENT).												
GROUP 5-REQUIRES NO RECREATION LAND OWNERSHIP.	PLEASURE DRIVING SIGHT-SEEING BICYCLING	THESE ACTIVITIES CAN BE ACCOMMODATED ENTIRELY WITHIN EXISTING PUBLIC RIGHTS-OF-WAY BUT MAY ALSO BE ACCOMMODATED ON RECREATION LANDS AND PRIVATE LANDS (NO SPECIFIC LAND AREA REQUIREMENT).												

[a] BASED ON LAND ACQUISITION AND DEVELOPMENT STANDARDS DEVELOPED OR COMPILED BY THE WISCONSIN DEPARTMENT OF NATURAL RESOURCES.

[b] AREA SPECIFICALLY DEVELOPED FOR THE MAJOR ACTIVITY.

[c] AREA AUXILIARY TO THE MAJOR ACTIVITY WHICH MAY ACCOMMODATE ONE OR ALL OF THE OTHER 15 MAJOR ACTIVITIES, AS WELL AS MINOR DEVELOPMENT AND INCIDENTAL DEVELOPMENT, SUCH AS PARKING.

[d] THE NUMBER OF TIMES EACH DAY ONE SPECIFIC AREA OF PRINCIPAL DEVELOPMENT IS USED BY INDIVIDUAL PARTICIPANTS IN THAT ACTIVITY.

SOURCE- WISCONSIN DEPARTMENT OF NATURAL RESOURCES AND SEWRPC.

Determination of Future Recreation Land Needs
Specific standards in terms of acres of area for each activity can only be readily developed for the five major activities in the first group. Demand for these five major activities is expressed in terms of participants per day. The first step in determining total land area requirements to meet the expected demand for these five major activities, therefore, is to convert area-use standards to area-participant requirements (see Table 134). This conversion is made by dividing total suggested minimum areas by the suggested maximum number of participants at any one time. Further dividing this area-participant figure by the daily participant turnover rate for each activity results in a minimum land area requirement per participant per day.

Application of the area per participant per day requirements to forecast 1990 participant demand for the five major outdoor recreational activities results in a total 1990 land demand of 17,484 acres to accommodate the anticipated recreational activity demand (see Table 135). Subtracting existing land area, including assignable open-space lands, as allocated in Table 128, from 1990 land demand will result in a total of 10,842 acres of additional land area required to meet the expected 1990 participant demand for each activity. The 10,842 acres of additional land required to meet the 1990 participant demand for the five major outdoor recreational activities, plus the existing supply of 29,065 acres of outdoor recreation land (see Table 125), total 39,907 acres. This required increase in land by 1990 represents an increase of 37 percent in total lands devoted to outdoor recreation in the watershed.

MEETING THE 1990 OUTDOOR RECREATION LAND DEMAND

It has been noted that intensive pressure is being, and will continue to be, exerted on the outdoor recreation resources of the Milwaukee River watershed by increased demand for both water-based and land-based activities. It has been shown that the use of certain recreational facilities has already reached critical levels, and expected additional use will tend to destroy the available resources through overuse.

This situation may be overcome without damage to the natural resource base of the watershed in most cases by the acquisition and development of additional lands for recreational use. The primary recreation resource base of the watershed, which must supply the majority of recreational opportunities, is encompassed in the primary environmental corridors of the watershed. As indicated in Chapter XIII of this volume, these primary environmental corridors encompass most of the surface water areas and best potential park and related open-space sites remaining in the watershed. Only isolated potential park sites and minor surface water areas important to future recreational development are found outside the corridor areas.

TABLE 135

EXISTING AND REQUIRED LAND FOR OUTDOOR RECREATION ACTIVITIES IN THE MILWAUKEE RIVER WATERSHED BY ACTIVITY- 1967 AND 1990

ACTIVITY	TOTAL 1990 PARTICIPANT DEMAND[a] (PARTICIPANTS)	MINIMUM LAND REQUIREMENT PER PARTICIPANT PER DAY[b] (ACRES)	TOTAL 1990 LAND DEMAND (ACRES)	TOTAL EXISTING 1967 RECREATIONAL LAND (ACRES)	TOTAL 1990 LAND NEEDS (ACRES)
SWIMMING	119,169	0.0045	536	200	336
PICNICKING	24,749	0.1250	3,094	1,387	1,707
GOLFING	22,294	0.3279	7,310	1,803	5,507
CAMPING	4,838	1.3333	6,451	3,186	3,265
SKIING	2,525	0.0370	93	66	27
SUBTOTAL	173,575	--	17,484	6,642	10,842
OTHER RECREATIONAL ACTIVITIES[c]	--	--	5,619	5,619	--[d]
TOTAL	173,575	--	23,103	12,261	10,842

[a] ON AN AVERAGE SEASONAL SUNDAY.

[b] INCLUDED REQUIRED SUPPLEMENTARY ACREAGE.

[c] DOES NOT INCLUDE WILDLIFE AREAS OR UNUSED (DEVELOPABLE) ACREAGE.

[d] FORECAST NEEDS FOR OTHER RECREATIONAL LANDS IS INCLUDED WITH MAJOR ACTIVITY NEEDS. IT IS ASSUMED THAT THE FORECAST DEMAND FOR THE FIVE MAJOR ACTIVITIES WILL MEET ACREAGE NEEDS FOR ALL OTHER ACTIVITIES.

SOURCE- WISCONSIN DEPARTMENT OF NATURAL RESOURCES AND SEWRPC.

The major lakes and rivers of the watershed form the basic framework of the corridor areas within the watershed, and these surface waters offer the best development potential for meeting the water acreage needs generated by rapidly increasing participation in water-based recreational activities. As previously indicated, recreational use of the surface waters in the watershed has reached a critical level. In fact, based on existing demand and applying the Wisconsin Department of Natural Resources suggested minimum water use standards of five acres per user, the surface water area within the watershed is already inadequate to accommodate properly the demand. Additional water access areas can be provided for improved public access to the water for swimming, fishing, boating, water skiing, and canoeing. The only means of securing additional water surface area in the watershed is to create such areas through the construction of artificial impoundments. The alternative to providing such impoundments is to lower water use standards to allow more intensive use and thereby risk damage to the resource base, as well as creating hazards to public health and safety.

The numerous small streams, ponds, and wetlands within the watershed, although not well suited to use for water-based recreational activities, nevertheless constitute a valuable recreational asset. Many of these areas are also included within the primary environmental corridors and provide the watershed with good water retention areas. These wetlands, ponds, and streams also provide areas of suitable habitat for fish, waterfowl, and other forms of wildlife. The inclusion and preservation of these unique areas within the corridors will be an important contribution to the total recreational potential of the watershed. Their value as scenic natural areas ranks high and will be a major factor in providing the desirable areas sought by the hiking, pleasure driving, sightseeing, and nature enthusiasts who enjoy this type of recreation environment.

Although surface water is in short supply considering forecast demand, prime potential recreation land is still in relative abundant supply throughout the watershed. That is to say that lands are still available in the watershed which have recreational potential, are not now used for either public or nonpublic recreational purposes, and have not yet been developed for urban purposes. As indicated in Chapter IV of this volume, there are a total of 131 potential park sites within the watershed, encompassing a total area of 21,935 acres. Of this total, 14,467 acres, or about 67 percent, are located within the primary environmental corridors, and 7,468 acres, or about 33 percent of the total, are included in potential park sites within the watershed but located outside the primary environmental corridors.

Of the 131 high-value potential sites within the watershed, two were recommended as new regional recreation areas in the adopted 1990 regional land use plan. These sites include the Lucas Lake site in Washington County and the Fredonia site in Ozaukee County. The remaining high-value potential park sites offer the best areas for development of additional multi-use outdoor recreation centers. Ozaukee and Washington Counties lead in the number of high-value potential park sites in the watershed, with 20 and 26, respectively, and in the total number of acres available, with 4,582 acres and 6,096 acres, respectively. The high-value sites total 12,786 acres, or about 58 percent of all potential park acreage. Many of these park facilities can be connected within the framework of the primary environmental corridors, thereby developing an integrated framework of regionwide outdoor recreation and open-space lands.

The medium-value sites include 5,451 acres, or about 25 percent of the land available for potential recreational development. These sites can provide many of the local or specialized recreational facilities. One- or two-use facilities, such as those which combine picnic areas with a boat launch area and a campground with hiking trails, are examples of the types of development possible to meet the needs at these scattered smaller potential park sites.

The remaining 38 potential park sites, totaling 3,698 acres, are low-value sites. Some of these may be suitable for development of highly specialized recreation areas under certain conditions, but usually they are hampered by poor soil conditions or locational disadvantages which limit the number of development choices. Locally, these sites may be significant as picnic areas, natural areas, or small wayside park facilities. Limited in size and development choice, their main contribution to meeting the recreation needs will be in the form of the specialized single-purpose recreational areas.

While not all potential park land is suited for every type of outdoor recreation development, land with some of the highest multiple-purpose recreational use potential is found in the watershed in areas such as Kettle Moraine, in areas adjacent to the main channel of the Milwaukee River, and in areas adjacent to the many lakes in the watershed. In addition, two Ice Age preserves have been delineated within the watershed. One is northwest of Campbellsport, in Fond du Lac County, encompassing approximately 3,600 acres of excellent drumlins and oval hills that generally aim in the direction of the moving ice field. The other is a 15,000-acre portion of the Kettle Moraine Northern Unit, which displays some fine eskers (long sinuous ridges of deposits left by glacial streams), kames, and kettle lakes.

The primary environmental corridor areas, it should be noted, include not only the surface water areas of the watershed but also encompass the areas of significant topographic and geologic features, prime woodlands, prime wildlife habitat areas, and significant wetland areas. All of these features, when combined, not only provide a pleasing view to the driving and walking public, but, as already mentioned, include areas of significant value as potential park areas to be developed for more intensive outdoor recreational use.

SUMMARY

Rapid population increase and urbanization, combined with rising income levels, are generating a rapidly increasing demand for outdoor recreation in southeastern Wisconsin. This demand is further intensified by the close proximity of the Southeastern Wisconsin Region, with its nearly 1.8 million urban residents, to the northeastern Illinois metropolitan region, with its nearly 7 million urban residents, many of whom seek outdoor recreational opportunities in southeastern Wisconsin. The Milwaukee River watershed, with its many streams and lakes, varied topography, woodlands, wetlands, and wildlife habitat areas comprising a recreational resource and its close proximity to the Chicago, as well as to the Kenosha, Milwaukee, and Racine, urbanized areas, serves to increase its potential recreational value. Forecasts indicate that over 12.2 million people may be expected to reside within the southeastern Wisconsin and northeastern Illinois metropolitan regions by 1990 and contribute to the increasingly intensive pressures being exerted on the limited recreational resource base of the watershed.

There are presently 186 public and nonpublic recreational sites located within the Milwaukee River watershed, encompassing a total area of 29,065 acres, or approximately 6 percent of the total watershed area. Publicly owned or controlled lands account for about 86 percent of the total acreage of existing recreation and related open-space sites within the watershed, with the remaining 14 percent being in private ownership.

A more detailed analysis of site activities, however, indicates that only 38 percent of the publicly controlled recreational lands within the watershed are available for the 16 major water- and land-based recreational activities and that wildlife areas which must be maintained in their natural state comprise over 81 percent of this area. Consequently, only 1,620 acres, or approximately 14 percent of the total publicly controlled recreational lands within the watershed, are available for all other major recreational activities.

Lands providing access to surface waters for water-based recreational activities, comprising over 47 percent of the total outdoor recreational demand, account for less than 1 percent of the total publicly owned recreational area within the watershed; and of this, 50 percent is owned and operated by local units of government. Water surface area within the watershed is already severely limited when related to the existing demand for water-based recreational activities. Lake and stream surface area in the watershed totals approximately 6,800 acres, or less than 1.5 percent of the total area of the watershed, of which approximately 3,055 acres, or about 45 percent, are available for swimming, provided that water quality levels suitable for full-body-contact recreation can be maintained; and 3,745 acres are available for all other water-based recreation uses. Of the total participation demand of 21,159 participants on an average seasonal Sunday, and with an average turnover rate of 3, only 1.0 acre of available lake and stream surface area can be allotted to each participant for water-based recreational activities other than swimming, far below the recommended standard of five acres per participant necessary to achieve good water resource management.

It is particularly important to note that only 13 percent of the total demand for water-based recreational activities within the watershed is generated by out-of-state users, while approximately 33 percent is generated from within the

State of Wisconsin but outside the watershed. The remaining 53 percent is generated within the watershed.

Although the total outdoor recreation land acreage in the watershed appears to be large, the proportion developed for land-based outdoor recreational activities is inadequate to meet the increasing demand for such activities. Of the total 13,772 acres of land devoted to land-based recreational activities, less than 29 percent is developed for active use; and 41 percent, or 1,620 acres of this developed land, are in public ownership. Possibly a limited acreage of the wildlife areas, comprising 58 percent of the total state ownership of outdoor recreation lands in the watershed, can be developed for the recreation uses other than those for which the lands were acquired.

Forecasts indicate that the participant demand for water-based outdoor recreational activities in the watershed may be expected to increase from 65,000 to 157,000 participants on an average seasonal Sunday by 1990, more than doubling. Swimming, fishing, and boating may be expected to constitute the most popular water-based recreational activities. Land-based participant demand for major recreational activities within the watershed may be expected to increase from 145,000 to 255,000 participants per average seasonal Sunday, almost doubling in numbers. Pleasure driving and sightseeing may be expected to remain the most popular land-based recreational activity, along with picnicking. These forecasts indicate that an additional 10,842 acres of land will have to be devoted to recreational use within the watershed, an increase of 37 percent over the present recreation area.

Three measures must be taken to assure that land having a high recreational potential will remain available within the watershed to meet the growing recreational demand:

1. Protection of the quality of the existing recreational resource base should be assured through the application of sound county and local land use control and development practices, ground and surface water quality management programs, application of sound soil and water conservation practices, and adherence to adequate minimum recreational land and water use standards.

2. Immediate public acquisition of the best remaining high-value recreational sites within the watershed having potential for multi-use development and thereby capable of serving large segments of the average seasonal Sunday participant demand should be accomplished.

3. A more judicious allocation of the available financial resources at the state, county, and local levels to the acquisition and development of public recreational areas which can facilitate one or more of the five major outdoor recreational activities requiring intensive land development, and particularly to those recreational areas offering the possibility of year-round multi-use, should be effected.

The demand for water-based activities other than swimming has already reached critical levels. With a participant demand of 21,159 for water-based activities other than swimming on an average seasonal Sunday, only about 0.3 acre of available lake and stream surface area can be allotted for each participant, far below the lake and stream water use standard of 5 acres per participant recommended for good water resource management by the Wisconsin Department of Natural Resources. It is clear that two alternatives exist with respect to meeting the future demand for such water-based activities, namely: 1) the creation of artificial impoundments to increase the supply of surface water available to meet the demand and 2) the limiting of the use of existing surface water area through the imposition of controls on water-based activities.

Although the participant demand for land-based outdoor recreational activities within the watershed may be expected to increase at an unprecedented rate, there remain sufficient potential park and outdoor recreation sites available to meet the expected 1990 land-based activity demand. In the absence of a sound resource management program, however, uncontrolled urbanization may encroach into, and destroy many of, the areas having a high potential for future recreation use. It is imperative, therefore, that all levels of government act to ensure that the future demand for land-based outdoor recreational activities in the watershed can be met, both by protecting the quality of the recreational resource base and by acquiring for future use the best remaining recreation sites.

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Chapter XV

WATER LAW

INTRODUCTION

In any sound planning and engineering effort, it is necessary to investigate the legal, as well as the physical and economic, factors affecting the problem under consideration. In comprehensive watershed planning, the law can be as important as the hydrology of the basin or the costs and benefits of proposed water control facilities in determining the ultimate feasibility of a given watershed plan. If the legal constraints bearing on the planning problem are ignored during plan formulation, serious obstacles may be encountered during plan implementation. This is particularly true in the area of water resources.

Water constitutes one of the most important natural resources. It is not only essential to many of the most important economic activities of man but is also essential to life itself. The available quantity and quality of this important resource are, therefore, among the most vital concerns of a host of interest groups representing agriculture, commerce, manufacturing, conservation, and government. Not only are rights to the availability and use of water of vital concern to a broad spectrum of public and private interest groups, but the body of law regulating these rights is far from simple or static. Moreover, changes in this complex, dynamic body of law will take place even more rapidly as pressure on regional, state, and national water resources becomes more intense.

To provide the basis for a careful analysis of existing water law in southeastern Wisconsin, a survey of the legal framework of public and private water rights affecting water resources management, planning, and engineering was undertaken as one of the important work elements of the first comprehensive watershed planning program in the Southeastern Wisconsin Region, that for the Root River watershed.[1] This survey was carried out under the direction of the late Professor J. H. Beuscher of the University of Wisconsin Law School and included an inventory of the existing powers and responsibilities of the various levels and agencies of government involved in water resources management, as well as of the structure of public and private water rights, which must necessarily be considered in the formulation of a comprehensive watershed plan.

The findings of this legal study have been fully set forth in SEWRPC Technical Report No. 2, Water Law in Southeastern Wisconsin, published in January 1966. This chapter consists of a summary presentation of this more detailed technical report, with appropriate modifications to reflect new developments that have taken place in the area of water law in Wisconsin since the comprehensive legal study was completed.[2] The major purpose of this chapter is to summarize the salient legal factors bearing on the water-related problems of the Milwaukee River watershed and on plans for their solution, thereby laying the basis for intelligent future action. It does not, however, dispense with the need for continuing legal study with respect to water law, since this aspect of the overall watershed planning effort becomes increasingly important as plan proposals reach the implementation phase.

Attention in this chapter is first focused upon those aspects of water law generally applicable to the planning and management of the water

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[1] *A companion survey of existing planning law in southeastern Wisconsin was conducted by the Commission and the findings published in SEWRPC Technical Report No. 6, Planning Law in Southeastern Wisconsin, October 1966.*

[2] *In August 1966 the Wisconsin Legislature enacted Chapter 614, Laws of Wisconsin 1965, which dealt broadly with the state's water resources. Included in this Act were provisions transferring the water quality functions of the State Board of Health and the Committee on Water Pollution and the water regulatory functions of the Public Service Commission to a reconstituted Department of Resource Development. Subsequent legislation transferred the Department of Resource Development to a newly created Department of Natural Resources and made it a Division therein. Further reorganization of the Department of Natural Resources consolidated the water resource function in a newly created Division of Environmental Protection. Chapter 614, Laws of Wisconsin 1965, also abolished the Committee on Water Pollution. All of these actions have important effects upon, and implications for, the legal framework within which water resources planning and management must be carried out in Wisconsin.*

resources of any watershed in southeastern Wisconsin. This is followed by more detailed consideration of certain important aspects of water law relating more specifically to the problems of the Milwaukee River watershed, including floodland and shoreland regulation, water pollution control, and water control facility construction.

GENERAL SUMMARY OF WATER LAW

Classifications of Water and Divisions of Water Law

In dealing with water regulation, the Wisconsin Supreme Court and the State Legislature have recognized the following five distinct legal classifications of water:

1. Surface water in natural watercourses—defined as water occurring or flowing in natural rivers, streams, lakes, and ponds, the limits of which are generally marked by banks or natural levees.

2. Diffused surface water—defined as water from falling rain or melting snow which is diffused over the ground and which occurs or flows in places other than natural watercourses; that is, not confined by banks.

3. Ground water in underground streams—defined as water occurring or flowing in a well-defined underground channel, the course of which can be distinctly traced. It is doubtful that such identifiable underground channels exist within the watershed or, indeed, within the Region.

4. Percolating ground water—defined as water which seeps, filters, or percolates through underground porous strata of earth or rock but without confinement to a definite channel.

5. Springs—defined as the natural discharge points for ground water from either an underground stream or percolating water.

Based in part on these definitions, three principal divisions of water law can be identified. These are: riparian law, ground water law, and diffused surface water law. Riparian law applies to the use of surface water occurring in natural rivers, streams, lakes, and ponds. This law has been evolved largely by the courts, case by case, as a matter of common law. Important here also are both court-made law and legislation defining public rights in those watercourses which are navigable. Ground water law applies to the use of water occurring in the saturated zone below the water table. Diffused surface water law applies to floodwater draining over the surface of the land. This law in Wisconsin relates not to water use but to conflicts that arise in trying to dispose of this surface water. Ground water and diffused surface water law have both evolved largely by court interpretation as common law.

The Wisconsin Supreme Court has developed many of the legal rules covering all three of these divisions of water law, case by case, over a long period of time. In addition, the State Legislature has, from time to time, enacted statutes affecting some of these divisions. Reference must also be made to the important body of administrative law made by state agencies in the day-to-day administration of state water statutes. Examples are statutes governing the issuance of permits by the Wisconsin Department of Natural Resources for irrigation and mining purposes; for hydroelectric power and other dams; for the fixing of bulkhead lines; and for the construction of bridges, piers, docks, and other shoreline improvements along navigable watercourses. The Wisconsin Department of Natural Resources is also authorized to fix levels for navigable lakes and flow rates for navigable streams.

Rights to the Use of Water in Natural Watercourses

Rights in water may be designated as private and public. Industrial cooling, irrigation, and power generation are examples of private rights, while fishing, boating, and swimming are examples of public rights. It is essential, however, to recognize that private and public rights to use water are interrelated and that, while these labels may be convenient for classification purposes, they tend to encourage oversimplification. In certain circumstances, it may be more in the public interest to promote a private use even though the conventional public rights are consequently limited. Conflicts may also arise among various segments of the public regarding which of the public rights is paramount, particularly where the exercise of one public right may seriously affect the possibility of exercising another.

Riparian Rights: The riparian doctrine, which in Wisconsin forms the primary basis of the law governing the use of surface water in natural watercourses, provides that owners of lands that adjoin a natural watercourse have rights to co-share in the use of the water so long as each riparian is reasonable in his use. Obviously, the definitions of the terms "reasonable" and "natural watercourse" are critical to the application of riparian law.

Natural Watercourses: The Wisconsin Supreme Court requires that, in order to constitute a natural watercourse, there must be:

> . . . a stream usually flowing in a particular direction, though it need not flow continually. It may sometimes be dry. It must flow in a definite channel, having a bed, sides, or banks, and usually discharges itself into some other stream or body of water.[3]

Although riparian rights are sometimes conceived to attach to artificial watercourses, usually they are restricted to watercourses which are natural in origin. The term watercourse comprehends springs, lakes, or marshes in which the stream originates or through which it flows. Natural lakes or ponds which are not a part of a stream system are, nevertheless, waters to which riparian rights also attach. Clearly, the Milwaukee River and its major tributaries meet the definitional requirements of a watercourse; and riparian law applies. The same body of doctrine also applies to natural lakes and ponds within the Milwaukee River watershed.

Natural Flow and Reasonable Use: With respect to the relative rights of riparian landowners along a watercourse, there is language in Wisconsin cases, still relied on by sportsmen, to the effect that a riparian owner is entitled to have a watercourse flow through his land without material diminution or alteration—the so-called "natural flow" doctrine. Strict application of such a rule would preclude effective use of the water for other than domestic needs.

In those cases in which the Wisconsin Court used "natural flow" language, however, the court was merely indulging in preliminary observations, for in each such case the language is subsequently modified or limited and the "reasonable use" rule applied to the particular situation presented. It is, therefore, an abstract statement to say that in Wisconsin riparian owners are entitled to the continuous full and natural flow of a watercourse, for in the words of the Wisconsin Supreme Court:

> To say, therefore, that there can be no obstruction or impediment whatsoever by the riparian owner in the use of the stream or its banks, would be in many cases to deny all valuable enjoyment of his property so situated. There may be, and there must be, allowed of that which is common to all a reasonable use.[4]

Thus, in Wisconsin the reasonable use doctrine qualifies the strict right to the natural flow of a stream or the natural level of a lake. This use right is not a right in the sense that a riparian proprietor owns the water running by, or over, his land. It is a right called "usufructuary" in that the riparian may make a reasonable use of the water as it moves past.

The term "reasonable use" implies that a question of fact must be resolved in each case, and the Wisconsin Court has recognized the concept as a flexible one in conceding that no rule can be stated to cover all possible eventualities. The court has said, in determining what is a reasonable use, that:

> Regard must be had to the subject matter of the use, the occasion and manner of its application, its object, extent and the necessity for it, to the previous usage, and to the nature and condition of the improvements upon the stream; and so also the size of the stream, the fall of the water, its volume, velocity and prospective rise and fall, are important elements to be considered.[5]

Thus, it may be concluded that a user's utilization of water must be reasonable under all the cir-

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[3]*Hoyt v. City of Hudson, 27 Wis. 656 (1871). A lengthy definition distinguishing watercourse from diffused surface water is contained in Fryer v. Warne, 29 Wis. 511 (1872). The Wisconsin Court has held that the existence of a watercourse is a question of fact for the jury. Eulrich v. Richter, 37 Wis. 226 (1875). In an equity case, the question of fact would be for the court.*

[4]*A. C. Conn Co. v. Little Suamico Lumber Mfg. Co., 74 Wis. 652, 43 N.W. 660 (1889).*

[5]*Timm v. Bear. 29 Wis. 254 (1871).*

cumstances; and he may meet this test despite substantial interference with the natural flow of a watercourse, for it is recognized that any rule preventing all, or almost all, interference with the flow would needlessly deprive riparian proprietors of much of the value of the stream and prevent its utilization for any beneficial purpose. In this respect, it should be recognized that, wherever the Department of Natural Resources, at the request of one or more riparians and after notice and hearing, fixes the level of a lake or grants a permit for the construction or enlargement of a dam or pier, other riparians will probably have a difficult time establishing that the permitted uses are unreasonable. A permit to irrigate imposes a similar burden of proof upon co-riparians who may later complain of unreasonable use. In addition, a water user may acquire a firm right to a specific quantity of water by adverse use (prescription) over a period of time, usually 20 years, or by contract with co-riparians.

Under Sections 30.03 and 30.19 of the Wisconsin Statutes, the construction or enlargement of any artificial waterway is prohibited without the permission of the Wisconsin Department of Natural Resources where the purpose of such enlargement is an ultimate connection with an existing navigable stream or lake or where any part of such artificial waterway is located within 500 feet of the ordinary high water mark of an existing navigable stream or lake. Authorization is required not only for the construction of an artificial waterway within 500 feet of navigable waters but also for the connection of any waterway with an existing body of navigable water and for the removal of topsoil from the banks of navigable streams and lakes. Public highway construction, improvements related to agricultural uses of land, and improvements within counties having a population in excess of 500,000 are excepted from these provisions and thus do not require permission from the Wisconsin Department of Natural Resources.

Lands Affected by Riparian Law: The Wisconsin Supreme Court has never defined the term "riparian land" with precision. It is clear, however, that, to be riparian, land must adjoin the watercourse; and probably it must lie within the watershed of that watercourse. It is also held in Wisconsin that riparian rights rest upon ownership of the bank or shore in lateral contact with the water, not upon title to the soil under the water. The Wisconsin Department of Natural Resources, in administering the issuance of permits to irrigators pursuant to Section 30.18 of the Wisconsin Statutes,[6] has limited riparian land to that land bordering a lake or stream which has been in one ownership in an uninterrupted chain of title from the original government patent. This is similar to the so-called "source of title" test. Under it, the conveyance by "A" of a back parcel of his riparian land to "B" renders the transferred parcel non-riparian unless the deed provides otherwise; and it remains so even though "A" subsequently repurchases it. Presumably, also, if "B," having first purchased the back parcel, later also buys the tract touching the water, the back parcel continues non-riparian. Thus, a riparian cannot assemble non-riparian land and make it riparian. A non-riparian cannot convert his land to riparian status by buying a riparian tract. Under this rule there is a continual dwindling of riparian land.

Non-Riparian Use: Non-riparian use occurs when a riparian uses an excessive quantity of water beyond his reasonable co-share; when a riparian uses water on non-riparian land which he owns or controls; or when a non-riparian takes water from a watercourse, usually with permission or by grant from a riparian, for use on non-riparian land. The latter situation deserves particular attention since, as a practical matter, problems of this sort are apt to arise in the Milwaukee River watershed because of possible withdrawals for municipal, irrigation, or industrial use.

In this respect, it is not known whether the Wisconsin Court would treat municipal use from a natural watercourse as a special case. Surprisingly, most states that have spoken on the subject refuse to do so. They treat a municipal water utility as just another water user and point with disapproval to the distribution of water to non-riparian customers of the utility. The courts insist that, if downstream riparians are hurt by the municipal diversion, the utility must acquire by eminent domain or otherwise the requisite downstream rights.

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[6] *The issuance of irrigation permits formerly was administered by the Wisconsin Public Service Commission. The Wisconsin Legislature transferred this function to the now Department of Natural Resources in Chapter 614, Laws of Wisconsin 1965.*

The irrigator who wants to use water from a stream must obtain a permit under the Wisconsin irrigation permit law, Section 30.18 of the Wisconsin Statutes. He must limit his irrigation to riparian and contiguous lands. Permits are not required of commercial or industrial water users as a precondition to withdrawal from a watercourse. Whether such users can use water or non-riparian land is an unresolved question, although the court in Munninghoff v. Wisconsin Conservation Commission has said:

> It is not within the power of the state to deprive the owner of submerged land of the right to make use of the water which passes over his land, or to grant the use of it to a non-riparian.[7]

The Wisconsin Attorney General has stated that:

> Previous decisions in other states have held that a riparian owner could make any reasonable use of the water even on non-riparian land providing there was no unreasonable diminishment of the current and no actual injury to the present or potential enjoyment of the property of the lower riparian owner.[8]

Public Rights in Navigable Water: When a riparian uses navigable water, his uses may impinge upon public rights in the water. Private water uses are often completely consistent with the exercise of public rights in navigable streams and lakes, but serious conflicts may arise between private riparians and those seeking to exercise public use of a given watercourse. In that event, in Wisconsin the public rights will likely prevail. This does not mean that private riparian rights may in every case be taken or substantially abridged without compensation, for it has long been recognized that such rights are property rights which cannot be "taken" for a public purpose without compensation.

The Wisconsin Court might, however, treat the riparian's private property right as "inherently limited" by public rights in the water. The court might say that this limitation existed at the time the riparian acquired his private right and that he took title subject to the limitation. This line of reasoning would permit a holding that compensation need not be paid even though public uses substantially impair private uses.

One of the important riparian rights attaching to lands bordering navigable lakes and streams is the right of access to water. It is recognized in Wisconsin that a riparian has a right of access from the front of his land to the navigable part of the stream or lake and the right to build a pier, subject only to legislative control and the test of reason.

Test of Navigability: In order for public rights to attach, the water must be navigable. The Wisconsin Court's test of navigability has moved from one of commercial transport only to include suitability for recreational boating. Earlier the question was whether the stream or lake could be used to float products of the country to market for a significant period during the year. The principal product floated to market in those days was the sawlog, hence the so-called "sawlog" test of navigability. More recently, in 1952 the Wisconsin Court said:

> Any stream is "navigable in fact" which is capable of floating any boat, skiff, or canoes of the shallowest draft used for recreation purposes.[9]

In order to qualify as navigable, the stream, pond, or lake clearly does not have to be capable of floating a product to market or of floating a boat, skiff, or canoe every day of the year or every rod of its length or surface area. The Wisconsin Court, however, has not ruled on the length of time needed to establish navigability. By the recreational boating test, most natural ponds and lakes are navigable; and streams of even modest size may be navigable. Clearly the Milwaukee River and its principal tributaries are navigable by this test.[10]

Ownership of the Land Underlying a Water Body
Determination of ownership of a stream or lake bed may have important consequences. If the bed is privately owned, removal of material from the bed may be authorized by the owner so long as there is no interference with the exercise of pos-

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[7] *255 Wis. 252, 38 N.W. 2d 712 (1949).*

[8] *39 Op. Atty. Gen. 654 (1950).*

[9] *Muench v. Public Service Comm., 261 Wis. 492, 53 N.W. 2d 514 (1952).*

[10] *Wisconsin Statutes 144.01(1).*

sible public rights to use the water and provided a permit is obtained from the Wisconsin Department of Natural Resources.[11] If the bed is publicly owned, removal can only be with permission of, and payment to, the state.

Wisconsin holds that the beds of streams, whether navigable or non-navigable, belong to the owners of the adjacent shorelands, always subject, however, to the overriding public servitude of navigation and other public rights that adhere to navigable water. Private proprietors whose lands make lateral contact with the waters of a stream own the bed to the middle or thread of that stream, regardless of whether the stream is navigable or not. The bed owner is in a position comparable to a landowner whose land is subject to a public highway easement.

Beds of natural navigable lakes are owned by the state in trust for all of the people. A private proprietor whose lands abut the waters of a natural lake has no claim to any portion of the bed. The ownership of beds underlying man-made lakes or reservoirs, caused by damming a stream or otherwise impounding a natural flow of water, remains in the hands of abutting landowners. Where the stream was navigable before it was dammed, the waters spread behind the dam are likewise navigable. Thus, the privately owned bed of the reservoir in such a case seems to be subject to the same public servitude that originally applied to the undammed stream.

Rights to the Use of Ground Water

Wisconsin ground water law is based upon the so-called English absolute rights doctrine. The landowner owns the ground water he captures in his well or otherwise. It is his to do with as he wishes, to use on the overlying land or elsewhere, and even to waste.

The Wisconsin Legislature has intervened in this rather primitive legal thicket in only one way. It has required that a permit be obtained from the Wisconsin Department of Natural Resources by anyone who desires to develop or redevelop a well or well field with facilities for withdrawal of water at a rate of 100,000 gallons a day[12] (70 gallons per minute) or more. The ground on which the Department of Natural Resources can deny a permit is narrow, however; namely, that the proposed well or wells will "adversely affect or reduce the availability of water to any public utility in furnishing water to or for the public." Thus, interference with a nonpublic utility well is not a ground for denial of a permit.

Diffused Surface Water Law

The Wisconsin Supreme Court has defined diffused surface waters, more commonly known as storm water, as

> ... waters from rains, springs, or melting snow which lie or flow on the surface of the earth but which do not form part of a watercourse or a lake.[13]

A ravine which was usually dry except in times of heavy rains or spring freshets was early held by the Wisconsin Court not to be a watercourse, and the water in it was held to be diffused surface water.[14]

Riparian law does not apply to diffused surface water. The law that does apply deals not with water use rights but with conflicts which arise in attempting to dispose of water. Where these conflicts arise between private landowners, the Wisconsin Court has evolved as case law the so-called "common enemy" rule regarding diffused surface waters. Basically, this rule permits a landowner who is seeking to improve his land to fight as a "common enemy" the diffused surface water in a particular drainage area. This he can do regardless of harm caused to others so long as he does it to improve his own land and so long as he does not tap a new drainage area. The improvements may include grading, diking, ditching, and damming but not the drainage of a natural pond or artificial reservoir.

The prohibition against tapping water from a new drainage area disappears where a municipal project is involved. Here the rule of law has been stated as follows:

> By constructing streets and gutters within its limits, a city may change the natural watercourse so as to increase the flow of water upon private land.[15]

[11] *Wisconsin Statutes 30.20(1)(b).*

[12] *Wisconsin Statutes 144.025 (2)(e). See also Regulation of Well Drillers, Wisconsin Statutes 162.01.*

[13] *Thomson v. Public Service Comm., 241 Wis. 243, 5 N.W. 2d 769 (1942).*

[14] *Hoyt v. City of Hudson, 27 Wis. 656 (1871).*

[15] *Tiedeman v. Middleton, 25 Wis. 2d 443 (1964).*

At least three general limitations upon this broad municipal power have been stated, two by the Court and one by the Legislature:

1. The municipality may not collect water in a body and then cast it on the land in a large volume.[16]

2. A municipality that has collected water in a sewer or drain is liable for damages if, because of negligent construction or maintenance, water is allowed to escape from the sewer or drain to adjacent land.[17]

3. The Wisconsin Legislature has required that:

   Whenever any county, town, city, village... or the state highway commission has heretofore constructed and now maintains or hereafter constructs and maintains any highway...in or across any marsh, lowland, natural depression, natural watercourse, natural or man-made channel or drainage course, it shall not impede the general flow of surface water or stream water in any unreasonable manner so as to cause either an unnecessary accumulation of waters flooding or water-soaking uplands or an unreasonable accumulation and discharge of surface waters flooding or water-soaking lowlands.[18]

Despite the above language, municipal construction projects are relatively immune from legal damages resulting from the interference with, or rerouting of, draining surface waters. The relative immunity enjoyed by municipalities presumably also applies to towns if the storm sewer system was built under appropriate statutory enabling authority. This authority exists where a town assumes village powers under Section 60.18(12) and 60.29(13) of the Wisconsin Statutes or where a special sanitary district has been created pursuant to Section 60.30 of the Wisconsin Statutes. It also exists, under Section 60.29(19) of the Wisconsin Statutes, where the county in which the town is located has a population of 150,000 or more.

[16] *Champion v. Crandon, 84 Wis. 405, 54 N.W. 775 (1893).*

[17] *Hart v. Neilsville, 125 Wis. 546, 104 N.W. 699 (1905).*

[18] *Wisconsin Statutes 88.87(2)(a).*

FLOODLAND ENCROACHMENTS IN AND ALONG STREAMS—FLOODLAND REGULATION

Effective abatement of flooding can be achieved only by a comprehensive approach to the problem. Certainly, physical protection from flood hazards through the construction of dams, flood control reservoirs, levees, channel improvements, and other water control facilities is not to be completely abandoned in favor of floodland regulation. As urbanization proceeds within a watershed, however, it becomes increasingly necessary to develop an integrated program of land use regulation of the floodlands within the entire watershed to supplement required water control facilities if efforts to provide such facilities are not to be self-defeating.

Definition of Floodlands

The precise delineation of floodlands is essential to the sound, effective, and legal administration of floodland regulations. This is especially true in urbanizing areas, such as the Milwaukee River watershed. A precise definition of floodlands is not found in the Wisconsin Statutes. Section 87.30(1) speaks only of those areas within a stream valley within which "serious (flood) damage may occur" or "appreciable (flood) damage...is likely to occur." This statutory description is not adequate per se for floodland determination. As a watershed urbanizes and the hydraulic characteristics of the stream are altered, additional areas of the stream valley become subject to flooding. It becomes necessary, therefore, to regulate the entire potential, as well as existing, floodland areas.

Floodlands may be defined as those parts of a stream valley which are periodically subject to inundation. To relate land use regulations in a reasonable manner to the various flood characteristics and hazards found in the floodland area of a stream valley, the Commission has recommended[19] that floodlands be identified and divided into the following three regulatory areas:

1. The channel area—defined as that portion of the floodlands normally occupied by a stream of water under average annual high-water-flow conditions.

[19] *See SEWRPC Planning Guide No. 5, Floodland and Shoreland Development Guide, November 1968.*

2. The floodway area—defined as that portion of the floodlands, including the channel required to carry and discharge the 100-year recurrence interval flood. If development and fill are to be prohibited in the floodplain, the floodway may be delineated as that area subject to inundation by the 10-year recurrence interval flood.

3. The floodplain area—defined as that portion of the floodlands, excluding the floodway, subject to inundation by the 100-year recurrence interval flood or, where such data are not available, by the maximum flood of record.

The delineation of the limits of these three regulatory areas should be based upon careful hydrologic and hydraulic engineering studies, such as have been conducted under the Milwaukee River watershed study for the Milwaukee River and its major tributaries.

Principles of Floodland Regulation

Certain legal principles must be recognized in the development of land use regulations to implement a comprehensive watershed plan. With respect to the floodland areas of the watershed, these are:

1. Sound floodland regulation must recognize that the flood hazard is not uniform over the entire floodland area. Restrictions and prohibitions in floodlands should, in general, be more rigorous in the channel itself and in the floodway than in the floodplain area.

2. While it is most desirable that floodland regulations seek to retain floodlands in open-space uses, sound floodland regulation may contemplate permitting certain buildings and structures at appropriate locations in the floodplain. Any such structure, however, should comply with special design, anchorage, and building material requirements.

3. Sound floodland regulation must recognize, and be adjusted to, existing land uses in the floodlands. Structures may already exist in the wrong places. Fills may be in place constricting flood flows or limiting the flood storage capacities of the river. The physical effects of such misplaced structures and materials on flood flows, stages, and velocities can be determined; and floodland regulation, based on such determinations, must include legal measures to bring about the removal of at least the most troublesome offenders.

4. In addition to the physical effects of structures or materials, sound floodland regulation must also be concerned with the social and economic effects, particularly the promotion of public health and safety. Beyond this, sound floodland regulation must take into account such diverse and general welfare items as impact upon property values, the property tax base, human anguish, aesthetics, and the need for open space.

5. Sound floodland regulation must coordinate all forms of land use controls, including zoning, subdivision control, and official map ordinances and housing, building, and sanitary codes.

Land Use Regulation in Floodlands

Based upon the above principles and upon the three-part definition of floodlands set forth above, the Commission has proposed that the local units of government within the Region utilize a variety of land use controls to effect proper floodland development. The use of these controls is thoroughly discussed in SEWRPC Planning Guide No. 5, Floodland and Shoreland Development Guide, and, therefore, will not be repeated here. The following, however, will summarize the various land use regulatory powers available to state, county, and local units of government for use in regulating floodland development.

Channel Regulation: Sections 30.11, 30.12, and 30.15 of the Wisconsin Statutes establish rules for the placement of material and structures on the bed of any navigable water and for the removal of material and structures illegally placed on such beds. With approval of the Wisconsin Department of Natural Resources,[20] pursuant to Section 30.11 of the Wisconsin Statutes, any town, village, city, or county may establish bulkhead lines along any section of the shore of any navigable water within its boundaries. Where a bulkhead line has been properly established, material may be deposited and structures built out to the bulkhead line.

[20] *This function was formerly assigned to the Wisconsin Public Service Commission.*

A Wisconsin Department of Natural Resources permit is required for deposit of material or erection of a structure beyond the bulkhead line. Where no bulkhead line has been established, it is unlawful to deposit any material or build any structure upon the bed of any navigable water unless a Wisconsin Department of Natural Resources permit has first been obtained.

The delineation of the outer boundary of the bed of a navigable lake or stream thus becomes a crucial legal issue, and the statutes provide no assistance in this problem. Where the lake or stream has sharp and pronounced banks, it will ordinarily be possible, using stage records, the testimony of knowledgeable persons, and evidence relating to types of vegetation and physical characteristics of the bank, to establish the outer limit of the stream or lake bed.[21] The task can, however, present a difficult practical problem, particularly where the stream is bordered by low-lying wetlands. Where bulkhead lines have been established, however, or where the outer limits of navigable waters can be defined, existing encroachments in the beds of these navigable waters can be removed and new encroachments prevented under existing Wisconsin legislation.

Floodway and Floodplain Regulation: While the Wisconsin Legislature long ago recognized that the regulation of stream channel encroachments was an areawide problem transcending county and municipal boundaries and, therefore, provided for state regulation, it was not until passage of the State Water Resources Act in August 1966 that a similar need was recognized for floodway and floodplain regulation. In that Act the Legislature created Section 87.30 of the Wisconsin Statutes. This section authorizes and directs the Wisconsin Department of Natural Resources to enact floodland zoning regulations where it finds that a county, city, or village has not adopted reasonable and effective floodplain regulations by January 1, 1968. The cost of the necessary floodplain determination and ordinance promulgation and enforcement by the state shall be assessed and collected as taxes from the county, city, or village by the state. Chapter NR 116 of the Wisconsin Administrative Code sets forth the general criteria for counties, cities, and villages to follow in enacting reasonable and effective floodplain regulations. In addition to providing for the proper administration of a sound floodplain zoning ordinance, the criteria include that, where applicable, floodplain zoning ordinances be supplemented with land subdivision regulations, building codes, and sanitary regulations.

The Wisconsin Department of Industry, Labor, and Human Relations[22] has long held power to establish state-level building safety codes.[23] These codes have never specifically focused on special anchorage, construction, safety, and material requirements of structures which are proposed to be or have been erected in a floodplain but could probably be amended to do so. The basic legal authority for such amendment already exists. The powers of the Wisconsin Department of Industry, Labor, and Human Relations, however, do not extend to all structures. It does not have jurisdiction, for example, over single- or two-family housing units. It does have jurisdiction with respect to buildings which are used in whole or in part as a place of resort, assemblage, lodging, trade, traffic, occupancy, or use by the public or by three or more families. It is also given power to assure safe places of employment.

The Wisconsin Division of Highways and the Wisconsin Division of Health presently possess state-level subdivision plat review powers. These powers do not stretch to encompass the full limits of the problem of regulating floodways and floodplains. Nevertheless, adaptations might be effected, where these reviews concern land located within a floodplain, to make a modest contribution to an integrated state-local program of floodland regulation. For example, the regulations of the Wisconsin Division of Highways might impose more stringent performance standards in those situations where flood damage to roadways, culverts, and bridge structures situated within, or close to, a subdivision seems likely. Wisconsin Division of Health regulations applying to subdivisions not to be served by public sewers prohibit

[21] *The ordinary normal high-water mark is defined by the Wisconsin Department of Natural Resources as that point at which the waters of the stream or lake remain long enough to cause an observable change in vegetative type, density of growth, and soil characteristics. In field practice state agencies attempt to establish the channel limits by determination of those points where the terrestrial vegetation ends and the aquatic vegetation begins.*

[22] *Formerly the State Industrial Commission.*

[23] *Wisconsin Statutes 101.01 (12), 101.10 (5); Habermann and Hoefeldt, "The Wisconsin State Building Code," 1947 Wis. L. Rev., 373.*

the development of subdivision lots which have more than 10 percent of the minimum lot area less than two feet above the 100-year recurrence interval flood elevation of a lake or stream. In addition, 80 percent of the minimum lot area of each lot shall be at least three feet, and 20 percent at least six feet, above the highest estimated ground water level.[24] Ground water level estimates are subject to verification by the Division, including a morphological study of soil conditions. These regulations could be supplemented by prohibitions against the development of any lot where floodwaters would be backed or constricted. Such regulation, however, under existing law would apply only to subdivisions not served by public sewer.

Another state-level control available for land use regulation in floodplains is through public nuisance actions brought by the Attorney General to remove, by injunction, existing structures or fill in the floodplain that substantially retard and constrict the flow of navigable streams. Wisconsin cases directly in point are lacking, but a number of out-of-state cases could be used as precedents.[25] Recently, the Wisconsin Legislature, in Section 87.30(2) of the Wisconsin Statutes, declared that every structure, building, fill, or development placed or maintained in violation of a duly adopted floodplain zoning ordinance is a public nuisance and may be enjoined or abated by action at suit of any municipality, the state, or any citizen thereof. In addition, there is power granted by Wisconsin Statutes[26] to abate old and dilapidated structures; and this power could be especially brought to bear on such structures situated in the floodplain. As a practical matter, however, an extensive program of floodplain clearance, like a program of slum clearance, would require the expenditure of substantial public funds to buy out landowners whose structures are located in the wrong places.

The best potential for intelligent land use regulation of floodlands exists at the county and local level of government if these units can be persuaded to coordinate their zoning, land subdivision, official mapping, and building and sanitary code activities through the medium of a comprehensive watershed plan prepared by the Regional Planning Commission. With the enactment of state floodplain zoning-enabling legislation providing for state action in the absence of sound and effective local governmental action, this potential should be fully realized in the Milwaukee River watershed.

With respect to local governmental land use regulatory controls in floodland areas, attention is directed to the following factors:

1. Local zoning ordinances have a substantial, and as yet largely unused, potential for effective regulation of floodway and floodplain areas. As discussed in SEWRPC Planning Guide No. 5, Floodland and Shoreland Development Guide, it appears more desirable in rapidly urbanizing regions to utilize a zoning approach that rejects special floodway and floodplain zoning districts in favor of the normal comprehensive zoning districts supplemented by additional floodland regulations properly related to the flood hazard. Grants of zoning enabling authority to cities, villages, and towns, under Section 62.23(7) of the Wisconsin Statutes, and to counties, under Section 59.97 of the Wisconsin Statutes, appear broad enough to permit this additional regulatory approach. To encourage the full development of this potential, the Commission has prepared a model zoning ordinance for consideration and adaptation by local units of government within the Region which contains suggested zoning district and related regulations, procedural regulations, special floodland overlay regulations, definitions, and other material necessary to construct a sound local zoning ordinance.[27] The Commission also offers assistance to any local unit of government in the Region that desires to incorporate these provisions in its ordinance.

2. Local land subdivision control ordinances also have a substantial, and as yet largely unused, potential for effective floodland regulation of new development. To encourage the full development of this potential, the Commission has prepared a model land subdivision control ordinance for consid-

[24] *Wis. Adm. Code, Section H65.05.*

[25] *See "State Regulation of Channel Encroachment," Beuchert, 5 Nat. Res. J., 486 (1965).*

[26] *Wisconsin Statutes 66.05 and 280.21.*

[27] *See SEWRPC Planning Guide No. 3, Zoning Guide, April 1964, and SEWRPC Planning Guide No. 5, Floodland and Shoreland Development Guide, November 1968.*

eration and adaptation by local units of government within the Region which contains suggested platting procedures, plat specifications, subdivision design standards, improvement standards, and other material necessary to construct a sound local subdivision control ordinance.[28] The Commission offers assistance to any local unit of government in the Region that desires to incorporate these provisions in its ordinance.

3. Local sanitary and building ordinances can also be utilized to apply special sanitation and construction regulations to any permitted floodland development. To encourage local governments to utilize these controls, the Commission has prepared a model sanitary ordinance and special floodland regulations designed to be incorporated into building ordinances.[29] The Commission offers assistance to any local unit of government in the Region that desires to incorporate these provisions in its code of ordinances.

To effectively regulate the use of land in the floodlands of the Milwaukee River, the land subdivision control ordinances, zoning ordinances, official map ordinances, building codes, sanitary codes, and nuisance control ordinances of all of the local units of government within the watershed must be closely coordinated. The medium for such coordination exists generally in the Southeastern Wisconsin Regional Planning Commission; more particularly in the hydrologic and hydraulic data and land use and water control facility plans prepared by the Commission as a part of the Milwaukee River watershed study; and in the model zoning, land subdivision control, sanitary, and building ordinances prepared by the Commission as a part of its continuing planning program. Final action, however, rests entirely with the local governing bodies. These bodies can, if they choose, not only request the Commission to assist them in preparing necessary plan implementation ordinances but can also request the Commission to assist them in the review of all floodland zoning and platting proposals affecting the Milwaukee River.

[28] *See SEWRPC Planning Guide No. 1, Land Development Guide, November 1963, and SEWRPC Planning Guide No. 5, Floodland and Shoreland Development Guide, November 1968.*

[29] *See Appendices K and L to SEWRPC Planning Guide No. 5, Floodland and Shoreland Development Guide, November 1968.*

POLLUTION CONTROL

Inasmuch as the Milwaukee River watershed study was intended to deal with problems of water quality, as well as quantity, and to recommend water use objectives and concomitant water quality standards for the Milwaukee River basin, it is necessary to examine the existing and potential legal machinery through which attainment of water quality goals may be sought at various levels of government and private action.

State Water Pollution Control Machinery

In the State Water Resources Act of 1965,[30] the Wisconsin Legislature completely revised the organizational structure of the state for water pollution control. The Act designated the now Department of Natural Resources as the:

> ...central unit of state government to protect, maintain and improve the quality and management of the waters of the state, ground and surface, public and private.[31]

Previous to this Act, responsibility for state water resource management was diffused among four state agencies: the State Committee on Water Pollution, the State Board of Health (now renamed the State Division of Health), the Wisconsin Public Service Commission, and the Wisconsin Conservation Commission. The State Water Resources Act accomplished the following:

1. Transferred to the Wisconsin Department of Natural Resources the water quality functions of the State Board of Health and the State Committee on Water Pollution.

2. Transferred to the Wisconsin Department of Natural Resources the water regulatory functions of the Public Service Commission.

3. Abolished the State Committee on Water Pollution.

[30] *Chapter 614, Laws of Wisconsin 1965.*

[31] *Wisconsin Statutes 144.025 (1).*

4. Provided for state financial incentives for pollution prevention and abatement facilities.

5. Provided for regulation of shorelands on navigable waters to assist in water quality protection and pollution prevention.

As a result the Wisconsin Department of Natural Resources has been delegated the following powers and duties directly related to water quality protection:

1. To adopt rules setting standards of water quality to be applicable to the waters of the state[32] and issue orders and adopt rules for the construction, installation, use, and operation of systems, methods, and means of preventing and abating pollution of the waters of the state.

2. To consult and advise on the best method of disposing of sewage or refuse and supervise chemical treatment of waters for the purpose of suppressing algae, aquatic weeds, and other nuisance-producing organisms and plants.

3. To order or cause the abatement of any nuisance, such as pumpage from septic tanks or the discharge of untreated domestic sewage, dry wells, or cesspools into any surface water or drainage ditch or any source of filth or cause of sickness created by improper sewage disposal facilities.

4. To prohibit the installation or use of septic tanks in any area where their use would impair water quality.[33]

5. To order sewage treatment systems constructed, secured, altered, extended, or replaced within a specified time if a nuisance or menace to health or comfort tends to be created.

The Department has also been given the power under Section 59.971(6) of the Wisconsin Statutes to adopt shoreland ordinances where counties have not adopted such an ordinance by January 1, 1968, or where the Department after notice and hearing determines that the county ordinance fails to adequately protect shorelands and water quality. In addition, Section 144.46 of the Wisconsin Statutes and Chapter NR 51 of the Wisconsin Administrative Code prohibit solid waste disposal sites and facilities in floodland and shoreland areas except by a permit issued by the Wisconsin Department of Natural Resources. The State's Shoreland Management Program[34] includes general criteria to assist counties in meeting the requirements of the State Water Resources Act of 1965.

Despite the fact that the Wisconsin Legislature has simplified the organizational structure for state-level water pollution control, the curative aspects of the state pollution control program remain, in order to be competent and thorough, quite time-consuming. Rather than attack pollution solely on a case-by-case basis, it has been the sound practice of the Wisconsin Department of Natural Resources, as it was of the predecessor agencies concerned, to examine or survey entire river basins or major sectors thereof. These basin studies involve a water quality sampling program; physical, chemical, and biological analyses of the samples; an inventory of all significant sources of water pollution within the basin; and a preliminary assessment of the results. All probable polluters—private, industrial, and municipal—who utilize a particular watercourse for waste disposal are given notice that such a study is taking place and will be followed by public hearings, usually held within the river basin under study, at which time the preliminary findings are presented and at which potential polluters can appear and submit statements in refutation, defense, or mitigation.

Findings, based upon the results of the study and subsequent hearing, are summarized in a stream pollution report, wherein the extent of each stream

[32] *The Wisconsin Department of Natural Resources has prepared and promulgated water use and quality standards for interstate and intra-state waters as Chapters RD 2, 3, and 4 of the Wisconsin Administrative Code.*

[33] *The Commission has recommended to the Wisconsin Department of Natural Resources that it prohibit septic tank systems on soils within the Region that have "very severe limitations" for such systems, as established in the regional detailed soil survey, or where ground or surface waters would be subject to contamination. The Commission has also recommended prohibiting septic tank systems on soils that have "severe limitations" for such systems, as established in the regional detailed soil survey, unless such limitations are overcome. See SEWRPC Planning Report No. 7, Volume 3, Recommended Regional Land Use and Transportation Plans--1990, 1966, p. 124.*

[34] *Wis. Adm. Code, Chapter NR 115.*

user's contribution to the total pollution load and individual efforts to minimize or control the polluting qualities of effluents are documented. After all analyses have been completed, the hearing of testimony ended, and the basin pollution report prepared, orders addressed individually to each polluter on the stream are issued directing such action as the Department deems necessary to reduce or eliminate water pollution within the basin. The unique circumstances of each polluter are thus known and can be taken into account in framing these orders, and a reasonable time limit in which to comply can be established.

The major difficulty with the curative aspects of the state water pollution control machinery is the often long-time lag between detection and remedy. The phase spanning initial investigation, sampling, analysis, and hearing to the issuance of an order for improvement requires from six to nine months. An additional six months to a year may be allowed for compliance, and time extensions for compliance are commonly given if cause can be shown. It was a basic policy of the former Committee on Water Pollution and the former State Board of Health to rely primarily on educational and persuasive efforts for pollution abatement action, rather than seek judicial enforcement of pollution control orders. While this basic policy of reliance on educational and persuasive efforts toward pollution control has been carried over by the Wisconsin Department of Natural Resources, recent enforcement actions by that Department, in conjunction with the Wisconsin Department of Justice, indicate an intent to make greater use of judicial enforcement procedures in securing compliance with orders.

The state water regulatory functions formerly vested in the Public Service Commission and now transferred to the Wisconsin Department of Natural Resources also bear upon water pollution control. Pursuant to Section 31.02(1) of the Wisconsin Statutes, the Department may "... regulate and control the level and flow of water in all navigable waters...." The ability of any body of water to assimilate wastes depends in part upon the quantity of water available for dilution. Therefore, stage and streamflow are key considerations in the determination of the total volume of pollutants which a body of water can naturally absorb with only minimal changes in water quality. There are instances of record where, prior to the recent reorganization, the Public Service Commission has refused to grant or has restricted irrigation permits on the grounds that the proposed diversion would reduce streamflows to the extent that the stream could not then properly assimilate existing municipal sewage treatment plant effluent loads and that a water pollution problem would thus be created.

Included within the responsibilities of the Wisconsin Department of Natural Resources are all the functions of the former Wisconsin Conservation Commission.[35] Under the provisions of Section 23.09(1) of the Wisconsin Statutes, the Department is charged with establishing:

> ... an adequate and flexible system for the protection, development and use of forests, fish and game, lakes, streams, plant life, flowers and other outdoor resources in this state.

This broad legislative charge is, of course, fully compatible with the water regulatory and quality responsibilities mentioned above.

In performing its functions relating to the maintenance and promotion of the public health, the Wisconsin Division of Health is charged with responsibility for regulating the installation of private septic tank sewage disposal systems. Such systems often contribute to the pollution of surface and ground waters. Pursuant to Chapter 236 of the Wisconsin Statutes, the Division of Health reviews plats of all land subdivisions not served by public sanitary sewerage systems and may object to such plats if sanitary waste disposal facilities are not properly provided for in the layout of the plat. To assist in this review, the Division has promulgated regulations governing lot size and elevation.[36] The Division also registers the installation of all septic tanks through permits issued pursuant to Section 144.03 of the Wisconsin Statutes.

In 1969 the Wisconsin Legislature created a Pesticide Review Board[37] to collect and analyze data and to make recommendations to, and coordinate the regulatory responsibilities of, state agencies on matters relating to the use of pesticides. The

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[35] *The Wisconsin Conservation Commission was merged into the newly created Wisconsin Department of Natural Resources by the State Government Reorganization Act, Chapter 75, Laws of Wisconsin 1967.*

[36] *Wis. Adm. Code, Chapter H65.*

[37] *Chapter 146, Laws of Wisconsin 1969.*

legislative charge to the Board is broadly stated and includes responsibility for the protection of water from pesticide pollution. The Board is functionally located in the Wisconsin Department of Health and Social Services and is composed of the State Secretaries of Agriculture, Natural Resources, and Health and Social Services. The new legislation grants to the Department of Natural Resources the power to adopt administrative rules governing the use of any pesticide which it finds is a serious hazard to wild animals other than those wild animals that the pesticide is intended to control[38] and to the Department of Agriculture a broader power to adopt administrative rules to protect persons or property from serious pesticide hazards.[39] All such administrative rules must be approved by the Pesticide Review Board.

Local Water Pollution Control Machinery

All towns, villages, and cities in Wisconsin have, as part of the broad grant of authority by which they exist, sufficient police power to regulate by ordinance any condition or set of circumstances bearing upon the health, safety, and welfare of the community. Presumably, the water quality of a receiving stream or the polluting capability of effluent generated within the municipal unit would fall within the regulative sphere by virtue of its potential danger to health and welfare.

Local and county boards of health have powers to adopt and enforce rules and regulations designed to protect and improve public health. This broad grant of authority includes regulatory controls relating to environmental sanitation and, hence, water pollution. County boards of health, established by action of the County Board of Supervisors pursuant to Section 140.09 of the Wisconsin Statutes, can provide an effective vehicle for the enactment of county-wide regulations designed in part to prevent and control further pollution of surface and ground waters. At the present time, only one county board of health has been established in the Region, that for Waukesha County.

In recent legislation[40] county park commissions, established pursuant to Section 27.02 of the Wisconsin Statutes, were granted powers to investigate the pollution of streams and lakes throughout the entire county and to engage in weed control and treatment practices in order to ameliorate one effect of such pollution. In so doing, county park commissions may cooperate and contract with other counties and municipalities to provide for pollution control and lake and stream treatment. Formerly, this power was limited to the Milwaukee County Park Commission and then only with respect to streams in county parks and parkways.

In addition to the broad grant of authority to general-purpose units of local government, the Wisconsin Statutes currently provide for the creation of three types of special-purpose units of government through which water pollution can be abated and water quality protected. These are: 1) the Metropolitan Sewerage District of the County of Milwaukee, 2) town sanitary districts, and 3) cooperative action by contract. Until recently, a fourth type of special-purpose unit of government—metropolitan sewerage districts outside Milwaukee County—was authorized by the Wisconsin Statutes. In a significant case,[41] the Wisconsin Supreme Court struck down the authorizing legislation for such metropolitan sewerage districts as an unconstitutional delegation of legislative power.

Metropolitan Sewerage District of the County of Milwaukee: The Metropolitan Sewerage District of the County of Milwaukee was established and operates under the provisions of Section 59.96 of the Wisconsin Statutes. It operates through the agency of the Sewerage Commission of the City of Milwaukee, which was established pursuant to Chapter 608, Laws of Wisconsin 1913, and the Metropolitan Sewerage Commission of the County of Milwaukee, which operates and exists pursuant to the provisions of Section 59.96 of the Wisconsin Statutes. The Metropolitan Sewerage Commission has the power to project, plan, and construct main sewers; pumping and temporary disposal works for the collection and transmission of house, industrial, and other sanitary sewage to and into the intercepting sewerage systems of such District; and may improve any watercourse within the District by deepening, widening, or otherwise changing the same, where, in the judgment of the Commission, it may be necessary in order to carry off surface or drainage waters. The Metropolitan Sewerage Commission, however, may only exercise its powers outside the City of Milwaukee. The Sewerage Commission of the City of Milwau-

[38] *Wisconsin Statutes 29.29(4).*

[39] *Wisconsin Statutes 94.69(10).*

[40] *Chapter 240, Laws of Wisconsin 1969.*

[41] *In re Petition for Fond du Lac Metropolitan Sewerage District, 42 Wis. 2d 323 (1969).*

kee, on the other hand, may build treatment plants and build main and intercepting sewers and may improve watercourses within its area of operation, which is within the City of Milwaukee.

In order to coordinate the activities of the two Commissions, the Statute provides that the Metropolitan Sewerage Commission must secure the approval of the Sewerage Commission of the City of Milwaukee before it is empowered to engage in any work and, when it has completed the work it proposes to do, it then turns over all of these facilities to the Sewerage Commission of the City of Milwaukee for operation and maintenance. The Statute further coordinates the sewer program in the City of Milwaukee by requiring that all towns, cities, and villages lying within the District must submit their sewerage system plans for approval before they can connect to the main and intercepting system owned by the District. The two Commissions have the power to promulgate and enforce reasonable rules for the supervision, protection, management, and use of the entire sewerage system.

The District at the present time includes all of the towns, cities, and villages within the County of Milwaukee, except for the City of South Milwaukee, which elected not to become part of the District (see Map 44). In addition, the District, through its two Commissions, may enter into contracts with areas in the same general drainage area and adjacent to the District to furnish sewer service to those municipalities. The two Commissions have the power to inspect all sewers and sewerage systems which drain into the main or intercepting system and further have the power to require any town, city, or village or the occupant of any premises engaged in discharging sewage effluent from sewage plants, sewage refuse, factory waste, or other materials into any river or canal within such county and within the drainage area to so change or rebuild any such outlet drain or sewer as to discharge said sewage waste or trade waste into the sewers of said town, city, or village or into the main or intercepting sewers owned by the District.

With regard to watercourse improvements, the District, through its two Commissions, has engaged on a broad program of improving watercourses by widening, deepening, or otherwise changing said watercourses so as to accommodate the expected flow of storm and surface drainage waters from the area within the District and from the areas surrounding the District. In connection with this work, many unauthorized waste discharges to watercourses were uncovered and eliminated, thus reducing the discharge of objectionable materials into the rivers and streams in Milwaukee County, as well as providing greater capacity for such streams and rivers and providing for more rapid and efficient runoff of storm and drain waters.

The term "same general drainage area" has been defined by the two Commissions to include all of the Kinnickinnic, Menomonee, and Milwaukee Rivers and Oak Creek watersheds and those portions of the Root River watershed draining into Milwaukee County. In theory the Metropolitan Sewerage District of the County of Milwaukee could, under existing legislation, contract to transmit, treat, and dispose of sewage originating throughout the entire Milwaukee River watershed. The present northerly terminus of the contract service limits of the Metropolitan Sewerage District in the Milwaukee River watershed, however, is the northerly corporate limits line of the City of Mequon, excluding therefrom, however, the Village of Thiensville (see Map 44).

Town Sanitary Districts: Town sanitary districts may be created, pursuant to Section 60.30 of the Wisconsin Statutes, to plan, construct, and maintain sanitary and storm sewers and sewage treatment and disposal systems. A town sanitary district may offer its services outside its jurisdictional area on a reimbursable basis. In addition, the Wisconsin Legislature, in Section 60.30(2) of the Wisconsin Statutes, evidenced an intent that town sanitary districts be created to provide auxiliary sewer construction in unincorporated areas of metropolitan sewerage districts created under Sections 66.20 through 66.209 of the Wisconsin Statutes. Town sanitary districts are usually created by the town board upon petition of 51 percent of the property owners or the owners of 51 percent of the property within the proposed district. The Wisconsin Department of Natural Resources may, however, upon finding that private sewage disposal or water supply systems constitute a public health menace and that there is no local action evident to correct the situation, order the creation of such districts.

As noted in Chapter III of this volume, there are a total of six town sanitary districts existing within the Milwaukee River watershed. These districts are: Big Cedar Lake Sanitary District in the Towns of Polk and West Bend, Washington County;

Little Cedar Lake Sanitary District in the Towns of Polk and West Bend, Washington County; Newburg Sanitary District in the Town of Trenton, Washington County; Sanitary District No. 1 (Lake Ellen area) in the Town of Lyndon, Sheboygan County; Silver Lake Sanitary District in the Town of West Bend, Washington County; and Wallace Lake Sanitary District in the Town of Trenton, Washington County. The location and service areas of these sanitary districts are shown on Map 4.

Cooperative Action by Contract: Section 66.30 of the Wisconsin Statutes permits the joint exercise by municipalities[42] of any power or duty required of, or authorized to, municipalities by statute. To jointly exercise any such power, such as the transmission, treatment, and disposal of sanitary sewage, municipalities would have to create commissions by contract. Appendix A to SEWRPC Technical Report No. 6, Planning Law in Southeastern Wisconsin, contains a model agreement creating such a cooperative contract commission.

Other Metropolitan Sewerage Districts: As noted above, other metropolitan sewerage districts had, until recently, been authorized under Sections 66.20 to 66.209 of the Wisconsin Statutes. These districts were given the broad power to plan, construct, and maintain interceptor and main sanitary sewers, storm sewers, and sewage treatment plants. One such district had been formed in the Region to provide sanitary sewer service to the Waterford-Rochester area in western Racine County.

On April 1, 1969, the Wisconsin Supreme Court struck down Sections 66.20 to 66.209 of the Wisconsin Statutes on the ground that the Wisconsin Legislature, in providing for the creation of such metropolitan sewerage districts by county courts, had unconstitutionally delegated legislative authority to the judiciary.[43] The court made it clear, however, that a question of a lack of legislative authority to provide for the creation of metropolitan sewerage districts was not at issue in the cited case but rather a question of the method by which legislative power had been exercised. If future metropolitan sewerage districts are to be created and existing districts expanded, then the Wisconsin Legislature must provide curative legislation designed to overcome the Supreme Court's objections.

During the 1969 Legislative Session, the Legislature enacted Chapter 132, Wisconsin Laws of 1969, which had the effect of validating the existence of all metropolitan sewerage districts already organized under Sections 66.20 to 66.209 of the Wisconsin Statutes. The new legislation, however, did not provide legislative machinery that would enable the creation of new metropolitan sewerage districts or the orderly expansion of the recently validated districts. Thus, this type of special-purpose areawide unit of government through which water pollution can be abated and water quality protected remains unavailable for use at the present time.

Local Shoreland Regulatory Powers: As previously noted, the State Water Resources Act of 1965 provides for the regulation of shoreland uses along navigable waters to assist in water quality protection and pollution abatement and prevention. In Section 59.971(1) of the Wisconsin Statutes, the Legislature defined shorelands as all that area lying within the following distances from the normal highwater elevation of all natural lakes and of all streams, ponds, sloughs, flowages, and other waters which are navigable under the laws of the State of Wisconsin: 1,000 feet from the shoreline of a lake, pond, flowage, or glacial pothole lake and 300 feet from the shoreline of a stream or to the landward side of the floodplain, whichever is greater.

The Navigable Waters Protection Law[44] specifically authorizes municipal zoning regulations for shorelands. The Law further defines municipality as meaning a county, city, or village. Section 59.971 of the Wisconsin Statutes specifically authorizes counties to enact shoreland zoning ordinances separately from comprehensive zoning ordinances in unincorporated areas without such enactment being subject to town board approval. Furthermore, the shoreland regulations authorized by the Navigable Waters Protection Law have been defined to include land subdivision controls and sanitary regulations.[45] The Wisconsin Depart-

[42] *As used in Section 66.30 of the Wisconsin Statutes, "municipality" includes the state or any department or agency thereof, or any city, village, town, county, school district or regional planning commission.*

[43] *In re Petition for Fond du Lac Metropolitan Sewerage District, 42 Wis. 2d 323 (1969).*

[44] *Wisconsin Statutes 144.26.*

[45] *Wis. Adm. Code, Chapter NR 115.*

ment of Natural Resources is specifically authorized by Section 59.971(6) of the Wisconsin Statutes to adopt county shoreland regulations in counties failing to adopt adequate local shoreland regulations. The cost of such action by the state would be assessed and collected as taxes from the county.

The purposes of zoning, land subdivision, and sanitary regulations in shoreland areas are specified in Section 144.26(1) of the Wisconsin Statutes as follows:

1. To maintain safe and healthful conditions.
2. To prevent and control water pollution.
3. To protect spawning grounds, fish, and aquatic life.
4. To control building sites, placement of structures, and land uses.
5. To preserve shore cover and natural beauty.

To assist local units of government in enacting shoreland regulations and in meeting the objectives of the State Water Resources Act of 1965, the Navigable Waters Protection Law directs the Wisconsin Department of Natural Resources to prepare recommended standards for navigable water protection regulations, with particular attention to the following:

1. Safe and healthful conditions for the enjoyment of aquatic recreation.
2. Demands of water traffic, boating, and water sports.
3. Capability of the water resource.
4. Proper operation of septic tank disposal fields.
5. Building setbacks from the water.
6. Preservation of shore growth and cover.
7. Conservancy uses for low-lying lands.
8. Layouts for residential and commercial development.

In accordance with this charge, the Department has prepared a Shoreland Management Program.[46] A more complete discussion of local shoreland regulatory powers and of the state's role where counties fail to adequately protect shoreland and water quality through county ordinances is contained in SEWRPC Planning Guide No. 5, Floodland and Shoreland Development Guide.

Federal Water Pollution Control Machinery

The Milwaukee River is an intra-state surface water subject to the water quality standards and use classifications adopted by the Wisconsin Department of Natural Resources and set forth in Chapter RD 4 of the Wisconsin Administrative Code. The Milwaukee River watershed, however, is a part of the Lake Michigan drainage basin and, as such, is subject to federal regulations governing the pollution of waters draining into the Great Lakes. The Federal Water Pollution Control Act, last amended by P. L. 91-224 (1970), provides in Section 10 for enforcement measures against the pollution of such waters. These enforcement measures, to date, have had an important impact on water pollution control efforts in the Milwaukee River watershed.

One of the first significant enforcement steps under the federal water pollution control efforts was the convening of a Lake Michigan Enforcement Conference in January, February, and March 1968 by the Secretary of the U. S. Department of the Interior to explore the abatement of pollution of Lake Michigan and its tributary waters. The conferees were comprised of official representatives of the States of Illinois, Indiana, Michigan, and Wisconsin, as well as of the Federal Government. The Conference was called by the Secretary of the Interior at the request of the Governor of the State of Illinois and upon the basis of studies conducted by the Federal Government on the matter of pollution of Lake Michigan. At this Conference 26 recommendations, dealing with water pollution control efforts in the Lake Michigan basin, were formulated and agreed to by the conferees. Of particular significance to the Milwaukee River watershed study are the following recommendations:[47]

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[46] *Ibid, footnote 45.*

[47] *"Lake Michigan Enforcement Conference, Summary of Conference (First Session)," Wisconsin Department of Natural Resources, no date.*

1. Waste treatment is to be provided by all municipalities to achieve at least 80 percent reduction of total phosphorus. This action is to be substantially accomplished by December 1972.

2. Industries not connected to municipal sewerage systems are to provide sewage treatment so as to meet the water quality standards for Lake Michigan as approved by the Secretary of the Interior. This action must also be substantially accomplished by 1972.

3. Continuous disinfection is to be provided throughout the year for all municipal waste treatment plant effluent. This action was to have been accomplished not later than May 1969.

4. Unified sewage collection systems serving contiguous urban areas are to be encouraged.

5. Combined storm and sanitary sewers are to be separated in coordination with all urban reconstruction projects and prohibited in all new developments, except where other techniques can be applied to control pollution from combined sewer overflows. Pollution from combined sewers is to be controlled by July 1977.

6. Discharge of treatable industrial wastes to municipal sewerage systems, following needed preliminary treatment, is to be encouraged.

7. Prohibition of the dumping of polluted material into Lake Michigan is to be accomplished as soon as possible.

8. State water pollution control agencies are to accelerate programs to provide for the maximum use of areawide sewerage facilities, to discourage the proliferation of small treatment plants in contiguous urbanized areas, and to foster the replacement of septic tanks with adequate collection and treatment.

Subsequent sessions of the conference on the pollution of Lake Michigan and its tributary waters have been held in February 1969 and March 1970. At the second session, the recommendation noted above to remove 80 percent of phosphorus from all municipal sewage treatment plants was modified to provide for a basin-wide approach to phosphorus reduction. Thus, so long as at least 80 percent of the total phosphorus contribution from municipal sewage treatment plants in the basin was removed, it would not matter whether each and every municipal plant mounted a phosphorus reduction program. The practical effect of this policy modification is to exempt small municipal sewage treatment plants from phosphorus reduction orders.

Pursuant to the recommendations of the Lake Michigan Enforcement Conference, the Wisconsin Department of Natural Resources has issued pollution abatement orders within the Milwaukee River watershed. These orders provide for 85 percent removal of phosphorus at those sewage treatment plants serving an equivalent population of 2,500 or more; for the continuous disinfection by chlorination of all sewage treatment plant effluent by May 31, 1970; and for the control of pollution from combined sewers in the City of Milwaukee and the Village of Shorewood by July 1977.

The foregoing recommendations of the conference have the practical effect of becoming the accepted standards for federal enforcement. If the Secretary of the Interior finds that any state or alleged polluter is not making effective progress toward the abatement of Lake Michigan pollution, he is directed by the Federal Water Pollution Control Act to recommend to the appropriate state water pollution control agency that it take the necessary remedial action; and he shall allow at least six months for compliance. If compliance is still not forthcoming, the Secretary is directed to call a public hearing and convene a hearing board. The hearing board is directed to make appropriate findings and recommendations to the Secretary concerning the measures it finds reasonable and equitable to secure abatement of pollution. The Secretary shall then allow at least six months for compliance with the hearing board recommendations. If compliance is still not forthcoming, the Secretary may then request the U. S. Attorney General to bring suit on behalf of the United States to secure the abatement of pollution.

Private Steps for Water Pollution Control

Each of the previously discussed methods of pollution control depends upon an agency of government taking action within the framework of statutorily delegated powers. Any number of factors may intervene to negate the application of such controls. Attempts to control water pollution by the direct action of a private individual or organization in the courts may not only be the quickest but also, in some cases, the most effective pollution control device available. This avenue of relief is little used, however, probably because of the heavy costs involved in meeting the burden of proving "unreasonable pollution." In seeking direct action for water pollution control, there are two legal categories of private individuals: riparians, or owners of land that adjoin a natural body of water, and non-riparians.

Riparians: It is not enough for a riparian proprietor seeking an injunction to show simply that an upper riparian is polluting the stream and thus he, the lower riparian, is being damaged. Courts will often inquire as to the nature and the extent of the defendant's activity; its worth to the community; its suitability to the area; and his present attempts, if any, to treat wastes. The utility of the defendant's activity is weighed against the extent of the plaintiff's damage within the framework of reasonable alternatives open to both. On the plaintiff's side, the court may inquire into the size and scope of his operations, the degree of water purity that he actually requires, and the extent of his actual damages. This approach may cause the court to conclude that the plaintiff is entitled to a judicial remedy. Whether this remedy will be an injunction or merely an award of damages depends on the balance which the court strikes after reviewing all the evidence. For example, where a municipal treatment plant or industry is involved, the court, recognizing equities on both sides, might not grant an injunction stopping the defendant's activity but might compensate the plaintiff in damages. In addition, the court may order the defendant to install certain equipment or to take certain measures designed to minimize the future polluting effects of his waste disposal. It is not correct to characterize this balancing as simply a test of economic strengths. If it were simply a weighing of dollars and cents, the rights of small riparians would never receive protection. The balance that is struck is one of reasonable action under the circumstances, and small riparians can be and have been adequately protected by the courts.

Riparians along the Milwaukee River are not foreclosed by the existence of federal, state, or local pollution control efforts from attempting to assert their common law rights in courts. The court may ask the Wisconsin Department of Natural Resources to act as its master in chancery, especially where unbiased technical evidence is necessary to determine the rights of litigants. The important point, however, is that nothing in the Wisconsin Statutes can be found which expressly states that, in an effort to control pollution, all administrative remedies must first be exhausted before an appeal to the courts may be had or that any derogation of common law judicial remedies was intended. Thus, the courts are not prevented from entertaining an original action brought by a riparian owner to abate pollution.

Non-Riparians: The rights of non-riparians to take direct action through the courts are less well-defined than in the case of riparians. The Wisconsin Supreme Court set forth a potentially far-reaching conclusion in Muench v. Public Service Commission[48] when it concluded that:

> The rights of the citizens of the state to enjoy our navigable streams for recreational purposes, including the enjoyment of scenic beauty, is a legal right that is entitled to all the protection which is given financial rights.

This language, however, was somewhat broader than necessary to meet the particular situation at hand, since the case involved an appeal from a state agency ruling. The case has not yet arisen where a private non-riparian citizen is directly suing to enforce his public rights in a stream. Only when such a case does arise can it be determined if the Court will stand behind the broad language quoted above or draw back from its implications. The more traditional view would be that a non-riparian citizen must show special damages in a suit to enforce his public rights.

It should be noted that the provisions of Chapter 144 of the Wisconsin Statutes presently enable any citizen, whether riparian or not, to file a complaint leading to a full-scale public hearing by the Department of Natural Resources on alleged or potential acts of water pollution. In addition, a review of Department orders may be had by "any owner or other person in interest."[49] This review contemplates eventual court determination under Chapter 227 of the Wisconsin Statutes

[48] *261 Wis. 492, 53 N.W. 2d 514 (1952).*

[49] *Wisconsin Statutes 144.56.*

when necessary. The phrase "or other person" makes it clear that non-riparians may seek such judicial review.

CONSTRUCTION OF FLOOD CONTROL FACILITIES BY LOCAL UNITS OF GOVERNMENT

Sound physical planning principles dictate that a watershed be studied in its entirety, if practical solutions are to be found to water-related problems, and that plans and plan implementation programs, including the construction of flood control facilities, be formulated to deal with the interrelated problems of the watershed as a whole. A watershed, however, typically is cut in a most haphazard fashion by a complex of man-made political boundaries—county, city, village, town, and special district. When public works projects, such as flood control works, covering and serving an entire watershed are required, these artificial demarcations become extremely important because they limit the jurisdiction—the physical area—within which any one particular arm of local government may act. Two general possibilities exist, with respect to the Milwaukee River watershed, by which this limitation may be overcome. These two possibilities are: 1) cooperative action by contract, and 2) the use of special districts.

Cooperative Action By Contract

The use of Section 66.30 of the Wisconsin Statutes to achieve cooperative contract action was previously discussed under the section on pollution control. The local units of government concerned with the construction of mutually advantageous flood control facilities could proceed under the provisions of Section 66.30 of the Wisconsin Statutes to implement specific water control facility plans under a contractual relationship. If it is assumed that the benefits of comprehensive watershed public works accrue in some rough proportion to all of the municipal units involved and that the self-interest and sense of propriety of each would impel them all to be party to a contract, then the contractual provisions of Section 66.30 of the Wisconsin Statutes seem completely capable of dealing with the problem. A commission could be created to administer the contract; or, seemingly, any other administrative device mutually agreed upon could be created to carry out the joint public works projects deemed necessary. Recent legislation may make this approach all the more feasible inasmuch as it is now possible to finance "the acquisition, development, remodeling, construction, and equipment of land, buildings and facilities for regional projects" by a joint bond issue backed in allocate shares by the contracting local units.[50]

Use of Special Districts

Several types of special districts are available or potentially available for use in the construction and operation of flood control facilities. These special districts are: 1) a comprehensive river basin district, 2) soil and water conservation districts, 3) town sanitary districts, 4) flood control boards, and 5) county drainage boards and drainage districts.

Comprehensive River Basin District: One possibility for areawide water control facility plan implementation is through the creation of a special comprehensive river basin district embracing the entire watershed and capable of raising revenues through taxation and bonding; acquiring land; constructing and operating the necessary facilities; and otherwise dealing with the wide range of problems, alternatives, and projects inherent in comprehensive watershed planning. Such a district might be specifically charged in the enabling legislation by which it is created with carrying out the plans formulated by the SEWRPC. Though enabling legislation to permit the creation of such districts has been proposed to the Wisconsin Legislature in the past, it has not, to date, received approval and, thus, is not presently available as a means of dealing with the problem.

Soil and Water Conservation Districts: Present legislation, Chapter 92 of the Wisconsin Statutes, authorizes the creation of soil and water conservation districts, the boundaries of which shall be coterminous with county lines. There exists such a district in each county of the Milwaukee River watershed. These districts, to date, have had a strong agricultural orientation; and in southeastern Wisconsin their efforts have been focused primarily on inducing individual farmers to use good soil management and conservation techniques. Respective county board agricultural committee members are ex officio the board of supervisors of the soil and water conservation districts. In general, these districts have conducted programs designed to encourage sound and proper land use and have been used by the Wisconsin Department of Natural Resources, the U. S. Soil Conservation Service, and the Uni-

[50] *Wisconsin Statutes 66.30 (3m).*

versity of Wisconsin-Extension as a vehicle for achieving good land use development objectives in rural areas. Of major practical significance is the fact that these districts have no taxing, special assessment, or bonding power but are completely dependent upon county funds and U. S. Department of Agriculture grants for financing. Federal grants under Public Law 83-566 can be obtained by such districts for the construction of flood control projects only if federal preconditions are met. If, however, any proposed flood control facilities within the Milwaukee River watershed can meet these requirements, these districts may serve as an agent for federal financing of the project.

The State Soil Conservation Board, which oversees the activities of the county soil and water conservation districts, performs an important role with with respect to flood control. The Board must approve all local applications for federal grants for flood control projects under P. L. 83-566. In addition, the Board must approve all work plans in the State of Wisconsin for projects under the P. L. 83-566 program and sets the planning priorities for the U. S. Soil Conservation Service operation within the state.

Town Sanitary Districts: Town sanitary districts organized pursuant to Section 60.30(1) of the Wisconsin Statutes are authorized to construct drainage improvements. Such town sanitary districts may include portions of two or more towns but may not include any incorporated area at the time of their creation.

Flood Control Boards: Chapter 87 of the Wisconsin Statutes makes provision for property owners living in a single drainage area, which may well involve more than a single municipal governmental unit, to petition for the formulation of a flood control board for the sole purpose of effecting flood control measures. These measures may include the:

> ... straightening, widening, deepening, altering, changing or the removing of obstructions from the course of any river, watercourse, pond, lake, creek or natural stream, ditch, drain or sewer, and the concentration, diversion or division of the flow of water therein, the construction and maintenance or the removal of ditches, canals, levees, dikes, dams, sluices, revetments, reservoirs, holding basins, floodways, pumping stations, sewers and siphons, and any other works reasonably adapted or required to accomplish the purposes of (this chapter)....[51]

Application for the creation of such a board must be made through the Department of Natural Resources, which determines the need and engineering feasibility of the proposed projects. Boards created under this statutory chapter are empowered to raise monies by the levy of a special assessment against the benefited property owners. The Board is also empowered to determine the benefits to be derived within each affected municipality. In addition, the Wisconsin Legislature, in Chapter 481, Laws of Wisconsin 1965, provided a more flexible financing procedure whereby flood control projects may be financed in whole or in part through funds received under agreements and contracts from municipalities, other governmental agencies, and other sources. In providing money for such projects, municipalities may utilize the powers of special assessment, bonding, and taxation. The Legislature also provided in 1965 a special procedure whereby the Department of Natural Resources may order the creation of flood control boards (see Section 87.075 of the Wisconsin Statutes).

The Milwaukee River watershed is unique in the Region in that a Milwaukee River Flood Control Board has been created in the watershed under Chapter 87 of the Wisconsin Statutes.[52] The original petition to create such a board was filed by 48 petitioners on March 12, 1964. After appropriate hearings, the Wisconsin Public Service Commission, the regulatory agency then having jurisdiction over such matters, on August 27, 1964, ordered the matter to proceed and requested the Governor to appoint a Milwaukee River Flood Control Board to take charge of the construction, maintenance, and operation of the improvements

[51] *Wisconsin Statutes 87.02.*

[52] *Chapter 87 of the Wisconsin Statutes implies that the jurisdiction of a flood control board extends only to a particular proposed flood control project on a named river. There is no provision in the Statutes which would clearly grant to such a flood control board, once established, jurisdiction over an entire watershed and thus make such a board responsible for additional flood control projects that may be required in the same watershed in future years. It is apparent that additional legislation is needed to clarify this question by defining specific geographical jurisdictional areas for each flood control board so created.*

proposed by the petitioners; namely, the construction of a diversion channel from the Milwaukee River to Lake Michigan in the vicinity of the Village of Saukville and the Town of Port Washington. The Public Service Commission further found that the major part of the proposed improvement was to be located in Ozaukee County and that the largest amount of property to be benefited was located in Milwaukee County. These latter findings were significant since Section 87.12(1) of the Wisconsin Statutes provides that one member of the three-member flood control board is to be certified by the board of supervisors of the county in which the major part of the proposed improvement is located; a second member is to be certified by the board of supervisors of the county in which the largest amount of property to be benefited is located; and the third member is to be appointed by the Governor on his own motion, with the only restriction being that the member reside in the drainage area.

Two of the three appointments to the Milwaukee River Flood Control Board were made effective December 30, 1964; namely, the member certified by the Ozaukee County Board of Supervisors and the member appointed by the Governor on his own motion. Subsequently, on September 26, 1968, a new member was appointed to replace the member appointed by the Governor on his own motion. The third appointment, to be certified by the Milwaukee County Board of Supervisors, has never been made. Members are appointed for a term of six years and until their successors are duly appointed. The Milwaukee River Flood Control Board, never being fully constituted, has never met; nor have any proposed flood control projects been undertaken. The two members appointed to the Board participated in the Milwaukee River watershed study through membership on the Milwaukee River Watershed Committee.

<u>County Drainage Boards and Drainage Districts:</u> Chapter 88 of the Wisconsin Statutes authorizes the creation of drainage districts, under the control of a county drainage board and with the consent of a county court, for the specific purpose of making areawide drainage improvements. Such districts may be composed of areas lying within more than one municipality and in more than one county. The costs of any drainage improvements are assessed against the lands that are specifically benefited. The State Soil Conservation Board must approve all contracts between federal agencies and drainage districts for the purpose of making areawide drainage improvements. It should be noted that, in view of the Wisconsin Supreme Court decision in the Fond du Lac metropolitan sewerage district case previously cited, the procedure for creating drainage districts through the county courts is now of questionable legality.

As noted in Chapter III of this volume, there are a total of eight legally established drainage districts in the Milwaukee River watershed. These districts are: Ozaukee County Drainage Districts, Numbers 1 (City of Mequon), 4 (City of Mequon), 6 (Town of Cedarburg), 8 (Town of Port Washington), 10 (City of Mequon), 11 (Town of Cedarburg), and 12 (City of Mequon), and the Jackson-Germantown Drainage District in the Towns of Germantown and Jackson and the Village of Germantown in Washington County. The Jackson-Germantown Drainage District is, however, the only one of the eight districts in the watershed which is still active. The location and service areas of these districts are shown on Map 3.

DEVELOPMENT AND OPERATION OF HARBORS

The authority to develop and operate harbors and make harbor improvements is granted to every municipality in Wisconsin having navigable waters within or adjoining its boundaries by Sections 30.30 through 30.38 of the Wisconsin Statutes. Such authority may be exercised directly by the governing body of the municipality or by a board of harbor commissioners created for that purpose, except that certain enumerated powers relating to the commercial aspects of harbor operation, such as the operation of publicly owned or leased wharf and terminal facilities, can only be exercised through a board of harbor commissioners. Boards of harbor commissioners are fiscally dependent upon the governing body of the municipality.

Under the statutory authority, boards of harbor commissioners are authorized to create or improve any inner or outer harbor turning basins, slips, canals, and other waterways; to construct, maintain, or repair dock walls and shore protection walls along any waterway adjoining or within the limits of the municipality; and to plan, construct, operate, and maintain docks, wharves, warehouses, piers, and related port facilities for the needs of commerce and shipping, including the handling of freight and passenger traffic between the waterways of the harbor and air and land transportation terminals. Boards may acquire land, develop industrial sites, build service roads, and construct and enlarge harbor facilities. All plans for harbor improvement projects, including the establishment of dock lines, must be approved by the governing body of the municipality.

Boards of harbor commissioners may also serve as a regulatory and enforcement agency for the municipality with respect to such harbor-related matters as the movement of vessels, dock wall construction, and shoreline encroachment. In this respect it is important to note that boards of harbor commissioners can, to promote the public health, safety, or welfare or to eliminate dilapidation, blight, or obsolescence, determine by resolution that it is essential that dock walls or shore protection walls be improved, altered, repaired, or extended. Property owners affected by such resolution can appeal the finding and order of the board to make improvements through the courts. Should the court eventually order the work to be performed, the property owner may elect to do the work or let the municipality do the work and assess the cost of such work to the property involved.

The City of Milwaukee Common Council has acted to create a Board of Harbor Commissioners to exercise the authority set forth in Sections 30.30 through 30.38 of the Wisconsin Statutes. The Board is composed of seven members, appointed by the Mayor for three-year terms, subject to confirmation by the Common Council. The Board retains its own staff to carry out its activities, but its annual budget for operation and facility construction is subject to approval of the Common Council. The geographic jurisdiction of the Milwaukee Board of Harbor Commissioners is not explicitly defined in the enabling legislation. The statutory language, however, implies that such jurisdiction extends to the inner and outer harbor areas plus all connected waterways navigable for commercial purposes. With respect to the Milwaukee River, this jurisdiction would extend from the harbor entrance upstream to the Humboldt Avenue Bridge, the first low-level fixed bridge on the lower river, located just downstream from the North Avenue Dam.

SPECIFIC LEGAL CONSIDERATIONS AND INVENTORY FINDINGS IN THE MILWAUKEE RIVER WATERSHED

Certain specific legal questions were raised as work on the Milwaukee River watershed study proceeded. These dealt with the backing of floodwaters into established agricultural drains, interbasin water diversion, the storage of sewage in underground reservoirs, and private dams. In addition, inventories were conducted with respect to the issuance of permits for surface water withdrawal and high capacity wells; the establishment of bulkhead lines; outstanding pollution abatement orders; and the designation of official trout streams.

Legal Implications of Temporarily Backing Floodwaters Into Agricultural Drains

One type of water control facility being considered for incorporation in the comprehensive plan for the Milwaukee River watershed is the retention reservoir. While retention reservoirs sometimes provide a practical engineering approach to water control problems, the construction of such reservoirs presents certain legal problems which must be recognized and considered before a final plan selection is made. One of these concerns the legal consequences of ponded water which may damage the improvements of drainage districts or nullify the effect of privately owned farm drains and tiles. A drainage district would have a cause for action if it could prove injury resulting from the backing of floodwaters into its drainage system. The legal remedy of damages can be employed even though the equitable remedy of injunction may not be available to prevent construction or use of retention reservoirs. From the standpoint of expediency and simplicity, the drainage district might negotiate the sale of a flowage right. If this is not feasible, an action can be brought by the drainage district each time that temporary flooding causing provable damage occurs. If the damage is permanent, that is, constitutes a "taking," the drainage district can initiate inverse condemnation proceedings.

The governmental unit considering construction of retention reservoirs seemingly has two approaches available to it. One of these might be called "active." Here the purchase of a flowage right is sought or condemnation proceedings commenced. An active approach has the advantage of doing today what might prove considerably more expensive if done at a later date. Furthermore, if any liability for damage appears imminent, it should be fixed and limited in advance, rather than left open and uncertain as to amount. The other general approach is just the opposite, an "inactive" or wait-and-see attitude. No actual injury to drainage districts may ever occur. Thus, simply building the retention reservoirs without seeking to condemn land or acquire flowage rights and dealing with any damage claims if and when they do arise may be the least costly and simplest way of proceeding.

While the above discussion refers to individual drainage districts acting on behalf of their constituent interests, individual farmers are in no way prevented from suing or acting on their own behalf either in law or in equity to preserve their interests in whatever drainage improvements they may have created on their lands.

Interbasin Water Diversion

One of the more important legal problems in water resources planning concerns interbasin diversion. The traditional common law riparian doctrine, which for the most part is still in effect today, forbade the transfer of water between watersheds. This was regarded as a non-riparian use of water. It must be recognized, however, that states, by legislative action, can and have created exceptions to this general doctrine and that major inter-watershed diversions, such as the so-called Chicago diversion of water from the Lake Michigan-St. Lawrence River drainage basin to the Mississippi River drainage basin, have on occasion taken place.

The problem of interbasin diversion was of significance in the Commission watershed studies for the Root and Fox Rivers, where alternative plan elements involved major interbasin water diversions. Such diversions are not, however, expected to be a factor in the preparation of alternative plan elements for the Milwaukee River watershed. One possible diversion would involve the construction of a floodwater diversion channel from the Milwaukee River to Lake Michigan in the vicinity of the Village of Saukville. Such a diversion, however, would not involve the transfer of water from the Lake Michigan-St. Lawrence River drainage basin to the Mississippi River drainage basin as in the case of the Chicago diversion noted above. The construction of such a floodwater diversion channel could, however, raise legal problems with respect to the riparian rights of landowners downstream from the channel location, as noted earlier in this chapter, under the discussion relating to the riparian rights doctrine.

Sewage Storage in Underground Reservoirs

One of the alternative stream water quality management plan elements under consideration in the Milwaukee River watershed study is the temporary storage of combined sewer overflows generated in the lower watershed in a mined storage reservoir constructed 200 to 300 feet below the land surface in the Niagara geologic group bedrock formations. An obvious concern, should this alternative be recommended for implementation, would be the effect of such temporary storage of sewage on the bedrock formations on ground water quality. By statute,[53] the Wisconsin Department of Natural Resources is charged with the responsibility of protecting, maintaining, and improving ground, as well as surface, water quality. The Department has formulated administrative rules governing the construction, operation, and maintenance of sewerage and water supply systems, including a prohibition against the use of wells for the disposal of sewage.[54] There is no specific rule, however, that applies directly to the question of the conveyance and temporary storage of sewage in underground reservoirs. Such conveyance and temporary storage would not differ substantially in concept from the construction of large sanitary trunk sewers in tunnel through the bedrock, such as has been accomplished by the Milwaukee-Metropolitan Sewerage Commissions in the Milwaukee area. Any such storage system, however, would have to be approved by the Wisconsin Department of Natural Resources and be so designed as to eliminate any potential for aquifer contamination.

Private Dams

One of the specific problems encountered in watershed planning programs involves the disposition of existing private dams. Such dams have created flowages or impoundments, and landowners whose lands abut the flowages have relied over a period of time on the artificial condition created by the dams. Often this reliance is evidenced by home and recreation facilities constructed in close proximity to, and because of, the flowed water. The Wisconsin Supreme Court has recently stated the applicable law:

> If an artificial body of water is created, landowners incidentally benefited are entitled to injunctive relief to prevent disturbance of the new state of the water. Wisconsin prescriptive-rights cases involve proprietors of land which border bodies of water, who in some way relied

[53] *Wisconsin Statutes 144.025(1).*

[54] *Wis. Adm. Code, Chapter RD 12.12.*

on the new water level which was maintained by another's dam. These cases hold that when the artificial level of the water is continued for a considerable period of time, usually twenty years, it becomes a natural condition.[55]

So in cases where a dam created a flowage, which is now more than 20 years old, owners on the flowage seemingly are able to compel the owner of the dam to continue to maintain it.

A local unit of government or the state itself has only limited powers to compel the owners of private dams to maintain them. These powers are based on some combination of arguments involving the preservation of public rights in the flowage created, public safety, health, and welfare or, in some instances, the specific terms or inferences which may be found in dam permits issued pursuant to statute by the Railroad Commission or its successors, the Public Service Commission and the Department of Natural Resources.

Water Resource-Related Permits

As noted earlier in this chapter, the Wisconsin Department of Natural Resources has broad authority under the Wisconsin Statutes to regulate the water resources of the state. An inventory was made under the Milwaukee River watershed study of all permits issued by the Department and predecessor agencies in the Milwaukee River watershed for surface water withdrawal and high-capacity wells.

Surface Water Withdrawal: Permits are required under Section 30.18 of the Wisconsin Statutes for surface water withdrawal when the withdrawn water is to be used for agricultural irrigation. In addition, under a broad interpretation of the statute, permits may be required for commercial irrigation, such as the watering of golf courses, parks, and cemeteries, and for industrial uses. Permits are not required for domestic uses, such as lawn and garden watering. A total of four permits have been issued in the Milwaukee River watershed for the withdrawal of surface water under this statute (see Table 136). Special conditions attach to each of these permits and are summarized in Table 136. It is important to note that an undetermined amount of water is withdrawn from the Milwaukee River stream system for nonagricultural purposes, not only by industrial land uses but also by residential, recreational, and institutional land uses for lawn and garden watering and other miscellaneous uses. This latter type of withdrawal may well be more significant than the former because of its impact on low-flow conditions particularly in the headwater reaches of the streams in the watershed.

High-Capacity Wells: Permits are required for high-capacity wells, defined in Section 144.05(2)(e) of the Wisconsin Statutes as a well or well field with facilities for withdrawal of water at a rate of 100,000 gallons a day (70 gallons per minute) or more. A total of 35 such permits have been issued in the watershed to date. These permits and their relevant conditions are summarized in Table 137.

Bulkhead Lines

Municipalities are authorized by Section 30.11 of the Wisconsin Statutes to establish by ordinance bulkhead lines, subject to review and approval of the Wisconsin Department of Natural Resources. Bulkheads are required to conform as nearly as practicable to existing shores and must be found by the Department of Natural Resources to be in the public interest. Bulkhead lines have been established by the City of Milwaukee for the entire length of the Milwaukee River from the harbor mouth to the North Avenue Dam, a distance of about 1.6 miles. These bulkhead lines are shown on a series of maps reproduced in Appendix O of this volume. Bulkhead lines have also been established in the City of West Bend for a total distance of about 2.4 miles and in the City of Mequon for a distance of about 100 feet. Additional bulkhead lines have been proposed in the City of West Bend for a distance of about 0.7 mile and the City of Cedarburg for a distance of about 400 feet. These existing and proposed bulkhead lines are also shown on maps reproduced in Appendix O.

Pollution Abatement Orders

An inventory was made of all outstanding pollution abatement orders in the Milwaukee River watershed. Twenty-three such orders, excluding amendments, have been issued as of February 27, 1970, against polluters within the Milwaukee River watershed by the Wisconsin Department of Natural Resources, pursuant to Section 144.025(2)(d) of the Wisconsin Statutes (see Table 138). These orders were designed to ensure compliance with the recommendations of the federal Lake Michigan Enforcement Conference discussed earlier in this chapter. All five municipal sewage treatment

[55] *Tiedeman v. Middleton, 25 Wis. 2d 443 (1964).*

TABLE 136

SURFACE WATER WITHDRAWAL PERMITS IN THE MILWAUKEE RIVER WATERSHED

PERMIT RECIPIENT	PROPOSED PROJECT	LOCATION	DATE PERMIT GRANTED	LEGAL AUTHORITY	SPECIAL CONDITIONS
OSWALD EBERHARDT	DIVERT WATER FROM THE MILWAUKEE RIVER IN SHEBOYGAN COUNTY FOR IRRIGATION	EAST 1/2 OF THE SOUTHWEST 1/4 OF SECTION 19, TOWN 13, NORTH, RANGE 21 EAST AND NORTH 1/2 OF THE EAST 1/2 OF THE NORTHWEST 1/4 OF SECTION 30, TOWN 13, NORTH, RANGE 21 EAST.	MARCH 9, 1959	SECTION 31.14 OF THE WISCONSIN STATUTES	1. TO DIVERT WATER FROM THE MILWAUKEE RIVER TO BE USED ON THE TILLABLE AREA OF THE FOLLOWING RIPARIAN LANDS CONSTITUTING 55 ACRES- EAST HALF OF THE SOUTHWEST QUARTER OF SECTION 19, TOWN 13 NORTH, RANGE 21 EAST. 2. TO DIVERT WATER AT A MAXIMUM RATE OF 700 GALLONS A MINUTE OR 1.56 CUBIC FEET A SECOND WHEN THE FLOW IN THE MILWAUKEE RIVER IS AT OR ABOVE 7.5 CUBIC FEET A SECOND NEAR THE POINT OF DIVERSION. TO DIVERT NO WATER WHEN THE FLOW IS LESS THAN 7.5 CUBIC FEET A SECOND. 3. (A) (MAY 1 AND OCTOBER 15) 4. (B) -- 5. (C) (55) ORDER (4) THAT NO DIVERSION SHALL TAKE PLACE DURING THE PERIOD WATER IS BEING DIVERTED UNDER THE PROVISIONS OF THE PERMIT ISSUED TO HAROLD J. KRIER IN DOCKET 2-WP-1239.
WALLACE E. FREUND	DIVERT WATER FROM THE MILWAUKEE RIVER IN WASHINGTON COUNTY FOR IRRIGATION PURPOSES	NORTH 1/2 OF THE NORTH 1/2 OF THE NORTHEAST 1/4 OF SECTION 2, TOWN 11 NORTH, RANGE 19 EAST	MARCH 19, 1959	SECTION 31.14 OF THE WISCONSIN STATUTES	1. TO DIVERT WATER FROM THE MILWAUKEE RIVER TO BE USED ON THE TILLABLE AREA OF THE FOLLOWING RIPARIAN LANDS CONSTITUTING 23 ACRES- NORTH 1/2 OF THE NORTH 1/2 OF THE NORTHEAST 1/4 OF SECTION 2, TOWN 11 NORTH, RANGE 19 EAST. 2. TO DIVERT WATER AT A MAXIMUM RATE OF 300 GALLONS A MINUTE OR 0.67 CUBIC FEET A SECOND WHEN FLOW IN THE MILWAUKEE RIVER IS AT OR ABOVE 10.0 CUBIC FEET A SECOND AT WEST BEND. TO DIVERT NO WATER WHEN FLOW IS LESS THAN 10.0 CUBIC FEET A SECOND. 3. (A) (MAY 1 AND OCTOBER 30) 4. (B) 5. (C) (23)
ROBERT M. LUDWIG	DIVERT WATER FROM THE MILWAUKEE RIVER IN THE TOWN OF GRAFTON, OZAUKEE COUNTY, FOR IRRIGATION	NORTHWEST 1/4 OF SECTION 6, TOWN 10 NORTH, RANGE 22 EAST	APRIL 19, 1965	SECTION 30.18 OF THE WISCONSIN STATUTES	1. SAID WATER SHALL BE USED ONLY ON THE TILLABLE AREA, CONSISTING OF 51 ACRES OF THE RIPARIAN LAND DESCRIBED IN FINDING NO. 2 (COLUMN 3) OR AS MAY OTHERWISE BE PERMITTED BY CHAPTER 32 LAWS OF 1963, BUT NOT TO EXCEED 30 ACRES ANNUALLY. 2. SAID WATER SHALL BE DIVERTED ONLY DURING THE PERIOD BETWEEN MAY 15 AND SEPTEMBER 15 OF EACH YEAR TO IRRIGATE A MAXIMUM OF 30 ACRES ANNUALLY. 3. SAID WATER SHALL BE DIVERTED FOR NOT TO EXCEED 270 HOURS IN ANY ONE YEAR AND AT A MAXIMUM RATE OF 250 GALLONS A MINUTE OR 0.56 CUBIC FEET A SECOND OR AT ANY LESSER RATE FOR A PROPORTIONATELY LONGER TIME WHEN FLOW IN THE MILWAUKEE RIVER AT THE LOCATION OF THE PROPOSED DIVERSION IS SUFFICIENT TO PROVIDE THE DIVERSION AND HOLD A MINIMUM STAGE FOR THE PROTECTION OF PUBLIC INTERESTS IN THE STREAM. SAID MINIMUM STAGE MAY BE DETERMINED BY SUPPLEMENTAL ORDER.
HARVEY SIEGMAN	DIVERT WATER FROM THE MILWAUKEE RIVER IN THE TOWN OF TRENTON, WASHINGTON COUNTY FOR IRRIGATION PURPOSES.	NORTHEAST 1/4 OF THE NORTHWEST 1/4 OF SECTION 15, AND GOVERNMENT LOT 2 OF SECTION 15, TOWN 11 NORTH, RANGE 20 EAST	OCTOBER 21, 1965 AND APRIL 15, 1966	SECTION 30.18 OF THE WISCONSIN STATUTES	1. SAID WATER SHALL BE USED ONLY ON THE TILLABLE AREA OF THE RIPARIAN LAND CONSTITUTING 50 ACRES DESCRIBED IN FINDING NO. 2 (COLUMN 3) OR AS MAY OTHERWISE BE PERMITTED BY SECTION 30.18(5), STATUTES. 2. SAID WATER SHALL BE DIVERTED ONLY DURING THE PERIOD BETWEEN MAY 1 AND OCTOBER 1 OF EACH YEAR. 3. SAID WATER SHALL BE DIVERTED FOR NOT TO EXCEED 426 HOURS IN ANY ONE YEAR AND AT A MAXIMUM RATE OF 1,000 GALLONS A MINUTE OR 2.23 CUBIC FEET A SECOND OR AT ANY LESSER RATE FOR A PROPORTIONATELY LONGER TIME WHEN FLOW IN THE MILWAUKEE RIVER AT THE LOCATION OF THE PROPOSED DIVERSION IS SUFFICIENT TO PROVIDE THE DIVERSION AND HOLD A MINIMUM STAGE FOR THE PROTECTION OF PUBLIC INTERESTS IN THE STREAM. SAID MINIMUM STAGE MAY BE DETERMINED BY SUPPLEMENTAL ORDER. REVISED 2. THE DIVERSION PERIOD WAS EXTENDED FROM APRIL 15 TO OCTOBER 1 BY PERMIT GRANTED APRIL 5, 1966.

SOURCE- WISCONSIN DEPARTMENT OF NATURAL RESOURCES AND SEWRPC.

plants, serving a population of over 2,500 persons, are under orders to provide 85 percent removal of phosphorus; and all municipal sewage treatment plants within the watershed are under orders to provide continuous chlorination facilities. One industry within the watershed is under orders to improve in-plant treatment of wastes, three industries are under orders to connect to public sewerage systems, and five industries are under orders to provide more adequate final treatment of wastes (see Table 138).

Trout Streams

Section 30.18 of the Wisconsin Statutes, dealing with permits for diversion of water for agricultural and irrigation purposes, provides for special consideration in the issuance of such permits which would divert water from officially designated trout streams. Upon annual review the Department of Natural Resources may revoke permits issued on such streams if it finds that continued withdrawal would be detrimental to the maintenance of a trout fishery. There are five

TABLE 137

HIGH-CAPACITY WELL PERMITS IN THE MILWAUKEE RIVER WATERSHED

PERMIT RECIPIENT	WELL LOCATION	TYPE OF USE	AUTHORIZED PUMPAGE	DATE OF APPROVAL
CALIFORNIA CANNERS AND GROWERS	NE 1/4, SEC. 3 T13N, R17E DODGE COUNTY	INDUSTRIAL	1,049,400 GPD	7/17/68
LUICK ICE CREAM CO.	NW 1/4, SEC. 9 T7N, R22E MILWAUKEE CNTY	INDUSTRIAL	317 GPM	11/23/49
JOHN OSTER MFG. CO.	SW 1/4, SEC.32 T8N, R22E MILWAUKEE CNTY	INDUSTRIAL	70,000 GPD	11/13/50
JOSEPH SCHLITZ BREWING CO.	SE 1/4, SEC.20 T7N, R22E MILWAUKEE CNTY	INDUSTRIAL	2,440,000 GPD	1/15/52
A. F. GALLUN AND SONS CORP.	NW 1/4, SEC.21 T7N, R22E MILWAUKEE CNTY	INDUSTRIAL	364,000 GPD	6/ 4/52
MILWAUKEE GEAR CO.	NE 1/4, SEC.32 T8N, R22E MILWAUKEE CNTY	INDUSTRIAL	49,150 GPD	3/11/53
SHELDON THOMAS CORP.	SE 1/4, SEC.29 T8N, R22E MILWAUKEE CNTY	COMMERCIAL	150,000 GPD	12/11/53
WEISEL & CO.	NE 1/4, SEC.21 T7N, R22E MILWAUKEE CNTY	INDUSTRIAL	144,000 GPD	10/15/54
NICOLET HIGH SCHOOL	SE 1/4, SEC.20 T8N, R22E MILWAUKEE CNTY	MISCELLANEOUS	45,000 GPD	3/ 1/55
GRANVILLE HIGH SCHOOL	NW 1/4, SEC.14 T8N, R21E MILWAUKEE CNTY	MISCELLANEOUS	20,000 GPD	7/28/55
OUTBOARD MARINE CO.	NE 1/4, SEC.27 T8N, R21E MILWAUKEE CNTY	INDUSTRIAL	296,000 GPD	4/11/56
SQUARE D CO.	NE 1/4, SEC.24 T8N, R21E MILWAUKEE CNTY	INDUSTRIAL	150,000 GPD	6/18/56
BAYSIDE-FOX POINT SCHOOL DISTRICT	NW 1/4, SEC. 9 T8N, R22E MILWAUKEE CNTY	MISCELLANEOUS	28,100 GPD	4/29/57
NEWPORT EXECUTIVE HOUSE, INC.	SE 1/4, SEC.21 T7N, R22E MILWAUKEE CNTY	MISCELLANEOUS	18 MGPY	7/17/59
MILWAUKEE COUNTRY CLUB	SE 1/4, SEC. 7 T8N, R22E MILWAUKEE CNTY	IRRIGATION	288,000 GPD	11/27/63
SIDNEY KOHL	SE 1/4, SEC. 3 T8N, R21E MILWAUKEE CNTY	MISCELLANEOUS	625 GPM	7/25/69
HUBERT A. NIEMAN & CO.	SE 1/4, SEC.27 T10N, R21E OZAUKEE COUNTY	INDUSTRIAL	250 GPM	2/ 1/46
FROMM ORCHARDS	SE 1/4, SEC. 2 T9N, R21E OZAUKEE COUNTY	IRRIGATION	300,000 GPS	2/26/46
LAKESHIRE-MARTY CO.	SE 1/4, SEC. 26 T12N, R21E OZAUKEE COUNTY	INDUSTRIAL	30,000 GPD	8/27/46
SCHOOL SISTERS OF NOTRE DAME	SE 1/4, SEC. 8 T9N, R22E OZAUKEE COUNTY	MISCELLANEOUS	87,000 GPD	6/10/57
MEQUON-THIENSVILLE SCHOOL DISTRICT NO. 1	SE 1/4, SEC.33 T9N, R21E OZAUKEE COUNTY	MISCELLANEOUS	18,000 GPD	10/21/58
WISCONSIN LUTHERAN SEMINARY	NE 1/4, SEC. 22 T9N, R21E OZAUKEE COUNTY	MISCELLANEOUS	40,000 GPD	9/ 6/60
OZAUKEE COUNTRY CLUB	NE 1/4, SEC. 26 T9N, R21E OZAUKEE COUNTY	MISCELLANEOUS	329,300 GPD	10/27/60
HAROLD HAHM	SE 1/4, SEC. 34 T9N, R21E OZAUKEE COUNTY	IRRIGATION	171,000 GPD	4/15/63
NORTH SHORE ESTATES, INC.	NE 1/4, SEC. 36 T9N, R21E OZAUKEE COUNTY	IRRIGATION	96,000 GPD	8/26/64
KRAMER-URBAN, INC.	SE 1/4, SEC. 35 T9N, R21E OZAUKEE COUNTY	INDUSTRIAL	24,000 GPD	10/ 6/64
MEQUON COLONY ESTATES, INC.	SE 1/4, SEC. 7 T9N, R22E OZAUKEE COUNTY	MISCELLANEOUS	25,000 GPD	6/29/66
KOHL'S FOOD STORES	NW 1/4, SEC. 29 T9N, R22E OZAUKEE COUNTY	COMMERCIAL	60,000 GPD	11/21/68
WESTERN CONDENSING CO.	SW 1/4, SEC. 1 T13N, R21E SHEBOYGAN COUNTY	INDUSTRIAL	1,100,000 GPD	2/15/46
LIBBY, MCNEILL & LIBBY	NW 1/4, SEC. 20 T10N, R20E WASHINGTON CNTY	INDUSTRIAL	315,000 GPD	12/ 6/47
LINE MATERIALS INDUSTRIES	SE 1/4, SEC. 2 T11N, R19E WASHINGTON CNTY	INDUSTRIAL	750,000 GPD	10/20/58
STOLPER INDUSTRIES, INC.	SE 1/4, SEC. 18 T10N, R20E WASHINGTON CNTY	INDUSTRIAL	48,000 GPD	6/ 8/67
CEDAR LAKE HOME FOR THE AGED	SE 1/4, SEC. 17 T11N, R19E WASHINGTON CNTY	MISCELLANEOUS	22,500 GPD	2/26/68
WEST BEND COUNTRY CLUB	SE 1/4, SEC. 21 T11N, R19E WASHINGTON CNTY	MISCELLANEOUS	18,000 GPD	3/26/68
ROBERT H. GIERINGER & SONS	SE 1/4, SEC. 3 T12N, R19E WASHINGTON CNTY	IRRIGATION	975,000 GPD	9/ 4/68

SOURCE- WISCONSIN DEPARTMENT OF NATURAL RESOURCES AND SEWRPC.

named streams in the Milwaukee River watershed that are officially designated as trout streams:[56] Lake Fifteen Creek in Fond du Lac County and Gooseville Creek, Melius Creek, Nichols Creek, and Watercress Creek in Sheboygan County (see Map 60).

SUMMARY

This chapter has described in summary form the legal framework within which comprehensive watershed planning and plan implementation must take place in southeastern Wisconsin. The salient findings having particular importance for planning in the Milwaukee River watershed include the following.

Water law is not a simple or fixed body of law. It has historical roots which reach back beyond the common law. The traditional riparian doctrine was early modified to include principles of reasonable use and, more recently, state permit systems. Renewed recognition of public water rights, state and local regulative activities, and federal regulations have further altered relationships between individuals and between individuals and government as they relate to water. The field of water law has never been in a greater and more constant state of change and development than it is today.

For purposes of flood control, flood-damage prevention, and proper use of the riverine environment, a stream valley can be divided into three main sectors: the channel, defined as that portion of the floodlands normally occupied by a stream of water under average annual high-water flow conditions; the floodway, defined as that portion of the floodlands, including the channel, required to carry and discharge the 100-year recurrence interval flood; and the floodplain, defined as that portion of the floodlands, excluding the floodway, subject to inundation by the 100-year recurrence interval flood.

In the State Water Resources Act of 1965, the Wisconsin Legislature recognized the need to encourage the regulation of shoreland and floodland development. The Wisconsin Department of Natu-

[56] *Wisconsin Trout Streams, Publication 213-69, Wisconsin Department of Natural Resources.*

TABLE 138

POLLUTION ABATEMENT ORDERS IN THE MILWAUKEE RIVER WATERSHED- 1970

ORDER RECIPIENT	WIS. DNR ORDER NUMBER	DATE OF ORDER	SUMMARY OF ORDER
VILLAGE OF ADELL	4B-68-5-1 4B-68-5-1A	JUNE 12, 1968 FEB. 27, 1970	EFFLUENT DISINFECTION; REMOVAL OF 80 PERCENT OF PHOSPHORUS. EFFLUENT DISINFECTION; UTILIZATION OF HOLDING POND.
BADGER WORSTED MILLS, INC. (VILLAGE OF GRAFTON)	4B-68-5-2	JUNE 12, 1968	CONNECTION TO VILLAGE OF GRAFTON SEWERAGE SYSTEM.
VILLAGE OF CAMPBELLSPORT	4B-68-5-4 4B-68-5-4A	JUNE 12, 1968 FEB. 27, 1970	REMOVAL OF 80 PERCENT OF TOTAL PHOSPHORUS. SEPARATION OF ALL CLEAR WATER FROM THE SANITARY SEWERAGE SYSTEM; ELIMINATION OF ALL SEWAGE BYPASS OUTLETS.
CITY OF CEDARBURG	4B-68-5-5 4B-68-5-5A	JUNE 12, 1968 FEB. 27, 1970	EFFLUENT DISINFECTION; REMOVAL OF 80 PERCENT OF PHOSPHORUS. REMOVAL OF 85 PERCENT OF ANNUAL AVERAGE PHOSPHORUS.
DESOTO CHEMICAL COATINGS, INC. (VILLAGE OF FREDONIA)	4B-68-5-6	JUNE 12, 1968	CONSTRUCT ADEQUATE TREATMENT FACILITIES FOR INDUSTRIAL WASTES.
FEDERAL FOODS, INC. (VILLAGE OF THIENSVILLE)	4B-68-5-7 4B-68-5-7A	JUNE 12, 1968 FEB. 27, 1970	CONSTRUCT ADEQUATE TREATMENT FACILITIES FOR INDUSTRIAL WASTES. CONSTRUCT ADEQUATE TREATMENT FACILITIES FOR INDUSTRIAL WASTES.
FOREMOST FOODS, INC. (VILLAGE OF ADELL)	4B-68-5-8 4B-68-5-8A	JUNE 12, 1968 FEB. 27, 1970	CONSTRUCT ADEQUATE TREATMENT FACILITIES FOR INDUSTRIAL WASTES. CONSTRUCT ADEQUATE TREATMENT FACILITIES FOR INDUSTRIAL WASTES.
VILLAGE OF FREDONIA	4B-68-5-9 4B-68-5-9A	JUNE 12, 1968 FEB. 27, 1970	EFFLUENT DISINFECTION; REMOVAL OF 80 PERCENT OF TOTAL PHOSPHORUS. EFFLUENT DISINFECTION.
VILLAGE OF GRAFTON	4B-68-5-12 4B-68-5-12A	JUNE 12, 1968 FEB. 27, 1970	EFFLUENT DISINFECTION; REMOVAL OF 80 PERCENT OF TOTAL PHOSPHORUS. EFFLUENT DISINFECTION; SEPARATION OF CLEAR WATER ENTRIES TO THE SANITARY SEWERAGE SYSTEM AND/OR CONSTRUCT ADEQUATE TREATMENT FACILITIES; REMOVAL OF A MINIMUM OF 85 PERCENT OF THE AVERAGE ANNUAL TOTAL PHOSPHORUS; ELIMINATION OF ALL BYPASS OUTLETS.
VILLAGE OF JACKSON	4B-68-5-13 4B-68-5-13A	JUNE 12, 1968 FEB. 27, 1970	EFFLUENT DISINFECTION; REMOVAL OF 80 PERCENT OF TOTAL PHOSPHORUS. EFFLUENT DISINFECTION.
VILLAGE OF KEWASKUM	4B-68-5-14 4B-68-5-14A	JUNE 12, 1968 FEB. 27, 1970	ELIMINATION OF WASTE DISCHARGES TO THE STORM SEWERAGE SYSTEM; EFFLUENT DISINFECTION; REMOVAL OF 80 PERCENT OF TOTAL PHOSPHORUS. EFFLUENT DISINFECTION; PREVENT THE DISCHARGE OF INDUSTRIAL WASTES INTO THE STORM SEWERAGE SYSTEM.
KIEKHAEFER CORPORATION (CITY OF CEDARBURG)	4B-68-5-15 4B-68-5-15	JUNE 12, 1968 FEB. 27, 1970	CONSTRUCTION OF IN-PLANT FACILITIES FOR SEPARATION OF OIL AND GASOLINE WASTES. ELIMINATE THE DISCHARGE OF OIL AND WASTES FROM THE COOLING WATER LINE AT THE DIE-CAST PLANT; ELIMINATE THE DISCHARGE OF COLORED MATERIAL FROM THE ASSEMBLY PLANT.
THE KRIER PRESERVING COMPANY (VILLAGE OF RANDOM LAKE)	4B-68-5-16	JUNE 12, 1968	CONSTRUCT ADEQUATE TREATMENT FACILITIES FOR INDUSTRIAL WASTES.
LINE MATERIAL INDUSTRIES (CITY OF WEST BEND)	4B-68-5-17	JUNE 12, 1968	CONNECTION TO CITY OF WEST BEND SEWERAGE SYSTEM.
CITY OF MEQUON	4B-68-5-19	JUNE 12, 1968	CONNECTION OF THE LAC DU COURS AND VILLE DU PARC SUBDIVISIONS TO THE MILWAUKEE METROPOLITAN SEWERAGE DISTRICT.
METROPOLITAN SEWERAGE DISTRICT OF MILWAUKEE COUNTY (INCLUDES MUNICIPALITIES SERVED BY DISTRICT)	4B-70-5-4	FEB. 27, 1970	EFFLUENT DISINFECTION AND REMOVAL OF NOT LESS THAN 85 PERCENT OF TOTAL PHOSPHORUS BE PROVIDED AT BOTH THE JONES ISLAND AND SOUTH SHORE TREATMENT PLANTS; CONNECTION OF THE NEW DEAL PLANT SEWAGE TO THE SOUTH SHORE PLANT; THAT THE CITIES OF CUDAHY, GLENDALE, MILWAUKEE, OAK CREEK, RIVER HILLS, ST. FRANCIS, WAUWATOSA, AND WEST ALLIS AND THE VILLAGES OF BAYSIDE, BROWN DEER, FOX POINT, SHOREWOOD, WEST MILWAUKEE, AND WHITEFISH BAY CONTINUE THEIR PROGRAMS FOR ELIMINATING OR TREATING THE SEWAGE DISCHARGED TO SURFACE WATERS WITHIN MILWAUKEE COUNTY AND THE REDUCTION AND CONTROL OF CLEAR WATER REACHING SANITARY, MAIN, AND INTERCEPTING SEWERS.
NEWBURG SANITARY DISTRICT	4B-68-5-20	JUNE 12, 1968	REMOVAL OF 80 PERCENT OF TOTAL PHOSPHORUS.
VILLAGE OF RANDOM LAKE	4B-68-5-21 4B-68-5-21A	JUNE 12, 1968 FEB. 27, 1970	EFFLUENT DISINFECTION; REMOVAL OF 80 PERCENT OF TOTAL PHOSPHORUS. EFFLUENT DISINFECTION.
RIVER ROAD CHEESE FACTORY (VILLAGE OF FREDONIA)	4B-68-5-22	JUNE 12, 1968	CONSTRUCT ADEQUATE TREATMENT FACILITIES FOR INDUSTRIAL WASTES.
VILLAGE OF SAUKVILLE	4B-68-5-23 4B-68-5-23A	JUNE 12, 1968 FEB. 27, 1970	EFFLUENT DISINFECTION; REMOVAL OF 80 PERCENT OF TOTAL PHOSPHORUS. EFFLUENT DISINFECTION.
VILLAGE OF THIENSVILLE	4B-68-5-24 4B-68-5-24A	JUNE 12, 1968 FEB. 27, 1970	EFFLUENT DISINFECTION; REMOVAL OF 80 PERCENT OF TOTAL PHOSPHORUS; EXCLUDE CLEAR WATER FROM THE SANITARY SEWERS OR CONSTRUCT ADEQUATE TREATMENT FACILITIES TO TREAT ALL WASTES AND WATERS TRIBUTARY TO THE SEWERAGE SYSTEM. EFFLUENT DISINFECTION; ELIMINATE CLEAR WATER ENTRIES TO THE SANITARY SEWERAGE SYSTEM AND/OR PROVIDE ADEQUATE TREATMENT FACILITIES FOR ALL WASTE LOADINGS; REMOVAL OF 85 PERCENT OF TOTAL PHOSPHORUS; ELIMINATE ALL BYPASS OUTLETS.
CITY OF WEST BEND	4B-68-5-25 4B-68-5-25A	JUNE 12, 1968 FEB. 27, 1970	REMOVAL OF 80 PERCENT OF TOTAL PHOSPHORUS. REMOVAL OF 85 PERCENT OF THE TOTAL PHOSPHORUS; COMPLETE CLEAR WATER EXCLUSION AND/OR PROVIDE ADEQUATE TREATMENT OF ALL WASTE LOADS.
THE WEST BEND COMPANY (CITY OF WEST BEND)	4B-68-5-26	JUNE 12, 1968	CONNECTION OF UTENSIL WASHING WASTE WATERS TO THE CITY OF WEST BEND SEWERAGE SYSTEM.

SOURCE- WISCONSIN DEPARTMENT OF NATURAL RESOURCES AND SEWRPC.

ral Resources is now empowered to enact floodplain regulations and apply them locally where counties, cities, villages, and towns do not effectively so regulate. Local governments have a variety of regulatory devices available to control floodland development. These include zoning ordinances, including zoning districts and special floodland regulations; land subdivision controls; building codes; sanitary codes; and extraterritorial zoning powers.

State-level responsibility for water resources is now concentrated in the Wisconsin Department of Natural Resources. In August 1966 the Wisconsin Legislature transferred all water quality functions of the former State Board of Health and the now defunct State Committee on Water Pollution to the Department. In addition, all water regulatory functions of the Public Service Commission were transferred to the Department. As a result the Department of Natural Resources is now charged with nearly all the responsibility for the protection and preservation of shorelands and water quality in the state. The only other state agency with responsibility in this area is the Division of Health, which retains supervision over the installation and placement of private septic tank sewage disposal systems.

The State Soil Conservation Board, which oversees the activities of the county soil and water conservation districts, performs a particularly important role with respect to flood control. The Board must approve all local applications for federal grants for flood control projects under Public Law 83-566. In addition, the Board must approve all work plans in the State of Wisconsin for projects under the Public Law 83-566 program and sets the planning priorities for the U. S. Soil Conservation Service operation within the state. Finally, the Board must approve all contracts between federal agencies and drainage districts for the purpose of making areawide drainage improvements.

Local governments have been specifically authorized and required by the Wisconsin Legislature to enact special shoreland and floodland regulations designed to protect the water quality of navigable streams. Shorelands are defined as all that area lying within the following distances from the normal high-water elevation of all natural lakes and of all streams, ponds, sloughs, flowages, and other waters which are navigable under the laws of the State of Wisconsin: 1,000 feet from the shoreline of a lake, pond, flowage, or glacial pothole lake and 300 feet from the shoreline of a stream or to the landward side of the floodplain, whichever is greater.

Counties in Wisconsin are now required to enact such special shoreland regulations in their unincorporated areas. Cities and villages are permitted, but not required, to enact shoreland regulations within their corporate boundaries. Such county regulations are not subject to town board approval. Shoreland regulations include special zoning regulations, subdivision controls, and sanitary ordinances.

As evidenced by the enactment of the State of Wisconsin Water Resources Act of 1965, pollution control and maintenance of water quality standards are problems of growing importance. Many more tools exist than are presently being used to control pollution. The State of Wisconsin, Metropolitan Sewerage District of the County of Milwaukee, town sanitary districts, local units of government, and private individuals acting through the courts each have powers to exercise in an effort to control pollution, powers which heretofore have been used only sparingly and with caution. The Federal Government has entered this field and has more forcefully dealt with the problem of pollution. In particular, the recommendations of the Lake Michigan Enforcement Conference, called by the U. S. Secretary of the Interior, dealing with phosphorus removal, effluent chlorination, and areawide sewerage systems have great significance for the Milwaukee River watershed study. The Regional Planning Commission itself can act as a research, liaison, and coordinating body to effect pollution control and desired water quality standards within the Region and its component watersheds, such as the Milwaukee River.

Flood control facilities may be constructed in the Milwaukee River watershed either through cooperative action by contract of the local municipalities or by the use of special-purpose districts. A comprehensive river basin district, which could have broad authority for implementing an areawide water control facility plan, is not presently permitted under the Wisconsin Statutes. Flood control boards, oriented toward a particular improvement, are authorized under Chapter 87 of the Wisconsin Statutes. Such a flood control board has been organized for the Milwaukee River, but all appointments have not been made nor has the Board ever met and organized. The authority of such a board to operate and maintain flood control works throughout an entire watershed is unclear.

There is little likelihood that the erection of retention reservoirs as a means of controlling flooding along the stream by holding peak runoffs will present serious legal problems. Some drainage districts or individual farmlands may be affected (damaged); but they can be suitably dealt with either before the dams and reservoirs are built, by means of purchasing flowage rights or condemning the necessary land, or after the dams and reservoirs are operational by settling with each claimant as, if, and when he comes forward.

The maintenance of private dams built along streams within Wisconsin is best attained by those riparians who have relied upon the existing flowage created by the dams, in that they have constructed housing or recreational facilities in close proximity to the water's edge. Local governmental units or the state have only limited powers to compel such upkeep; and these powers must be based on some aspect of public rights in the flowage of the preservation of health, safety, and welfare.

Chapter XVI

SUMMARY

STUDY ORGANIZATION AND PURPOSE

The Milwaukee River watershed study, which resulted in the preparation of this report, is the third comprehensive watershed planning program to be undertaken by the Southeastern Wisconsin Regional Planning Commission. It is, however, the first such study to be conducted by the Commission for a watershed planning area, significant portions of which lie within Wisconsin but outside the boundaries of the Southeastern Wisconsin Region. Approximately 264 square miles, or 38 percent, of the approximately 694 square mile Milwaukee River watershed are located beyond the jurisdictional boundaries of the seven-county Southeastern Wisconsin Planning Region, primarily in Fond du Lac and Sheboygan Counties, with a very small portion of the watershed being located in Dodge County. Consequently, Fond du Lac and Sheboygan Counties were requested and did join in the watershed study, along with Milwaukee, Ozaukee, and Washington Counties within the Southeastern Wisconsin Planning Region.

The entire Milwaukee River watershed, from its headwater area in Fond du Lac and Sheboygan Counties to its outlet into Lake Michigan in the City of Milwaukee, was thus included in the comprehensive watershed planning program. Because the delineation of watersheds as rational planning areas must recognize not only the natural and man-made topographic features influencing a technologically sound watershed operation but also the existence of a significant community of interest through which the active participation of local officials and citizen leaders in the planning effort can be obtained, the Menomonee and Kinnickinnic River basins were not, for the purposes of the watershed study, considered to be a part of the Milwaukee River watershed. The Menomonee and Kinnickinnic Rivers join the Milwaukee River in its estuary portion and do so virtually at the Lake Michigan shoreline. Any attempt to relate the water resource problems of the Menomonee and Kinnickinnic River basins to those of the Milwaukee River basin would, therefore, be tenuous even from a purely physical standpoint. More importantly, however, the promotion of a single community of interest throughout all three of these river basins would be most difficult, for the residents of the Menomonee and Kinnickinnic River basins have little in common with respect to land and water resource problems with residents of the Milwaukee River basin, as defined herein. The planning area chosen for the Milwaukee River watershed study thus excluded about 19 percent of the combined 856 square mile drainage area of the Milwaukee, Menomonee, and Kinnickinnic Rivers.

The Milwaukee River watershed study was undertaken within the statutory authority of the Commission and upon the request and approval of the local units of government concerned. The study was guided from its inception by the Milwaukee River Watershed Committee, an advisory Committee to the Commission, composed of 26 elected and appointed public officials, technicians, and citizen leaders from throughout the watershed. The technical work was carried out jointly by the Commission staff; cooperating governmental agencies, including the U. S. Department of Agriculture, Soil Conservation Service; the U. S. Department of the Interior, Geological Survey; the Wisconsin Department of Natural Resources; and private consultants engaged by the Commission, including the Harza Engineering Company of Chicago, Illinois, and Alster & Associates, Inc., of Madison, Wisconsin. Each of these organizations was selected by the Commission for participation in the watershed planning program by virtue of their exceptional skills and experience in specialized phases of water resources planning and engineering. The disciplines provided included specialization in ground and surface water hydrology, hydraulics, ecology and natural resource conservation, sanitary engineering, and control survey and photogrammetric engineering, as well as comprehensive areawide planning.

The study was founded upon the recognition by public officials, technicians, and citizen leaders within the watershed that problems, such as flooding and water pollution, transcend local governmental boundaries and that solutions to such areawide problems must be sought on a regional basis. Furthermore, it was recognized that the water and water-related resource problems of the Milwaukee River watershed are directly and inextricably interrelated, not only with each other, but also with problems of areawide urbanization and associated increasing and often misdirected demands upon the natural resource base.

The primary objective of the Milwaukee River watershed planning program is to assist the federal, state, and local units of government in abating the serious water and water-related resource problems of the Milwaukee River watershed by developing a workable plan to guide the staged development of multi-purpose water resource-related facilities and related resource conservation and management programs for the watershed. More specifically, the objectives of the planning program are to:

1. Prepare a plan for effective flood damage abatement in and along the major waterways and floodlands of the Milwaukee River watershed.

2. Prepare a plan for water quality management and water pollution abatement for the Milwaukee River and its major tributaries and for the major lakes of the watershed.

3. Prepare a plan for the protection and conservation of the quality and quantity of the basin ground water supplies.

4. Prepare a plan for the preservation and enhancement of the fish and wildlife habitat areas of the watershed.

5. Prepare a plan for the public open-space reservation and recreational development within the watershed.

6. Refine and adjust the adopted regional land use plan to reflect the conveyance, storage, and waste assimilation capabilities of the perennial waterways and floodplains of the watershed, including any feasible water control facilities, and generally to promote the adjustment of land use development in the basin to the underlying and sustaining natural resource base.

If the watershed plan is to be effective in abating problems of water pollution, soil and water conservation, deteriorating fish and wildlife habitat, water supply, flood damage, dwindling open space, and changing land use within the watershed, it must be amenable to cooperative adoption and joint implementation by all levels and agencies of government concerned and must be capable of functioning as a practical guide to the making of development decisions concerning both land use and water control facility development within the watershed on a day-to-day basis. Accordingly, the watershed study has been broad in scope and detailed in content, with application of a full range of scientific disciplines to the tasks of study design; formulation of watershed development objectives and standards; inventory, analysis, and forecasts; plan design; plan test and evaluation; and plan selection and adoption.

The major findings and recommendations of the three-year comprehensive watershed planning program are presented in a two-volume planning report. This, the first volume of the report, sets forth the basic concepts underlying the study and presents in summary form the factual findings of the extensive inventories conducted under the study. It identifies and, to the extent possible, quantifies the developmental and environmental problems of the watershed and sets forth forecasts of future economic activity, population growth, and concomitant land use and natural resource demands. The second volume of the report presents the watershed development objectives and standards, alternative land use and water control facility plan elements, and a recommended comprehensive watershed development plan, together with recommendations concerning the best means for the implementation of that plan.

The report can only summarize in brief fashion the large volume of information assembled in, and the recommendations growing out of, the extensive data collection, analysis, forecasting plan design, and plan evaluation phases of the Milwaukee River watershed study. Although, due to the volume and complexity of the data collected, the reproduction of the complete study data files in published format is impossible, all of the data are generally available from the Commission files to the member units and agencies of government upon specific request.

INVENTORY, ANALYSIS, AND FORECAST FINDINGS

Geography

The Milwaukee River watershed is a surface water drainage unit approximately 694 square miles in areal extent, discharging to Lake Michigan within the City of Milwaukee. Approximately 62 percent of the total watershed area, or 430 square miles, lie within the seven-county Southeastern Wisconsin Planning Region. The remaining 38 percent, consisting of the headwater portions of the watershed, lies adjacent to the Region in adjoining Dodge, Fond du Lac, and Sheboygan Counties. The watershed is the second largest of the 11 major natural surface water drainage units within the Region and comprises approximately 16 percent of the total land and water area of the Region. A portion of the watershed is bounded on the west by a subcontinental divide, which separates surface waters flowing westerly and southerly through the Mississippi River system to the Gulf of Mexico from surface waters flowing northerly and easterly through Lake Michigan and the St. Lawrence River system to the North Atlantic Ocean. The southern portions of the watershed lie in intensely urbanized Milwaukee County and in rapidly urbanizing Ozaukee and Washington Counties, while the central and northern portions lie in the important agricultural and recreational areas of Fond du Lac and Sheboygan Counties.

Superimposed upon the natural meandering watershed boundary is a rectangular pattern of local political boundaries. The watershed occupies portions of three of the seven counties comprising the Southeastern Wisconsin Region—Milwaukee, Ozaukee, and Washington—parts of three counties adjacent to, but outside the Southeastern Wisconsin Planning Region—Dodge, Fond du Lac, and Sheboygan—and portions or all of 5 cities, 18 villages, and 28 towns. Six soil and water conservation districts have jurisdiction over portions of the watershed. In addition, certain other special-purpose districts have important responsibilities for water resource management within the watershed, including the Metropolitan Sewerage District of the County of Milwaukee, six sanitary districts, and eight legally established farm drainage districts.

Superimposed on these local, general, and special-purpose units of government are the state and federal governments, certain agencies of which also have important responsibilities for resource conservation and management. These include the Wisconsin Department of Natural Resources; the University of Wisconsin Extension Service; the State Soil Conservation Board; the U. S. Department of Agriculture, Soil Conservation Service; the U. S. Department of the Interior, Federal Water Quality Administration; and the U. S. Department of the Army, Corps of Engineers.

Population and Economic Activity

The present (1967) population of the watershed is estimated at 543,790 persons, of which 531,680 persons reside within the Region and 12,110 persons reside outside the Region. The portion of the watershed population within the Region comprises about 30 percent of the total regional population. The population of the watershed has increased steadily since 1850. From 1950 to 1960, the population of the watershed increased by 32 percent, somewhat more than the 27 percent increase experienced by the Region as a whole during this same decade. Since 1960, however, the rate of population increase within the Region has exceeded the rate of increase within the watershed. The watershed population growth rate since 1940 can be attributed primarily to natural increase, that is, to an excess of births over deaths; and this indicates that migration from other parts of the nation, state, and Region has not been a significant factor in the recent population increase of the watershed.

Preliminary 1970 U. S. Bureau of the Census population estimates became available late in the Milwaukee River watershed study. The 1970 estimated watershed population, based upon the preliminary census figures, is 527,652, as compared to the 1960 estimated watershed population of 526,823 and the 1967 estimated watershed population of 543,790. A close inspection of the preliminary 1970 census results reveals a pattern that includes substantial growth of population in the middle and upper reaches of the watershed combined with substantial losses of population in the lower watershed consisting of Milwaukee County communities and, more particularly, the City of Milwaukee itself. The 1960 City of Milwaukee population in the Milwaukee River watershed was estimated at about 405,000. By 1970 this figure had dropped to about 376,000, a 7 percent decline. Although many factors contributed to this decline, it is clear that at least three factors were of particular significance; namely, urban renewal activities involving wholesale clearance of housing units with little or no replacement by April 1970, essential freeway and other public works construction involving a loss of housing units, and a reduction in the average household size. At the same time that the City of Milwaukee was exhibiting a rather sharp decline in population within the watershed, however, the remainder of the watershed continued to grow in close accord with the population forecasts prepared by the Commission under its comprehensive regional planning program. Thus, while total watershed growth was very small in the 1960-1970 decade, the substantial population loss in the City of Milwaukee was more than offset by rapid growth in the middle reaches of the watershed and, in particular, the rapidly urbanizing portions of Ozaukee and Washington Counties.

Because of this rapid growth in the urbanizing areas of the watershed, the population of the watershed is anticipated to increase to about 678,000 persons by 1990, or by an additional 25 percent. Changes in the characteristics of the watershed population are expected to parallel closely those of the regional population, as described in SEWRPC Planning Report No. 7, Volume 2, Chapter III. In 1990 there will be proportionately more older people (ages 65 and over) and more younger people (ages 34 and under) than there were in 1967.

Employment within the watershed presently (1967) totals about 290,000 jobs and is expected to increase to about 346,000 jobs by 1990, an increase of about 56,000 jobs, or 19 percent, in 20 years. The largest concentration of industry within the watershed lies in the City of Milwaukee, where 62 of the 75 industrial firms within the watershed, employing 150 or more persons each, are located. Other major industrial concentrations within the watershed are located in the Cities of Cedarburg, Glendale, and West Bend and in the Village of Grafton. Most of the resident labor force of the watershed finds employment in the watershed industrial centers, primarily in the urbanized areas of the lower watershed. Although the watershed within the Region contains approximately 31 percent of the regional population, it accounts for more than 42 percent of the total regional employment.

Agriculture is still an important component of the economy of the watershed. Although the number of farms in operation, the number of acres being farmed, and the number of farm operators have been declining, the average farm size and the total value of farm products sold have been increasing. About 60 percent of the agricultural lands of Ozaukee County, 50 percent of the agricultural lands of Washington County, 15 percent of the agricultural lands of Fond du Lac County, and 20 percent of the agricultural lands of Sheboygan County lie within the Milwaukee River watershed.

Land Use

Land within the watershed is undergoing a rapid transition from rural to urban use in response to increasing population and economic activity levels. Urbanization is particularly rapid in the lower reaches of the watershed, especially in the Mequon, Thiensville, Cedarburg, and Grafton areas of Ozaukee County and in the West Bend area of Washington County. Urbanization is occurring in a highly diffused pattern outward from the historic urban centers into the woodlands, wetlands, and fertile farmlands of the watershed. In the 17-year period, extending from 1950 to 1967, a 36 percent increase in the population of the watershed was accompanied by an 80 percent increase in the amount of land devoted to urban use within the watershed and by a decrease in the density of the developed portions of the watershed, from 9,500 persons per square mile to 7,500 persons per square mile. This areawide diffusion of low-density urban development within the watershed is a major factor contributing to a number of the serious environmental and developmental problems existing within the watershed.

Agricultural use is still by far the predominant land use within the watershed, occupying about 61 percent of the total watershed area. Urban land use presently occupies about 15 percent of the total watershed area; and residential development, devoted almost exclusively to single-family dwellings, accounts for almost half of this total area devoted to urban land uses. Only 1 percent of the watershed area is presently devoted to active outdoor recreational use. A high potential for development of additional recreational land, however, exists within the watershed.

Continuation of present development trends within the watershed may be expected to result in an increase in urban land use, from approximately 102 square miles in 1967 to 133 square miles by 1990, an increase of 30 percent. Residential land use may be expected to increase from 42 square miles in 1967 to 60 square miles by 1990, an increase of 42 percent. All other urban land uses may be expected to increase from 60 square miles to 73 square miles over this same period of time, an increase of 23 percent. This demand for urban land will have to be satisfied primarily by the conversion of agricultural lands, woodlands, and wetlands, which collectively may be expected to decline by about 31 square miles, a decrease of about 6 percent. If existing trends continue, much of this new urban development will not be related sensibly to the natural resource base—the soils, the lakes and streams and associated floodlands and shorelands, the woodlands, the wetlands, and the wildlife habitat areas of the watershed—nor to long-standing public utility systems and service areas.

Public Utility Service

The construction of public sanitary sewer and water supply facilities has not fully kept pace with the rapid urbanization taking place within the watershed, necessitating the widespread use of individual on-site sewage disposal systems and private wells. In 1967 about 64 percent of the developed area of the watershed and 92 percent of the total watershed population were served by public sanitary sewerage facilities, while public water supply systems served about 60 percent of the total developed area of the watershed and about 91 percent of the total watershed population. The planned service area of the Metropolitan Sewerage Commission of the County of Milwaukee, which includes all of the Milwaukee County portion of the watershed and the City of Mequon in the Ozaukee County portion of the watershed, comprises about 32 square miles within the watershed, or nearly 5 percent of the total watershed area.

Detailed operational soil surveys indicate that approximately 205 square miles, or about 30 percent of the watershed, are covered by soils which are poorly suited for urban development of any kind. Approximately 319 square miles, or about 46 percent of the watershed, are covered by soils which are poorly suited for residential development without public sanitary sewer service on lots of one acre or more in area; and about 386 square miles, or about 56 percent of the watershed, are covered by soils poorly suited for urban development without public sanitary sewer service on lots of less than one acre in size.

Climate

The Milwaukee River watershed is subject to a semi-humid continental type climate and is characterized by the extremes in weather common to its latitude and interior position on the North American continent. Cyclonic activity is the main cause of weather conditions over the watershed, which lies in the path of frontal systems moving across the continent in a generally easterly and southerly direction. Lake Michigan has a moderating effect on the climate of the watershed, which effect, although generally limited to a narrow band located within five miles of the Lake Michigan shoreline, may extend as far as 30 miles inland under some conditions.

Air temperatures within the watershed generally lag about three weeks behind the summer and winter solstices, resulting in July being the warmest month and January the coldest. The mean daily temperature of the watershed ranges from 45.1°F in the lower watershed to 46.4°F in the upper watershed, with recorded extremes ranging from a -29°F to 107°F. The growing season averages about 164 days within the watershed, from about the first week of May to the second week of October.

The average annual precipitation within the watershed is 29.35 inches but has varied from a recorded low of 19.10 inches to a recorded high of 41.86 inches. Approximately 55 percent of the average annual precipitation occurs as rainfall during the growing season. Snowfall accounts for approximately 14 percent of the average annual precipitation and has ranged from a recorded minimum cumulative seasonal snowfall of 12.1 inches to a recorded maximum of 93.3 inches. The maximum recorded 24-hour rainfall within the watershed was 7.58 inches, and the maximum recorded 24-hour snowfall was 16.7 inches.

Northwesterly winds prevail during the winter, whereas southwesterly winds prevail during the summer. The percent of maximum possible sunshine averages about 55 percent during the year, ranging from 40 percent in November through February to 60 percent in June through September.

Physiography

The Milwaukee River watershed is an irregularly shaped drainage basin, with its major axis lying in an approximately north and south direction. The watershed has a total area of approximately 694 square miles, with a length of approximately 46 miles and a width varying from about 26 miles in the northern portions of the watershed to about 4 miles in the lower portions of the watershed. In the lower reaches of the watershed, the boundary of the watershed lies very close to, and parallels the Lake Michigan shoreline.

The topography of the watershed, which is controlled by the bedrock and overlying glacial deposits, is characterized by hills and ridges interspersed with broad undulating plains and poorly drained wetlands. The important rock units underlying the watershed include sandstone, dolomite, and shale and are buried under glacial sand, gravel, and till deposits. Surface elevations range from a high of approximately 1,311 feet above sea level in the Town of Mitchell, Sheboygan County, to approximately 580 feet at the entrance to the Milwaukee Harbor, a maximum relief of 731 feet. The areas of greatest local relief are located northwest of West Bend in Washington County and northeast of Long Lake in Sheboygan County and in places exceed 200 feet, although the local relief is generally less than 100 feet.

The surface drainage pattern of the watershed is poorly developed, and relatively large areas of the watershed are covered by lakes and wetlands. The flow of the Milwaukee River, from its origin in Kettle Moraine Lake in the Town of Osceola, Fond du Lac County, is generally southerly to West Bend, easterly from West Bend to Fredonia, then southerly to its mouth on the Lake Michigan shoreline in Milwaukee. A relatively complex pattern of major tributaries includes the north, east, and west branches of the Milwaukee River and Cedar Creek.

Wetlands

Wetlands having an individual surface area of 50 acres or more cover an aggregate area of about 62 square miles, or about 9 percent of the total area of the watershed. Of this total wetland area, only 11.2 square miles, or 18 percent, are in public ownership.

It is estimated that, at the turn of the century, approximately 120 square miles, or 17 percent of the total area of the watershed, were covered by such wetlands. Thus, nearly one-half of the original wetlands existing within the watershed have been destroyed. This destruction is continuing at the rate of approximately 0.9 square mile per year, with most of the loss being due to the conversion of wetlands to agricultural use through drainage improvements, although urbanization is taking an increasing total. At the same time, the natural quality of the remaining wetlands is deteriorating as a result of human activities within the watershed.

The wetlands are among the most important elements of the natural resource base of the watershed. Wetlands are important not only to the maintenance of a desirable hydrologic regimen within the watershed, reducing flood flows, but are important also to the maintenance of the overall quality of the environment. Wetlands provide habitat for thousands of species of organisms involved in soil formation, plant and animal growth, and nutrient recycling. Requiring thousands of years to form, wetlands once destroyed are irreplaceable.

Woodlands

Woodlands presently cover an aggregate area of about 111 square miles, or 16 percent of the total area of the watershed. Although the in-Region portion of the watershed constitutes only 16 percent of the total area of the Region, it contains over 27 percent of the total regional woodland area. Primarily located on ridges and steep slopes, along lakes and streams, and in wetlands, these woodlands provide an attractive countryside resource of immeasurable value. Woodlands assist in maintaining unique natural relationships between plant and animal communities, reduce storm water runoff, contribute to the atmospheric oxygen and water supply, provide a resource base for the forest products industry, and make an invaluable contribution to the natural beauty of the countryside.

It is estimated that, at the time of settlement by Europeans, approximately 576 square miles, or 83 percent of the total area of the watershed, were covered by woodlands. Thus, over 80 percent of the original woodland cover of the watershed has been destroyed. This destruction is continuing at the rate of approximately 400 acres per year, with most of the loss being due to land clearing, highway construction, drainage of wetlands, and degeneration and neglect. Approximately 250 acres of land are being planted to woodlands each year within the watershed, primarily to conifer species. The present rate of loss may be expected to accelerate rapidly in the foreseeable future unless a sound woodland management and active reforestation program is instituted within the watershed. This is so because many of the remaining woodlands of the watershed consist entirely of even-aged old trees, with no reproduction or saplings to maintain the stands after the present trees mature and die. In this connection, it is particularly important to note that, of the total area of woodland cover presently existing within the watershed, less than 24 percent is in public ownership. Thus, private action will be essential to the maintenance of a healthy woodland cover within the watershed.

Water Resources

The surface water resources, consisting of lakes and streams, provide the singularly most important feature of the landscape within the Milwaukee River watershed and serve to enhance all proximate land uses. The ground water resources of the watershed are closely interrelated with the surface water resources, sustaining lake levels and providing the base flows of streams, as well as providing important sources of supply for municipal, industrial, commercial, and domestic water users.

There are approximately 330 lineal miles of perennial streams and watercourses within the watershed and 71 lakes, 21 of which have a surface water area of 50 acres or more. These 21 major lakes provide a combined surface water area of 5.4 square miles, or about 0.8 percent of the total watershed area, and a total of 59 miles of shoreline. The 50 smaller lakes provide a combined surface water area of about 1.1 square miles, or about 0.2 percent of the total watershed area, and a total of 41 miles of shoreline.

The Milwaukee River watershed is richly endowed with ground water resources. Three ground water aquifers underlie the watershed: 1) the unconsolidated sand and gravel deposits of the glacial drift; 2) the dolomite aquifer, consisting of dolomite strata of the underlying and interconnected bedrock; and 3) the sandstone aquifer, consisting mainly of sandstone and dolomite strata.

The sandstone aquifer comprises the deepest of the three aquifer systems. Wells tapping this aquifer are sometimes more than 1,200 feet deep and are, therefore, relatively expensive to drill. This aquifer, except for minor leakage and connection to the natural recharge area, is hydraulically separated from the shallower aquifer systems by an overlying, nearly impermeable shale formation. This separation makes the deep aquifer less susceptible to man-made pollution. The sandstone aquifer is the source of water supply for three municipalities located within the watershed but outside Milwaukee County and for several large industrial and commercial firms within the watershed. Pumpage from this aquifer approximates 3 million gallons per day, of which slightly over 2 million gallons per day are pumped by the three municipal water utilities. Recharge of the deep sandstone aquifer is by percolation in the recharge areas located in Dodge, Fond du Lac, Jefferson, and Waukesha Counties outside the watershed boundaries. Presently, the rate of withdrawal of water from the sandstone aquifer exceeds the rate of recharge, and this has resulted in large declines in piezometric levels in the southern portion of the watershed.

The dolomite aquifer, one of the two "shallow" aquifers, is the most widely used aquifer in the watershed. It furnishes water for seven municipalities, several industries, and nearly all of the rural domestic and agricultural users. Pumpage from this aquifer approximates 7.4 million gallons per day, of which about 2.6 million gallons per day are pumped by the seven municipal water utilities. Recharge is by leakage from the overlying glacial deposits.

The sand and gravel aquifer, the other "shallow" aquifer, is not widely used within the watershed. It furnishes part of the water supply of the City of West Bend and a few rural domestic users. Recharge is by direct infiltration of precipitation.

The shallow aquifers are recharged locally, and the average annual recharge is estimated to range between 1 and 4 inches of water over the watershed, depending mainly upon the type of surficial deposits present. This recharge rate represents the range of sustained yield of the shallow aquifers in the watershed. Ground water pumpage from the shallow aquifers may affect local ground water movement and runoff; and shallow wells located near streams, lakes, or wetlands may directly or indirectly affect streamflow and the stages of lakes and wetlands. Ground water within the Milwaukee River watershed is discharged both naturally and artificially to the lakes and streams. The long-term average rate of ground water discharge to the Milwaukee River is estimated at about 100 cfs, as measured at the Milwaukee stream gaging station, although ground water discharge fluctuates from year to year with climatic conditions.

Water from the watershed aquifers is chemically classified as hard, containing relatively high concentrations of calcium, magnesium, and sulfate among other dissolved solids. The quality, however, is superior to stream water quality and, if protected from pollution, is generally well suited to domestic and industrial use. Pollution of the ground water in the shallow aquifers is a potential problem in localized areas of the watershed, particularly in those areas where residential land uses are concentrated and waste is discharged into septic tank systems, where the water supply is obtained from shallow wells, where the water table is close to the land surface, where the soil is highly pervious, or where creviced bedrock extends near the land surface. Without preventive measures pollution of the shallow aquifers can become a serious local problem within the watershed. These shallow aquifers constitute the most important source of water available to meet small, highly dispersed demands, such as those generated by residential development not served by public water supply systems.

Saline ground water is a naturally occurring pollutant of the deep sandstone aquifer. Such saline waters are present in the sandstone aquifer along the eastern edge of the watershed and move under the stress of pumping. Control of this source of natural pollution will require managed pumping of the deep aquifer and increasing use of Lake Michigan or the dolomite aquifer as a source of municipal, industrial, and commercial water supply in the Mequon and Milwaukee County area of the watershed.

Existing and Potential Park Sites

An inventory conducted as a part of the watershed study indicated that 186 park and related open-space sites existed within the watershed in 1967, totaling 29,065 acres, or about 45.5 square miles in area. Approximately 68 percent of these sites and 86 percent of this total area are in public ownership. About 11 percent of the publicly owned sites and 89 percent of the area held in public ownership are held by the state, consisting, however, primarily of large woodland and wildlife conservancy areas in the Kettle Moraine State Forest. Only 38 percent of the publicly controlled recreational lands within the watershed are actually available to meet the growing demand for the 16 major water- and land-based recreational activities. Hunting lands comprise over 81 percent of this available area. Consequently, only 2,124 acres, or about 19 percent of the total publicly controlled recreational lands within the watershed, are available for all other major outdoor recreational uses.

Lands providing access to surface waters for water-based recreational activities, which activities comprise over 30 percent of the total outdoor recreational demand within the watershed on an average seasonal Sunday, account for less than 1 percent of the total publicly owned recreational land area within the watershed; and, of this total, 50 percent is owned or operated by local units of government. Surface water area in the watershed totals approximately 6,800 acres, or less than 1.5 percent of the total area of the watershed, of which approximately 3,055 acres, or approximately 45 percent, are available for swimming, provided that water quality levels suitable for full-body-contact recreation can be maintained; and 3,745 acres, or about 55 percent, are available for all other water-based recreational uses. Currently, the existing water-oriented participation demand of 21,159 participants, excluding swimming, on an average seasonal Sunday, and assuming an average turnover rate of three participants per day have only 1.0 acre of available lake and stream surface area allocated to each participant for the water-based recreational activities other than swimming, which is far below the recommended overall standard of five acres per participant necessary to achieve good water management per Department of Natural Resources recommendations. Over 20 percent of the total demand for water-based recreational activities within the watershed is generated by out-of-state users, while approximately 32 percent is generated from within the state but outside the watershed. Yet, over 50 percent of the publicly owned water-based recreational land development is provided by local governments whose residents make the least use of the facilities provided.

Forecasts indicate that the participant demand for the water-based recreational activities within the watershed may be expected to more than double, from 65,000 to 157,000 participants on an average seasonal Sunday by 1990. Swimming, fishing, and boating may be expected to constitute the most popular water-based recreational activity. Land-based participant demand for major recreational activities within the watershed may be expected to almost double, from 145,000 to 255,000 participants per average seasonal Sunday. Pleasure driving and sightseeing may be expected to remain the most popular land-based activities, along with picnicking. These forecasts, when related to the existing supply of recreational lands within the watershed, indicate that an additional 10,842 acres of land will have to be devoted to recreational use within the watershed by 1990, an increase of 87 percent over present levels.

Inventories conducted as a part of the watershed planning program indicate that 131 potential park and related open-space sites, totaling 21,935 acres, or approximately 34 square miles in area, exist within the watershed, of which almost one-half are considered to possess high recreational resource value. These high-value sites, moreover, comprise over one-half of the total potential park and related open-space site acreage within the watershed and constitute one of the most valuable resources of the watershed.

Fish and Wildlife

Of the 21 major lakes within the watershed, 15 sustain a moderate fishery and must support the major proportion of the heavy fishing demand exerted upon the fishery resources of the watershed. Dominant fish species of these lakes, in order of importance, include bluegill, largemouth bass, northern pike, walleye, bullhead, black crappie, yellow perch, and carp. Stream fisheries are limited within the watershed to five major streams—the Milwaukee River and its three branches—the East, North, and West Branches—and Cedar Creek. The Milwaukee River and its branches support fisheries consisting of smallmouth bass, northern pike, bullheads, carp, and white suckers. The streams supporting fisheries have a combined length of 197 miles, or about 60 percent of the total perennial stream channel mileage within the watershed. There are five officially designated trout streams in the watershed, having a combined length of about 15 miles, including: Lake Fifteen Creek in Fond du Lac County and Gooseville Creek, Melius Creek, Nichols Creek, and Watercress Creek in Sheboygan County. Maintenance and improvement of these fishery resources are ultimately dependent upon water pollution abatement and lake eutrophication control efforts, although maintenance of the lake fisheries requires protection of the remaining natural spawning areas.

The watershed contains an estimated 67,662 acres, or 105 square miles, of wildlife habitat, exclusive of open-water areas exceeding 10 acres in surface area. The in-Region portion of this total approximates 16 percent of all the remaining wildlife habitat within the Region. Of the total within the watershed, 45 square miles, or 43 percent, are rated as high-value habitat areas. Game within the watershed consists primarily of small upland game, such as rabbit and squirrel; some predators, such as fox and raccoon; and game birds, including pheasant and waterfowl. Deer are also found in significant numbers in some parts of the watershed. This wildlife provides a valuable and much sought recreational resource and thereby contributes both directly and indirectly to the overall quality of the environment within the watershed. The productivity of the remaining wildlife habitat is dependent not only upon the maintenance of the habitat areas in natural open space but also upon the use of surrounding lands. Use of such lands for agricultural purposes can abet the productivity of certain types of wildlife habitat, while use of such lands for intensive urban development can stifle such productivity. Competing land uses and improper development practices are continually lowering the quality, as well as the quantity, of the remaining wildlife habitat; and many species of wildlife, particularly pollinating insects and other lower forms of species required to maintain an ecological balance, will be threatened with extinction over the watershed unless the remaining high quality natural areas are protected and preserved.

Environmental Corridors

One of the most important tasks completed as part of the regional planning effort has been the identification and delineation of environmental corridors. These corridors are defined as elongated areas which encompass the best remaining elements of the natural resource base, including the lakes and streams and their associated shorelands and floodlands, wetlands, woodlands, wildlife habitat areas, areas containing rough topography and significant geological formations, and the best remaining potential park and related open-space sites. These corridors also contain significant areas of wet or poorly drained and highly organic soils poorly suited to urban development of any kind. The preservation of these corridors in a natural state or in park or related open-space uses, including limited agricultural and large estate-type residential uses, is essential to maintaining the quality of the environment within the watershed and to the protection of its natural beauty.

The primary environmental corridors encompass a total area of about 157 square miles, or about 23 percent of the total area of the watershed. These corridors contain, however, 52 lineal miles, or 88 percent, of the total lake shoreline on the 21 major lakes within the watershed and 282 miles, or 85 percent, of the major stream channel length within the watershed. The corridors encompass almost 68 percent of all the remaining wetlands and 63 percent of all the remaining woodlands within the watershed. The corridors also encompass 67 percent of the wildlife habitat areas remaining within the watershed.

Surface Water Hydrology

The Milwaukee River watershed is a composite hydrologic unit of 11 subwatersheds, with flow occurring in a generally southeasterly direction. The major axis of the watershed lies in an approximately north-south direction.

Historical streamflow records representing runoff from the entire watershed as measured at Milwaukee indicate that severe floods are seasonal in nature, being concentrated in the late winter-early spring period, with five of the six largest annual peak discharges during the 54-year period of record occurring in March or April. The transition from winter to spring offers the greatest potential for large, relatively rapid runoffs to the watershed stream system, with those runoffs generally being generated by snowmelt-rainfall combinations accentuated in severity by frozen ground.

The drainage pattern of the Milwaukee River watershed is basically dendritic, although much of that pattern has been modified by the erratic topography created by glaciation. The drainage system is inefficient. Average land slopes within the basin are generally less than 5 percent, producing relatively long times of concentration and low-peak, long-duration runoff contributions to the channel system. Bed slopes of the channel system are irregular, with steep slopes near the channel heads and often alternating flat and steep slopes in the mid and lower reaches, resulting in generally low streamflow velocities and long flood passage times, approximating 12 days for a major flood on the main stem of the Milwaukee River at the Milwaukee gage.

The long-term average rate of annual water loss through evapotranspiration is estimated at about 23 inches for the watershed, or approximately 77 percent of the average annual precipitation of about 30 inches. Annual watershed runoff, which accounts for the remaining 7 inches of precipitation, occurs at a nonuniform rate during the year and is accomplished by several different physical processes. It is composed of direct runoff coincident with rainfall precipitation events, runoff from melting snowpack, and discharge from ground water storage as reflected in the base flow of the watershed stream system. About 65 percent of the watershed runoff occurs in the six-month period extending from November through April, although only about 38 percent of the precipitation occurs during this period. Streamflow varies widely from season to season and from year to year. Over a long period of time, however, the outflow from, and inflow to, the watershed have been about equal, indicating that there is no apparent long-term trend toward a net gain or loss in the total quantity of water within the basin. Streamflows average about 250 cfs during much of the summer, fall, and winter months, with only minor rises after heavy rainfalls. High streamflows and floods are generally associated with snowmelt, and most critical flood flows result from rainfall during a snowmelt period.

A profusion of surface water storage areas exists within the watershed and serves to decrease peak discharges and increase the duration of runoff. The 71 lakes within the Milwaukee River watershed have a total surface area of about 6.5 square miles, or approximately 0.9 percent of the total watershed area. An additional 62 square miles, or 9 percent of the watershed area, are covered by permanent wetland areas which also serve to reduce peak runoffs. Major wetland areas having an important effect on streamflow include the wetlands along the East Branch of the Milwaukee River, the Lake Fifteen area wetlands, the wetlands tributary to the Kettle Moraine Lake Outlet, Jackson Marsh on Cedar Creek, and the Cedarburg Bog tributary to Cedar Creek. These lakes and wetlands, together with the temporary floodplain overflow area storage of the riverine areas, tend to provide a large degree of natural flood control within the basin.

The peak discharge of a 100-year recurrence interval flood on the Milwaukee River at the Estabrook Park gaging station in the City of Milwaukee is estimated at 16,000 cfs, or 23.3 cfs per square mile of tributary drainage area. This is higher than the peak discharge of the 100-year recurrence interval flood of the Fox River at Wilmot, Wisconsin, estimated at 9,400 cfs, or 10.8 cfs per square mile of tributary drainage area. The unit discharge is, however, considerably lower than the comparable unit discharge of the Root River at Racine, Wisconsin, estimated at 53 cfs per square mile of tributary drainage area, equivalent to a total discharge of 9,900 cfs. Thus, although the Milwaukee River watershed system is not as naturally a well-regulated system as the Fox River watershed system, a considerable potential still exists for maintaining a well-regulated streamflow regimen through maintenance of existing lakes and wetlands. The mean daily discharge of the Milwaukee River at Milwaukee may be expected to equal or exceed about 59 cfs 90 percent of the time and has been known to range from a maximum of 14,800 cfs to a minimum of 0 cfs at the Milwaukee (Estabrook Park) gage.

Existing Water Control Structures

There are 48 man-made water control structures within the Milwaukee River watershed, not including bridges and culverts, which serve to regulate or modify the natural flow regimen of the stream system to some degree. Eleven of these dams are located at natural lake outlets and were constructed to regulate and control the lake levels, while 37 are located on the stream network proper and were originally constructed primarily to impound water for either power generation or transportation purposes, although one structure—the dam at Estabrook Park in the City of Milwaukee—was constructed specifically and primarily for flood control, maintaining normal water level and providing recreational facilities.

The water surface area of the 48 pools controlled by all of the existing dams within the watershed totals about 3,200 acres. About 40 percent of this total area is provided by Big and Little Cedar Lakes. The 11 natural lakes controlled by dams are considerably larger in area than the man-made ponds controlled by dams, ranging in size from a maximum of 932 acres for Big Cedar Lake to a minimum of 35 acres for Erler Lake. The artificial ponds controlled by dams located on the Milwaukee River system vary in surface area during normal streamflows, from a maximum of about 200 acres for the impoundment behind the Thiensville Dam to less than 0.1 acre for the Nature's Friends Dam. Only two of the 37 man-made impoundments—the ponds behind the West Bend and Woolen Mills Dams—are capable of providing any measurable degree of floodwater storage, although even the amount of floodwater storage available behind these two dams is insignificant in terms of flood control on a watershed-wide basis.

Under existing conditions, if full utilization of the storage capacity of the 14 impoundments on the main stem of the Milwaukee River could be achieved, the peak flood flow of 16,000 cfs for a 100-year recurrence interval flood on the Milwaukee River at the Estabrook Park gaging station in the City of Milwaukee might be reduced by about 2 percent. The natural lakes and impoundments controlled by dams do exert a moderating effect, however, on major flood flows on Silver Creek in the West Bend area of Washington County (Silver Lake Dam, Lucas Lake Dam, and Pick Dam); on Silver Creek in the Sherman Township area of Ozaukee and Sheboygan Counties (Random Lake Dam); on the East Branch of the Milwaukee River in the Osceola and Auburn Townships area of Fond du Lac County (Dundee Dam, Mauthe Lake Dam, and New Fane Dam); and on that reach of Cedar Creek extending upstream from the Village of Jackson in Washington County (Schweitzer Dam, Lent Dam, Little Cedar Lake Outlet, and Big Cedar Lake Outlet); but, in each case, the effect does not extend very far downstream from the dams and is not significant with respect to the watershed as a whole. All of the dams in the watershed are relatively low, having a height of 25 feet or less, and are about equally divided between dams with free overflow weirs and dams with spillways controlled by stoplogs or gates.

The dams controlling the Cedar Lakes and the Barton Pond in the West Bend area have potential for low-flow augmentation. A three-foot drawdown of the Barton Pond over a period of one week would yield a flow of about 13 cfs, nearly twice the seven-day low flow of the Milwaukee River at West Bend. A one-foot drawdown of the two Cedar Lakes over a period of one month would yield a flow of about 17 cfs, nearly 17 times the seven-day low flow of Cedar Creek and twice that of the lower Milwaukee River.

Failure of any of the existing dams within the watershed would not be expected to result in significant damage because the dams impound only small volumes of water at low heads. An inspection of all of the dams, carried out as a part of the watershed study, indicates that more detailed engineering investigations should be carried out for the existing North Avenue Dam in the City of Milwaukee and the Woolen Mills Dam in the City of West Bend in order to determine properly the stability and safety of these two major dams. In addition, a program under which all of the dams within the watershed are inspected twice annually should be mounted to monitor changes in seepage, slide, scour, or other signs of distress. Such a program should be carried out under the direction of a professional engineer qualified in the design, construction, and repair of dams.

Approximately 49 miles, or 15 percent of the perennial stream system of the Milwaukee River watershed, have been modified by straightening, deepening, or by increasing the cross-sectional area; by improving the horizontal gradeline; or by diking, all of which result in increased velocities of flow and decreased times of concentration. The most intensive channel improvements have been made on Lincoln and Cedar Creeks and the main stem of the Milwaukee River in the lower watershed and have served to affect peak flood flows along Lincoln and Cedar Creeks and the Milwaukee River itself. Because of the large amount of natural storage which still exists within the watershed and because of the time delay effects which the Lincoln and Cedar Creek improvements have had on peak flows in the Milwaukee River, the net effect on the overall flow regimen of the stream system has been relatively insignificant.

Artificial subsurface drainage improvements for agricultural purposes have been made in an approximately 33 square mile area, or 5 percent of the total watershed area. It is doubtful, however, that this tiling has had any perceptible influence on the hydrologic performance of the watershed, particularly during spring snowmelt-rainfall floods, when ice conditions may prevent operation of the tiled drains.

There are a total of 209 highway and railroad bridge crossings over the main channel system of the Milwaukee River watershed, with the greatest number of crossings per river mile being 3.26 in the Lincoln Creek subwatershed and the least number being 0.49 per river mile in the upper Milwaukee River subwatershed. The average distance between crossings for the entire watershed is approximately one mile. The retardation effect of these structures on peak flood flows is significant but greatly overshadowed by the influence of the natural characteristics of the watershed.

Flood Characteristics and Damages

The watershed, while having a history of relatively frequent minor flooding, has experienced five major floods in recent times. The record of river discharge maintained at Estabrook Park in the City of Milwaukee since 1914 indicates that, over the past 54-year period through 1968, 32 of the yearly peak flood discharges, including five of the six highest recorded, have occurred in March or April, many as combination snowmelt-rainfall floods.

The most recent of the major floods within the watershed occurred in March-April of 1960 and was a flood having an approximately 10-year recurrence interval. The peak rate of discharge of this flood, as measured at the Estabrook Park gaging station in the City of Milwaukee, was 9,300 cfs. Other major significant flood events which have occurred within the watershed took place in March of 1959, March of 1929, August of 1924, and March of 1918. The August 1924 flood was the result of a high-intensity thunderstorm centered approximately over the City of West Bend and was a flood having an approximately 77-year recurrence interval. The peak discharge of this flood was 15,100 cfs. The snowmelt-rainfall March 1918 flood also had a discharge of 15,100 cfs, thus also having a recurrence interval of approximately 77 years.

Extensive field surveys carried out as a part of the watershed study revealed that the flood damage potential within the watershed is substantial and may be expected to increase if development of the floodways and floodplains of the watershed for urban land uses is allowed to continue. The floodways and floodplains along the 216 miles of the watershed stream system included in the flood-flow simulation model comprise only 7 percent of the total area of the watershed and lie almost entirely within the primary environmental corridors of the watershed. As of 1967, approximately 2 square miles, or 4 percent of these floodways and floodplains, had been developed for urban use. If existing land use development trends are allowed to continue in the riverine areas of the watershed, urban land uses within these floodways and floodplains may be expected to increase by an additional 11 square miles; and the total average annual flood damage risk may be expected to increase from the 1967 level of approximately $119,000 per year to approximately $159,900 per year by 1990. Damages from a single 100-year recurrence interval flood may be expected to increase from a present level (1967) of $1,800,000 to over $2,000,000 by 1990. If the March-April 1960 flood on the Milwaukee River were to recur under present (1967) land use development conditions, it could be expected to cause monetary damages totaling about $334,800, about 78 percent of which would be incurred by private property owners and 22 percent by public or quasi-public agencies. If the August 1924 or the March-April 1918 flood on the Milwaukee River were to recur under present land use development conditions, each could be expected to cause monetary damages totaling about $1.8 million. In the absence of sound regulation of floodland development within the watershed by the local units of government responsible for such regulation, these damages could be expected to increase to $485,000 and $2.2 million, respectively, by the year 1990.

The reaches of heaviest potential flood damages along the Milwaukee River are in the City of Glendale, from W. Silver Spring Drive to a point approximately one-quarter mile south of Bradley Road, where total flood damages from a 100-year recurrence interval flood could be expected to exceed a total of $584,000, or nearly 32 percent of the total of such flood damages throughout the watershed, and in the City of Mequon and Village of Thiensville, from the Milwaukee County Line Road to CTH C, where such damages could be expected to exceed $688,000, or about 43 percent of the total watershed flood damages. These five reaches of the watershed could be expected to experience total damages of over $1,270,000, or about 69 percent of the total flood damages accompanying a 100-year recurrence interval flood within the watershed. It is important to note that no significant flood damages would be expected to occur in that highly urbanized reach of the river below the North Avenue Dam in the City of Milwaukee, since the channel section in this reach is able to pass the 100-year recurrence interval flood with only minor local overbank flooding and then only if the peak flood flows occur concurrently with high lake levels.

A flood-flow simulation model, consisting of two sequential submodels, was used to simulate the hydrologic and hydraulic performance of the watershed. The backwater submodel was first used to develop stage-discharge relationships at 694 locations corresponding to 208 channel-floodplain cross-sections and at the upstream and downstream sides of 243 dams, bridges, and culverts along the 216 miles of perennial channel studied. With this information as input, the flood-routing submodel was then used to compute peak discharges and corresponding stages for selected major flood events. The accuracy of these simulated discharges and stages was verified by comparison with historic peak discharges, hydrographs, and runoff volumes, as measured at two U. S. Geological Survey gaging stations—one at Milwaukee and one at Cedarburg—and by correlation with historic high water marks. Maximum 10- and 100-year recurrence interval water surface elevations, as computed by the calibrated simulation model, were then used to prepare flood profiles and to delineate on maps the lateral extent of inundation and thus identify flood-prone riverine areas in the watershed, including those that may be expected to experience flood damage. The model was also used to develop discharge-frequency relationships at 14 key watershed locations in addition to the two discharge-frequency relationships obtained by statistical analysis of historic streamflow records at the Milwaukee and Cedarburg gages. The relative effectiveness of alternative flood control measures was evaluated with the assistance of discharges and stages synthesized by the flood-flow simulation model, and the model also facilitated an assessment of the probable effect of future urbanization on major flood events within the watershed.

Continuing urbanization may be expected to have an insignificant influence on peak streamflows in the perennial channel system of the watershed. Four rapidly urbanizing sub-basins in the West Bend and Mequon areas, however, are expected to exhibit increases in future local peak discharge of up to 25 percent for major snowmelt-rainfall flood events.

Stream Water Quality and Pollution

The existing stream water quality data collated and the new stream water quality data collected under the Milwaukee River watershed study indicate that, although stream water quality conditions vary greatly from the upper to the lower reaches of the watershed, pathogenic contamination and nutrient pollution, as indicated by coliform count and phosphorus concentrations, are serious problems throughout almost all of the watershed. Organic pollution, as indicated by dissolved oxygen levels, is not yet as serious a problem in the Milwaukee River watershed as in some other watersheds of the Region, particularly the Root and Fox River watersheds; but relatively long reaches of the Milwaukee River, nevertheless, exist in which dissolved oxygen levels drop below the minimum levels required to sustain fish life during the night-time hours of the summer months. Inorganic pollution is not widespread but constitutes a constant danger, while aesthetic pollution is clearly in evidence, particularly in the lower reaches of the watershed.

Existing water quality conditions do not, considering the watershed as a whole, meet the standards for the state-established water use objectives. These objectives include the maintenance of a warm-water fishery and whole-body-contact-recreational use for all streams in the watershed except Lincoln and Indian Creeks and, in addition, industrial and cooling water use of the entire main stem of the Milwaukee River and of Cedar Creek at Cedarburg. Over 84 miles, or about 85 percent of the total length of the main stem of the Milwaukee River, from its source in the Town of Osceola (Fond du Lac County) to its discharge to the Lake Michigan estuary at the North Avenue Dam in Milwaukee, presently do not meet one or more of the standards for one or more of the state-established water use objectives. Similarly, over 44 miles, or about 20 percent of the total length of the 29 major tributaries of the Milwaukee River, do not meet one or more of the standards for one or more of the state-established water use objectives. Stream water pollution, while generally widespread throughout the watershed, is particularly severe below the Milwaukee County line; and the Milwaukee River and its tributaries in the lower reaches of the watershed may be considered to be grossly polluted.

Twelve major municipal sewage treatment plants, all of which provide secondary treatment, discharge wastes to surface waters of the Milwaukee River watershed. These 12 plants are all located upstream from the Milwaukee County line. The major pollutants associated with the wastes from these treatment plants are oxygen-demanding organic materials (BOD), pathogenic bacteria, and nutrients. The water quality analyses conducted in the watershed study, including the development and calibration of a water quality simulation model, led to the conclusion that, above the Milwaukee County line, most of the average daily organic waste loading was contributed by the waste discharges of these sewage treatment plants and that the BOD contributions from other sources, such as urban and rural runoff, were minor, particularly during times of low stream flow. The BOD loading under low flow stream flow conditions above the Milwaukee County line averaged, in 1967, about 1,200 pounds per day.

A similar analysis at the North Avenue Dam indicated a total average daily organic waste loading contribution to the river system of about 18,200 pounds. Of this total, 7 percent, or 1,200 pounds, are contributed by the sewage treatment plants located above the Milwaukee County line, and 93 percent, or 17,000 pounds, are contributed by the sewer overflows located on the river system between the Milwaukee County line and the North Avenue Dam. Of the latter, 85 percent, or 14,450 pounds, are contributed by the 85 separate sanitary sewer overflows, and 15 percent, or 2,550 pounds, by the 10 combined sewer overflows. Thus, it is estimated that more than 6 million pounds of BOD enter the Milwaukee River above the North Avenue Dam annually as a direct result of sewer overflows.

High coliform counts are found in major reaches of the Milwaukee River. Coliform counts of 9,500 MFCC/100 ml are found below the Kewaskum sewage treatment plant; 5,000 MFCC/100 ml above the Barton Dam; 19,500 MFCC/100 ml in the vicinity of the railroad bridge in West Bend; 5,000 MFCC/100 ml in a reach extending six miles downstream from the West Bend sewage treatment plant; 22,000 MFCC/100 ml above the Chair Factory Dam; 36,000 MFCC/100 ml above the Limekiln Dam in Grafton; 65,000 MFCC/100 ml above the Estabrook Park Dam; 50,000 MFCC/100 ml downstream from the Estabrook Park Dam; and 170,000 MFCC/100 ml upstream from the North Avenue Dam in Milwaukee. Coliform concentrations greater than 1,000 MFCC/100 ml throughout the Milwaukee River, Cedar Creek,[1] Lincoln Creek, the lower reaches of the North Branch, and several small tributaries indicate that these streams are all unsuitable bacteriologically for whole-body-contact-recreational use. Coliform concentrations in excess of 5,000 MFCC/100 ml throughout all, or most of, Cedar Creek, Silver Creek (Sheboygan County), the Adell tributary, and Lincoln Creek and for major reaches of the Milwaukee River downstream from Kewaskum, West Bend, Fredonia, Saukville, Grafton, Thiensville, and Lincoln Creek indicate that these reaches and streams are bacteriologically unsuitable for any recreational use. The principal causes of these high coliform levels outside the Milwaukee County portion of the watershed are effluent discharges from municipal sewage treatment plants. Such high coliform levels in streams within Milwaukee County are principally caused by untreated overflows from the combined and separate sewer systems serving areas tributary to the stream network.

[1] *Water quality sampling data collected by the Wisconsin Department of Natural Resources during the period from 1968 through 1970 indicates a substantial improvement in the water quality of Cedar Creek, primarily due to the correction of malfunctioning septic tank systems located in the watershed area tributary to Cedar Creek and to the improvement of the waste treatment facilities serving the Libby, McNeill, and Libby, Inc. cannery at Jackson. Such corrective action and improvements have been largely due to the efforts of the Cedar Creek Restoration Council, a citizens' organization.*

The major surface water quality problem existing within the Milwaukee River watershed, however, is excessive fertilization. This problem affects all of the river and its major tributaries. The major sources of phosphorus reaching the streams of the watershed are waste discharges from the municipal sewage treatment plants, agricultural runoff, urban runoff, and overflows from the combined and separate sewer systems in Milwaukee County. Approximately 54 percent of the total nutrient loading on the stream system above the Milwaukee County line is contributed by municipal sewage treatment plants, approximately 33 percent by agricultural runoff, approximately 7 percent by urban runoff, and the remaining 6 percent by all other miscellaneous sources. In direct contrast, approximately 18 percent of the nutrient loading on the stream system above the North Avenue Dam is contributed by municipal sewage treatment plants, approximately 11 percent by agricultural runoff, approximately 9 percent by urban runoff, and approximately 60 percent by combined sanitary sewer and storm sewer system overflows, and the remaining 2 percent by all other sources.

The connected population served by municipal sewage treatment plants discharging to the Milwaukee River system above the Milwaukee County line may be expected to increase from about 38,000 persons at the present time (1967) to about 65,000 persons by 1990; and the average rate at which these plants discharge treated sewage to the stream system may be expected to increase from the present level of about 7 cfs to almost 19 cfs. This increase may be expected to take place even though the Mequon-Thiensville area is connected to the Milwaukee metropolitan system by the year 1990. Thus, about 23 percent of the sustained low flow of the Milwaukee River at the Milwaukee County line presently consists of sewage treatment plant effluent; and this proportion may be expected to increase to 44 percent by the year 1990.

If adequate disinfection of the effluent from all of the municipal sewage treatment plants is provided, the streams of the watershed outside Milwaukee County may be expected to be bacteriologically suitable for all recreational uses. Within Milwaukee County, however, the streams may be expected to remain unsuitable for such uses because of the effects of the untreated sewage overflows from both the separate and combined sewer systems serving this area of the watershed. In addition, dissolved oxygen levels in over 20 percent of the total length of the main stem of the Milwaukee River may be expected to fall below the levels required for the maintenance of a warmwater fishery throughout relatively long periods of time. Even if an average of 80 percent phosphorus removal is provided at all of the existing municipal sewage treatment plants within the watershed, the total amount of phosphorus discharged to the surface waters of the watershed upstream from the Milwaukee County line by 1990 may be expected to remain at approximately the same level as is presently entering these surface waters and causing nuisance aquatic plant growths.

Thirty-nine industrial waste sources exist in the Milwaukee River basin, with 26 being concentrated in the vicinity of Lincoln Creek and the Milwaukee River downstream from the Milwaukee County line. Major pollutants associated with industrial outfalls are oxygen-demanding organic materials, toxic chemicals, and heat. Although all of the industrial waste discharges affect stream water quality in the immediate vicinity of the outfall, these at present represent a relatively minor contribution to the overall deterioration of surface water quality within the Milwaukee River watershed.

Drainage and runoff from both urban and agricultural lands are also major sources of water pollution within the watershed. Major pollutants associated with such drainage and runoff are silt, nutrients, pesticides, and oxygen-demanding organic materials. All of the Milwaukee County portion of the watershed is served by a centralized public sanitary sewerage system; and, therefore, no significant problem of stream pollution from septic tanks exists within Milwaukee County. About 42 square miles, or 78 percent of the developed urban area of the watershed outside Milwaukee County and all of the rural area, containing a combined population of about 40,000 persons, rely primarily on individual septic tank soil absorption systems for the disposal of domestic wastes. As already noted, about 56 percent of the Milwaukee River watershed is overlain by soils having severe limitations for intensive urban development utilizing soil absorption sewage disposal systems; and some areas of the basin, particularly certain large residential subdivisions, are experiencing problems of faulty soil absorption disposal systems and are thereby contributing to surface water pollution.

Lake Water Quality and Pollution

With respect to lake water quality, the study found that several of the 21 major lakes within the watershed—including Wallace, Smith, Little Cedar, Mauthe, Random and Ellen Lakes—are in an advanced state of eutrophication, as indicated by high phosphorus contents, low dissolved oxygen contents, and excessive growths of algae and aquatic weeds. Coliform levels or concentrations of ions indicative of pollution are found to be high in several of the 21 major lakes in the watershed, including Little Cedar, Ellen, and Random Lakes, and are indicative of the sanitary hazard resulting from sewage discharges resulting from urban type residential development around these lakes. Existing and future water uses of the major lakes in the watershed are and may be expected to remain exclusively related to recreational activities. Thus, present and expected future lake water quality problems include public health hazards and overfertilization. Although eutrophication was, in the past, basically a natural phenomenon, nutrient inflow to the lakes of the watershed as a result of human activities has increased the rate of eutrophication in recent years. Over 90 percent of the phosphorus and 41 percent of the nitrogen presently entering the major lakes of the watershed are estimated to be derived from human activities in the watershed. Major artificial sources of nutrient contributions to the lakes in the watershed are drainage from septic tanks and runoff from agricultural lands. Significant amounts of nutrients leak out of drained and filled wetlands which also contribute to the eutrophication of surface waters. Unless effective water quality management programs are mounted, the number of lakes suitable for recreational and aesthetic enjoyment will continue to decrease rapidly in the future.

Water Use and Supply

Surface water from Lake Michigan is presently the principal source of municipal and industrial water supply within the Milwaukee River watershed. Water use within the basin in 1967 totaled 67 million gallons per day, of which 80 percent was obtained from Lake Michigan to supply the lower reaches of the watershed within Milwaukee County. The remaining 11.8 million gallons per day were obtained primarily from ground water sources to supply users in the Villages of Bayside and River Hills in the lower watershed and all of the watershed above the Milwaukee County line. The quantity of water used within the basin averaged 123 gallons per capita per day, ranging from a high of 293 gallons per capita per day in the Village of Random Lake to a low of 81 gallons per capita per day in the Village of Brown Deer. Municipal and private water utilities supplied 59.2 million gallons per day, or 88 percent of the total use within the basin, of which 53.4 million gallons per day, or almost 91 percent, constituted Lake Michigan water; self-supplied domestic and agricultural users, 4.3 million gallons per day, or 6 percent of the total use, almost all of which constituted ground water; and self-supplied commercial and industrial users, 3.4 million gallons per day, or 6 percent of the total use, almost all of which also constituted ground water.

About 74 percent of the total of 11.8 million gallons of ground water supplied within the basin on an average day was obtained from the shallow aquifers and about 3.1 million gallons per day, or 26 percent, from the deep sandstone aquifer underlying the watershed. Approximately 37 percent of the ground water for municipal and private utilities was derived from the deep sandstone aquifer; almost none of the self-supplied domestic and agricultural water supplies were derived from the deep aquifer; and approximately 50 percent of the self-supplied commercial and industrial use was obtained from the deep aquifer.

Total water use may be expected to increase by about 51 percent within the watershed by 1990, reaching an approximate total pumping rate of 103 million gallons per day, or 37.6 billion gallons per year. Lake Michigan and the Milwaukee River may be expected to supply approximately 76 percent of this total use, while ground water may be expected to supply the remaining 24 percent.

Municipal and self-supplied commercial and industrial use in those portions of the watershed outside the Milwaukee water utility service area may be expected to depend almost entirely upon the ground water for supply and may be expected to pump approximately 16 million gallons per day. The water supply available from ground water sources is believed to be adequate for both municipal and industrial pumpage beyond the year 1990, provided that a properly spaced network of wells is used to develop these supplies and that the recharge areas are protected from incompatible land use development in order to assure both the quantity and quality of the recharge water reaching the aquifers.

The City of Mequon and the Villages of Thiensville, River Hills, and Bayside within the watershed will, by 1990, need to provide public water supply systems. Such systems will become necessary not only because of increasing demand for water and the growing concentration of this demand in small areas but also because of declining water levels in the deep aquifer underlying this portion of the watershed, because of the possibility of the natural pollution of the deep aquifer as the water level continues to decline, because of the susceptibility of the shallow aquifers to man-made pollution, and because of the need for fire protection within the communities. Lake Michigan is the most dependable alternate source from which to obtain such public supply. The Villages of Cascade and Jackson, along with the unincorporated Villages of Newburg and Waubeka within the watershed, will also have to provide public water supply systems by 1990. These communities, however, will be able to obtain the supplies from ground water sources.

CONCLUSION

The publication of this, the first of two volumes comprising the final planning report documenting the findings and recommendations of the Southeastern Wisconsin Regional Planning Commission's comprehensive Milwaukee River watershed planning program, marks the completion of the first phase of that program. That phase has, of necessity, been directed to careful inventory, analyses, and forecast operations in order to provide the definitive knowledge of the existing and probable future state of the 694 square mile watershed necessary as a basis for the preparation of a long-range development plan for the watershed. The inventory findings and forecasts picture a dynamic and rapidly changing watershed, one in which the population may be expected to increase by 25 percent, from 544,000 to more than 678,000 persons within the next 23 years (1967-1990), and one in which the area of land devoted to urban use may be expected to increase by 30 percent, from 102 square miles in 1967 to 133 square miles by 1990. If existing trends are allowed to continue within the watershed, much of this new urban development will not be related sensibly to the underlying and sustaining natural resource base of the watershed, particularly to its soils, its lakes and streams and associated floodlands, its woodlands and wetlands, and its wildlife habitat areas, nor the long-established public utility systems and service areas. The deterioration and, in some cases, the complete destruction of the wetlands, woodlands, wildlife habitat areas, and potential park sites remaining within the watershed can, in the absence of a sound comprehensive watershed development plan, and implementation of that plan, be expected to continue, as can the encroachment of urban development onto the historic floodlands of the watershed. Deficiencies in land and water area for outdoor recreational use, already evident, can be expected to become more severe, as can the serious and widespread environmental problems of flooding and water pollution already existing within the watershed.

The first phase of the watershed planning program and this, the first volume of the watershed planning report, have, of necessity, been confined, as already noted, to documenting the existing and probable future water resource and water resource-related problems of the watershed. This documentation, however, provides the basis for the development of definitive plans and concrete recommendations for both the public works facility construction and the land and water management policies required to solve the pressing environmental and developmental problems existing within the watershed and thereby to realize the full potential of this important watershed. The alternative courses of action available for abating the problems of the Milwaukee River watershed, together with the recommendations concerning the best courses of action and the means for implementing these, are set forth in Volume 2 of this report.

APPENDICES

Appendix A

TECHNICAL ADVISORY COMMITTEE ON NATURAL RESOURCES AND ENVIRONMENTAL DESIGN

Cyril Kabat . . . . Chairman	Assistant Director, Bureau of Research, Wisconsin Department of Natural Resources
Kurt W. Bauer . . . . Secretary	Executive Director, SEWRPC
Jacob D. Dumelle	Director, Chicago Program Office, Federal Water Quality Administration, Great Lakes Region
William E. Frantz.	Public Hearing Engineer, Division of Highways, Wisconsin Department of Transportation
George F. Hanson.	State Geologist and Director, University of Wisconsin Extension Division-Geological and Natural History Survey
Charles L. R. Holt, Jr. . . .	District Chief, Water Resources Division, U. S. Geological Survey
Al J. Karetski	Director, Bureau of Local and Regional Planning, Wisconsin Department of Local Affairs and Development
Robert J. Mikula	County Landscape Architect, Milwaukee County Park Commission
Donald W. Niendorf	Conservation Education Specialist, Soil Conservation Board of The University of Wisconsin
William W. Russell	State Conservationist, U. S. Soil Conservation Service
William Sayles	Director, Bureau of Water and Shoreland Management, Division of Environmental Protection, Wisconsin Department of Natural Resources
Walter J. Tarmann	Executive Director, Waukesha County Park and Planning Commission
Harold W. Weber	Division Engineer, Sewer Construction and Maintenance, Sewerage Commission of the City of Milwaukee
George B. Wesler.	Chief, Planning and Reports Branch, U. S. Army Corps of Engineers
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Harvey E. Wirth	State Sanitary Engineer, Division of Health, Wisconsin Department of Health and Social Services
Theodore F. Wisniewski . . .	Assistant to the Administrator, Division of Environmental Protection, Wisconsin Department of Natural Resources
Kenneth B. Young	Associate Chief, Water Resources Division, U. S. Geological Survey

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Appendix B

MILWAUKEE RIVER WATERSHED COMMITTEE

Richard W. Cutler. . . . . . Chairman	Attorney, Brady, Tyrrell, Cotter & Cutler, Milwaukee; Member, Village of Fox Point Plan Commission; Commissioner, SEWRPC
Richard D. Ziegler . . . . . Vice-Chairman	Vice-President, The West Bend Company; Member, Milwaukee River Flood Control Board
Kurt W. Bauer . . . . Secretary	Executive Director, SEWRPC
Vinton W. Bacon	Professor, College of Applied Science and Engineering, University of Wisconsin-Milwaukee
Ray F. Blank	Ozaukee County Board Supervisor; Commissioner, SEWRPC
Clarence E. Boyke	Fond du Lac County Board Supervisor
Delbert J. Cook.	Chairman, Cedar Creek Restoration Council
Arthur G. Degnitz	Washington County Board Supervisor
Nick R. Didier	Realtor, Port Washington
Herbert A. Goetsch	Commissioner of Public Works, City of Milwaukee
Howard W. Gregg	General Manager, Milwaukee County Park Commission
LeRoy W. Grossman.	Director Emeritus, Capitol Marine Bank; Member, Milwaukee River Flood Control Board
Gilbert J. Howard.	Fond du Lac County Board Supervisor
John J. Juntenen	County Planner, Sheboygan County
John T. Justen	President, Pfister & Vogel Tanning Company, Milwaukee
J. Bryan Keating	District Conservationist, U. S. Soil Conservation Service, Fond du Lac County
Thomas A. Kroehn	Director, Region 2, Division of Environmental Protection, Wisconsin Department of Natural Resources
Ray D. Leary.	Chief Engineer and General Manager, Milwaukee-Metropolitan Sewerage Commissions
Dean Livingston.	District Conservationist, U. S. Soil Conservation Service, Sheboygan County
Reuben T. Lueloff.	President, Village of River Hills
Dr. Darrell M. Martin. . . .	Resident Manager, St. Regis Paper Company, Milwaukee
Carl Otte.	Sheboygan County Board Supervisor
L. N. Peterson	Executive Vice-President, Regal Ware, Inc., Kewaskum
Fred Schmit	Citizen Member, Saukville
George Watts	President, George Watts & Sons, Milwaukee
Donald W. Webster	Consulting Civil Engineer, Milwaukee

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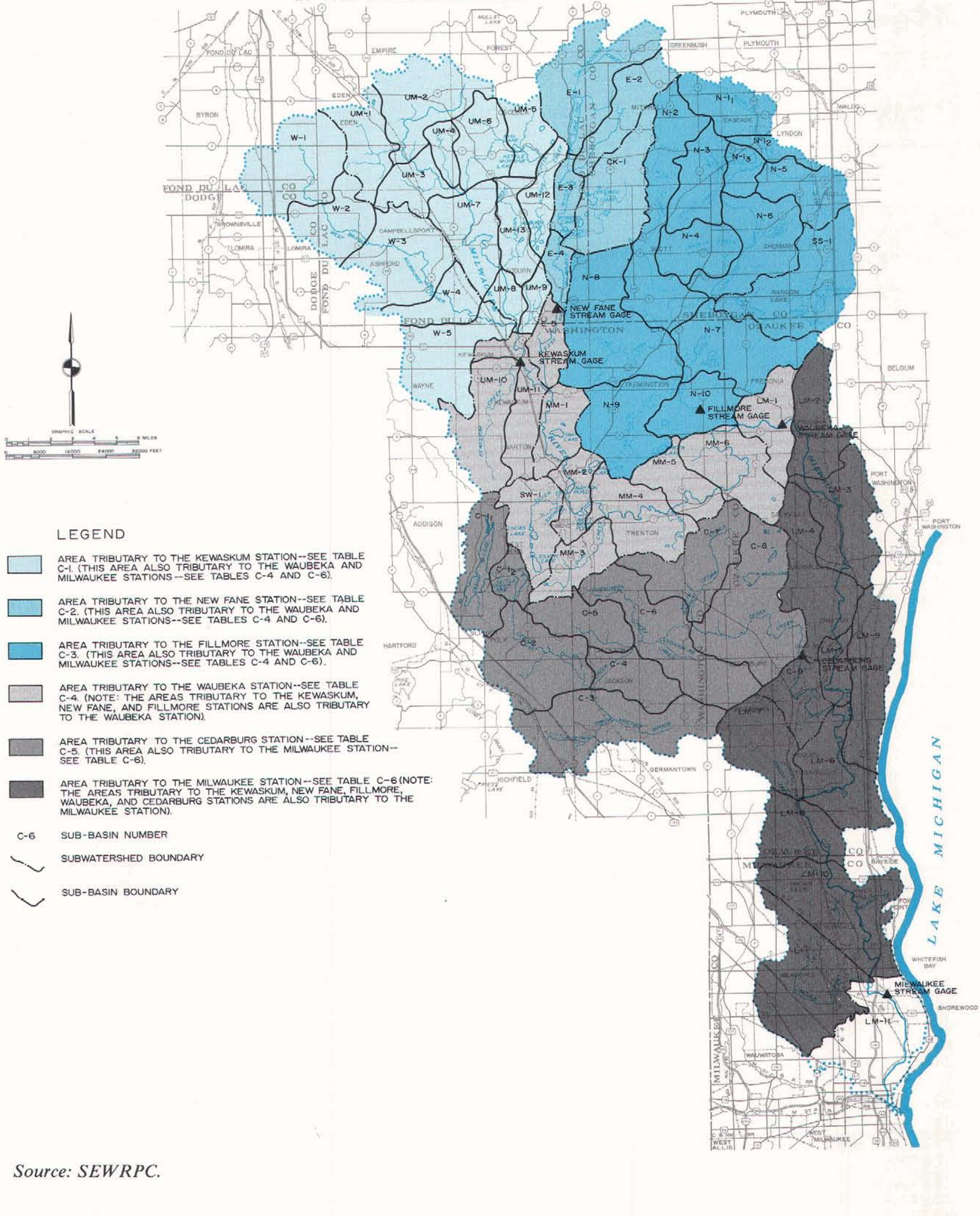
Appendix C

LAND USE IN THE MILWAUKEE RIVER WATERSHED TRIBUTARY TO EXISTING STREAM GAGING STATIONS

Map C-1
AREAS TRIBUTARY TO EXISTING STREAM GAGING STATIONS IN THE MILWAUKEE RIVER WATERSHED



Source: SEWRPC.

TABLE C-1

EXISTING LAND USE IN THE MILWAUKEE RIVER WATERSHED TRIBUTARY TO THE KEWASKUM STREAM - GAGING STATION - 1967

LAND USE CATEGORY	AREA IN ACRES	AREA IN SQUARE MILES	PERCENT OF MAJOR CATEGORY	PERCENT OF WATERSHED AREA
URBAN LAND USE				
RESIDENTIAL				
UNDER DEVELOPMENT............	36.50	0.06	1.1	0.1
DEVELOPED....................	671.08	1.05	19.9	0.8
SUBTOTAL	707.58	1.11	21.0	0.8
COMMERCIAL....................	33.35	0.05	1.0	0.1
INDUSTRIAL....................	32.20	0.05	1.0	0.1
MINING........................	162.28	0.25	4.8	0.2
TRANSPORTATION AND UTILITIES[a]..	2,274.83	3.56	67.3	2.8
GOVERNMENTAL AND INSTITUTIONAL.	86.04	0.13	2.5	0.1
RECREATIONAL[b].................	82.67	0.13	2.4	0.1
TOTAL URBAN LAND USE	3,378.95	5.28	100.0	4.1
RURAL LAND USE				
AGRICULTURAL..................	56,725.93	88.64	71.7	68.8
OPEN LAND				
WATER AND WETLAND............	17,077.32	26.68	21.6	20.7
WOODLAND.....................	4,310.36	6.73	5.4	5.2
UNUSED LAND..................	990.88	1.55	1.3	1.2
TOTAL RURAL LAND USE	79,104.49	123.60	100.0	95.9
TOTAL LAND USE	82,483.44[c]	128.88[c]	--	100.0

[a] INCLUDES OFF-STREET PARKING.

[b] INCLUDES MAJOR AND NEIGHBORHOOD PARKS.

[c] TO SUMMARIZE EXISTING LAND USE AS TABULATED IN THE SEWRPC LAND USE INVENTORY, THE TRIBUTARY AREA WAS APPROXIMATED BY U.S. PUBLIC LAND SURVEY QUARTER-SECTION BOUNDARIES, RESULTING IN A TOTAL AREA OF 128.9 SQUARE MILES. THE ACTUAL MEASURED AREA TRIBUTARY TO THE KEWASKUM STREAM-GAGING STATION IS 132.4 SQUARE MILES.

SOURCE- SEWRPC.

TABLE C-2

EXISTING LAND USE IN THE MILWAUKEE RIVER WATERSHED TRIBUTARY TO THE NEW FANE STREAM - GAGING STATION - 1967

LAND USE CATEGORY	AREA IN ACRES	AREA IN SQUARE MILES	PERCENT OF MAJOR CATEGORY	PERCENT OF WATERSHED AREA
URBAN LAND USE				
RESIDENTIAL				
UNDER DEVELOPMENT............	15.86	0.03	0.9	0.1
DEVELOPED...................	323.05	0.50	17.2	1.0
SUBTOTAL	338.91	0.53	18.1	1.0
COMMERCIAL....................	21.52	0.03	1.2	0.1
INDUSTRIAL....................	2.07	0.01	0.1	0.1
MINING........................	16.94	0.03	0.9	0.1
TRANSPORTATION AND UTILITIES[a]..	768.88	1.20	41.0	2.3
GOVERNMENTAL AND INSTITUTIONAL.	161.74	0.25	8.6	0.5
RECREATIONAL[b].................	564.46	0.88	30.1	1.7
TOTAL URBAN LAND USE	1,874.52	2.93	100.0	5.6
RURAL LAND USE				
AGRICULTURAL..................	15,936.21	24.90	50.2	47.4
OPEN LAND				
WATER AND WETLAND............	8,147.14	12.73	25.6	24.2
WOODLAND.....................	5,800.98	9.06	18.3	17.2
UNUSED LAND..................	1,887.53	2.95	5.9	5.6
TOTAL RURAL LAND USE	31,771.86	49.64	100.0	94.4
TOTAL LAND USE	33,646.38[c]	52.57[c]	--	100.0

[a]INCLUDES OFF-STREET PARKING.

[b]INCLUDES MAJOR AND NEIGHBORHOOD PARKS.

[c]TO SUMMARIZE EXISTING LAND USE AS TABULATED IN THE SEWRPC LAND USE INVENTORY, THE TRIBUTARY AREA WAS APPROXIMATED BY U.S. PUBLIC LAND SURVEY QUARTER-SECTION BOUNDARIES, RESULTING IN A TOTAL AREA OF 52.6 SQUARE MILES. THE ACTUAL MEASURED AREA TRIBUTARY TO THE NEW FANE STREAM - GAGING STATION IS 45.2 SQUARE MILES.

SOURCE- SEWRPC.

TABLE C-3

EXISTING LAND USE IN THE MILWAUKEE RIVER WATERSHED TRIBUTARY TO THE FILLMORE STREAM - GAGING STATION - 1967

LAND USE CATEGORY	AREA IN ACRES	AREA IN SQUARE MILES	PERCENT OF MAJOR CATEGORY	PERCENT OF WATERSHED AREA
URBAN LAND USE				
RESIDENTIAL				
UNDER DEVELOPMENT............	34.32	0.06	0.8	0.1
DEVELOPED....................	1,038.32	1.62	22.5	1.1
SUBTOTAL	1,072.64	1.68	23.3	1.1
COMMERCIAL....................	57.96	0.09	1.2	0.1
INDUSTRIAL....................	46.28	0.07	1.0	0.1
MINING........................	163.45	0.26	3.5	0.2
TRANSPORTATION AND UTILITIES[a]...	2,914.52	4.55	63.3	3.1
GOVERNMENTAL AND INSTITUTIONAL.	114.03	0.18	2.5	0.1
RECREATIONAL[b].................	237.88	0.37	5.2	0.3
TOTAL URBAN LAND USE	4,606.76	7.20	100.0	4.9
RURAL LAND USE				
AGRICULTURAL..................	66,470.78	103.86	73.9	70.3
OPEN LAND				
WATER AND WETLAND............	13,682.74	21.38	15.2	14.5
WOODLAND.....................	8,928.02	13.95	9.9	9.4
UNUSED LAND..................	851.56	1.33	1.0	0.9
TOTAL RURAL LAND USE	89,933.10	140.52	100.0	95.1
TOTAL LAND USE	94,539.86[c]	147.72[c]	--	100.0

[a]INCLUDES OFF-STREET PARKING.

[b]INCLUDES MAJOR AND NEIGHBORHOOD PARKS.

[c]TO SUMMARIZE EXISTING LAND USE AS TABULATED IN THE SEWRPC LAND USE INVENTORY, THE TRIBUTARY AREA WAS APPROXIMATED BY U.S. PUBLIC LAND SURVEY QUARTER-SECTION BOUNDARIES, RESULTING IN A TOTAL AREA OF 147.7 SQUARE MILES. THE ACTUAL MEASURED AREA TRIBUTARY TO THE FILLMORE STREAM - GAGING STATION IS 147.5 SQUARE MILES.

SOURCE- SEWRPC.

TABLE C-4

EXISTING LAND USE IN THE MILWAUKEE RIVER WATERSHED TRIBUTARY TO THE WAUBEKA STREAM - GAGING STATION - 1967

LAND USE CATEGORY	AREA IN ACRES	AREA IN SQUARE MILES	PERCENT OF MAJOR CATEGORY	PERCENT OF WATERSHED AREA
URBAN LAND USE				
RESIDENTIAL				
UNDER DEVELOPMENT............	436.17	0.68	2.6	.2
DEVELOPED....................	4,287.65	6.70	25.9	1.7
SUBTOTAL	4,723.82	7.38	28.5	1.9
COMMERCIAL.....................	222.51	.35	1.3	.1
INDUSTRIAL.....................	341.73	.53	2.0	.1
MINING.........................	658.24	1.03	4.0	.3
TRANSPORTATION AND UTILITIES[a]..	8,530.34	13.33	51.4	3.1
GOVERNMENTAL AND INSTITUTIONAL.	688.53	1.08	4.2	.3
RECREATIONAL[b]..................	1,418.64	2.22	8.5	.5
TOTAL URBAN LAND USE	16,583.81	25.92	100.0	6.2
RURAL LAND USE				
AGRICULTURAL...................	177,672.49	277.61	69.7	65.4
OPEN LAND				
WATER AND WETLAND............	47,338.40	74.00	18.6	17.4
WOODLAND.....................	25,470.65	39.80	10.0	9.4
UNUSED LAND..................	4,418.75	6.90	1.7	1.6
TOTAL RURAL LAND USE	254,900.29	398.31	100.0	93.8
TOTAL LAND USE	271,484.10[c]	424.13[c]	--	100.0

[a]INCLUDES OFF-STREET PARKING.

[b]INCLUDES MAJOR AND NEIGHBORHOOD PARKS.

[c]TO SUMMARIZE EXISTING LAND USE AS TABULATED IN THE SEWRPC LAND USE INVENTORY, THE TRIBUTARY AREA WAS APPROXIMATED BY U.S. PUBLIC LAND SURVEY QUARTER-SECTION BOUNDARY RESULTING IN A TOTAL AREA OF 424.1 MILES. THE ACTUAL MEASURED AREA TRIBUTARY TO THE WAUBEKA STREAM GAGING STATION IS 419.2 SQUARE MILES.

SOURCE- SEWRPC.

TABLE C-5

EXISTING LAND USE IN THE MILWAUKEE RIVER WATERSHED TRIBUTARY TO THE CEDARBURG STREAM - GAGING STATION - 1967

LAND USE CATEGORY	AREA IN ACRES	AREA IN SQUARE MILES	PERCENT OF MAJOR CATEGORY	PERCENT OF WATERSHED AREA
URBAN LAND USE				
RESIDENTIAL				
UNDER DEVELOPMENT............	116.75	0.18	2.2	0.2
DEVELOPED....................	1,688.45	2.64	31.9	2.2
SUBTOTAL	1,805.20	2.82	34.1	2.4
COMMERCIAL....................	36.79	0.06	0.7	0.1
INDUSTRIAL....................	38.18	0.06	0.7	0.1
MINING........................	165.86	0.26	3.1	0.2
TRANSPORTATION AND UTILITIES[a]...	3,022.66	4.72	57.1	3.9
GOVERNMENTAL AND INSTITUTIONAL.	76.87	0.12	1.4	0.1
RECREATIONAL[b]................	153.98	0.24	2.9	0.2
TOTAL URBAN LAND USE	5,299.54	8.28	100.0	7.0
RURAL LAND USE				
AGRICULTURAL..................	53,669.15	83.86	75.1	69.9
OPEN LAND				
WATER AND WETLAND............	11,195.26	17.49	15.7	14.6
WOODLAND.....................	6,314.80	9.87	8.8	8.2
UNUSED LAND..................	293.25	0.46	0.4	0.4
TOTAL RURAL LAND USE	71,472.46	111.68	100.0	93.1
TOTAL LAND USE	76,772.00[c]	119.96[c]	--	100.0

[a]INCLUDES OFF-STREET PARKING.

[b]INCLUDES MAJOR AND NEIGHBORHOOD PARKS.

[c]TO SUMMARIZE EXISTING LAND USE AS TABULATED IN THE SEWRPC LAND USE INVENTORY, THE TRIBUTARY AREA WAS APPROXIMATED BY U.S. PUBLIC LAND SURVEY QUARTER-SECTION BOUNDARIES, RESULTING IN A TOTAL AREA OF 120.0 SQUARE MILES. THE ACTUAL MEASURED AREA TRIBUTARY TO THE CEDARBURG STREAM - GAGING STATION IS 119.9 SQUARE MILES.

SOURCE- SEWRPC.

TABLE C-6

EXISTING LAND USE IN THE MILWAUKEE RIVER WATERSHED TRIBUTARY TO THE MILWAUKEE STREAM - GAGING STATION - 1967

LAND USE CATEGORY	AREA IN ACRES	AREA IN SQUARE MILES	PERCENT OF MAJOR CATEGORY	PERCENT OF WATERSHED AREA
URBAN LAND USE				
RESIDENTIAL				
UNDER DEVELOPMENT............	2,174.99	3.40	4.0	0.5
DEVELOPED....................	20,492.90	32.02	37.6	4.7
SUBTOTAL	22,667.89	35.42	41.6	5.2
COMMERCIAL....................	882.97	1.38	1.7	0.2
INDUSTRIAL....................	1,085.48	1.69	2.0	0.3
MINING........................	1,112.76	1.74	2.0	0.3
TRANSPORTATION AND UTILITIES[a]..	21,451.10	33.52	39.4	5.0
GOVERNMENTAL AND INSTITUTIONAL.	2,846.34	4.45	5.2	0.6
RECREATIONAL[b].................	4,419.89	6.90	8.1	1.0
TOTAL URBAN LAND USE	54,466.43	85.10	100.0	12.6
RURAL LAND USE				
AGRICULTURAL..................	271,368.45	424.01	71.6	62.6
OPEN LAND				
WATER AND WETLAND............	64,752.90	101.18	17.1	14.9
WOODLAND.....................	35,032.18	54.74	9.2	8.1
UNUSED LAND..................	7,791.01	12.17	2.1	1.8
TOTAL RURAL LAND USE	378,944.54	592.10	100.0	87.4
TOTAL LAND USE	433,410.97[c]	677.20[c]	--	100.0

[a]INCLUDES OFF-STREET PARKING.

[b]INCLUDES MAJOR AND NEIGHBORHOOD PARKS.

[c]TO SUMMARIZE EXISTING LAND USE AS TABULATED IN THE SEWRPC LAND USE INVENTORY, THE TRIBUTARY AREA WAS APPROXIMATED BY U.S. PUBLIC LAND SURVEY QUARTER-SECTION BOUNDARIES, RESULTING IN A TOTAL AREA OF 677.2 SQUARE MILES. THE ACTUAL MEASURED AREA TRIBUTARY TO THE MILWAUKEE STREAM - GAGING STATION IS 675.4 SQUARE MILES.

SOURCE- SEWRPC.

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Appendix D

FLOOD DAMAGE SURVEY FORMS

SURVEY OF FLOOD DAMAGE

FORM 1

PUBLIC BUILDINGS AND GROUNDS

Serial Number ______

River ______ Period of Flood ______ Date of Crest ______ Bldg. No. ______ of ______ Bldgs.

County or City ______ Flood Zone ______ Flood Crest ______ ft. on ______ gage

Name of Public Agency ______ Person Interviewed ______

Address of Property Appraised ______

Damage	Cost Estimates: Sub-total	Cost Estimates: Total	Remarks
Direct			
Building:			
Foundation	$		
Superstructure			
Improvements			
Decorations			
Other ______			
Contents:			
Furnishings			
Equipment			
Supplies			
Records, Etc.			
Miscellaneous:			
Minor Bldgs., Contents			
Other Improvements ______			
Grounds			
Parks and Playgrounds			
Cars, Trucks, Etc.			
Total Direct		$	
Indirect			
Loss of Earnings by Employees	$		
Cost of Flood Fighting			
Evacuation and Reoccupation			
Other ______			
Total Indirect		$	
Grand Total		$	

Relevant Data

Value of Building ______ Value of Contents ______ No. of Persons Disrupted From Work ______

Size of Building ______ X ______ ft. ______ No. of Floors ______ Max. Height of Water From Ground at Building ______ ft.

Condition of Buildings Good ______ Fair ______ Poor ______

No. of Days Water in Basement ______ on First Floor ______ on Second Floor ______

No. of Days Use of Facilities Prevented by Flood ______

Ht. of Floors Above or Below Ground (Feet) B ______ 1 ______ 2 ______ 3 ______

Percentage of Value of Contents by Floors B ______ 1 ______ 2 ______ 3 ______

Percentage of Total Losses to Building and Contents by Floors B ______ 1 ______ 2 ______ 3 ______

Data Collected/Submitted by ______ Title ______ Date ______

Signature ______

SOUTHEASTERN WISCONSIN REGIONAL PLANNING COMMISSION

SURVEY OF FLOOD DAMAGE

FORM 3

STREETS AND HIGHWAYS

Serial Number ______

River ______ Period of Flood ______ Date of Crest ______ Name of Street/Highway ______

County or City ______ Flood Zone ______ Flood Crest ______ ft. on ______ gage

Section From ______ State or U. S. Route No. ______ to ______ Length of Section ______

Length Submerged ______ Other Zones Reported ______ Depth Submerged ______ ft.

Damage	Sub-total	Total	Remarks
Direct			
Roadway:			
Embankment	$		
Shoulders			
Roadbed			
Pavement			
Other Surface			
Culverts			
Signposts and Fences			
Cleanup			
Other ______			
Total Direct		$	
Indirect			
Temporary Repairs (Net Cost)	$		
Rerouting Traffic			
Highway Department Patrols			
Cost of Flood Fighting			
Total Indirect		$	
Grand Total		$	

Relevant Data

Number of Days Lowest Point of this Section Was Submerged ______

Number of Days Traffic Was Interrupted ______

Length of Highway Damaged ______

Type of Surface ______ Width of Surface ______

Condition of Surface Before Flood Good ______ Fair ______ Poor ______

Average Daily Traffic Before Flood Cars ______ Buses and Trucks ______

Route of Detour ______

Increased Distance of Detour ______ Miles ______

Losses Prevented by Emergency Preparation ______

Intangibles (Effect on Fire Protection, Ambulance and School Bus Service, etc.) ______

Data Collected/Submitted by ______ Title ______ Date ______

Signature ______

SOUTHEASTERN WISCONSIN REGIONAL PLANNING COMMISSION

SURVEY OF FLOOD DAMAGE

FORM 2

RAILROADS

Serial Number ______

River ______ Period of Flood ______ Date of Crest ______ Flood Crest ______ ft. on ______ gage

County ______ Flood Zone ______ Other Zones Reported ______

Railroad ______ Person Interviewed ______

Section ______ to ______ Length of Section ______ Length Submerged ______ Depth Submerged ______ ft.

Damage	Cost Estimates: Sub-total	Cost Estimates: Total	Remarks
Direct			
Roadway:			
Roadbed or Embankment	$		
Track			
Electric Power Line			
Culverts			
Signal System			
Switching System			
Other ______			
Rolling Stock			
Minor Buildings, Contents, Grounds			
Item ______			
Outdoor Equipment (Stationary)			
Item ______			
Goods in Transit			
Total Direct		$	
Indirect			
Extra Cost of Maintaining Emergency Service	$		
Loss of Profits to Railroad and Shipper by Interruption of Business			
Loss of Earnings by Employees			
Cost of Flood Fighting			
Evacuation and Reoccupation			
Other			
Total Indirect		$	
Grand Total		$	

Relevant Data

Number of Days Track Submerged at Lowest Point ______ Number of Days Service Suspended ______

Number of Parallel Tracks ______

Data Collected/Submitted By ______ Title ______ Date ______

Signature ______

SOUTHEASTERN WISCONSIN REGIONAL PLANNING COMMISSION

SURVEY OF FLOOD DAMAGE

FORM 4

BRIDGES

Serial Number ______

River ______ Period of Flood ______ Date of Crest ______ Owner ______

County or City ______ Flood Zone ______ Flood Crest ______ ft. on ______ gage

Damage	Cost Estimates: Sub Total	Cost Estimates: Total	Remarks
Direct			
Piers and Abutments	$		
Superstructure			
Approaches			
Utilities			
Other ______			
Total Direct		$	
Indirect			
Temporary Structure or Repairs (Net Cost)	$		
Extra Cost of Emergency Rail Service			
Rerouting:			
Highway Department Patrols			
Trucking Companies or Railroads			
Shippers by Truck or Rail			
Other Travelers ______			
Loss of Earnings by Transportation Employees			
Cost of Flood Fighting			
Total Indirect		$	
Grand Total		$	

Relevant Data

Height of Flood Above or Below Bridge Flood ______ Feet Above ______ Below ______

Maximum Head on Bridge ______ Feet. (Refer to Low Steel) ______

Number of Days Superstructure Submerged ______

Parts of Bridge Damaged Beyond Repair ______

Type of Structure ______

Age of Structure ______ Years ______ Condition of Structure Good ______ Fair ______ Poor ______

Original Cost of Structure $ ______

Estimated Remaining Useful Life Just Prior to Flood ______ Years ______

Number of Hours Warning of Flood Stage ______

Losses Prevented by Emergency Preparation ______

Debris or Ice Jam Conditions ______

Route of Detour ______

Increased Distance of Detour ______ Miles ______

Average Daily Traffic Count Before Flood ______ Cars ______ Buses and Trucks ______

Intangibles (Effect on Fire Protection, Ambulance and School Bus Service, etc.) ______

Data Collected/Submitted by ______ Title ______ Date ______

Signature ______

SOUTHEASTERN WISCONSIN REGIONAL PLANNING COMMISSION

SURVEY OF FLOOD DAMAGE

FORM 5
UTILITIES AND COMMUNICATIONS

Serial Number ______

Gas Electric Telephone Telegraph Steam Water Oil

River ______ Period of Flood ______ Date of Crest ______ Location of Damage ______

Owner or Agency ______ Represented by ______ Flood Zone ______

Other Zones Reported On ______ Flood Crest At ______ Depth Submerged ______

______ ft. on ______ gage ______ ft.

Property Damaged (Use Separate Sheet For Each Major Subdivision).

Damage	Cost Estimates: Sub-total	Cost Estimates: Total	Remarks
Direct (Itemize)			
Plant	$		
Other Buildings and Contents			
Loss of Records			
Equipment (Specify)			
Lines or Mains (Feet)			
Other ______			
Total Direct		$	
Indirect			
Emergency Repairs and Services (Additional Net Cost)	$		
Lost Production			
Lost Profit			
Loss of Wages to Employees			
Cost of Flood Fighting or Emergency Precautions			
Evacuation and Reoccupation			
Cleanup			
Other ______			
Total Indirect		$	
Grand Total		$	

Relevant Data

Number of Days Interruption to Normal Service ______ All Service ______
Parts of Utility Damaged Beyond Repair ______
Age of Pertinent Items ______
Condition of Pertinent Items ______
Original Costs of Pertinent Items ______
Estimated Remaining Useful Life Prior to Flood ______ Years ______
Number Hours Warning of Flood Stage ______
Emergency Precautions Taken ______
Losses Prevented by Emergency Precautions ______

Data Collected/Submitted by ______ Title ______ Date ______

______
Signature

SOUTHEASTERN WISCONSIN REGIONAL PLANNING COMMISSION

SURVEY OF FLOOD DAMAGE

FORM 6
RELIEF AND HEALTH EXPENDITURES BY PUBLIC AGENCIES

Serial Number ______

River ______ Period of Flood ______ Flood Zone ______

County ______ Township ______

Official Supplying Information

Agency ______ Name ______

Indirect Losses		Expenditures
Evacuation, Rescue, and Reoccupation	$	
Emergency Supplies		
Food		
Clothing		
Shelter		
Total		$
Administration of Rescue Camps	$	
Medical, Surgical and Hospital Care		
Policing		
Cleanup (Public)		
Public Health Protection of Water Supplies		
Other Sanitary Measures		
Total		$
Grand Total		$

Relevant Data

Sickness and Injury Incident to Flood, Including Drownings

Nature of Sickness or Injury	Number Cases	Number Recovered	Percent Recovered	Deaths	Remarks

Number of Cases of Illness and Injury Receiving No Treatment ______

Number of Persons Immunized Against ______

Typhoid ______ Small Pox ______ Diptheria ______ Tetanus ______ Others ______

Remarks ______

Data Collected/Submitted By ______ Title ______ Date ______

______
Signature

SOUTHEASTERN WISCONSIN REGIONAL PLANNING COMMISSION

SURVEY OF FLOOD DAMAGE

FORM 7
AGRICULTURAL DAMAGES

Serial Number ______

River ______ Period of Flood ______ Date of Crest ______ Total Acreage: Owned ______ Cultivated ______

State ______ County ______ Township ______ Acreage Flooded: Cultivated ______ Other ______

Flood Zone ______ Occupant ______ Owner ______ Flood Stage ______

Name ______ ft. on ______ gage

Damage	Cost Estimates: Sub Total	Cost Estimates: Total	Remarks
Direct			
Crops in Ground	$		
Stored Crops			
Feed and Supplies			
Livestock			
Livestock Products			
Farm Machinery and Equipment			
Cars, Trucks, Wagons, etc.			
Fences			
Farm Roads, Bridges			
Miscellaneous Outdoor Improvements			
Drainage and Irrigation Works			
Land By:			
Bank Erosion			
Sheet Erosion			
Infertile Deposition			
Other ______			
Total Direct		$	

Item Number	Item	Damaged Crops
	Actual Crop Damaged	
1	Acreage Damaged	
2	Stage of Maturity Percent	
3	Expected Yield Per Acre (Based on Average Non-Flood Year: State Unit)	
4	Unit Value at Current Prices	$ ____ $ ____ $ ____ $ ____ $ ____
5	Direct Crop Loss if No Replant Is Possible (Item 1 x 3 x 4)	$ ____ $ ____ $ ____ $ ____ $ ____
6	Unexpended Cash Expenses (Cultivating, Harvesting, etc.) of Damaged Crop on Total Acreage	$ ____ $ ____ $ ____ $ ____ $ ____

Relevant Data

Data Collected/Submitted By ______ Title ______ Date ______

______
Signature

SOUTHEASTERN WISCONSIN REGIONAL PLANNING COMMISSION

SURVEY OF FLOOD DAMAGE

FORM 8
NON-PUBLIC BUILDING AND GROUNDS

Serial Number ______

Farm ______ Residence ______ Commercial ______ Manufacturing ______

River ______ Periods of Flooding ______

City ______ County ______ Township ______ Flood Zone ______

Name of Owner ______ Address ______

Name of Occupant ______ Address ______

Type of Business ______

Damage	Cost Estimates: Sub-Total	Cost Estimates: Total	Remarks
Direct			
Building:			
Foundation	$		
Superstructure			
Improvements			
Other ______			
Contents:			
Furnishings			
Personal Effects			
Equipment			
Stock			
Records			
Miscellaneous:			
Minor Buildings, Contents			
Cars, Trucks, etc.			
Grounds			
Total Direct		$	
Indirect			
Profits Loss From Business Interruption	$		
Increased Cost of Operations or Loss of Earnings			
Cost of Flood Fighting			
Evacuation and Reoccupation			
Total Indirect		$	
Grand Total		$	

Relevant Data

Market Value of Bldg. ______ Number of Persons Affected by Flood ______
Condition of Bldgs. Good ______ Fair ______ Poor ______ Days out of Business or Use ______
Size of Bldgs. ______ Number of Floors ______ Maximum Height of Water from Ground at Bldg. Ft. ______
Number of Days Water in Basement ______ On First Floor ______ On Second Floor ______
Damage Occurred By Direct ______ Overflow ______ Sewer Back-Up ______ Seepage ______
Height of Floors Above or Below Ground (feet) ______ B ______ 1 ______ 2 ______ 3 ______
Individual Flood Protection Measures ______

Data Collected/Submitted By ______ Title ______ Date ______

______
Signature

SOUTHEASTERN WISCONSIN REGIONAL PLANNING COMMISSION

Source: U.S. Army Corps of Engineers and SEWRPC.

Appendix E

FLOOD DAMAGE DERIVATION DATA

Table E-I
RESIDENCE FLOOD DAMAGE

Current Dollar Value	Items	Total Value Of Furniture	Basement Damage	Dollar Damage At Depth Flooded Over First Floor																		
				.0'-.4'	.5'-1.4'	1.5'-2.0'	2.5'	3.0'	3.5'	4.0'	4.5'	5.0'	5.5'	6.0'	6.5'	7.0'	7.5'	8.0'	8.5'	9.0'	9.5'	10.0'
1,000	Floors and Walls			75	85	95	105	115	125	135	140	150	160	170	180	190	200	250	250	250	250	250
	Furniture	$ 330		165	215	250	250	250	260	265	275	280	280	280	280	280	280	280	280	280	280	280
	Lawn			50	50	50	55	55	60	60	65	65	70	70	75	75	80	80	85	85	90	90
	TOTAL with Basement		$ 110	400	460	505	520	530	555	570	590	605	620	630	645	655	670	720	725	725	730	730
1,500	Floors and Walls			110	125	140	155	170	185	200	210	225	240	255	270	285	300	375	375	375	375	375
	Furniture	495		240	310	360	365	370	385	395	410	420	420	420	420	420	420	420	420	420	420	420
	Lawn			50	50	50	55	55	60	60	65	65	70	70	75	75	80	80	85	85	90	90
	TOTAL with Basement		120	520	605	670	695	715	750	775	805	830	850	865	885	900	920	995	1000	1000	1005	1005
2,000	Floors and Walls			150	170	190	210	225	245	265	285	305	325	340	360	380	400	500	500	500	500	500
	Furniture	660		315	406	475	485	495	515	530	545	560	560	560	560	560	560	560	560	560	560	560
	Lawn			50	50	50	55	55	60	60	65	65	70	70	75	75	80	80	85	85	90	90
	TOTAL with Basement		130	645	755	845	880	905	950	985	1025	1060	1085	1100	1125	1145	1170	1270	1275	1275	1280	1280
2,500	Floors and Walls			185	210	235	260	280	305	330	355	380	405	430	450	475	500	625	625	625	625	625
	Furniture	830		380	500	590	605	620	645	665	685	705	705	705	705	705	705	705	705	705	705	705
	Lawn			50	50	50	55	55	60	60	65	65	70	70	75	75	80	80	85	85	90	90
	TOTAL with Basement		140	755	900	1015	1060	1095	1150	1195	1245	1290	1320	1345	1370	1395	1425	1550	1555	1555	1560	1560
3,000	Floors and Walls			220	250	280	310	335	365	395	425	455	485	510	540	570	600	750	750	750	750	750
	Furniture	1000		450	600	700	725	750	750	800	825	850	850	850	850	850	850	850	850	850	850	850
	Lawn			50	50	50	55	55	60	60	65	65	70	70	75	75	80	80	85	85	90	90
	TOTAL with Basement		150	870	1050	1180	1240	1290	1325	1405	1465	1520	1555	1580	1615	1645	1680	1830	1835	1835	1840	1840
3,500	Floors and Walls			255	290	325	360	390	425	460	495	530	565	595	630	665	700	875	875	875	875	875
	Furniture	1150		505	670	785	825	865	895	920	950	980	980	980	980	980	980	980	980	980	980	980
	Lawn			50	50	50	55	55	60	60	65	65	70	70	75	75	80	80	85	85	90	90
	TOTAL with Basement		160	970	1170	1320	1400	1470	1540	1600	1670	1735	1775	1805	1845	1880	1920	2095	2100	2100	2105	2105
4,000	Floors and Walls			290	330	370	410	445	485	525	565	605	645	680	720	760	800	1000	1000	1000	1000	1000
	Furniture	1300		560	740	870	925	975	1010	1040	1075	1105	1105	1105	1105	1105	1105	1105	1105	1105	1105	1105
	Lawn			50	50	50	55	55	60	60	65	65	70	70	75	75	80	80	85	85	90	90
	TOTAL with Basement		165	1065	1285	1455	1555	1640	1720	1790	1870	1940	1985	2020	2065	2105	2150	2350	2355	2355	2360	2360
4,500	Floors and Walls			330	375	420	460	505	550	595	635	680	725	770	810	855	900	1125	1125	1125	1125	1125
	Furniture	1475		620	825	960	1035	1105	1145	1180	1220	1255	1255	1255	1255	1255	1255	1255	1255	1255	1255	1255
	Lawn			50	50	50	55	55	60	60	65	65	70	70	75	75	80	80	85	85	90	90
	TOTAL with Basement		175	1175	1425	1605	1725	1840	1930	2010	2095	2175	2225	2270	2315	2360	2410	2635	2640	2640	2645	2645
5,000	Floors and Walls			375	425	470	520	570	615	665	710	760	810	860	905	950	1000	1250	1250	1250	1250	1250
	Furniture	1650		680	910	1050	1145	1240	1280	1320	1365	1405	1405	1405	1405	1405	1405	1405	1405	1405	1405	1405
	Lawn			50	50	50	55	55	60	60	65	65	70	70	75	75	80	80	85	85	90	90
	TOTAL with Basement		185	1290	1570	1755	1905	2050	2140	2230	2325	2415	2470	2520	2570	2615	2670	2720	2725	2725	2730	2730
5,500	Floors and Walls			410	465	515	560	625	675	730	780	835	890	940	995	1045	1100	1375	1375	1375	1375	1375
	Furniture	1825		730	985	1130	1250	1370	1415	1460	1505	1550	1550	1550	1550	1550	1550	1550	1550	1550	1550	1550
	Lawn			55	55	55	60	60	65	65	70	70	75	75	80	80	85	85	90	90	95	95
	TOTAL with Basement		190	1385	1695	1890	2070	2245	2345	2445	2545	2645	2705	2755	2815	2865	2925	3200	3205	3205	3210	3210
6,000	Floors and Walls			440	500	555	615	675	735	790	850	910	965	1025	1085	1140	1200	1500	1500	1500	1500	1500
	Furniture	2000		780	1060	1210	1355	1500	1550	1600	1650	1700	1700	1700	1700	1700	1700	1700	1700	1700	1700	1700
	Lawn			60	60	60	65	65	70	70	75	75	80	80	85	85	90	90	95	95	100	100
	TOTAL with Basement		200	1480	1820	2025	2235	2440	2555	2660	2775	2885	2945	3005	3070	3125	3190	3490	3495	3495	3500	3500

Source: U. S. Department of Agriculture.

Table E-1 (continued)
RESIDENCE FLOOD DAMAGE

Current Dollar Value	Items	Total Value Of Furniture	Basement Damage	Dollar Damage At Depth Flooded Over First Floor																		
				.0'-.4'	.5'-1.4'	1.5'-2.0'	2.5'	3.0'	3.5'	4.0'	4.5'	5.0'	5.5'	6.0'	6.5'	7.0'	7.5'	8.0'	8.5'	9.0'	9.5'	10.0'
6,500	Floors and Walls			475	540	600	665	730	795	855	920	985	1045	1110	1175	1235	1300	1625	1625	1625	1625	1625
	Furniture	$2150		815	1105	1270	1445	1615	1670	1720	1775	1830	1830	1830	1830	1830	1830	1830	1830	1830	1830	1830
	Lawn			65	65	65	70	70	75	75	80	80	85	85	90	90	95	95	100	100	105	105
	TOTAL with Basement		$ 210	1565	1920	2145	2390	2625	2750	2860	2985	3105	3170	3235	3305	3365	3435	3760	3765	3765	3770	3770
7,000	Floors and Walls			510	580	645	715	785	855	920	990	1060	1125	1195	1265	1330	1400	1750	1750	1750	1750	1750
	Furniture	2300		850	1150	1330	1530	1725	1785	1840	1900	1955	1955	1955	1955	1955	1955	1955	1955	1955	1955	1955
	Lawn			70	70	70	75	75	80	80	85	85	90	90	95	95	100	100	105	105	110	110
	TOTAL with Basement		225	1655	2025	2270	2545	2810	2945	3065	3200	3325	3395	3465	3540	3605	3680	4030	4035	4035	4040	4040
8,000	Floors and Walls			580	660	735	815	895	975	1050	1130	1210	1285	1365	1445	1520	1600	2000	2000	2000	2000	2000
	Furniture	2650		925	1270	1450	1720	1990	2055	2120	2190	2255	2255	2255	2255	2255	2255	2255	2255	2255	2255	2255
	Lawn			80	80	80	85	85	90	90	95	95	100	100	105	105	110	110	115	115	120	120
	TOTAL with Basement		250	1835	2260	2515	2870	3220	3370	3510	3665	3810	3890	3970	4055	4130	4215	4615	4620	4620	4625	4625
9,000	Floors and Walls			640	730	820	910	995	1085	1175	1265	1355	1445	1535	1620	1710	1800	2250	2250	2250	2250	2250
	Furniture	3000		1020	1380	1560	1905	2250	2325	2400	2475	2550	2550	2550	2550	2550	2550	2550	2550	2550	2550	2550
	Lawn			90	90	90	95	95	100	100	105	105	110	110	115	115	120	120	125	125	130	130
	TOTAL with Basement		275	2025	2475	2745	3185	3615	3785	3950	4120	4285	4380	4470	4560	4650	4745	5195	5200	5200	5205	5205
10,000	Floors and Walls			685	785	890	990	1090	1190	1290	1395	1495	1595	1695	1800	1900	2000	2500	2500	2500	2500	2500
	Furniture	3300		1090	1480	1680	2080	2475	2560	2640	2725	2805	2805	2805	2805	2805	2805	2805	2805	2805	2805	2805
	Lawn			100	100	100	105	105	110	110	115	115	120	120	125	125	130	130	135	135	140	140
	TOTAL with Basement		305	2180	2670	2975	3480	3975	4165	4345	4540	4720	4825	4925	5035	5135	5240	5740	5745	5745	5750	5750
11,000	Floors and Walls			735	850	960	1075	1185	1300	1410	1525	1635	1750	1860	1975	2085	2200	2750	2750	2750	2750	2750
	Furniture	3650		1170	1610	1820	2280	2740	2830	2920	3015	3105	3105	3105	3105	3105	3105	3105	3105	3105	3105	3105
	Lawn			110	110	110	115	115	120	120	125	125	130	130	135	135	140	140	145	145	150	150
	TOTAL with Basement		345	2360	2915	3235	3815	4385	4595	4795	5010	5210	5330	5440	5560	5670	5790	6340	6345	6345	6350	6350
12,000	Floors and Walls			775	900	1025	1150	1275	1400	1525	1650	1775	1900	2025	2150	2275	2400	3000	3000	3000	3000	3000
	Furniture	4000		1240	1720	1960	2480	3000	3100	3200	3300	3400	3400	3400	3400	3400	3400	3400	3400	3400	3400	3400
	Lawn			120	120	120	125	125	130	130	135	135	140	140	145	145	150	150	155	155	160	160
	TOTAL with Basement		390	2525	3130	3495	4145	4790	5020	5245	5475	5700	5830	5955	6085	6210	6340	6940	6945	6945	6950	6950
13,000	Floors and Walls			820	955	1095	1230	1370	1505	1640	1780	1915	2050	2190	2325	2465	2600	3250	3250	3250	3250	3250
	Furniture	4300		1290	1805	2065	2645	3225	3335	3440	3550	3655	3655	3655	3655	3655	3655	3655	3655	3655	3655	3655
	Lawn			130	130	130	135	135	140	140	145	145	150	150	155	155	160	160	165	165	170	170
	TOTAL with Basement		425	2665	3315	3715	4435	5155	5405	5645	5900	6140	6280	6420	6560	6700	6840	7490	7495	7495	7500	7500
14,000	Floors and Walls			860	1010	1160	1310	1455	1605	1755	1905	2055	2205	2350	2500	2650	2800	3500	3500	3500	3500	3500
	Furniture	4600		1330	1890	2160	2805	3450	3565	3680	3795	3910	3910	3910	3910	3910	3910	3910	3910	3910	3910	3910
	Lawn			140	140	140	145	145	150	150	155	155	160	160	165	165	170	170	175	175	180	180
	TOTAL with Basement		460	2790	3500	3920	4720	5510	5780	6045	6315	6580	6735	6880	7035	7185	7340	8040	8045	8045	8050	8050
15,000	Floors and Walls			900	1060	1225	1385	1545	1710	1870	2030	2190	2355	2515	2675	2840	3000	3750	3750	3750	3750	3750
	Furniture	4950		1390	1980	2280	3000	3715	3840	3960	4085	4210	4210	4210	4210	4210	4210	4210	4210	4210	4210	4210
	Lawn			150	150	150	155	155	160	160	165	165	170	170	175	175	180	180	185	185	190	190
	TOTAL with Basement		505	2945	3695	4160	5045	5920	6215	6495	6785	7070	7240	7400	7565	7730	7895	8645	8650	8650	8655	8655
16,000	Floors and Walls			960	1140	1310	1470	1650	1820	2000	2160	2340	2510	2690	2850	3020	3200	4000	4000	4000	4000	4000
	Furniture	5280		1490	2110	2432	3200	3970	4100	4220	4350	4500	4500	4500	4500	4500	4500	4500	4500	4500	4500	4500
	Lawn			160	160	160	160	160	180	180	180	180	180	180	190	190	190	190	190	190	210	210
	TOTAL with Basement		540	3150	3950	4442	5370	6320	6640	6940	7230	7560	7730	7910	8080	8250	8430	9230	9230	9230	9250	9250

Source: U. S. Department of Agriculture.

Table E-I (continued)
RESIDENCE FLOOD DAMAGE

Current Dollar Value	Items	Total Value of Furniture	Basement Damage	Dollar Damage at Depth Flooded Over First Floor																		
				.0'-.4'	.5'-1.4'	1.5'-2.0'	2.5'	3.0'	3.5'	4.0'	4.5'	5.0'	5.5'	6.0'	6.5'	7.0'	7.5'	8.0'	8.5'	9.0'	9.5'	10.0'
17,000	Floors and Walls	$5610		1020	1210	1390	1560	1750	1940	2120	2300	2480	2670	2860	3030	3210	3400	4250	4250	4250	4250	4250
	Furniture			1580	2240	2580	3400	4220	4350	4490	4620	4780	4780	4780	4780	4780	4780	4780	4780	4780	4780	4780
	Lawn			170	170	170	170	170	190	190	190	190	190	190	200	200	200	200	200	200	220	220
	TOTAL with Basement		$580	3350	4200	4720	5710	6720	7060	7380	7690	8030	8220	8410	8590	8770	8960	9810	9810	9810	9830	9830
18,000	Floors and Walls	5940		1080	1280	1480	1660	1850	2050	2250	2430	2630	2830	3020	3200	3400	3600	4500	4500	4500	4500	4500
	Furniture			1670	2380	2740	3600	4460	4610	4750	4900	5060	5060	5060	5060	5060	5060	5060	5060	5060	5060	5060
	Lawn			180	180	180	180	180	200	200	200	200	200	200	220	220	220	220	220	220	230	230
	TOTAL with Basement		610	3540	4450	5010	6050	7100	7470	7810	8140	8500	8700	8890	9090	9290	9490	10390	10390	10390	10400	10400
19,000	Floors and Walls	6270		1140	1350	1560	1750	1960	2170	2380	2560	2770	2980	3190	3380	3590	3800	4750	4750	4750	4750	4750
	Furniture			1770	2510	2890	3800	4710	4860	5020	5170	5340	5340	5340	5340	5340	5340	5340	5340	5340	5340	5340
	Lawn			190	190	190	190	190	210	210	210	210	210	210	230	230	230	230	230	230	250	250
	TOTAL with Basement		650	3750	4700	5290	6390	7510	7890	8260	8590	8970	9180	9390	9600	9810	10020	10970	10970	10970	10990	10990
20,000	Floors and Walls	6600		1200	1420	1640	1840	2060	2280	2500	2700	2920	3140	3360	3560	3780	4000	5000	5000	5000	5000	5000
	Furniture			1860	2640	3040	4000	4960	5120	5280	5440	5620	5620	5620	5620	5620	5620	5620	5620	5620	5620	5620
	Lawn			200	200	200	200	200	220	220	220	220	220	220	240	240	240	240	240	240	260	260
	TOTAL with Basement		680	3940	4940	5560	6720	7900	8300	8680	9040	9440	9660	9880	10100	10320	10540	11540	11540	11540	11560	11560
21,000	Floors and Walls	6930		1260	1490	1720	1930	2160	2390	2625	2840	3070	3300	3530	3740	3970	4200	5250	5250	5250	5250	5250
	Furniture			1950	2770	3190	4200	5210	5380	5540	5710	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900
	Lawn			210	210	210	210	210	230	230	230	230	230	230	250	250	250	250	250	250	270	270
	TOTAL with Basement		710	4130	5180	5830	7050	8290	8710	9105	9490	9910	10140	10370	10600	10830	11060	12110	12110	12110	12130	12130
22,000	Floors and Walls	7260		1320	1560	1800	2020	2270	2510	2750	2970	3210	3450	3700	3920	4160	4400	5500	5500	5500	5500	5500
	Furniture			2050	2900	3340	4400	5460	5630	5810	5980	6180	6180	6180	6180	6180	6180	6180	6180	6180	6180	6180
	Lawn			220	220	220	220	220	240	240	240	240	240	240	260	260	260	260	260	260	290	290
	TOTAL with Basement		750	4340	5430	6110	7390	8700	9130	9550	9940	10380	10620	10870	11110	11350	11590	12690	12690	12690	12720	12720
23,000	Floors and Walls	7590		1380	1630	1890	2120	2370	2620	2875	3100	3360	3610	3860	4090	4350	4600	5750	5750	5750	5750	5750
	Furniture			2140	3040	3500	4600	5700	5890	6070	6260	6460	6460	6460	6460	6460	6460	6460	6460	6460	6460	6460
	Lawn			230	230	230	230	230	250	250	250	250	250	250	280	280	280	280	280	280	300	300
	TOTAL with Basement		780	4530	5680	6400	7730	9080	9540	9975	10390	10850	11100	11350	11610	11870	12120	13270	13270	13270	13290	13290
24,000	Floors and Walls	7920		1440	1700	1970	2210	2470	2740	3000	3240	3500	3770	4030	4270	4540	4800	6000	6000	6000	6000	6000
	Furniture			2230	3170	3650	4800	5950	6140	6340	6530	6740	6740	6740	6740	6740	6740	6740	6740	6740	6740	6740
	Lawn			240	240	240	240	240	260	260	260	260	260	260	290	290	290	290	290	290	310	310
	TOTAL with Basement		820	4730	5930	6680	8070	9480	9960	10420	10850	11320	11590	11850	12120	12390	12650	13850	13850	13850	13870	13870
25,000	Floors and Walls	8250		1500	1760	2050	2300	2580	2850	3120	3380	3650	3920	4200	4450	4720	5000	6250	6250	6250	6250	6250
	Furniture			2320	3300	3800	5000	6200	6400	6600	6800	7020	7020	7020	7020	7020	7020	7020	7020	7020	7020	7020
	Lawn			250	250	250	250	250	270	270	270	270	270	270	300	300	300	300	300	300	320	320
	TOTAL with Basement		850	4920	6180	6950	8400	9880	10370	10840	11300	11790	12060	12340	12620	12890	13170	14420	14420	14420	14440	14440
26,000	Floors and Walls	8580		1560	1850	2130	2390	2680	2960	3250	3510	3800	4080	4370	4630	4910	5200	6500	6500	6500	6500	6500
	Furniture			2420	3430	3950	5200	6450	6660	6860	7070	7310	7310	7310	7310	7310	7310	7310	7310	7310	7310	7310
	Lawn			260	260	260	260	260	290	290	290	290	290	290	310	310	310	310	310	310	340	340
	TOTAL with Basement		880	5120	6420	7220	8730	10270	10790	11280	11750	12280	12560	12850	13130	13410	13700	15000	15000	15000	15030	15030
27,000	Floors and Walls	8910		1620	1920	2210	2480	2780	3080	3380	3640	3940	4240	4540	4810	5100	5400	6750	6750	6750	6750	6750
	Furniture			2510	3560	4100	5400	6700	6910	7130	7340	7590	7590	7590	7590	7590	7590	7590	7590	7590	7590	7590
	Lawn			270	270	270	270	270	300	300	300	300	300	300	320	320	320	320	320	320	350	350
	TOTAL with Basement		920	5320	6670	7500	9070	10670	11210	11730	12200	12750	13050	13350	13640	13930	14230	15580	15580	15580	15610	15610
28,000	Floors and Walls	9240		1680	1990	2300	2580	2880	3190	3500	3780	4090	4400	4700	4980	5290	5600	7000	7000	7000	7000	7000
	Furniture			2600	3700	4260	5600	6940	7170	7390	7620	7870	7870	7870	7870	7870	7870	7870	7870	7870	7870	7870
	Lawn			280	280	280	280	280	310	310	310	310	310	310	340	340	340	340	340	340	360	360
	TOTAL with Basement		950	5510	6920	7790	9410	11050	11620	12150	12660	13220	13530	13830	14140	14450	14760	16160	16160	16160	16180	16180
29,000	Floors and Walls	9570		1740	2060	2380	2670	2990	3310	3625	3920	4230	4550	4870	5160	5480	5800	7250	7250	7250	7250	7250
	Furniture			2700	3830	4410	5800	7190	7420	7660	7890	8150	8150	8150	8150	8150	8150	8150	8150	8150	8150	8150
	Lawn			290	290	290	290	290	320	320	320	320	320	320	350	350	350	350	350	350	380	380
	TOTAL with Basement		990	5720	7170	8070	9750	11460	12040	12595	13120	13690	11010	14330	14650	14970	15290	16740	16740	16740	16770	16770
30,000	Floors and Walls	9900		1800	2130	2460	2760	3090	3420	3750	4050	4380	4710	5040	5340	5670	6000	7500	7500	7500	7500	7500
	Furniture			2790	3960	4560	6000	7440	7680	7920	8160	8430	8430	8430	8430	8430	8430	8430	8430	8430	8430	8430
	Lawn			300	300	300	300	300	330	330	330	330	330	330	360	360	360	360	360	360	390	390
	TOTAL with Basement		1020	5910	7410	8340	10080	11850	12450	13020	13560	14160	14490	14820	15150	15480	15810	17310	17310	17310	17340	17340

Source: USDA.

Table E-1 (continued)

Foundation Damage								
House Value	1-Side Failure	2-Side Failure	House Value	1-Side Failure	2-Side Failure	House Value	1-Side Failure	2-Side Failure
$ 1,000	$ 65	$ 95	$ 7,000	$ 250	$ 375	$ 19,000	$ 480	$ 720
1,500	80	120	8,000	270	405	20,000	500	760
2,000	100	150	9,000	280	420	21,000	520	800
2,500	120	180	10,000	300	450	22,000	550	840
3,000	145	220	11,000	315	475	23,000	580	870
3,500	160	240	12,000	330	495	24,000	600	910
4,000	175	265	13,000	345	520	25,000	620	950
4,500	190	285	14,000	365	550	26,000	650	990
5,000	205	310	15,000	380	570	27,000	680	1,030
5,500	220	330	16,000	400	610	28,000	700	1,060
6,000	230	345	17,000	420	650	29,000	720	1,100
6,500	240	360	18,000	450	680	30,000	750	1,140

Note: All information pertaining to properties valued at less than $16,000 was provided by the Division Office, Army Corps of Engineers, Omaha, Nebraska.

Source: U. S. Department of Agriculture.

Appendix F

MILWAUKEE RIVER WATERSHED FLOOD STAGE-DAMAGE CURVES EXISTING 1967 LAND USE AND PROJECTED 1990 LAND USE UNDER UNCONTROLLED FLOODLAND DEVELOPMENT

Figure F-1
REACH 1
SILVER SPRING DRIVE TO ESTABROOK PARK

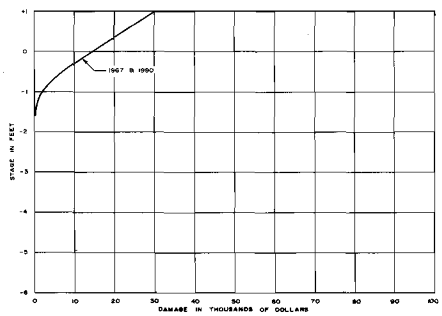


Figure F-2
REACH 2
SILVER SPRING DRIVE TO 1/4 MILE SOUTH OF BRADLEY ROAD

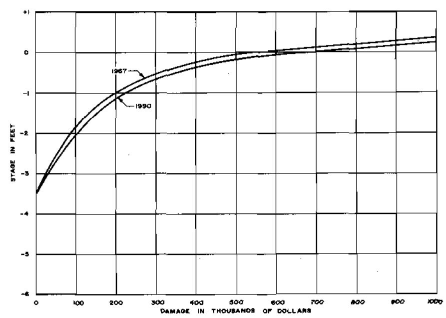


Figure F-3
REACH 3
GREEN TREE ROAD TO COUNTY LINE ROAD

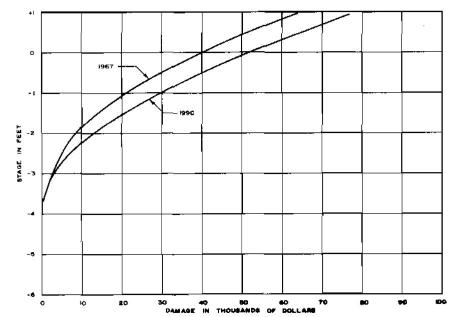


Figure F-4
REACH 4
1/4 MILE SOUTH OF BRADLEY ROAD TO COUNTY LINE ROAD

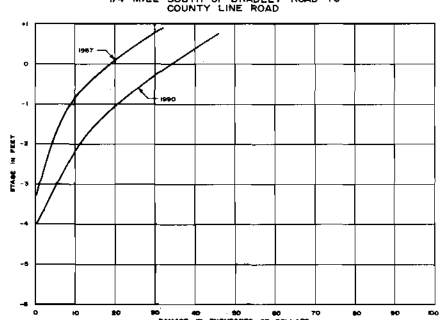


Figure F-5
REACH 5
COUNTY LINE ROAD TO STH 167

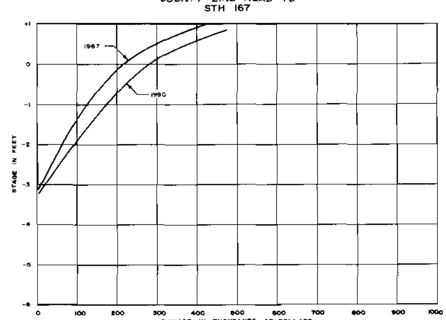


Figure F-6
REACH 6
VILLAGE OF THIENSVILLE

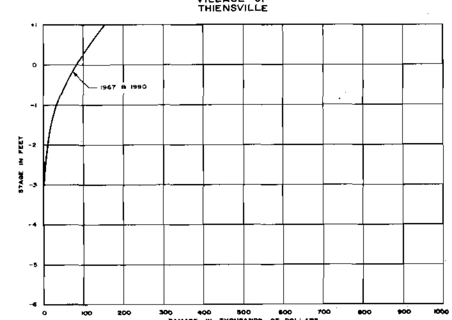


Figure F-7
REACH 7
STH 167 TO SW CORNER OF SECTION 18, T.9 N., R.22 E.

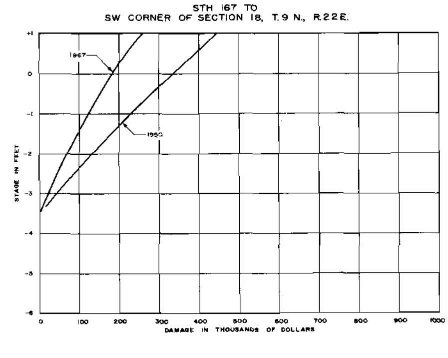


Figure F-8
REACH 8
SW CORNER OF SECTION 16, T. 9 N., R. 22 E.
TO CTH C

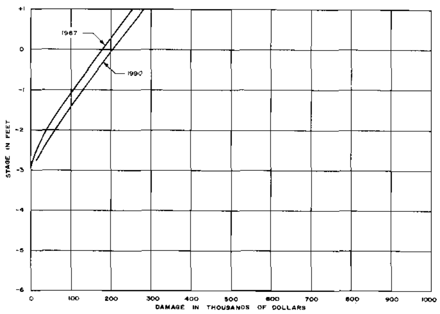


Figure F-9
REACH 9
CTH C TO
3/4 MILE SOUTH OF STH 60

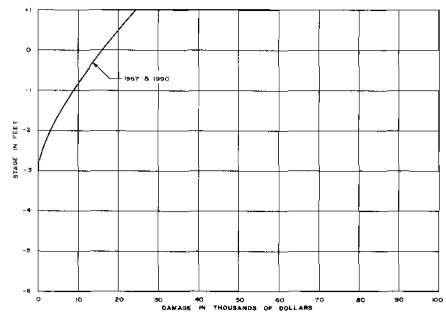


Figure F-10
REACH 10
3/4 MILE SOUTH OF STH 60 TO
3/4 MILE NORTH OF STH 60

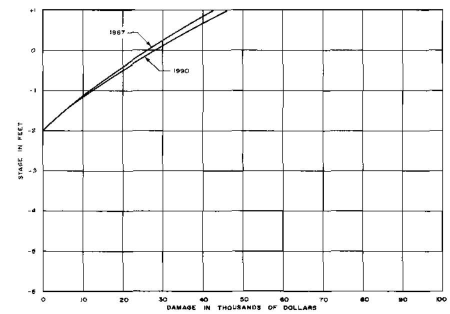


Figure F-11
REACH 11
3/4 MILE NORTH OF STH 60 TO
SAUKVILLE TOWN LINE

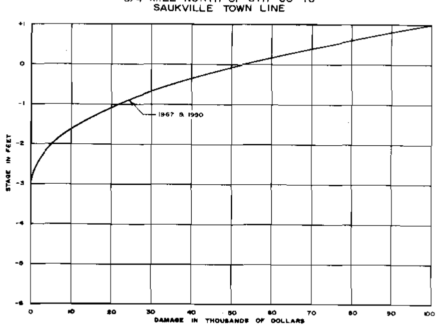


Figure F-12
REACH 12
VILLAGE OF
SAUKVILLE

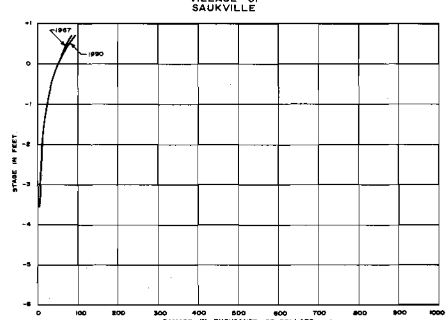


Figure F-13
REACH 13
NORTHERN VILLAGE LINE OF SAUKVILLE TO
4 MILES NORTH

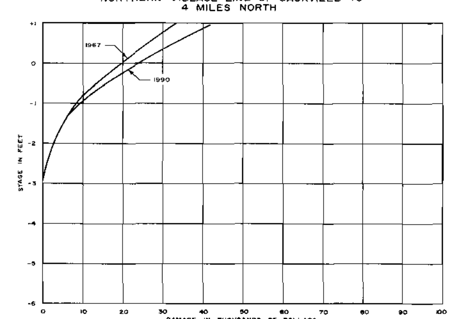
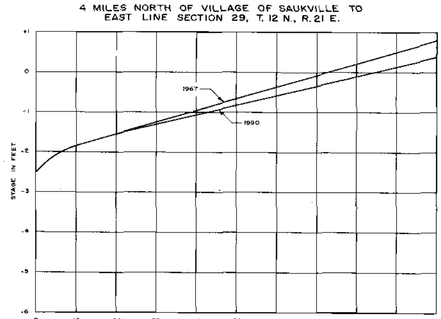


Figure F-14
REACH 14
4 MILES NORTH OF VILLAGE OF SAUKVILLE TO
EAST LINE SECTION 29, T. 12 N., R. 21 E.



NOTE [a]FLOOD STAGES ARE EXPRESSED IN FEET ABOVE OR BELOW THE 100-YEAR FLOOD STAGE AS DETERMINED BY THE FLOOD SIMULATION MODEL.
[b]DAMAGES ARE BASED ON 1967 HOUSE COUNTS AND 1969 DOLLARS.

Source: Harza Engineering Company

Appendix G

MILWAUKEE RIVER WATERSHED DAMAGE-FREQUENCY CURVES EXISTING 1967 LAND USE AND PROJECTED 1990 LAND USE UNDER UNCONTROLLED FLOODLAND DEVELOPMENT

Figure G-1
REACH 1
SILVER SPRING DRIVE TO ESTABROOK PARK

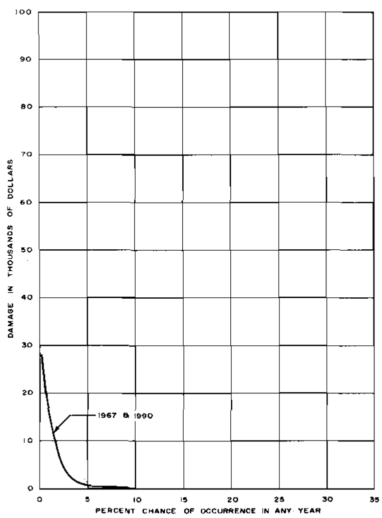


Figure G-2
REACH 2
SILVER SPRING DRIVE TO 1/4 MILE SOUTH OF BRADLEY ROAD

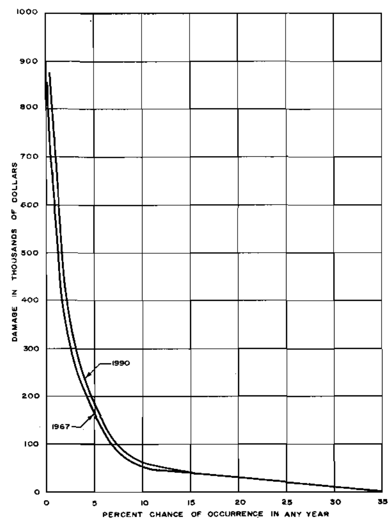


Figure G-3
REACH 3
GREEN TREE ROAD TO COUNTY LINE ROAD

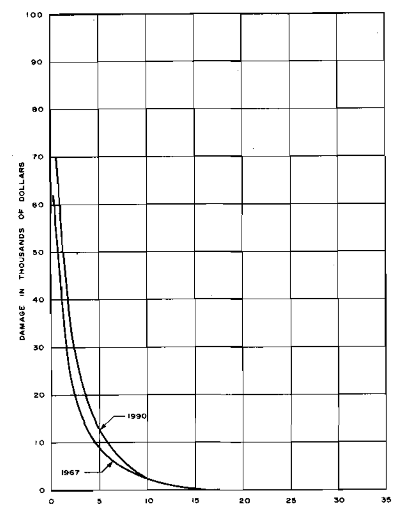


Figure G-4
REACH 4
1/4 MILE SOUTH OF BRADLEY ROAD TO COUNTY LINE ROAD

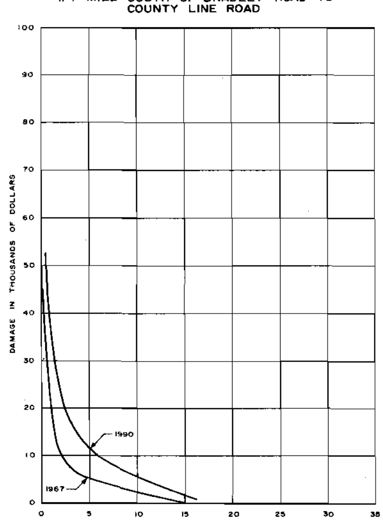


Figure G-5
REACH 5
COUNTY LINE ROAD TO STH 167

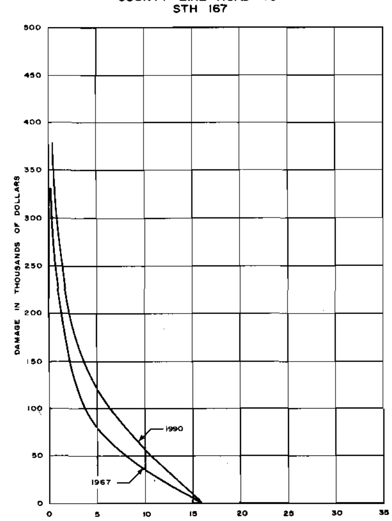


Figure G-6
REACH 6
VILLAGE OF THIENSVILLE

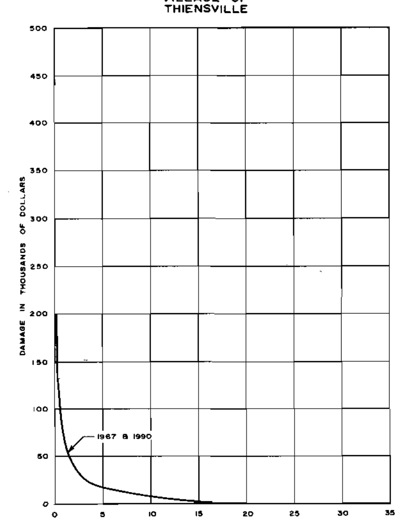


Figure G-7
REACH 7
STH 167 TO
SW CORNER OF SECTION 18, T. 9 N., R. 22 E.

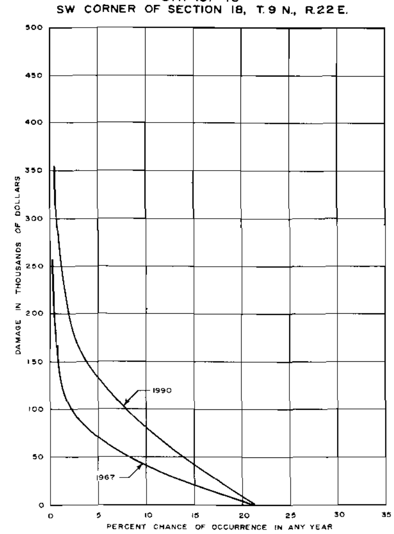


Figure G-8
REACH 8
SW CORNER OF SECTION 18, T. 9 N., R. 22 E.
TO CTH C

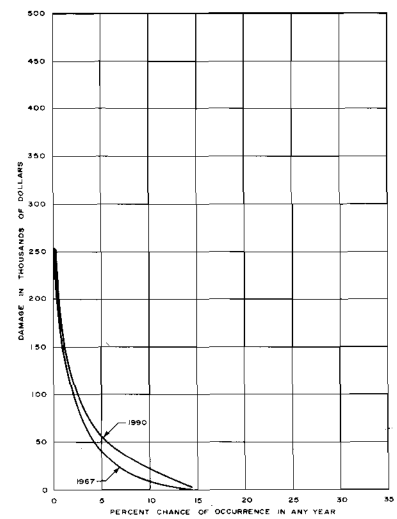


Figure G-9
REACH 9
CTH C TO
3/4 MILE SOUTH OF STH 60

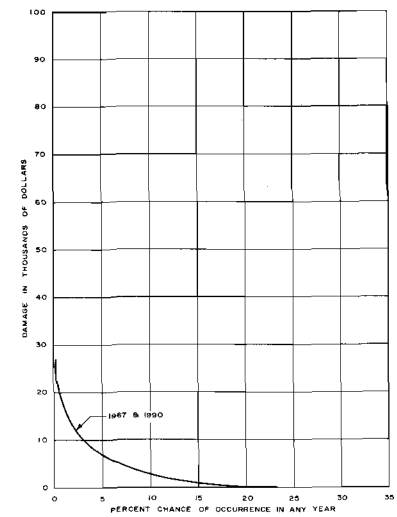


Figure G-10
REACH 10
3/4 MILE SOUTH OF STH 60 TO
3/4 MILE NORTH OF STH 60

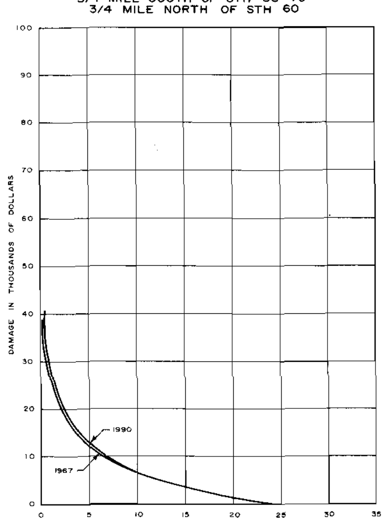


Figure G-11
REACH 11
3/4 MILE NORTH OF STH 60 TO
SAUKVILLE TOWN LINE

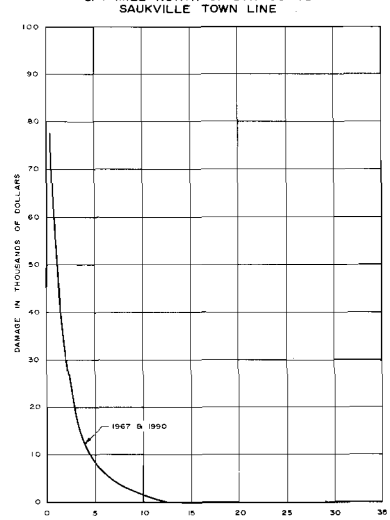


Figure G-12
REACH 12
VILLAGE OF
SAUKVILLE

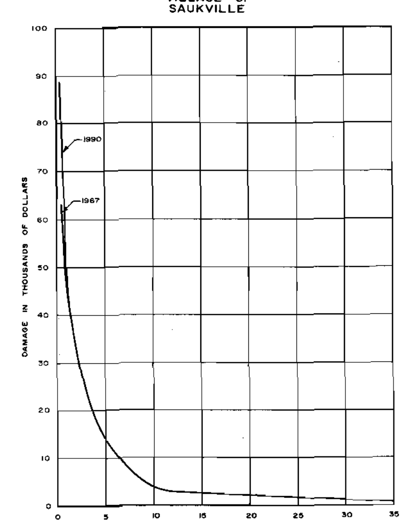


Figure G-13
REACH 13
NORTHERN VILLAGE LINE OF SAUKVILLE TO
4 MILES NORTH

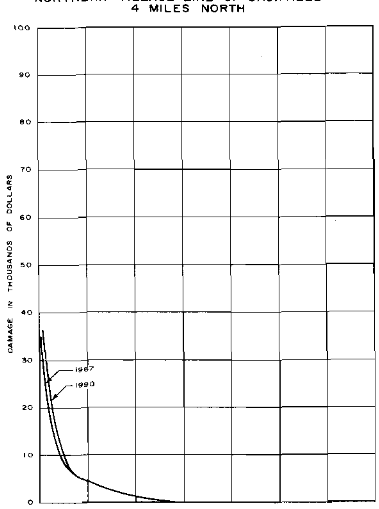
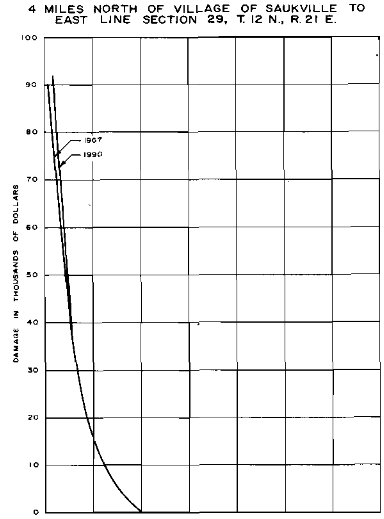


Figure G-14
REACH 14
4 MILES NORTH OF VILLAGE OF SAUKVILLE TO
EAST LINE SECTION 29, T. 12 N., R. 21 E.



NOTE: *DAMAGES ARE BASED ON 1967 HOUSE COUNTS AND 1969 DOLLARS

Source: Harza Engineering Company

Appendix H

DETAILED LISTING OF KNOWN COMBINED SEWER OUTFALLS AND FLOW RELIEF FEATURES IN THE MILWAUKEE RIVER WATERSHED

GLOSSARY OF TERMS USED IN CHAPTER IX

Branch Sewer . . . . A common sewer receiving sewage from two or more lateral sewers serving relatively small tributary drainage areas.

Building Sewer. . . . . . . A private or individual sewer conveying sewage from a single building to a common sewer. Also called house connection.

Bypass . . . . A flow relief device by which sanitary sewers entering a lift station, pumping station, or sewage treatment plant can discharge a portion or all of their flow, by gravity, into a receiving body of surface water to alleviate sewer surcharge. Also a flow relief device by which intercepting or main sewers can discharge a portion or all of their flow by gravity into a receiving body of surface water to alleviate intercepting or main sewer surcharge.

Common Sewer . . . . . . A sewer in which all abutters have equal rights. Also called public sewer.

Combined Sewer . . . . . . A common sewer intended to carry sanitary sewage, with component domestic, commercial, and industrial wastes, at all times and which, during periods of rainfall or snowmelt, is intended to also carry storm water runoff from streets and other sources.

Crossover . . . . A flow relief device by which sanitary sewers discharge a portion of their flow, by gravity, into storm sewers during periods of sanitary sewer surcharge or by which combined sewers discharge a portion of their flow, by gravity, into storm sewers to alleviate sanitary or combined sewer surcharge.

Dry-Weather Flow . . . . . The normal flow of sanitary sewage, including component domestic, commercial, and industrial wastes and ground water infiltration, but specifically excluding storm water and excessive ground water infiltration caused by rainfall or snowmelt.

Force Main. . . . . A pipeline joining the discharge of a pumping station with a point of gravity flow designed to transmit sewage under pressure flow throughout its length.

Infiltration . . . . Ground and storm water that leaks or seeps into sewers through defective joints, ruptured or porous pipes, manholes, or other sewer system appurtenances.

Intercepting Structure . . . . A structure designed to intercept all dry-weather sanitary sewage flow in a combined sewer and a proportionate amount of the mixed storm water and sanitary sewage flow during periods of rainfall or snowmelt and discharge such flows to an intercepting sewer.

Intercepting Sewer . . . . . A common sewer that receives dry-weather sanitary sewage flows from a combined sewer system and predetermined proportionate amounts of the mixed storm water and sanitary sewage flows during periods of rainfall or snowmelt and conducts these flows to a point of treatment or disposal.

Lateral Sewer. . . . . A common sewer discharging into a branch or other common sewer and having no other common sewer tributary to it.

Lift Station. . . . . A relatively small sewage pumping device designed to lift sewage from a gravity flow sewer to a higher elevation when the continuance of the gravity flow sewer would involve excessive depths of trench or designed to lift sewage from areas too low to drain into available sewers. Lift stations normally discharge through relatively short force mains to gravity flow points located at or very near the lift station.

Main Sewer. . . . . A common sewer which receives flows from many lateral and branch sewers serving relatively large tributary drainage areas for conveyance to a treatment plant. Also called trunk sewer.

Outfall . . . . A sewer that receives flows from a collecting system or from a treatment plant and conveys the untreated or treated waste flows to a point of discharge into a receiving body of surface water.

Overflow . . . . That part of the flow in a separate or combined sewerage system which is deliberately not conveyed to a plant for treatment but is discharged through an outfall directly to a receiving body of surface water to avoid sewer, lift station, pumping station, or sewage treatment plant surcharging.

Portable Pumping Station . . . A point of flow relief at which flows from surcharged sanitary sewers are discharged into storm sewers or directly into a receiving body of surface water through the use of portable pumping units.

Pumping Station . . . . . . A relatively large sewage pumping device designed not only to lift sewage to a higher elevation but to convey it through force mains to gravity flow points located relatively long distances from the pumping station.

Relief Pumping Station . . . . A flow relief device by which flows from surcharged main sewers are discharged into storm sewers or directly into a receiving body of surface water through the use of permanent lift or pumping stations.

Relief Sewer . . . . A common sewer built to carry the flows in excess of the capacity of an existing sewer, thus relieving surcharging of the latter.

Sanitary Sewer . . . . . . A common sewer which carries sewage flows from residences, commercial buildings, and institutions, certain types of liquid from industrial plants, together with minor amounts of storm, surface, and ground waters that are not intentionally admitted.

Sewage . . . . The spent or waste water of a community consisting of a combination of the liquid and water-carried wastes from streets and other open areas, residences, commercial buildings, industrial plants, and institutions, together with any ground water, surface water, and storm water that may be present.

Sewer . . . . A pipe or conduit, generally closed but not normally flowing under pressure, for carrying sewage.

Storm Sewer . . . . A common sewer which carries surface water and storm water runoff from open areas, rooftops, streets, and other sources, including street wash and other wash waters, but from which sanitary sewage or industrial wastes are specifically excluded.

Sewer Surcharge . . . . . . A condition in which the amount of flow entering a sewer is greater than the capacity of the sewer, resulting in a backup of flow.

Table H-1

KNOWN COMBINED SEWER OUTFALLS IN
THE MILWAUKEE RIVER WATERSHED: 1970[a]

Outfall Location on the Milwaukee River	Size
Mouth of the Milwaukee River to Confluence With the Menomonee River	
1. E. Bruce Street	24"
2. E. Harbor Place.	30"
3. E. Florida Street	60"
4. E. Polk Street	54"
5. South of E. Oregon Street. . .	30"
6. E. Pittsburg Avenue	24"
7. N. Broadway Street.	30"
8. S. Water Street	24"
9. S. 1st Street.	30"
Confluence With the Menomonee River to the North Avenue Dam	
10. N. Broadway and E. Erie. . .	30"
11. E. Chicago Street	6'x4'
12. E. Buffalo Street	42"
13. W. St. Paul Avenue.	6'x3'
14. E. St. Paul Avenue.	8'-6"x4'-0"
15. North of W. St. Paul Avenue. .	30"
16. W. Clybourn Street.	48"
17. E. Clybourn Street	Double 48"
18. North of W. Clybourn Street . .	24"x26"
19. W. Michigan Street.	54"
20. E. Michigan Street	42"
21. North of W. Michigan Street. .	30"
22. E. Wisconsin Avenue	30"
23. W. Wisconsin Avenue	24"
24. North of W. Wisconsin Avenue .	18"x30"
25. E. Wells Street	36"
26. W. Wells Street	54"
27. North of W. Wells Street . . .	30"
28. W. Kilbourn Avenue	72"x54"
29. W. Kilbourn Avenue	36"
30. E. Kilbourn Avenue.	54"
31. W. State Street	46"
32. E. State Street	60"
33. W. Highland Avenue	9'-3"x4'-6"
Confluence With the Menomonee River to the North Avenue Dam (continued)	
34. E. Highland Avenue.	36"
35. W. Juneau Avenue	36"
36. E. Juneau Avenue	42"
37. N. 3rd (Between McKinley and Juneau)	84"
38. W. McKinley Avenue	60"
39. E. Ogden Avenue	6'x3'
40. W. Cherry Street	90"
41. Ship Street (North of W. Cherry Street and the River)	5'x4'
42. E. Lyon Street	36" & 18"
43. E. Pleasant Street	7'x3'
44. E. Walnut Street.	24"
45. North of E. Walnut Street. . .	96"
46. E. Brady Street	30"
47. N. Holton Street.	7'x4'
48. N. Marshall Street	24"
49. N. Pulaski Street	72"
50. N. Humboldt Avenue	72"
51. E. Tunnel Place.	12"
52. E. Boylston Street	40"x51"Egg
Upstream From the North Avenue Dam	
53. E. Bradford Avenue	72"
54. E. Park Place	60"
55. E. Locust Street.	78"
56. E. Chambers Street	21"
57. E. Burleigh Street	Dbl. 9'-6"x 4'-3"
58. E. Hampshire Avenue	24"
59. E. Auer Avenue	84"
60. E. Auer Avenue	36"
61. E. Keefe Avenue.	54"
62. E. Edgewood Avenue	72"

[a] The number beside each listed combined sewer outfall corresponds to a code number on Map 46.

Source: City of Milwaukee Bureau of Engineering and the Sewerage Commission of the City of Milwaukee.

Table H-2

KNOWN CROSSOVERS IN THE MILWAUKEE RIVER WATERSHED: 1970[a]

Crossover Location	Initial Receiving Stream
City of Milwaukee	
1. E. Meinecke Avenue and N. Gordon Place	Milwaukee River
2. N. Sherman Boulevard and W. Burleigh Street	Lincoln Creek
3. N. 44th Street and W. Burleigh Street	Lincoln Creek
4. N. 51st Street and W. Burleigh Street	Lincoln Creek
5. N. 54th Street and W. Burleigh Street	Lincoln Creek
6. N. 55th Street and W. Burleigh Street	Lincoln Creek
7. N. 56th Street and W. Burleigh Street	Lincoln Creek
8. N. 51st Boulevard and W. Auer Avenue	Lincoln Creek
9. N. 51st Boulevard and W. Concordia Avenue	Lincoln Creek
10. N. 49th Street and W. Concordia Avenue	Lincoln Creek
11. N. 47th Street and W. Concordia Avenue	Lincoln Creek
12. N. 51st Boulevard and W. Roosevelt Drive	Lincoln Creek
13. N. Sherman Boulevard and Fond du Lac Avenue	Lincoln Creek
14. N. 26th Street and W. Vienna Avenue	Lincoln Creek
15. N. 31st Street and W. Capitol Drive	Lincoln Creek
16. N. 31st Street and W. Capitol Drive	Lincoln Creek
17. N. 27th Street and W. Fiebrantz Avenue	Lincoln Creek
18. N. 24th Street and W. Hope Avenue	Lincoln Creek
19. N. 25th Street and W. Hope Avenue	Lincoln Creek
20. N. 30th Street and W. Hope Avenue	Lincoln Creek
21. N. 31st Street and W. Hope Avenue	Lincoln Creek
22. N. 47th Street and W. Hope Avenue	Lincoln Creek
23. N. 66th Street between W. Congress Street and W. Ruby Avenue	Lincoln Creek
24. N. 47th Street and W. Congress Street	Lincoln Creek
25. N. 41st Street and W. Congress Street	Lincoln Creek
26. N. Sherman Boulevard and W. Ruby Avenue	Lincoln Creek
27. N. 53rd Street and W. Glendale Avenue	Lincoln Creek
28. N. 53rd Street and W. Courtland Avenue	Lincoln Creek
29. N. 20th Street and W. Fairmount Avenue	Lincoln Creek
30. N. 31st Street and W. Villard Avenue	Lincoln Creek
31. N. 31st Street and W. Villard Avenue	Lincoln Creek
32. N. 27th Street and W. Silver Spring Drive	Lincoln Creek
33. N. 35th Street and W. Silver Spring Drive	Lincoln Creek
34. N. 36th Street and W. Silver Spring Drive	Lincoln Creek
35. N. 37th Street and W. Silver Spring Drive	Lincoln Creek
36. N. 38th Street and W. Silver Spring Drive	Lincoln Creek
37. N. 39th Street and W. Silver Spring Drive	Lincoln Creek
38. N. 41st Street and W. Silver Spring Drive	Lincoln Creek
39. N. 35th Street and W. Oriole Drive	Lincoln Creek
40. N. 36th Street between W. Carmen Avenue and W. Florist Avenue	Lincoln Creek
41. Humboldt Avenue and Capitol Drive	Milwaukee River
42. E. Auer Avenue at the Milwaukee River	Milwaukee River
43. N. Richards Street and E. Congress Street	Milwaukee River
44. N. 2nd Street and W. Hampton Avenue	Milwaukee River
45. N. 31st Street and W. Fairmount Avenue	Milwaukee River
46. N. 51st Street at Lincoln Creek (N. or Congress Street)	Lincoln Creek
47. N. 51st Street and W. Congress Street	Lincoln Creek
48. N. 47th Street and W. Roosevelt Drive	Lincoln Creek

Table H-2 (continued)

Crossover Location	Initial Receiving Stream
Village of Shorewood	
49. E. Edgewood Avenue and N. Cambridge Avenue	Milwaukee River
50. E. Edgewood Avenue and N. Oakland Avenue	Milwaukee River
51. E. Olive Street and N. Wilson Drive	Milwaukee River
52. N. Woodburn Street and E. Olive Street	Milwaukee River
53. N. Morris Boulevard and E. Lake Bluff Boulevard	Milwaukee River
54. E. Glendale Avenue and N. Morris Boulevard	Milwaukee River
55. E. Glendale Avenue and N. Larkin Street	Milwaukee River
Village of Whitefish Bay	
56. E. Hampton Avenue and N. Idlewild Avenue	Milwaukee River
57. E. Hampton Avenue and N. Sheffield Avenue	Milwaukee River
58. E. Lancaster Avenue and N. Diversey Boulevard	Milwaukee River
59. N. Lydell Avenue and E. Lancaster Avenue	Milwaukee River

[a] All crossovers are located upstream from the North Avenue Dam. The number beside each listed crossover corresponds to a code number on Map 46.

Source: City of Milwaukee Bureau of Engineering and the Sewerage Commission of the City of Milwaukee.

Table H-3

KNOWN BYPASSES IN THE MILWAUKEE RIVER WATERSHED: 1970[a]

Bypass Location	Initial Receiving Stream
Mouth of Milwaukee River to Confluence With the Menomonee River City of Milwaukee	
1. E. Bruce Street at Milwaukee River	Milwaukee River
2. E. Bruce Street at Milwaukee River	Milwaukee River
3. E. Erie Street at Milwaukee River	Milwaukee River
Confluence With the Menomonee River to the North Avenue Dam City of Milwaukee	
4. North of W. McKinley Avenue at N. Commerce Street	Milwaukee River
5. E. Brady Street and N. Van Buren Street	Milwaukee River
6. N. Marshall Street at Milwaukee River	Milwaukee River
Upstream From the North Avenue Dam City of Milwaukee	
7. N. Green Bay Road and W. Hampton Avenue	Milwaukee River
8. N. Green Bay Road and W. Hampton Avenue	Milwaukee River
9. N. 31st Street North of W. Hampton Avenue	Lincoln Creek
10. N. 35th Street and W. Congress Street	Lincoln Creek
Upstream From the North Avenue Dam Village of Fox Point	
11. Cherokee Circle (One-Half Block South of E. Spooner Road)	Indian Creek
12. 8506 N. Manor Road	Indian Creek

[a] The number beside each listed bypass corresponds to a code number on Map 46.

Source: City of Milwaukee Bureau of Engineering and the Sewerage Commission of the City of Milwaukee.

Table H-4

KNOWN RELIEF PUMPING STATIONS IN THE MILWAUKEE RIVER WATERSHED: 1970[a]

Relief Pumping Station Location	Initial Receiving Stream
City of Milwaukee	
1. N. 27th Street and W. Villard Avenue	Lincoln Creek
2. N. 32nd Street and W. Hampton Avenue	Lincoln Creek
3. N. 63rd Street and W. Hampton Avenue	Lincoln Creek
4. N. 35th Street and W. Roosevelt Drive	Lincoln Creek
Village of Fox Point	
5. Mall Road and Crossway Road	Indian Creek
6. Santa Monica Boulevard and Willow Road	Indian Creek
Village of River Hills	
7. Range Line Road	Milwaukee River

[a] All relief pumping stations are located upstream from the North Avenue Dam. The number beside each listed relief pumping station corresponds to a code number on Map 46.

Source: City of Milwaukee Bureau of Engineering and the Sewerage Commission of the City of Milwaukee.

Table H-5

KNOWN PORTABLE PUMPING STATIONS IN THE MILWAUKEE RIVER WATERSHED: 1970[a]

Portable Pumping Station Location	Initial Receiving Stream
City of Milwaukee	
1. N. 20th Street and W. Hampton Avenue	Milwaukee River
2. N. 47th Street and W. Hampton Avenue	Lincoln Creek
3. N. 48th Street and W. Luscher Avenue	Lincoln Creek
4. N. 49th Street and W. Luscher Avenue	Lincoln Creek
5. N. 47th Street and W. Eggert Place	Lincoln Creek
6. N. 55th Street and W. Fairmount Avenue	Lincoln Creek
7. N. 57th Street and W. Sheridan Avenue	Lincoln Creek
8. N. 61st Street and W. Lawn Avenue	Lincoln Creek
9. N. 63rd Street and W. Fairmount Avenue	Lincoln Creek
10. N. 64th Street and W. Stark Street	Lincoln Creek
11. N. 66th Street and W. Ruby Avenue	Lincoln Creek
12. N. 66th Street and W. Marion Street	Lincoln Creek
13. N. 67th Street and W. Marion Street	Lincoln Creek

[a] All portable pumping stations are located upstream from the North Avenue Dam. The number beside each portable pumping station corresponds to a code number on Map 46.

Source: City of Milwaukee Bureau of Engineering and the Sewerage Commission of the City of Milwaukee.

Appendix I

COMPARISON OF REGIONAL FLOOD FREQUENCY ANALYSIS DATA AND THE MILWAUKEE RIVER WATERSHED FLOOD SIMULATION MODEL DETERMINED FLOOD FREQUENCY DATA FOR 16 STRUCTURE LOCATIONS IN THE MILWAUKEE RIVER WATERSHED

Figure I-1
DISCHARGE - FREQUENCY
LOWER MILWAUKEE RIVER
AT STRUCTURE NO. 220, NORTH AVENUE DAM

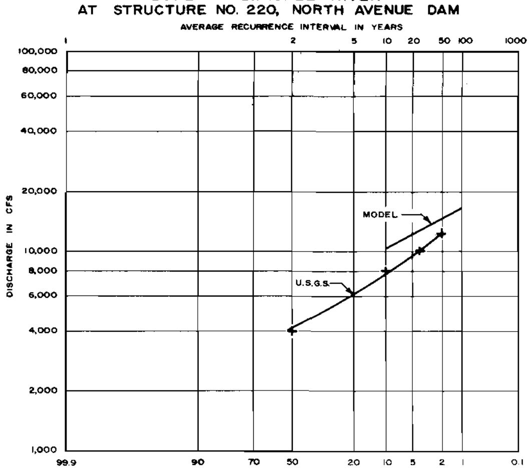


Figure I-2
DISCHARGE - FREQUENCY
LOWER MILWAUKEE RIVER
AT STRUCTURE NOS. 213 TO 215, ESTABROOK PARK DAM

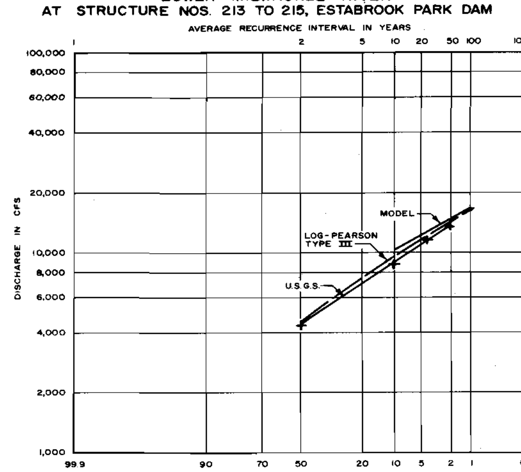


Figure I-3
DISCHARGE - FREQUENCY
LOWER MILWAUKEE RIVER
AT STRUCTURE NO. 197, BROWN DEER ROAD

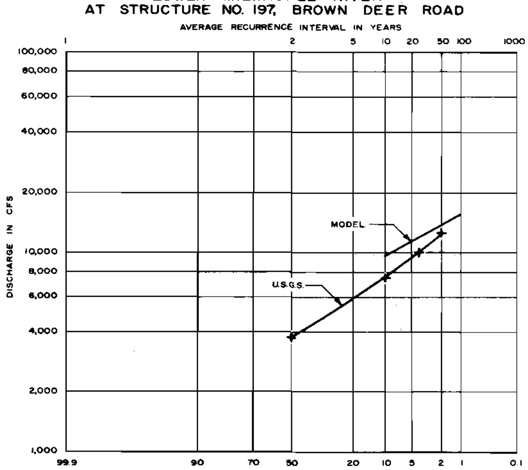


Figure I-4
DISCHARGE - FREQUENCY
LOWER MILWAUKEE RIVER
AT STRUCTURE NO. 196, MEQUON ROAD STH 167

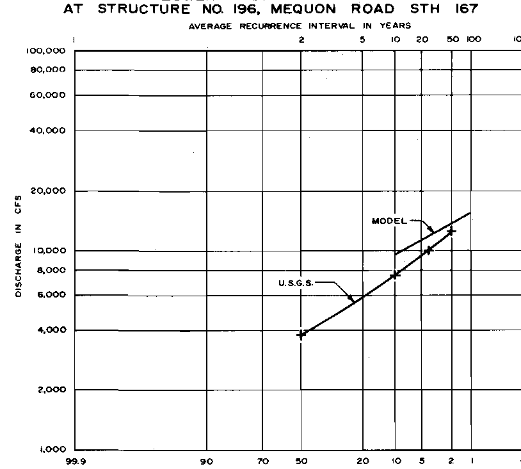


Figure I-5
DISCHARGE - FREQUENCY
LOWER MILWAUKEE RIVER
AT STRUCTURE NO. 193, PIONEER ROAD CTH C

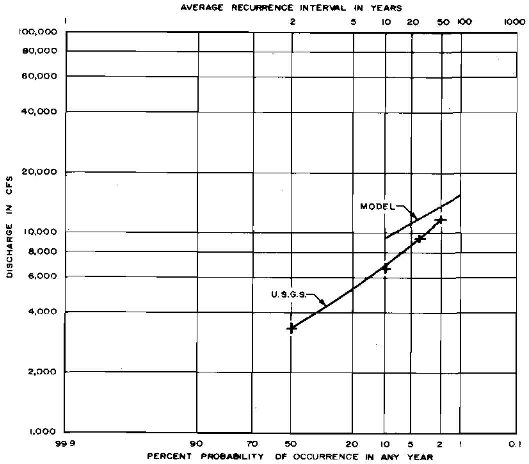


Figure I-6
DISCHARGE - FREQUENCY
CEDAR CREEK
AT STRUCTURE NO. 192, HAMILTON ROAD

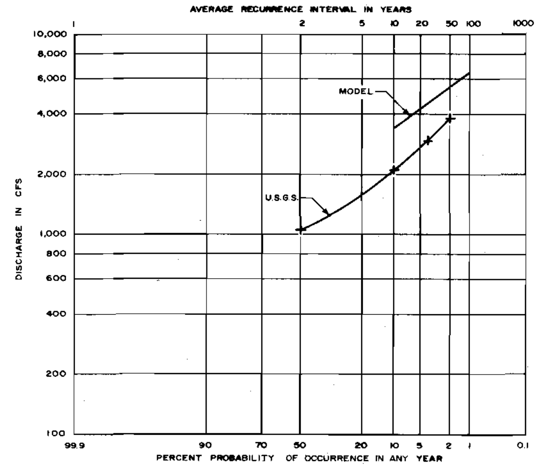


Figure I-7
DISCHARGE - FREQUENCY
CEDAR CREEK
AT STRUCTURE NO. 179, U.S.G.S. GAGING STATION STH 60

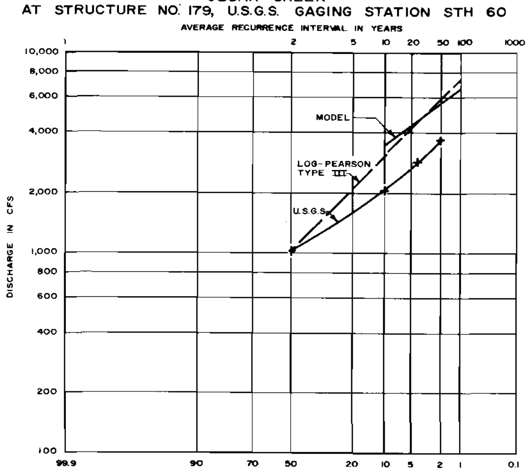


Figure I-8
DISCHARGE - FREQUENCY
LOWER MILWAUKEE RIVER
AT STRUCTURE NO. 146, GRAFTON STH 57

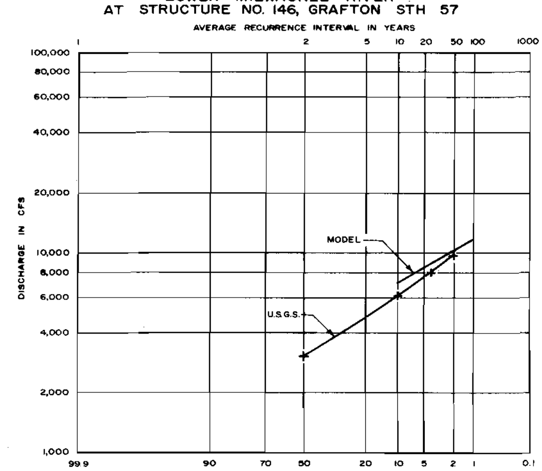


Figure I-9
DISCHARGE - FREQUENCY
NORTH BRANCH OF THE MILWAUKEE RIVER
AT STRUCTURE NO. 140, RIVERSIDE ROAD

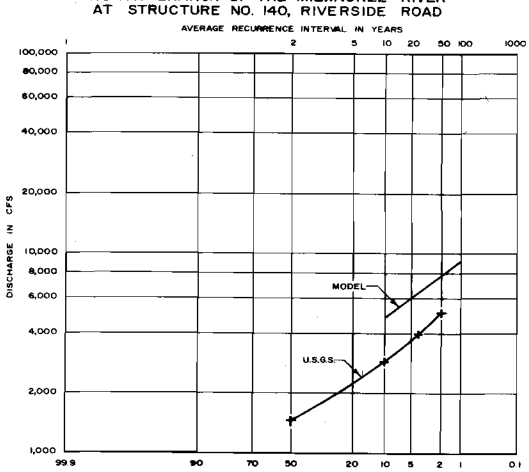


Figure I-10
DISCHARGE - FREQUENCY
MIDDLE MILWAUKEE RIVER
AT STRUCTURE NO. 89, DOWNSTREAM NEWBURG CTH A

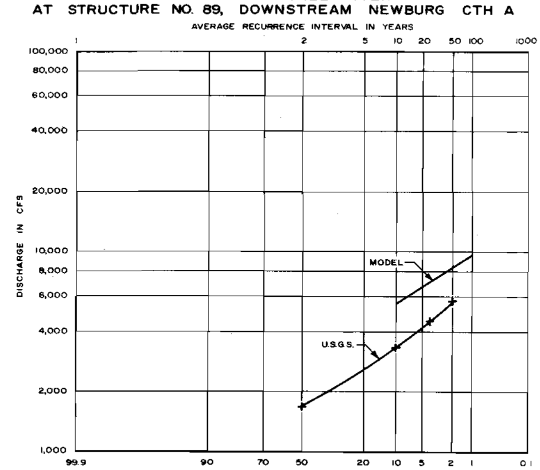


Figure I-11
DISCHARGE - FREQUENCY
MIDDLE MILWAUKEE RIVER
AT STRUCTURE NO. 78, WEST BEND STH 33

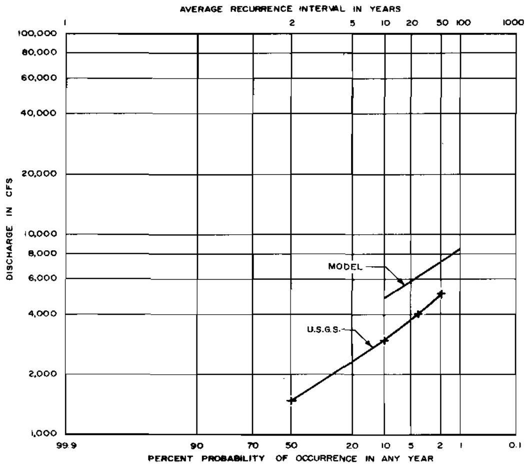


Figure I-12
DISCHARGE - FREQUENCY
EAST BRANCH OF THE MILWAUKEE RIVER
AT STRUCTURE NO. 52, STH 28

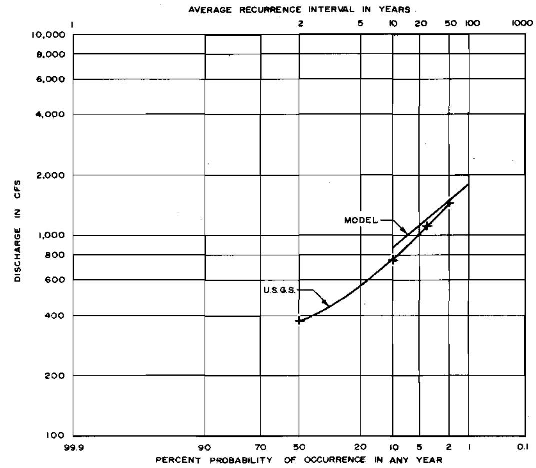


Figure I-13
DISCHARGE - FREQUENCY
UPPER MILWAUKEE RIVER
AT STRUCTURE NO. 29, KEWASKUM STH 28

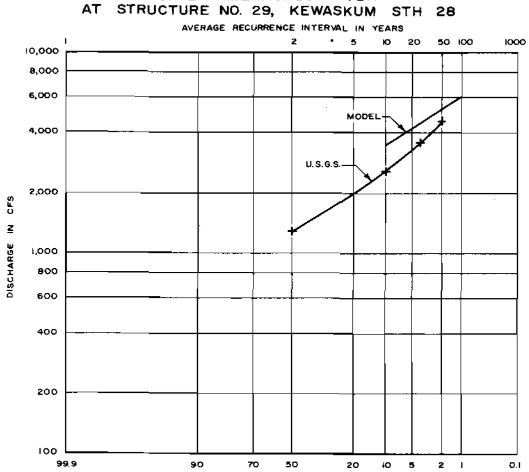


Figure I-14
DISCHARGE - FREQUENCY
WEST BRANCH OF THE MILWAUKEE RIVER
AT STRUCTURE NO. 28, USH 45

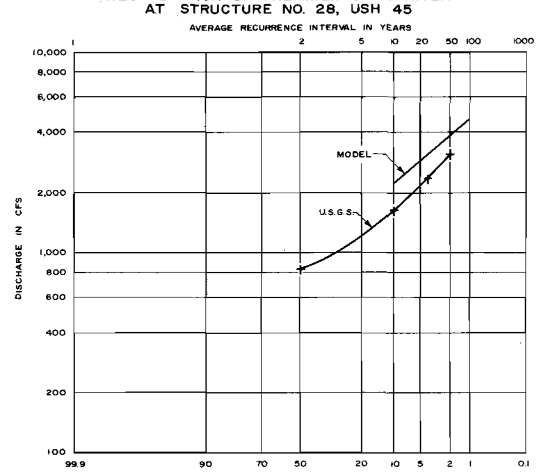


Figure I-15
DISCHARGE - FREQUENCY
UPPER MILWAUKEE RIVER
AT STRUCTURE NO. 11, AUBURN – ASHFORD ROAD

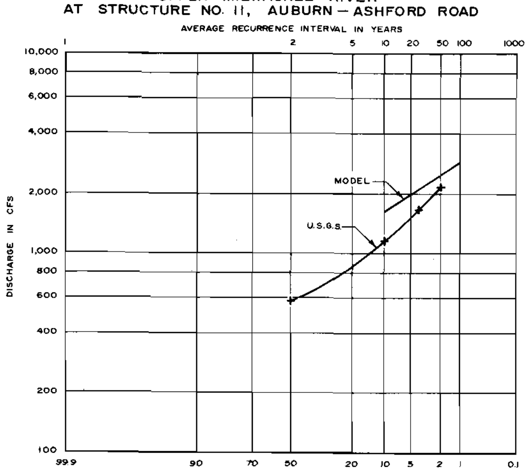
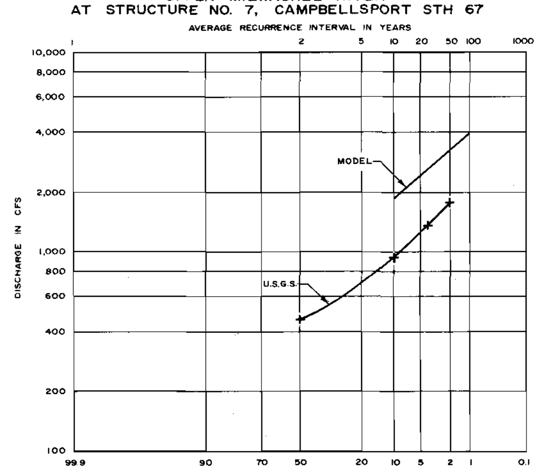


Figure I-16
DISCHARGE - FREQUENCY
UPPER MILWAUKEE RIVER
AT STRUCTURE NO. 7, CAMPBELLSPORT STH 67



Source: Harza Engineering Company and SEWRPC.

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Appendix J

LAKE AND STREAM RECREATIONAL USE CLASSIFICATION STANDARDS PREPARED BY THE WISCONSIN DEPARTMENT OF NATURAL RESOURCES

LAKE AND STREAM CLASSIFICATION RECOMMENDATION NO. 1

Recommendation: That lakes of less than 50 acres, not part of a connected chain, be limited to boats without motors.

Explanation: Lakes of this size are small. If circular in shape, as most lakes tend to be, they will be only 0.33 mile wide. Crossing a lake of this size at a rowing or paddling speed of four miles per hour would take only five minutes. A planing type of boat traveling at 10 miles per hour would only require two minutes to cross and a boat traveling at 20 miles per hour would require one minute. At 40 miles per hour, the near maximum speed, it would take 0.5 minute to cross. When the space for intensive shoreline activities is taken into account, a distance of 200 feet from shore, only 32.48 acres of open water surface remain. A boat traveling four miles per hour would be able to make 3.3 circles of the lake in an hour on a perimeter 200 feet from shore. A boat traveling 20 miles per hour could make 16.59 circles on this 0.829 mile perimeter.

Lakes of small sizes also have a high ratio of shoreline length to water area which contributes to a heavy load of lake users per unit area of water. A circular 10-acre lake would provide 3.65, 60-foot lots on its 0.22 mile shoreline per acre of water and a 50-acre lake would provide 1.8, 60-foot lots per acre on its 1.04 mile shoreline.

Since the available distances are short and the open water space limited, it is concluded that motorboats can cause substantial interference with other activities.

This recommendation would affect 2,221 named lakes, according to the 1958 publication entitled ''Wisconsin Lakes.''

LAKE AND STREAM CLASSIFICATION RECOMMENDATION NO. 2

Recommendation: That a shoreline activity zone 200 feet wide be established for all lakes in which the speed of boats would be limited to five miles per hour.

Explanation: Most activities on water take place near the shore, so crowding and conflicts between activities will be most intense here. This space is used by people for swimming, placement of piers, anchoring of boats, shore and shallow water fishing, wildlife observation, and duck hunting. It is also the nesting, feeding, and nursery area for fish and waterfowl. All shore activities named take place at a relatively slow speed or are stationary, so the capability to dodge or move out of the way is limited.

The number of persons engaged in shore activities is always much greater than the number engaged in boating during the summer, so if there is interference, shore activities should be accorded protection. Motorboats are capable of traveling at speeds ranging from four up to 40 miles per hour, and usually a speed of at least eight miles per hour is required to achieve planing for most boats of the planing type. Space consumption at high rates of speed will, therefore, be high, particularly when indulging in the sharp turn and maneuvers associated with water skiing. Fast moving activities and slow moving activities do not mesh well, and usually fast activities will drive slow activities away.

Motorboat travel through weed beds tends to damage submergent species and destroy emergent species. Since both types, if not in excess, contribute to the fish and game resource and the aesthetic opportunities, some protection is justified. Fast boat travel in shallow water near shores tends to stir up the bottom and create waves which do not have much space in which to be dampened. These circumstances contribute to water turbidity.

The shoreline activity zone 200 feet wide also will limit boat speed in narrow bays. Application of this speed rule, however, is not deemed practical for rivers.

LAKE AND STREAM CLASSIFICATION RECOMMENDATION NO. 3

Recommendation: That overnight anchoring, drifting, or mooring of boats on open water on which people are living, sleeping, or camping be prohibited on all inland waters except Great Lakes and its commercial harbors, the Mississippi River, the St. Croix River upstream to the first dam, the lower Fox River, Lake Winnebago, the upper Fox River and connecting lakes upstream to the Berlin Dam, and the Wolf River upstream to New London.

Explanation: Most of the inland waters are small and are not capable of inoffensively absorbing the sewage contribution anticipated from boat lodging. Adoption of this recommendation would in no way prohibit mooring of a boat to the shore and using it for sleeping purposes. When moored at the shore, occupants have the opportunity to seek shore disposal of wastes. Present law prohibits discharge of human wastes or operation of a marine toilet in all inland waters except the Mississippi River and Lake Winnebago. This rule is, however, ineffective if people are living aboard a boat on open water.

Operation of this recommendation would cause boats with living accomodations to be associated with private or public shore facilities and would, therefore, tend to achieve better control of physical nuisances in the form of pollution, garbage disposal, and social nuisances. The suggested control would impose no handicap on use of any type of boat for pleasure boating purposes on any waters.

LAKE AND STREAM CLASSIFICATION RECOMMENDATION NO. 4

Recommendation: That mooring of boats for more than 24 hours, either on shore or in the water, be prohibited at public landings except where landings, anchorages, or public piers have been designated by the agency owning the landing.

Explanation: Landings will usually consist of an access road leading down to a lakeshore. Being narrow, they do not provide enough space to moor many boats and, if boats are moored, the free movement of boats into and out of the water, or navigation on the water, is hampered. Boats are used but a small percentage of the total time available for use. Therefore, they will be at their moorings much more than in use. Transportation of boats no longer poses the problem it did years back. At the present time about 40 per cent of the boating public is transient, and trailer haulage has developed to a high degree of efficiency.

To moor all boats currently registered (200,000+) on the shore would mean occupation of 200 miles of shoreline. It will be clear from this fact that public landings will not have space to accommodate so many boats.

Where space does permit mooring of boats, anchorages or mooring areas should be designated by the agency owning the landing to avoid indiscriminate location of boats, with damage to aesthetic values, obstruction of launching sites, and interference with navigation and private property rights. To have access sites free of obstacles should permit a higher level of upkeep.

LAKE AND STREAM CLASSIFICATION RECOMMENDATION NO. 5

Recommendation: Boat control on lakes in the 50- to 200-acre size range, and in some cases larger lakes, will be necessary when they become heavily used. A limitation on speed to five miles per hour by the appropriate governmental agency will provide the best general control.

Explanation: Lakes in this size range are large enough so that boaters may want to use motor power to get around. They are also large enough to accommodate some fast boating when the level of all types of boating is not high. Yet they are not large enough to accommodate heavy fast boating traffic without becoming crowded and dangerous and subjected to considerable interference between activities.

Space consumption by swimmers, fishermen, and boaters traveling slowly is relatively low, while space consumption by fast boats is high. It is estimated that a water skier requires between 20 and 40 acres of space. A lake will be capable of accommodating more of the slow uses than fast uses and also has a higher level of participation in the slower uses.

Lakes in the 50- to 200-acre size class whose shores are completely occupied by residences and recreation facilities will have fast boating densities exceeding one boat per 20 acres, plus other boating activities. Lakes with complex shapes--much shoreline per unit of water--will have an aggravated problem.

Some idea of spatial relationships may be gained from the following notes. A lake of 100 acres circular in shape will have 70 acres of open water when due allowance is made for shoreline activities--a 200-foot wide shoreline activity zone. A 200-acre lake would have 150 acres when the shoreline activity zone is taken out. A circular 100-acre lake would be 0.4 mile across and a 200-acre lake would be 0.6 mile across. At five miles per hour, it would take five minutes to cross the 100-acre lake and 7½ minutes to cross the 200-acre lake. At 20 miles per hour, it would take one minute to cross the 100-acre lake and two minutes to cross the 200-acre lake. A circular course set 200 feet from shore would measure 1.16 miles on a 100-acre lake and 1.7 miles on a 200-acre lake. Four laps of this course on a 100-acre lake could be made at five miles per hour and 17 laps at 20 miles per hour in one hour's time. These facts suggest a very high traffic level can develop.

As levels of use become too high, imposition of a five mile per hour speed limit will be the best regulatory approach. A speed limit imposes no restrictions on type or size of boat and motor. Although some will argue that a speed limit cannot be enforced, it should be pointed out that this is approximately the speed of brisk walking and, therefore, has a land type of motion for comparison. Also, planing boats--the capability for traveling fast--will not take place until a boat is traveling at about eight miles per hour. A planing boat, therefore, will be easily detectable and known to be exceeding the speed limit.

Because of great variation in the levels of use and characteristics of lakes, it will not be possible to provide a single state regulation for the whole state covering all lakes of these sizes. As regulations are required for individual bodies of water, the regulating authority, whether state or local, should adopt the five miles per hour speed limit. In this way, uniform regulations will be developed as required.

There are 1,302 lakes which could be affected by this regulation.

LAKE AND STREAM CLASSIFICATION RECOMMENDATION NO. 6

Recommendation: That boats passing within 200 feet of swimmers, slow moving boats, anchored boats, or the shore be required to slow to five miles per hour.

Explanation: Maintenance of safe and enjoyable water recreation requires that there should be respect for the slower activities and that competing and conflicting activities be given separation. This intent will best be served by having fast craft slow down when they come close. ''Close'' is regarded as a distance of less than 200 feet. The five miles per hour is a safe speed with little wake and will cause little interference.

A 200-foot separation would provide an area around each boat or swimmer of about 0.7 of an acre, enough space relatively undisturbed to pursue activities without interference. Municipalities which already have adopted boating ordinances have required 100- to 200-feet separation of fast moving and anchored or slow moving craft with most adopting a 200-foot separation. Present state law prohibits operating a motorboat on a circular course within 200 feet of another boat or swimmer.

LAKE AND STREAM CLASSIFICATION RECOMMENDATION NO. 7

Recommendation: Lake and stream classification and zoning are usually thought of in terms of the water area, but the recreational use of water begins on the shore. Therefore, the Wisconsin Conservation Department, which provides guidance in recreational use of navigable waters, a public right, recommends that: 1) settlement, building, and platting along river and stream shores be based upon size of the body of water; and 2) streams and small rivers should not be platted or buildings constructed on their banks if these waters are to supply broadly based recreation of high quality.

Explanation: Large rivers will provide nearly full recreational use of a public resource from boats on the water; but aquatic recreation on streams and small rivers, which generally takes place from the bank, requires movement along the bank to seek the ''holes,'' ''flats,'' or ''riffles'' where the particular aquatic resource is located. Each little portion of stream or small river makes a contribution to the whole by providing any or all of such items as food for fish or waterfowl, resting or loafing sites, or spawning grounds; and there is considerable movement of these resources. Small parcels of frontage will seldom contain all values, and owners and users of these will also be dependent upon other frontage and locations for their package of recreation activity.

As streams and small rivers become splintered into small holdings, trespass problems will arise; and the ability to enjoy free movement up and down stream and riverbanks diminishes. Also, improvements by private frontage owners in the form of lawns, gardens, buildings, and sewage disposal usually occurring with residential or industrial building and platting may have a substantial impact on habitat. It is, therefore, recommended that streams and small river frontage should be regarded as public ways where appropriate and maintained in large ownership blocks in other places. To splinter holdings into numerous small ownerships will significantly reduce the value of streams and small rivers as a community recreation resource.

Large rivers, on the other hand, provide the opportunity for boat navigation and allow free movement in the water. The banks of the large rivers, which are similar in many respects to a lakeshore, provide a situation from which to enjoy aquatic recreation. Most of the large rivers inherently have greater navigation ease and more water space because they have low gradients approximating one foot per mile. Streams and many of the small rivers have gradients as high as 15 feet per mile with greater currents and more riffle areas less adaptable for boat use. However, utilization of the banks of large rivers for building purposes should only include frontage above flood stage and the modest slopes if flooding and erosion is to be avoided and valuable wetland habitat preserved.

A width of 200 feet is a good width to distinguish a ''large'' river from a ''small'' one. In order to furnish a concept of size, dimensions of some rivers are noted. Black Earth Creek has an average width of 16 feet. The Fox River in Kenosha County has an average width of 180 feet within its banks. The lower Rock, Wisconsin, Chippewa, and Fox, to name a few, would all be large rivers over 200 feet wide.

The present state program of acquiring stream frontage and fishing easements on streams and small rivers fits the concept of providing a public way ideally. Local units of government could also effectively make use of the zoning tool to assure the stream and river recreation values. Ideally, there could be a platting requirement enforced by the State Planning Division. This recreational concept for water use is highly compatible with floodplain zoning.

The miles and area of large rivers and small rivers in a number of counties where data is available are noted in the following table:

County	Large Rivers		Small Rivers And Streams	
	Miles	Area	Miles	Area
Dane	14	1,358	421	689
Dunn	75	2,177	386	1,614
Green	--	--	310	274
Kenosha	--	--	110	470
Polk	40	1,313	325	413
Racine	--	--	105	610
St. Croix	11	575	124	515
Vilas	--	--	402	1,274
Walworth	--	--	165	380
Washington	--	--	221	662

LAKE AND STREAM CLASSIFICATION RECOMMENDATION NO. 8

Recommendation: People desire a whole range of recreational values from inland glacial lakes and impoundments, including fishing, wildlife study and observation, hunting and trapping, and aesthetics. These important values require, in part, the existence of wild shore. Therefore, it is the Conservation Department's opinion that at least 25 percent of the shore of a particular lake or impoundment ought to be preserved in a wild state through zoning and acquisition if these values are to be protected.

Explanation: The various recreational demands made on water have a space requirement in the form of required habitat. For the fishery, this will be spawning grounds for various species, especially the marsh spawners, and nursery grounds for young fish; or it may be the subtle contribution of a food-producing area where frogs, turtles, and other lower vertebrates hold forth. For hunting, trapping, and wildlife observation, this wild land space is the nesting ground from which wetland wildlife has its necessary seclusion for family rearing and finds abundant food. It is the base of operations for this community. Many of the aesthetic demands of water users are met by the wild shore. This shore grows stands of bulrush and wild rice and supports clones of water lilies. From here terns and other types of birds will be able to fan out over the whole lake. This shore is an element of varied landscape which should not ''grow'' buildings like most of rest of the shore. Also, it makes a subtle contribution to the health of the lake where influent waters are cleansed of the silts and excessive nutrients.

The natural characteristics of inland lakes commonly make reservation of 25 percent, plus or minus, of the shore feasible. Prevailing westerly winds permit marshes to develop on west shores and protected shores and keep exposed shores well sorted and most adapted to the needs of people. By reserving a portion of the shore, whether marsh or other important habitat for fish and wildlife and aesthetic purposes, we would be contributing to preservation of at least half of the recreational demands made on water.

Without a measure of this kind, losses of water-recreational values are to be expected.

LAKE AND STREAM CLASSIFICATION RECOMMENDATION NO. 9

Recommendation: In situations where there is adequate space for water skiing but where there is substantial interference with other activities, that hours for water skiing be established. Recommended hours are 10 A.M. to 6 P.M. Savings Time.

Explanation: Lakes over 50 acres have at least some space for water skiing, but water skiing is so consumptive of space, taking 20 to 40 acres per boat, that there is substantial interference with other activities, particularly fishing. Where there is interference, the best manner in which to accommodate activities will be to establish hours during which water skiing can take place. Suggested hours will take advantage of the activity patterns of the activities.

Fishing is an activity most profitably pursued in early morning and in the later afternoon and evening. Water skiing is most commonly pursued in the warmth of the day when the sun is bright. Accordingly, it would be most appropriate to have hours which capture these activity patterns. If water skiing hours are maintained from 10 A.M. to 6 P.M., water skiing would not interfere with fishing, and prime fishing hours are reserved from interference. Water skiing could take place during the middle of the day.

This recommendation has meaning to more than a million anglers. It will be a restriction on water skiing, limiting the activity, to some extent, at both extremes of the normal activity period. Out of samples of motorboats in use, less than 10 percent had motors with more than 12 horsepower which might feasibly be used for water skiing. The hours as provided would tend to favor activities which are pursued by the greatest numbers.

LAKE AND STREAM CLASSIFICATION
RECOMMENDATION
NO. 10

Recommendation: That the decision regarding construction of lagoons or boat channels to lakes be based on the size of the lake and the amount of shoreline relative to the area of water. The intrinsic quality of the water recreation experience declines when density of boating for all purposes is excessive.

Specifics: 1. The intrinsic qualities of the water recreation experience decline significantly when the density of boating exceeds one boat per 10 acres. Since channels are in effect another means of boat access, density of boating should be one governing factor. A graph is provided indicating relationship of water space and shore space for lakes of various sizes and for lakes having various shapes (or shoreline development factors[1]) for aid in determining the size of waters on which this type of development is appropriate. An ellipse shape will be descriptive of most waters with complex shapes (i.e., elongated, many lobed, etc.).

2. Channels inherently have problems because of their characteristics. They, therefore, should be built only where they are importantly functional and where there is some possibility of having circulation. They should not be in competition with critical habitat.

3. That authority to construct a channel also be accompanied by the responsibility for maintenance.

Explanation: Channels or lagoons are usually a narrow waterway intended to provide boat access to those living on banks of the channel. They normally lead off the main basin of a lake, are dug to 5 or 6 foot depths and will be as much as 50 feet wide. A channel with these characteristics will be protected from wind and wave action, will be susceptible to growth of rooted plants and filamentous algae throughout, and will be subjected to encroachment from marsh plants growing along the edge.

Furthermore, a narrow channel with any amount of boat traffic and little space for dissipation of wake waves will face a problem with bank erosion. Entrances to channels if located along wind-swept shores face difficulties from lateral transport of beach and littoral sediments which can plug up a channel. A channel is, therefore, a potential maintenance problem to those responsible for upkeep. Under the circumstances, unless a channel is highly functional and heavily utilized and unless arrangements have been made for future upkeep, construction of a channel should be avoided.

Channels serving larger lakes generally have greater potential for flushing and circulation than those serving smaller lakes because they are subjected to modest wind induced changes in water levels (seiches). However, channels serving any lake have a high ratio of housing to water area and are, therefore, affected by local groundwater conditions and waste disposal. As a consequence, they are commonly very enriched if not polluted situations, particularly with poor circulation. Therefore, in the development of channels, attention should be given to provision of adequate sewage handling and disposal facilities.

[1] *The shoreline development factor is defined as the ratio of the length of the shoreline of the lake to the length of the shoreline in a circle of the same area. This ratio is never less than one and will be high for lakes with complex shapes.*

Since channels are intended primarily for boat access for homes or businesses on the banks, the question of lake size and amount of use has a bearing on the decision. An appropriate question in this regard is, ''Can the river or lake absorb more use without interference with existing uses?'' In dealing with lake use problems, we have noted that usually acceptable boating densities tend to be not more than one boat per 10 acres of useable water. Consequently, in making a decision on the construction of channels, present and prospective levels of use should be considered. Also, we have noted that up to 10% of the boats on a lake, plus those using an access site, will be in use at any one time. Thus, to help in arriving at a decision on capacity, there could be a summation of existing use. The accompanying graph can also be helpful for it provides a plot of shore length versus lake area for lakes of different shapes. The number of lots that might be placed on the shoreline can be calculated. Then, combined with expected loading from the channel, the potential density can be visualized.

Purely from the standpoint of levels of use, the ratio of shore length to lake size indicates a lake would have to be at least 50 acres before a ratio of one 100-foot shore unit (or lot for housing) per acre unit of water was reached for a circular lake. With higher shoreline development factors and considering public access, the lake would have to be larger still. Assuming that 10% of all boats present at any one time might be in operation during a peak activity period and by using as a basis for a decision a ratio of one 100-foot shore unit to one acre of water, all lakes having less than one acre of water per 100-foot unit of shore would be screened out as potential situations for channel development. Those having more than one acre per unit of shore would be potentially eligible, provided there were not other extenuating circumstances, such as excessive shallow waters and unuseable waters. With this background, it will not even be appropriate to discuss channels for lakes less than 100 acres. The minimum size would be larger still when giving consideration to water circulation factors--probably not less than 500 acres.

A lake under Wisconsin law is regarded as a common which all have the right of navigation and privilege to partake of the incidents of navigation such as fishing and swimming. A channel serves to foster community use of the navigable water and, therefore, will be a desirable manner in which to enjoy this common, provided intrinsic qualities are not devalued and provided there is adequate assurance of upkeep. From the fisheries standpoint, channels usually have seasonal migrations of fish, particularly in the spring and sometimes in early winter. Fish apparently seek the warmer waters of these channels. At other times, fishing is poor and channel waters may become stagnant or depleted of oxygen. Casual observations suggest there is better circulation of water and greater fish significance for channels leading from the large lakes.

This recommendation is an initial attempt to relate boat channels and lagooning to lake use. As more and better information becomes available, this recommendation may be modified accordingly.

Source: Wisconsin Department of Natural Resources.

Appendix K

DEFINITION OF WETLAND TYPES IN WISCONSIN

A wetland, as defined for the 1961 Wisconsin Department of Natural Resources inventory of wetlands, is any area where the water table is at such a level that raising of a cultivated crop is not usually possible. Seven specific wetland types are further defined as follows:

1. Pothole
   Ponds or stock watering areas, often with little cover or fringe vegetation. Vegetation is usually grass and weedy growth, with occasional brush or aquatics. Restricted to a maximum area of 10 acres.

2. Fresh Meadow
   Soggy ground or seasonally flooded areas which are normally too wet for agricultural practices. Growth of smartweeds; grasses, such as bluejoint and reed canary; sedges; or broad-leaved plants may be present. Burreed may sometimes be found in moist pockets.

3. Shallow Marsh
   Water present during most of the growing season, at least in parts of the area. Vegetation of rice cut-grass, cattails, burreed, arrowheads, bulrushes, and spikerushes.

4. Deep Marsh
   Water from six inches to three feet in depth during growing season. Vegetation of cattails, reeds, bulrushes, spikerushes, pondweed, and water lily.

5. Shrub Swamp
   Waterlogged soil, with occasional standing water. Vegetation of shrub types, such as alders, willow, and dogwoods.

6. Timber Swamp
   Waterlogged soil, with occasional standing water. Vegetation of timber types, such as tamarack, white cedar, green ash, and elm.

7. Bog
   Waterlogged soil conditions. Vegetation of leatherleaf, sphagnum moss, and labrador tea.

The correlation between the U. S. Department of the Interior system and the Wisconsin Department of Natural Resources wetland classification systems is shown in the following lists:

Wisconsin Wetland Type	U. S. Wetland Type
1. Pothole	5. Open fresh water (up to 10 acres)
2. Fresh meadow	1. Seasonally flooded plains or flats (wetter portions only) and 2. Fresh meadow
3. Shallow marsh	3. Shallow fresh marsh
4. Deep marsh	4. Deep fresh marsh
5. Shrub swamp	6. Shrub swamp
6. Timber swamp	7. Wooded swamp
7. Bog	8. Bog

The 199 numbered wetland units studied in the Milwaukee River watershed are composite complexes of one or more of the seven listed Wisconsin wetland types, although some of the units may consist of monotypes.

The 199 numbered wetland units identified in the Milwaukee River watershed can be generally defined as geographical wetland complexes. Each has a minimum aggregate area of 50 acres. No determination of the composition by types was specifically performed during identification of the units. For the entire group of 199 units, a determination of average type composition was carried out by a point sampling method using the 1961 state wetland inventory as a basis for the determination of types. Examination of 349 points for types yielded the following data:

Wisconsin Wetland Type Number	Wetland Type Name	Number of Points	Percent of Total Points
2	Meadow	90	26
1, 3, 4, 7	Marsh	14	4
5	Shrub swamp	61	17
6	Timber swamp	184	53
Total		349	100

The marsh category (wetland types 1, 3, 4, and 7) included the shallow and deep marsh classes, as well as potholes and bogs, as it was not thought that a type breakdown within this category could be accurately made from the 10-year old survey. An approximate breakdown of this category would be 2 percent shallow marsh, 1 percent deep marsh, and 1 or less percent each of pothole and bog. Reference was made to the 1967 regional aerial photos to help resolve difficult type identifications. This category (1, 3, 4, and 7) includes types usually wetter and with exposed surface water and totals 4 percent. The remaining categories are drier types and comprise 96 percent.

Appendix L

MANAGEMENT RECOMMENDATIONS FOR WETLAND UNITS IN THE MILWAUKEE RIVER WATERSHED

Wetland Unit Number[1]	Area in Acres[2]	Major Species to be Managed[3]	Quality Rating[4]	Recommended Management[5]
1	63	D, P	3	M
2	288	D, P	1	M
3	73	P	3	M
4	124	P	3	M
5	110	P, W, M	2	M
6	184	D, W	1	P
7	34	M, W	3	M
8	61	D, P	1	M
9	122	P	3	M
10	2,109	P, D, W	1	SWA
11	142	P, D	2	M
12	94	P, D	3	M
13	68	P, D	3	M
14	340	D, P	2	M
15	152	D, P	2	M
16	72	D, P	2	M
17	180	P, W, D	2	M
18	79	W, D, M, P	2	M
19	268	D, P	1	LWA
20	59	P	3	M
21	91	P, M, W	3	M
22	419	P	2	LWA
23	154	P, D	2	P
24	71	P, W	2	M, P
25	205	D	2	M
26	30	Aesthetic	3	M
27	91	M, W	3	M
28	103	W, M	2	LD
29	58	W, P, M	3	M
30	338	P, D	1	M
31	306	D, P	1	M
32	83	P, D	3	M
33	67	D	2	M
34	259	P, D	2	M
35	94	D, P	2	M
36	167	D, P	1	M
37	106	W, P, D, M	2	LoD, P
38	80	P, D, M	2	M
39	61	D, P	3	M
40	55	P, W	3	M
41	63	M, W, P	3	M
42	82	D, P	2	P
43	36	P	3	M
44	188	P, M, W	2	M
45	117	P	3	M
46	80	P, W	2	M
47	248	P, W, D	2	M
48	99	P, W	3	M
49	301	D, P	2	M
50	58	P	3	M
51	266	D	1	M
52	65	P	3	M
53	148	P	2	M
54	58	W, M	1	M
55	304	D	1	M
56	210	D, W, M, P	1	M
57	1,937	D, W, M, P	1	LWA
58	136	P	3	M
59	189	P	3	M
60	1,218	D, P	1	M
61	55	P	3	M
62	66	P	3	M
63	48	P	3	M
64	58	W, D, M	2	M
65	48	M, D, P	3	P
66	59	W, M	2	P, M
67	758	D, M, P	1	P
68	107	M, W, P	3	M
69	136	M, W	2	M
70	411	W, D, M, P	2	P
71	372	D, P	3	LWA
72	65	P, D	2	LWA
73	153	D, P	1	M
74	58	D	3	M
75	666	D, P, W, M	1	M
76	87	W, M, P	2	M
77	44	P	2	M
78	50	W, M, P	3	M
79	72	P	3	M
80	66	P	2	M
81	61	W, M	2	M
82	52	P	2	M
83	48	P, M, W,	2	M
84	376	D, P	1	M
85	217	P, D	2	M
86	107	P, D	2	M
87	452	D, P, W	1	M
88	136	D, P	2	M
89	53	P, W, M	3	M
90	74	P	3	M
91	56	D, P	3	M
92	196	P, D	3	M
93	117	D, P	3	M
94	91	P	3	M
95	103	P	2	M
96	151	P, D	3	M
97	574	P, W, M, D	1	M
98	318	P, W, M	2	M
99	91	P	2	M
100	205	M, W, P, D	3	M
101	34	P	3	M
102	644	P	1	M
103	96	P, D	3	M
104	345	D	1	M
105	880	D, W, M	1	M
106	173	D	2	M
107	760	D	1	M
108	295	D, P	2	M

Wetland Unit Number[1]	Area in Acres[2]	Major Species to be Managed[3]	Quality Rating[4]	Recommended Management[5]
109	64	P	3	M
110	18	W	3	M
111	267	P, W, D, M	2	M
112	153	P	2	M
113	79	P	3	M
114	187	W, M, D	1	M
115	118	P, D	2	M
116	66	P, D	3	M
117	75	P, D, W, M	2	M
118	290	D, P, W, M	1	M
119	71	P, W, M	1	M
120	84	P, W	2	M
121	60	D, W, M	1	M
122	44	W, M, D	2	M
123	175	D, W	1	M
124	341	D, W, P, M	1	M
125	91	P, D, W, M	2	M
126	44	P, D	3	M
127	149	P, D	1	M
128	106	D, W, P	1	M
129	42	D, P	3	M
130	64	P, D	3	M
131	153	P, D	2	M
132	39	P	3	M
133	95	P, D	2	M
134	51	P, M, W	3	M
135	92	P, W, M	2	M
136	102	D	2	M
137	144	M, W, P	3	M
138	92	W, M	3	M
139	166	D, P	1	M
140	76	P	3	M
141	539	D, P	1	M
142	82	D, P	2	M
143	106	D	1	M
144	146	D, P	1	M
145	300	D, P	1	M
146	190	D, P	1	M
147	78	D, P	1	M
148	127	P, D	2	M
149	155	W, M, P	2	M
150	44	D	3	M
151	127	P, W, M, D	2	M
152	55	W, M, P	2	M
153	47	W, P, M	2	M
154	86	D, P	1	M
155	86	P, W, M	3	M
156	86	P, W	3	M
157	315	P, D	1	M
158	355	D, P	1	LWA
159	671	P	1	M
160	357	P	2	M
161	294	P	2	LWA
162	62	D	2	M
163	360	D	1	M
164	23	P	3	M
165	90	P	3	M
166	53	P	3	M
167	132	W, M, P	3	M
168	60	P	3	M
169	260	P	2	M
170	421	D	2	M
171	915	D	1	M
172	668	D	2	M
173	243	D	1	M
174	411	D, W, M	1	M
175	234	D, W	2	M
176	115	D	2	M
177	661	P, D	1	M
178	95	P, W	2	M
179	44	M, W	2	M
180	447	W, M, D, P	1	M
181	75	P, W, M	3	M
182	703	D, P, W	1	M
183	71	P, D	3	M
184	15	W, M	2	M
185	47	W, M	2	M
186	77	P, D, W	2	M
187	241	D, P, W	1	M
188	54	W, M	1	M
189	323	D, P	1	M
190	106	D, P	2	M
191	152	P, D	2	M
192	92	P	2	M
193	85	D, P	2	M
194	110	D	1	M
195	161	P, W, M	2	M
196	136	W, M, P	1	M
197	513	M, W, P, D	1	M
198	151	P, W, M	2	M
199	52	P	3	M

[1]*See Map 21.*

[2]*Areas of under 50 acres were ignored unless several desirable contiguous pieces could be lumped together or unless the area was of very high quality, as a deep marsh. Continuous wetlands exceeding three miles on the east-west axis or two miles on the north-south axis were subdivided to conform to this limit. Also, a break was made at town or county lines.*

[3]*The listing in this column is that of the species of most prominence on the wetland. However, recommended management may make some areas suitable for additional species. The code is P for pheasant, D for deer, W for waterfowl, and M for muskrat-mink.*

[4]*The quality evaluation is not done in a sense of priority for preservation, since all the designated areas are desirable. Rather, the designation generally estimates the degree to which the wetland conforms to Wisconsin type standards and is undisturbed. The rating is modified by guidelines as follows:*

1. *Size--small size is a negative factor, since the major species have certain minimal spatial requirements. If the area has adjunctive features, the wetland, though small, still may enhance the habitat. For this reason, there are some exceptions to the 50 acre minimum size requirement (see footnote 1).*
2. *Vegetation--this factor is a major factor contributor to wildlife production and use potential. Certain types also greatly enhance the aesthetic appeal of an area. Tamarac swamps and other lowland timber types are rated highly. Marsh types of vegetation are especially valuable.*
3. *Location--areas immediately adjacent to urban expansion were rated lower than those more removed from urban encroachment; areas in or adjacent to public land were rated somewhat higher than those outside, especially those in or near existing wildlife areas. Nearness to stream courses or lakes often boosted the rating.*

[5]*Many wetlands are on excellent balance and condition. Preservation of the present conditions is the only requirement. Submarginal water supply is the factor limiting improvement possibilities in some areas. The management code used in this column is as follows: M--maintain; P--potholes; LD--level (blind) ditch; LoD--low dike; SWA--presently a state-owned wildlife area; and LWA--presently a leased wildlife area.*

Source: Wisconsin Department of Natural Resources.

Appendix M

LIST OF MAMMALS IN THE MILWAUKEE RIVER WATERSHED (ARRANGED SYSTEMATICALLY)

Virginia Opossum
Cinereous Shrew
Smoky Shrew
Saddle-Backed Shrew
Water Shrew
Pygmy Shrew
Mole Shrew (Short-Tailed)
Little Shrew (Short-Tailed)
Common Mole
Star-Nosed Mole
Little Brown Bat
Long-Eared Bat
Silver-Haired Bat
Big Brown Bat
Red Bat
Hoary Bat
White-Tailed Jack Rabbit
Mearns' Cottontail
Woodchuck
Striped Ground Squirrel (13-lined)
Franklin's Ground Squirrel
Gray Chipmunk
Ohio Chipmunk
Gray Squirrel
Fox Squirrel
Red Squirrel
Flying Squirrel
Beaver (may occur)
Prairie Mouse
Northern White-Footed Mouse
Cooper's Lemming Mouse
Meadow Jumping Mouse
Red-Backed Vole
Meadow Vole (Field Mouse)
Prairie Vole
Pine Vole
Common Muskrat
Norway Rat
Porcupine (may occur)
Northeastern Coyote
Red Fox
Gray Fox
Raccoon
Short-Tailed Weasel
Least Weasel
Long-Tailed Weasel
Mink
Badger
Northern Plains Skunk
Canada Otter (may occur)
Northern White-Tailed Deer

Source: Wisconsin Department of Natural Resources.

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Appendix N

LIST OF BIRDS IN THE MILWAUKEE RIVER WATERSHED (ARRANGED SYSTEMATICALLY)

	Migrant	Breeder	Rare
Common Loon	M		
Horned Grebe	M		
Pied-Billed Grebe		B	
Double-Crested Cormorant	M		
Great Blue Heron		B	
Green Heron		B	
Common Egret (American)	M		
Black-Crested Night Heron		B	
Least Bittern		B	
American Bittern		B	
Whistling Swan	M		
Canada Goose	M		
Snow Goose	M		
Blue Goose	M		
Mallard		B	
Black Duck		B	
Gadwall	M		
Pintail		B	
Green-Winged Teal		B	
Blue-Winged Teal		B	
American Widgeon (Baldpate)	M		
Shoveler		B	
Wood Duck		B	
Redhead		B	
Ring-Necked Duck		B	
Canvasback	M		
Greater Scaup	M		
Lesser Scaup	M		
Com. Golden-Eye (American)	M		
Bufflehead	M		
Old Squaw	M		
White-Winged Scoter	M		
Ruddy Duck		B	
Hooded Merganser	M		
Common Merganser	M		
Red-Breasted Merganser	M		
Goshawk	M		
Sharp-Shinned Hawk	M		
Cooper's Hawk		B	
Red-Tailed Hawk		B	
Red-Shouldered Hawk		B	
Broad-Winged Hawk	M		
Rough-Legged Hawk	M		
Bald Eagle	M		
Marsh Hawk		B	
Osprey	M		
Pigeon Hawk	M		
Sparrow Hawk		B	
Ruffed Grouse		B	
Bobwhite			R
Ring-Necked Pheasant		B	
Hungarian Gray Partridge		B	
Sandhill Crane	M		
King Rail		B	
Virginia Rail		B	
Sora Rail		B	

	Migrant	Breeder	Rare
Florida Gallinule		B	
Coot		B	
Semipalmated Plover	M		
Killdeer		B	
Golden Plover	M		
Black-Bellied Plover	M		
Ruddy Turnstone	M		
Woodcock		B	
Wilson's Snipe	M		
Upland Plover		B	
Spotted Sandpiper		B	
Solitary Sandpiper	M		
Greater Yellow-Legs	M		
Lesser Yellow-Legs	M		
Pectoral Sandpiper	M		
White-Rumped Sandpiper	M		
Baird's Sandpiper	M		
Least Sandpiper	M		
Red-Backed Sandpiper	M		
S.-Bill. Dowitcher	M		
L.-Bill. Dowitcher	M		
Stilt Sandpiper	M		
Semipalmated Sandpiper	M		
Sanderling	M		
Wilson's Phalarope		B	
Northern Phalarope	M		
Herring Gull	M		
Ring-Billed Gull	M		
Franklin's Gull	M		
Bonaparte's Gull	M		
Forster's Tern		B	
Common Tern	M		
Caspian Tern		B	
Black Tern		B	
Rock Dove		B	
Mourning Dove		B	
Yellow-Billed Cuckoo		B	
Black-Billed Cuckoo		B	
Barn Owl			R
Screech Owl		B	
Great-Horned Owl		B	
Snowy Owl	M		
Barred Owl		B	
Long-Eared Owl		B	
Short-Eared Owl	M		
Saw-Whet Owl			R
Whip-Poor-Will		B	
Nighthawk		B	
Chimney Swift		B	
Ruby-Throated Hummingbird		B	
Belted Kingfisher		B	
Flicker		B	
Pileated Woodpecker		B	
Red-Bellied Woodpecker		B	
Red-Headed Woodpecker		B	
Yellow-Bellied Sapsucker		B	

	Migrant	Breeder	Rare
Hairy Woodpecker		B	
Downy Woodpecker		B	
Eastern Kingbird		B	
Crested Flycatcher		B	
Phoebe		B	
Yellow-Bellied Flycatcher			R
Acadian Flycatcher		B	
Traill's Flycatcher (Alder)		B	
Least Flycatcher		B	
Wood Pewee		B	
Olive-Sided Flycatcher	M		
Horned Lark		B	
Tree Swallow		B	
Bank Swallow		B	
Rough-Winged Swallow		B	
Barn Swallow		B	
Cliff Swallow			R
Purple Martin		B	
Blue Jay		B	
Crow		B	
Black-Capped Chickadee		B	
Tufted Titmouse		B	
White-Breasted Nuthatch		B	
Red-Breasted Nuthatch	M		
Brown Creeper		B	
House Wren		B	
Winter Wren	M		
Bewick's Wren	M		
Long-Billed Marsh Wren		B	
Short-Billed Marsh Wren		B	
Catbird		B	
Brown Thrasher		B	
Robin		B	
Wood Thrush		B	
Hermit Thrush	M		
Swainson's Olive-Back Thrush	M		
Gray-Cheeked Thrush	M		
Veery (Willow)		B	
Bluebird		B	
Blue-Gray Gnatcatcher			R
Golden-Crowned Kinglet	M		
Ruby-Crowned Kinglet	M		
American Water Pipit	M		
Bohemian Waxwing	M		
Cedar Waxwing		B	
Northern Shrike	M		
Migrant Loggerhead Shrike			R
Starling		B	
Yellow-Throated Vireo		B	
Blue-Headed Solitary Vireo	M		
Red-Eyed Vireo		B	
Philadelphia Vireo	M		
Warbling Vireo		B	
Black & White Warbler		B	
Prothonotary Warbler	M		
Golden-Winged Warbler		B	
Blue-Winged Warbler		B	
Tennessee Warbler	M		
Nashville Warbler		B	
Parula Warbler	M		
Yellow Warbler		B	
Magnolia Warbler	M		
Cape May Warbler	M		

	Migrant	Breeder	Rare
Black-Throated Blue Warbler	M		
Myrtle Warbler	M		
Black-Throated Green Warbler	M		
Cerulean Warbler		B	
Blackburnian Warbler	M		
Chestnut-Sided Warbler		B	
Bay-Breasted Warbler	M		
Blackpoll Warbler	M		
Pine Warbler	M		
Palm Warbler	M		
Ovenbird Warbler		B	
Grinnell's No. Water Thrush Warbler		B	
Connecticut Warbler	M		
Mourning Warbler		B	
Yellow-Throat Warbler		B	
Wilson's Warbler	M		
Canada Warbler	M		
Redstart		B	
English House Sparrow		B	
Bobolink		B	
Eastern Meadowlark		B	
Western Meadowlark		B	
Yellow-Headed Blackbird		B	
Redwing		B	
Orchard Oriole Blackbird		B	
Baltimore Oriole Blackbird		B	
Rusty Blackbird	M		
Brewer's Blackbird	M		
Grackle		B	
Cowbird		B	
Scarlet Tanager		B	
Cardinal		B	
Red-Breasted Grosbeak		B	
Indigo Bunting		B	
Dickcissel		B	
Evening Grosbeak	M		
Purple Finch	M		
Pine Grosbeak	M		
Common Redpoll	M		
Pine Siskin	M		
Goldfinch		B	
Red Crossbill	M		
White-Winged Crossbill	M		
Towhee		B	
Savannah Sparrow		B	
Grasshopper Sparrow		B	
Henslow's Sparrow		B	
Vesper Sparrow		B	
Lark Sparrow		B	
Slate-Colored Junco	M		
Tree Sparrow	M		
Harris' Sparrow	M		
White-Crowned Sparrow	M		
White-Throated Sparrow	M		
Fox Sparrow	M		
Lincoln's Sparrow	M		
Swamp Sparrow		B	
Song Sparrow		B	
Lapland Longspur	M		
Snow Bunting	M		

Source: Wisconsin Department of Natural Resources.

Appendix O

BULKHEAD LINES IN THE MILWAUKEE RIVER WATERSHED

Table O-1

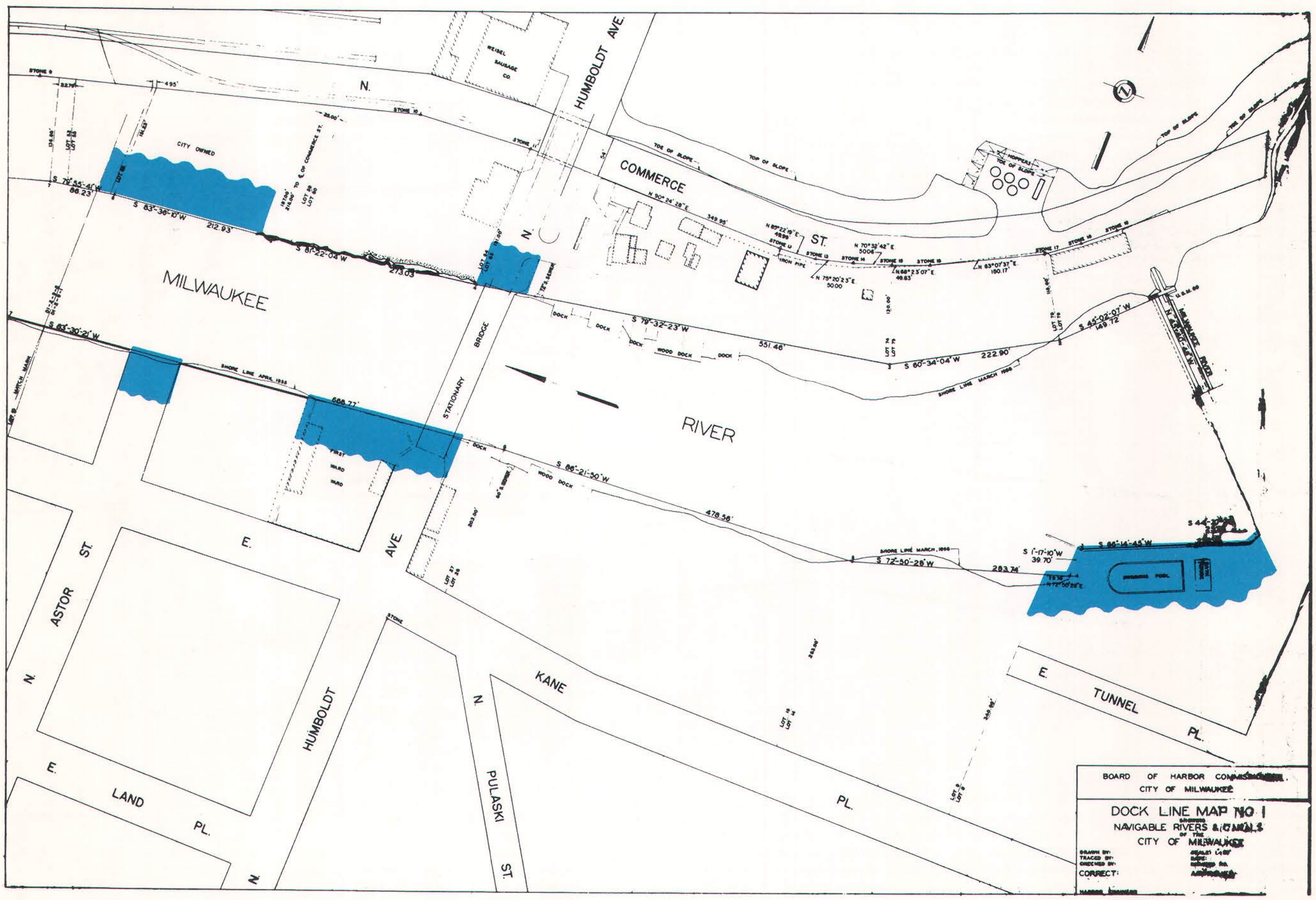
PUBLICLY-OWNED LANDS ALONG THE MILWAUKEE RIVER
FROM THE HARBOR ENTRANCE TO THE NORTH AVENUE DAM: 1969

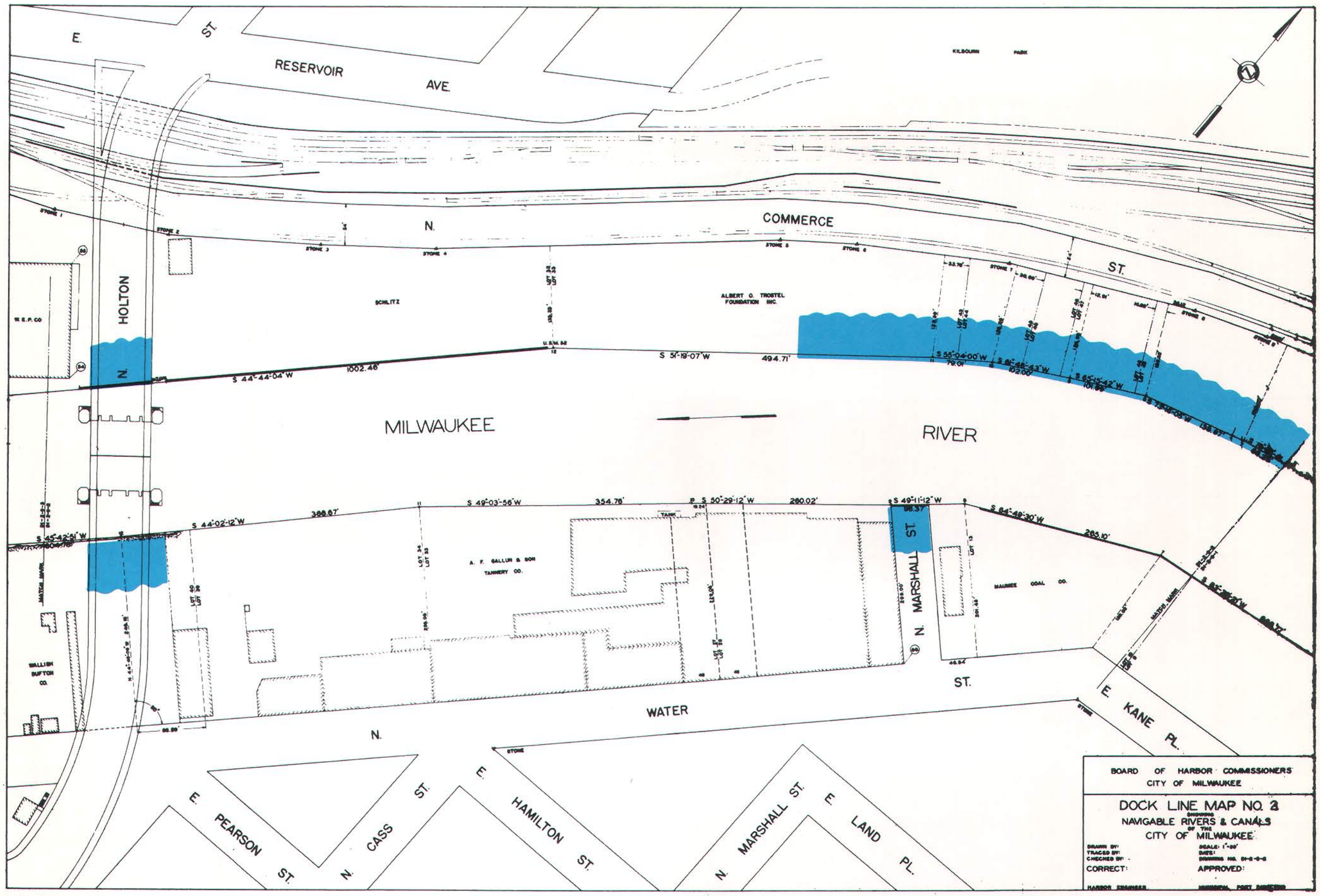
Owner	East River Bank		West River Bank		Total	
	Lineal Feet	Percent of Total River Bank[a]	Lineal Feet	Percent of Total River Bank[a]	Lineal Feet	Percent of Total River Bank[a]
City of Milwaukee. . .	4,371	24	3,560	22	7,931	23
Milwaukee County. . .	613	3	618	3	1,231	3
Total	4,984	27	4,178	25	9,162	26

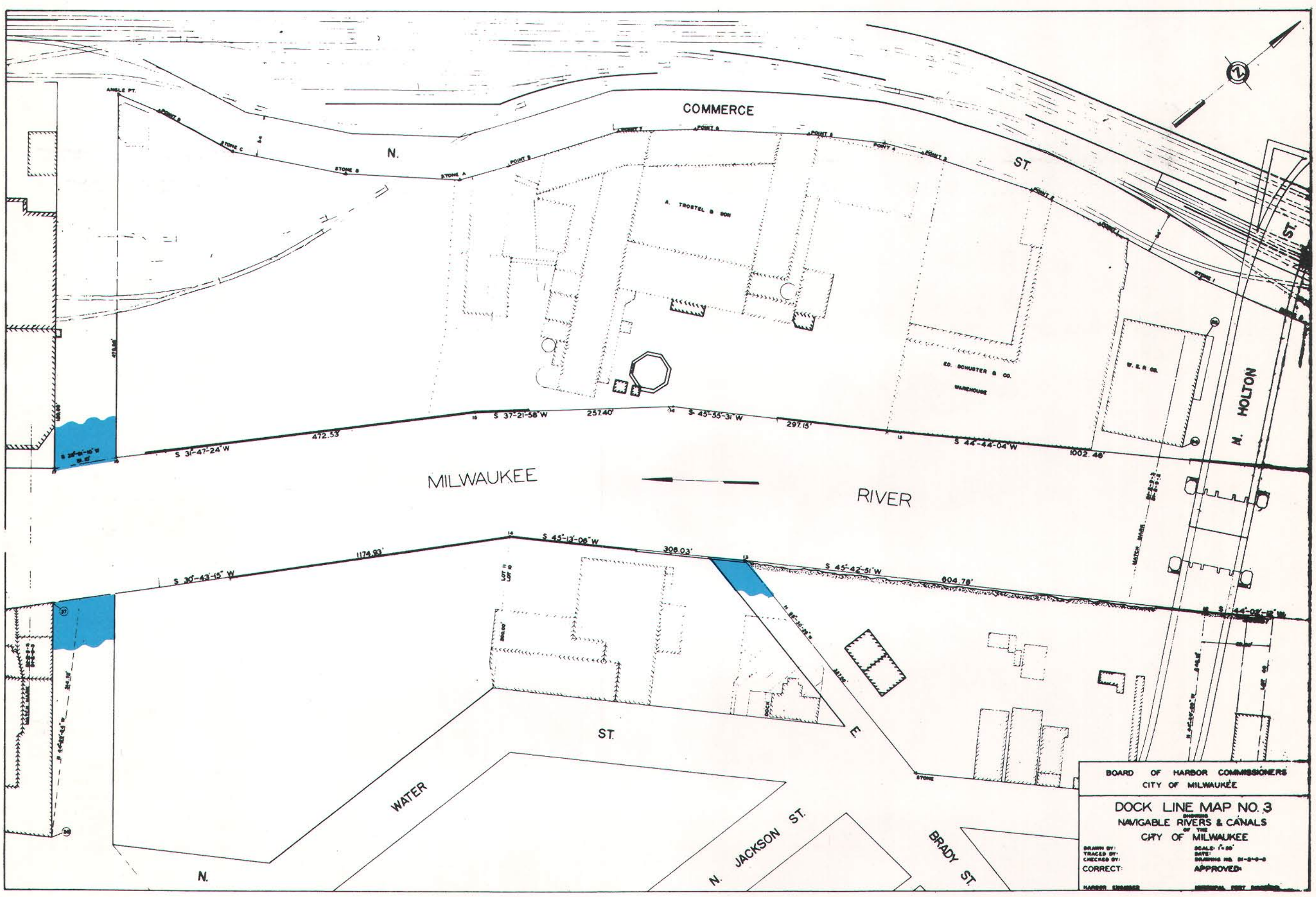
[a] The total length of the east river bank, measured from the beginning of the harbor entrance bulkhead to the North Avenue Dam, is 17,875 feet. The total length of the west river bank, measured from a point on the west bank opposite the center of the harbor entrance to the North Avenue Dam, is 16,000 feet. The total length of the river bank is 33,875 feet.

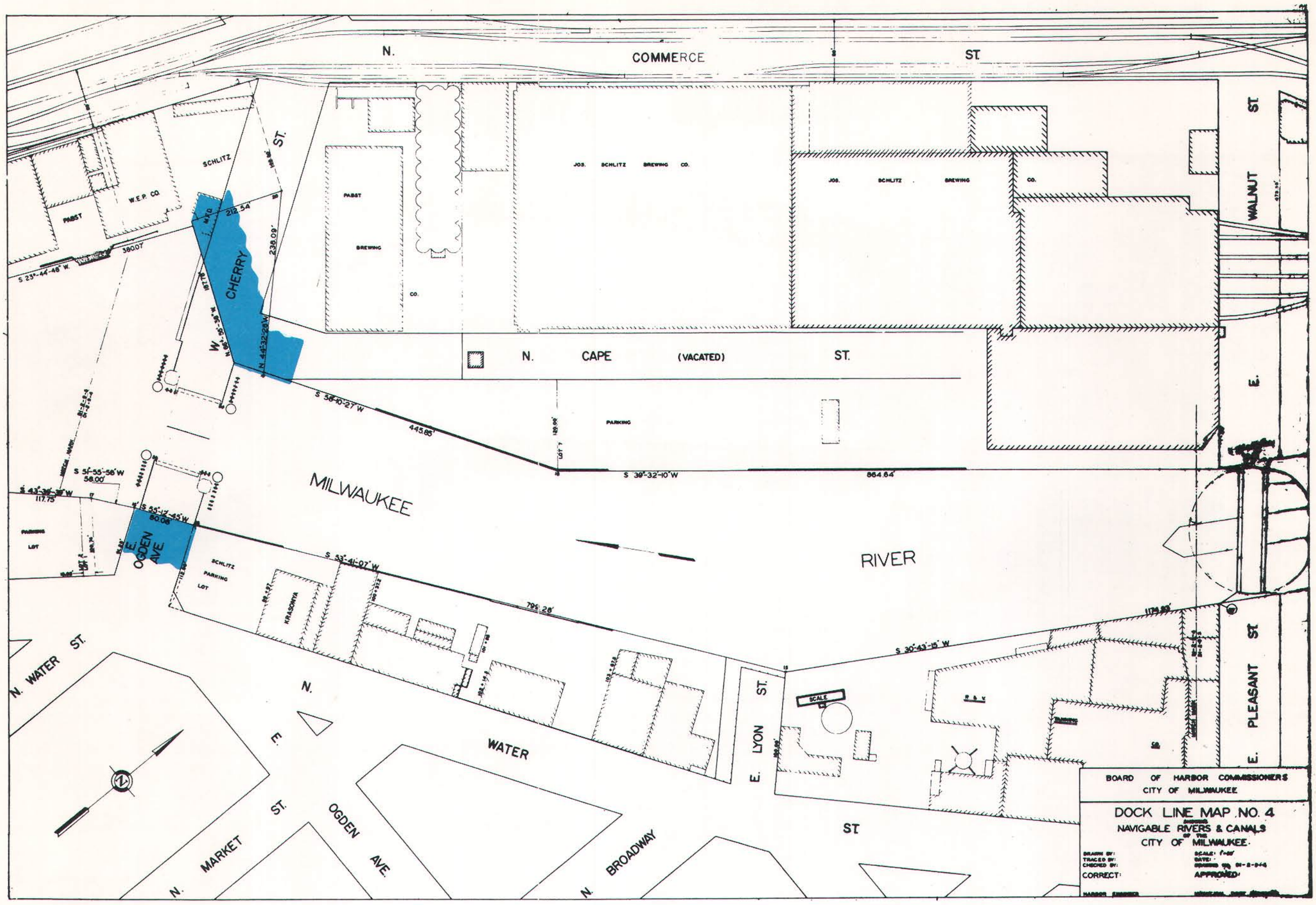
Figure O-1

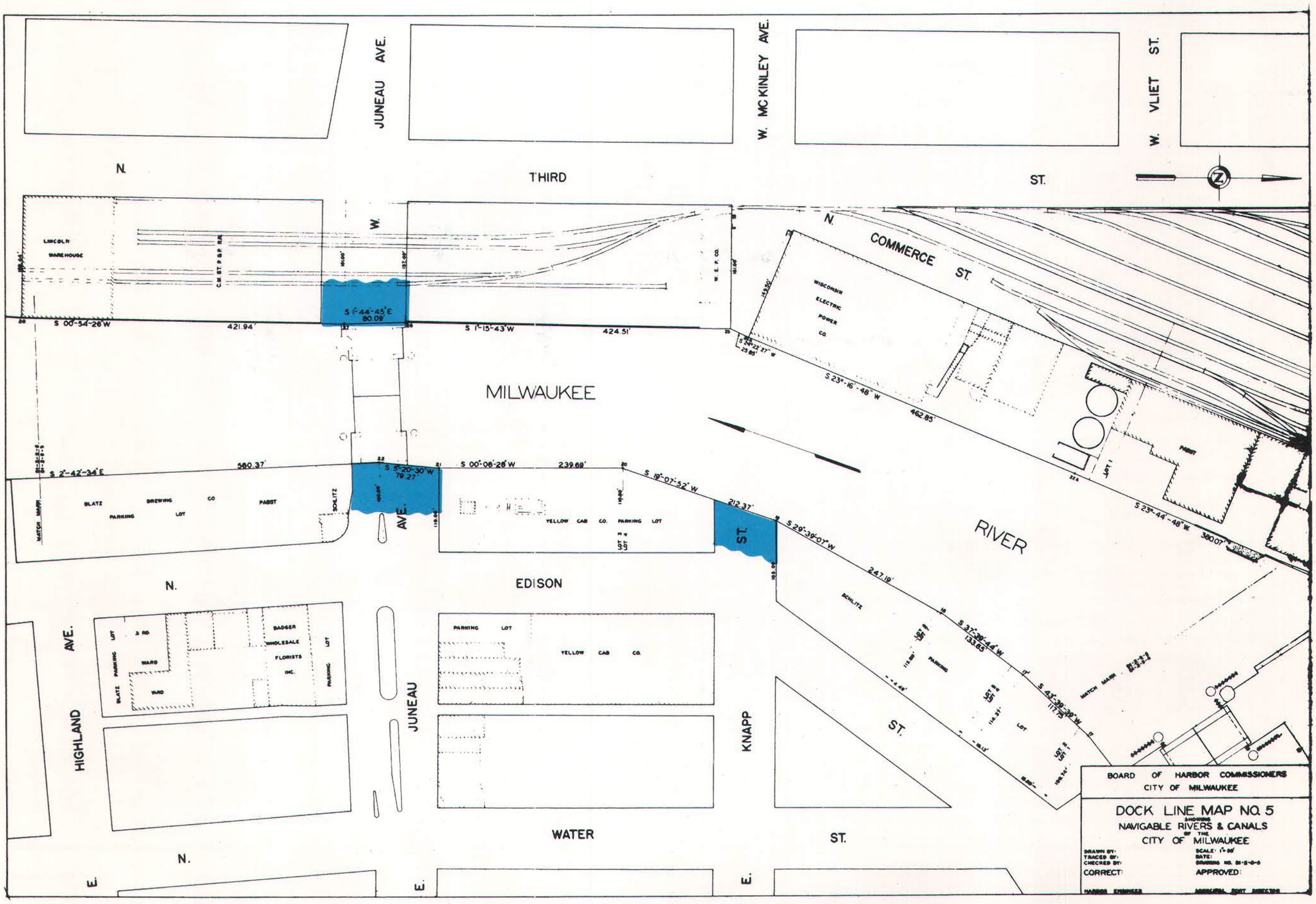
EXISTING BULKHEAD LINES ON THE MILWAUKEE RIVER
IN THE CITY OF MILWAUKEE: 1967

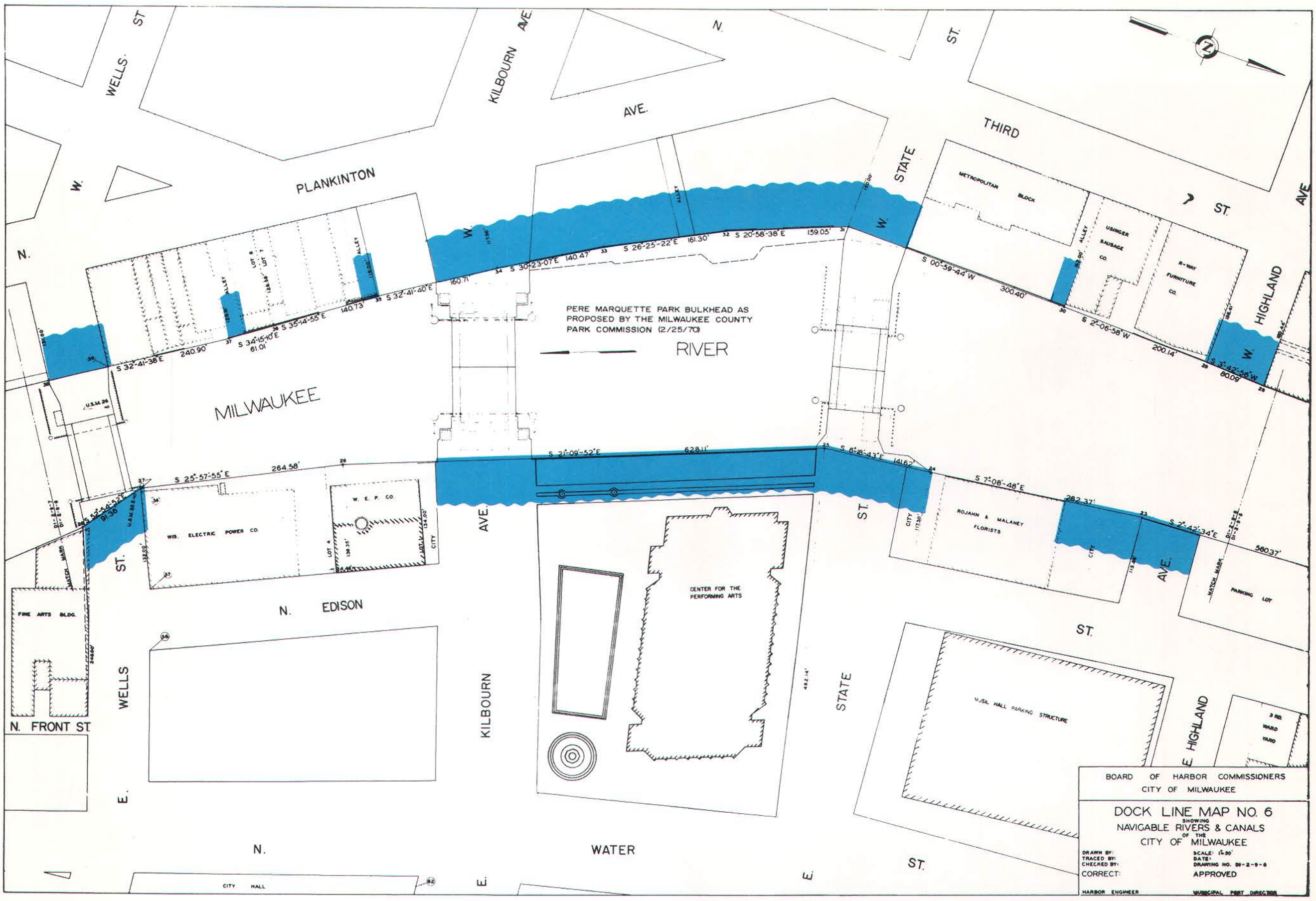


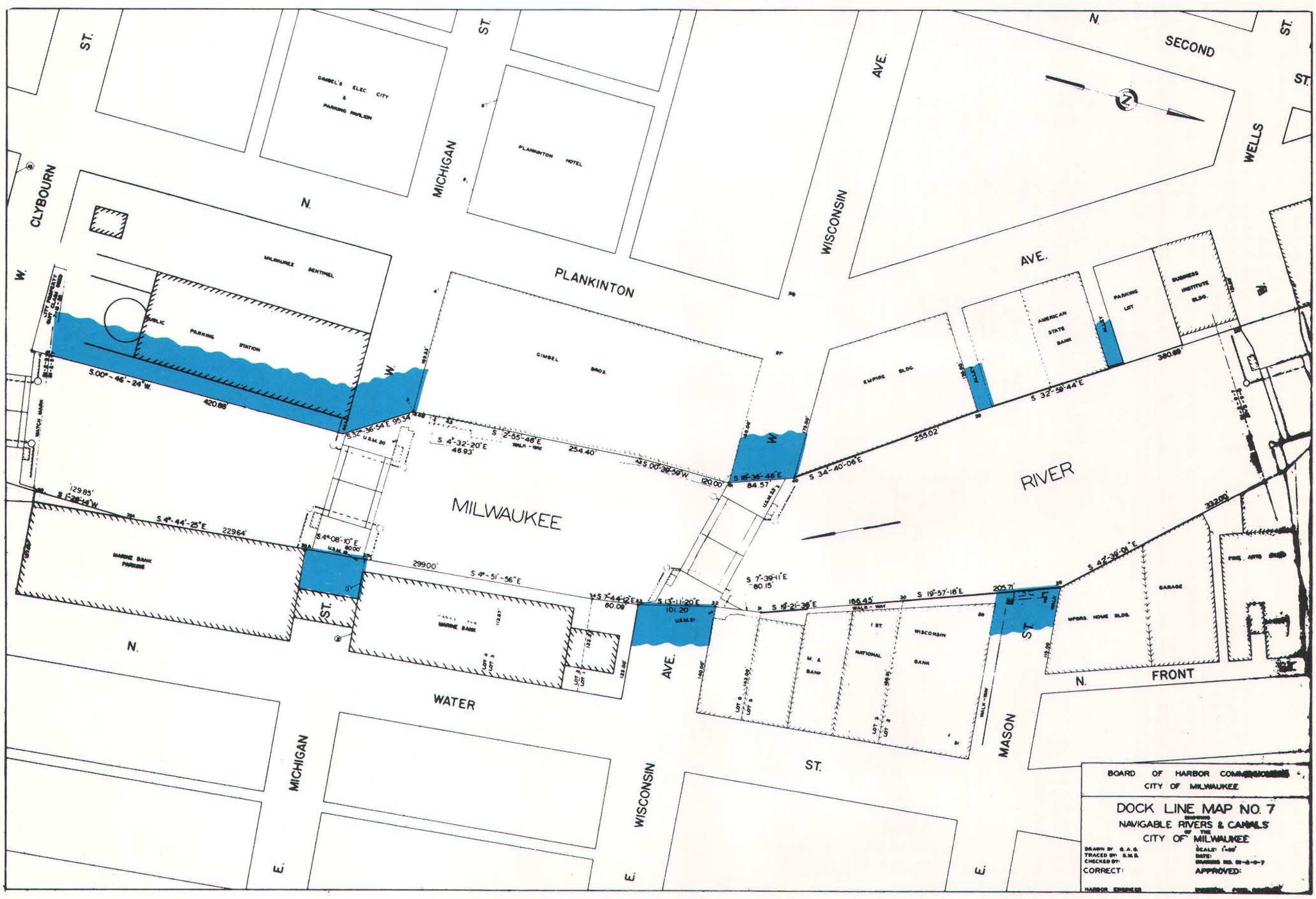

E. RESERVOIR AVE.
ST.
KILBOURN PARK
N. COMMERCE ST.
N. HOLTON
SCHLITZ
ALBERT O. TROSTEL FOUNDATION INC.
W. E. P. CO.
S 44°-44'-04" W 1002.46'
S 51°-19'-07" W 494.71'
MILWAUKEE RIVER
S 44°-02'-12" W 388.67'
S 49°-03'-56" W 354.76'
S 50°-29'-12" W 260.02'
S 49°-11'-12" W
S 64°-49'-30" W 285.10'
A. F. GALLUN & SON TANNERY CO.
TANK
N. MARSHALL ST.
MILWAUKEE COAL CO.
WALLISH BUFTON CO.
N. WATER ST.
E. KANE PL.
E. PEARSON ST.
N. CASS ST.
E. HAMILTON ST.
N. MARSHALL ST.
E. LAND PL.
BOARD OF HARBOR COMMISSIONERS
CITY OF MILWAUKEE
DOCK LINE MAP NO. 2
NAVIGABLE RIVERS & CANALS
CITY OF MILWAUKEE
CORRECT:
APPROVED:

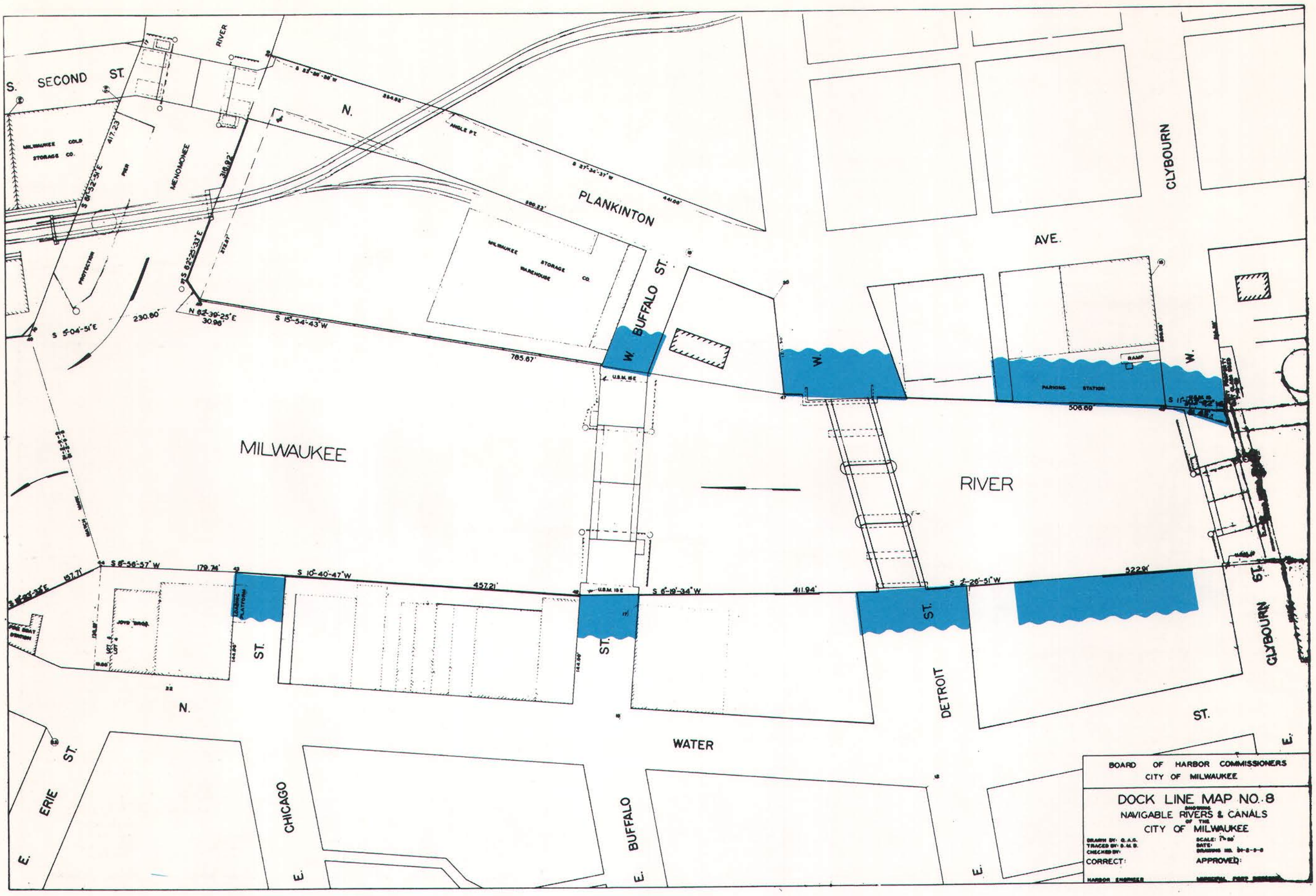

N. COMMERCE ST.
ANGLE PT.
A. TROSTEL & SON
ED. SCHUSTER & CO. WAREHOUSE
W. E. P. CO.
N. HOLTON ST.
S 31°-47'-24" W 472.53'
S 37°-21'-58" W 257.40'
S 45°-55'-31" W 297.13'
S 44°-44'-04" W 1002.46'
MILWAUKEE RIVER
S 30°-43'-15" W 1174.93'
S 45°-13'-06" W 308.03'
S 45°-42'-51" W 604.78'
N. WATER ST.
E.
N. JACKSON ST.
BRADY ST.
BOARD OF HARBOR COMMISSIONERS
CITY OF MILWAUKEE
DOCK LINE MAP NO. 3
NAVIGABLE RIVERS & CANALS
CITY OF MILWAUKEE
CORRECT:
APPROVED:

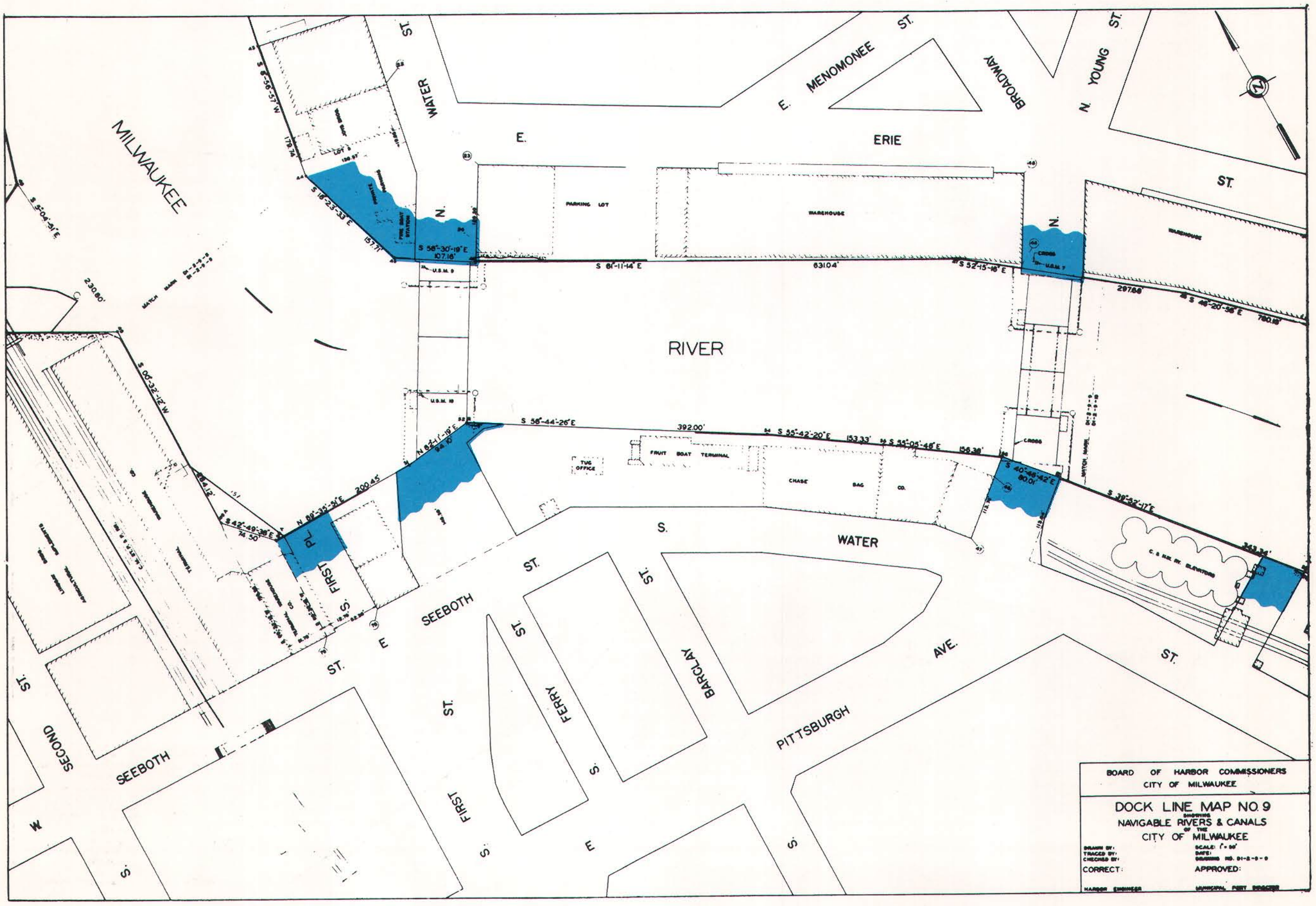

N. COMMERCE ST
JOS. SCHLITZ BREWING CO.
PABST BREWING CO.
SCHLITZ
W.E.P. CO.
PABST
W. CHERRY ST.
N. CAPE (VACATED) ST.
PARKING
MILWAUKEE RIVER
E. OGDEN AVE.
SCHLITZ PARKING LOT
KRASOWIA
N. WATER ST.
N. WATER ST
E. LYON ST.
SCALE
N. MARKET ST.
OGDEN AVE.
N. BROADWAY
N. WALNUT ST
E. PLEASANT ST
S 58°-10'-27" W
S 39°-32'-10" W
S 30°-43'-15" W
BOARD OF HARBOR COMMISSIONERS
CITY OF MILWAUKEE
DOCK LINE MAP NO. 4
NAVIGABLE RIVERS & CANALS
CITY OF MILWAUKEE
CORRECT:
APPROVED:

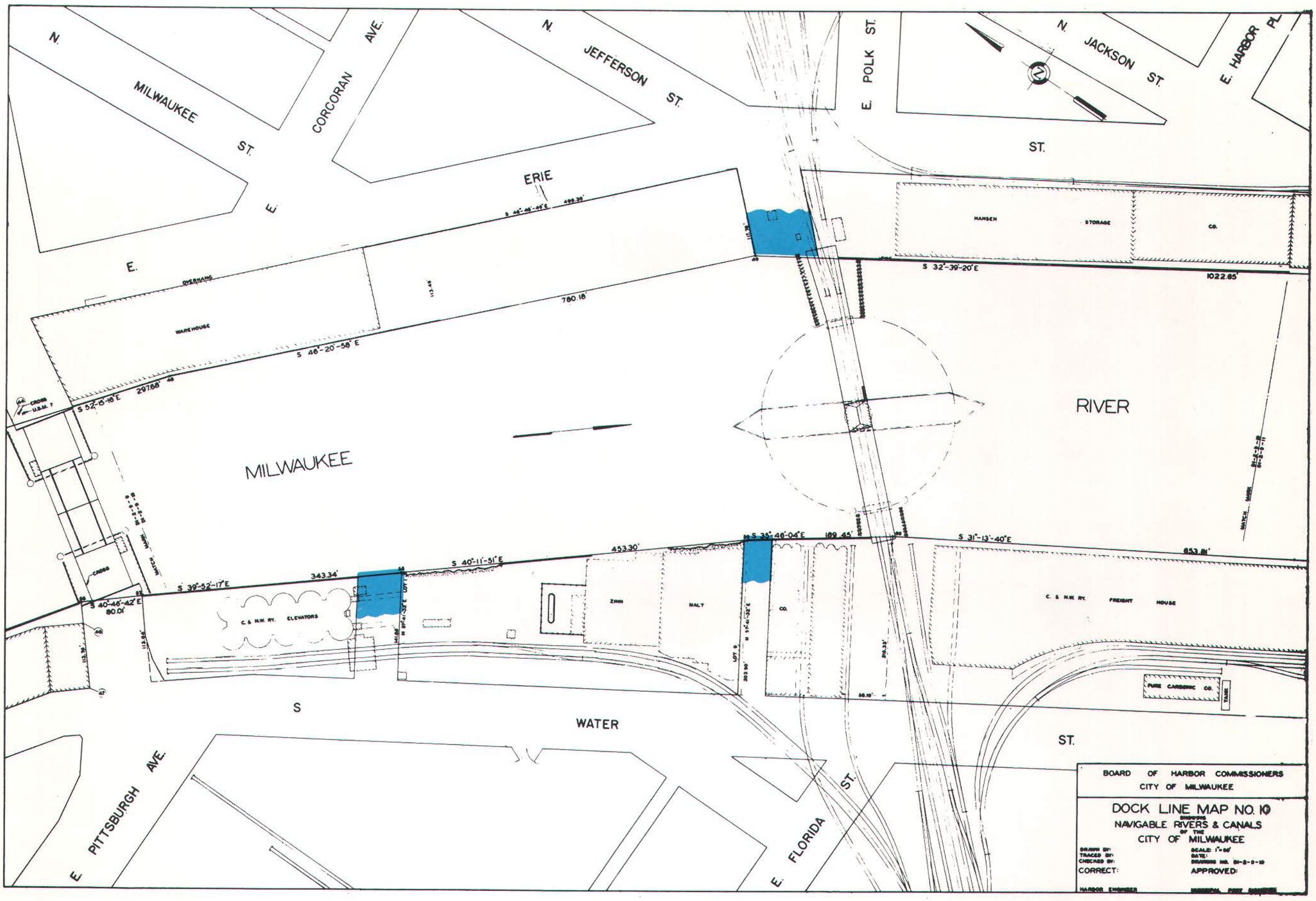

W. JUNEAU AVE.
W. MCKINLEY AVE.
W. VLIET ST.
N. THIRD ST.
N. COMMERCE ST.
LINCOLN WAREHOUSE
W.E.P. CO.
WISCONSIN ELECTRIC POWER CO.
S 1°-44'-45" E 80.09
S 00°-54'-26" W
S 1°-15'-43" W
S 23°-16'-48" W
MILWAUKEE RIVER
BLATZ BREWING CO PABST PARKING LOT
YELLOW CAB CO. PARKING LOT
SCHLITZ
S 5°-20'-30" W 78.27
S 19°-07'-52" W
S 29°-39'-07" W
S 23°-44'-48" W
N. EDISON ST.
BADGER WHOLESALE FLORISTS INC.
YELLOW CAB CO.
N. HIGHLAND AVE.
E. JUNEAU AVE.
E. KNAPP ST.
N. WATER ST.
BOARD OF HARBOR COMMISSIONERS
CITY OF MILWAUKEE
DOCK LINE MAP NO. 5
NAVIGABLE RIVERS & CANALS
CITY OF MILWAUKEE
CORRECT:
APPROVED:


BOARD OF HARBOR COMMISSIONERS
CITY OF MILWAUKEE
DOCK LINE MAP NO. 6
SHOWING
NAVIGABLE RIVERS & CANALS
OF THE
CITY OF MILWAUKEE
PERE MARQUETTE PARK BULKHEAD AS PROPOSED BY THE MILWAUKEE COUNTY PARK COMMISSION (2/25/70)
MILWAUKEE
RIVER
N. WELLS ST.
KILBOURN AVE.
N. PLANKINTON AVE.
W. STATE ST.
THIRD
W. HIGHLAND AVE.
METROPOLITAN BLOCK
WIS. ELECTRIC POWER CO.
N. EDISON
E. WELLS
E. KILBOURN AVE.
E. STATE ST.
E. HIGHLAND
CENTER FOR THE PERFORMING ARTS
N. WATER ST.
N. FRONT ST
FINE ARTS BLDG.
CITY HALL

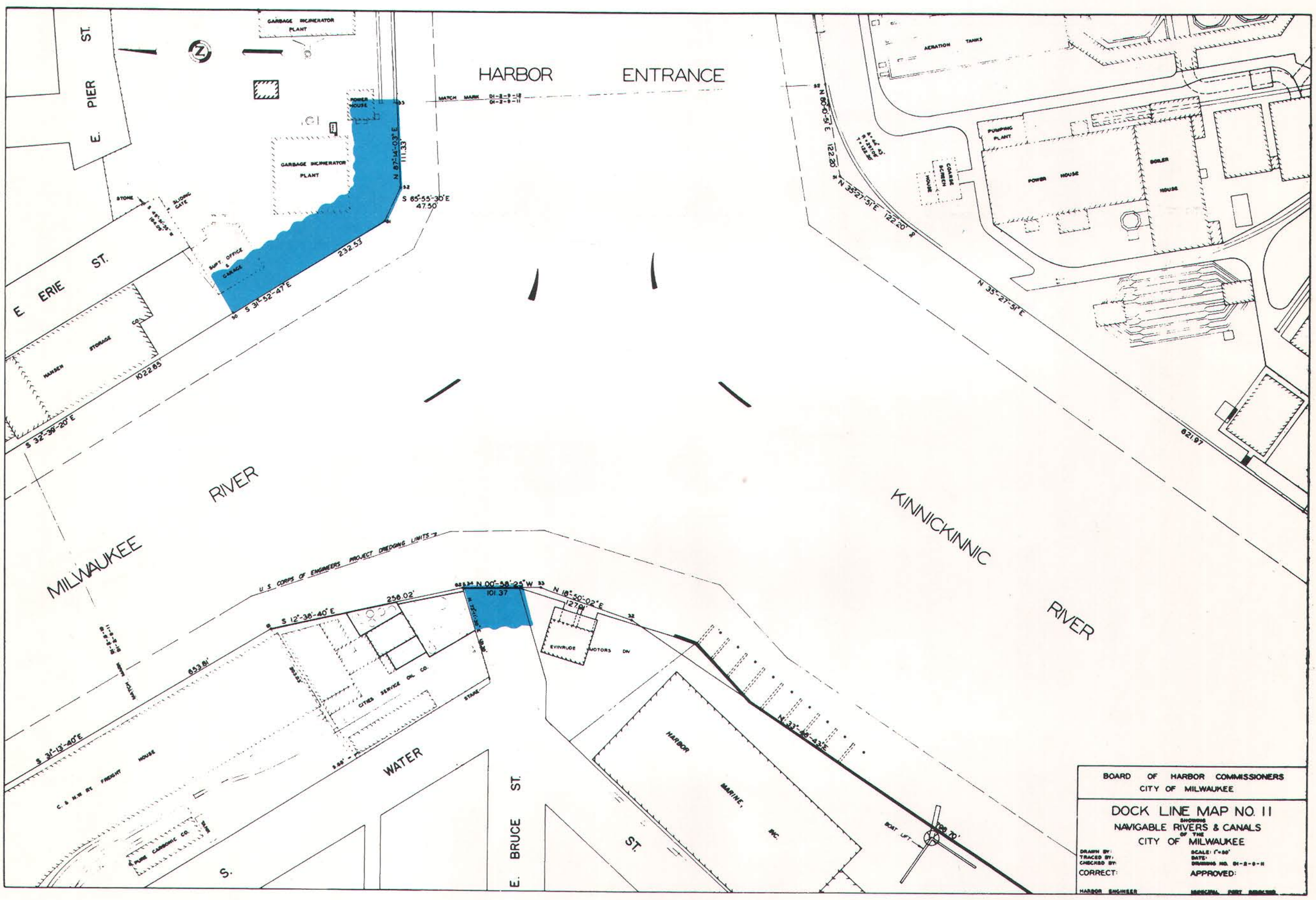

BOARD OF HARBOR COMMISSIONERS
CITY OF MILWAUKEE
DOCK LINE MAP NO. 7
SHOWING
NAVIGABLE RIVERS & CANALS
OF THE
CITY OF MILWAUKEE
MILWAUKEE
RIVER
W. CLYBOURN ST.
N. MICHIGAN ST.
N. PLANKINTON AVE.
WISCONSIN AVE.
N. SECOND ST.
WELLS ST.
PLANKINTON HOTEL
GIMBEL BROS.
MILWAUKEE SENTINEL
PUBLIC PARKING STATION
EMPIRE BLDG.
AMERICAN STATE BANK
MARINE BANK PARKING
MARINE BANK
WISCONSIN NATIONAL BANK
GARAGE
FINE ARTS BLDG.
N. FRONT
N. WATER ST.
E. MICHIGAN
E. WISCONSIN
E. MASON


BOARD OF HARBOR COMMISSIONERS
CITY OF MILWAUKEE
DOCK LINE MAP NO. 8
SHOWING
NAVIGABLE RIVERS & CANALS
OF THE
CITY OF MILWAUKEE
CORRECT:
APPROVED:
MILWAUKEE
RIVER
S. SECOND ST.
N. PLANKINTON AVE.
CLYBOURN
W. BUFFALO ST.
W.
W.
CLYBOURN ST.
N. WATER ST.
E. ERIE ST.
E. CHICAGO ST.
E. BUFFALO ST.
E. DETROIT ST.
E.
MENOMONEE
MILWAUKEE STORAGE CO. WAREHOUSE
PARKING STATION
RAMP
785.67'
457.21'
411.94'
179.74'
506.69'
522.91'

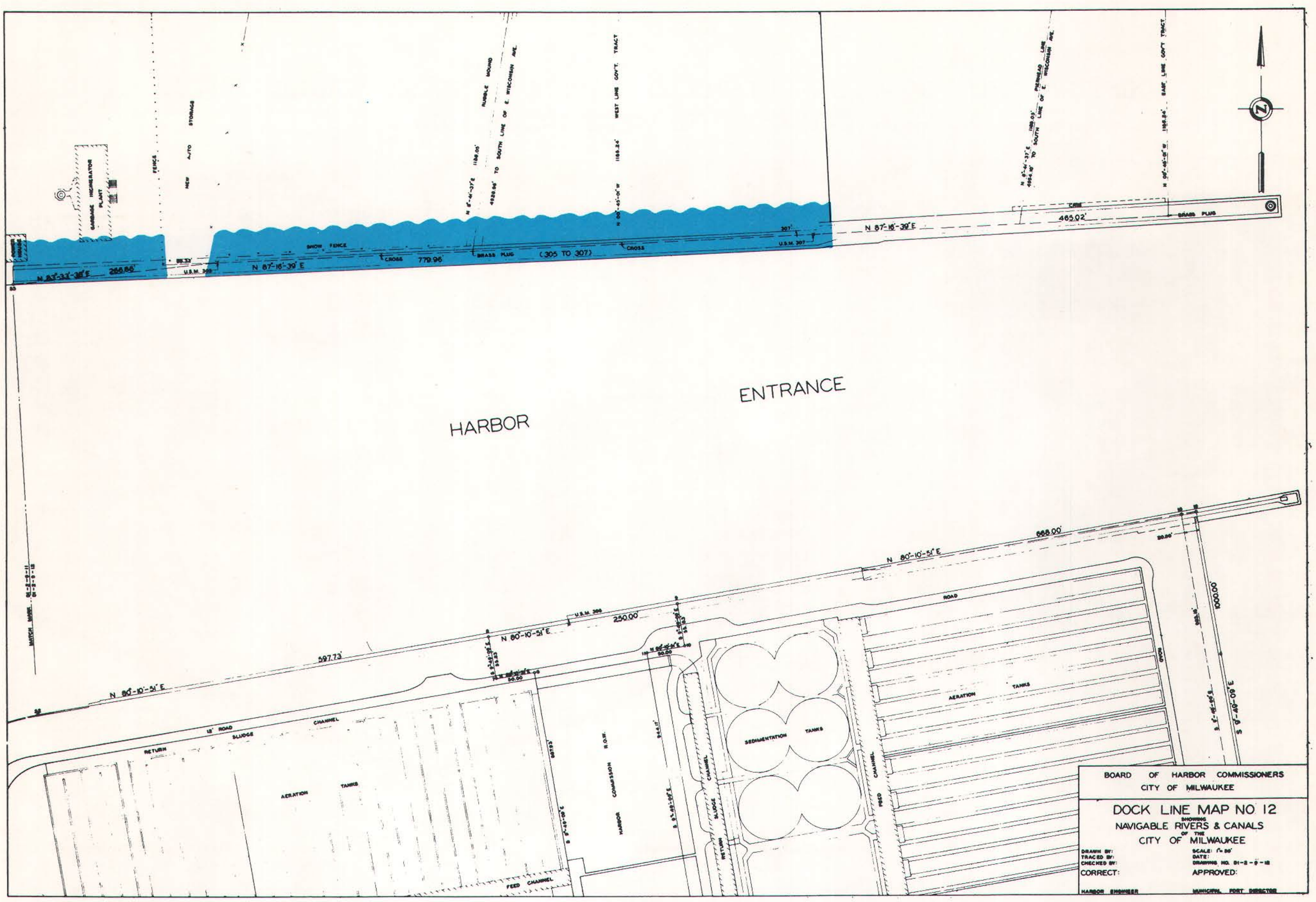

BOARD OF HARBOR COMMISSIONERS
CITY OF MILWAUKEE
DOCK LINE MAP NO. 9
SHOWING
NAVIGABLE RIVERS & CANALS
OF THE
CITY OF MILWAUKEE
CORRECT:
APPROVED:
MILWAUKEE
RIVER
N. WATER ST.
E. MENOMONEE ST.
BROADWAY
N. YOUNG ST.
E. ERIE ST.
PARKING LOT
WAREHOUSE
S. FIRST PL.
S. WATER
E. SEEBOTH ST.
S. FIRST ST.
S. FERRY ST.
S. BARCLAY ST.
E. PITTSBURGH AVE.
W. SEEBOTH ST.
S. SECOND ST.
TUG OFFICE
FRUIT BOAT TERMINAL
CHASE BAG CO.
S 81°-11'-14" E
631.04'
S 58°-44'-26" E
392.00'
S 58°-30'-19" E
107.16'
230.80'
200.45'



N. MILWAUKEE ST.
CORCORAN AVE.
N. JEFFERSON ST.
E. POLK ST.
N. JACKSON ST.
E. HARBOR PL.
E. ERIE ST.
HANSEN STORAGE CO.
WAREHOUSE
MILWAUKEE
RIVER
C. & N.W. RY. ELEVATORS
C. & N.W. RY. FREIGHT HOUSE
PURE CARBONIC CO.
S. WATER ST.
E. PITTSBURGH AVE.
E. FLORIDA ST.
BOARD OF HARBOR COMMISSIONERS
CITY OF MILWAUKEE
DOCK LINE MAP NO. 10
NAVIGABLE RIVERS & CANALS
CITY OF MILWAUKEE
CORRECT:
APPROVED:



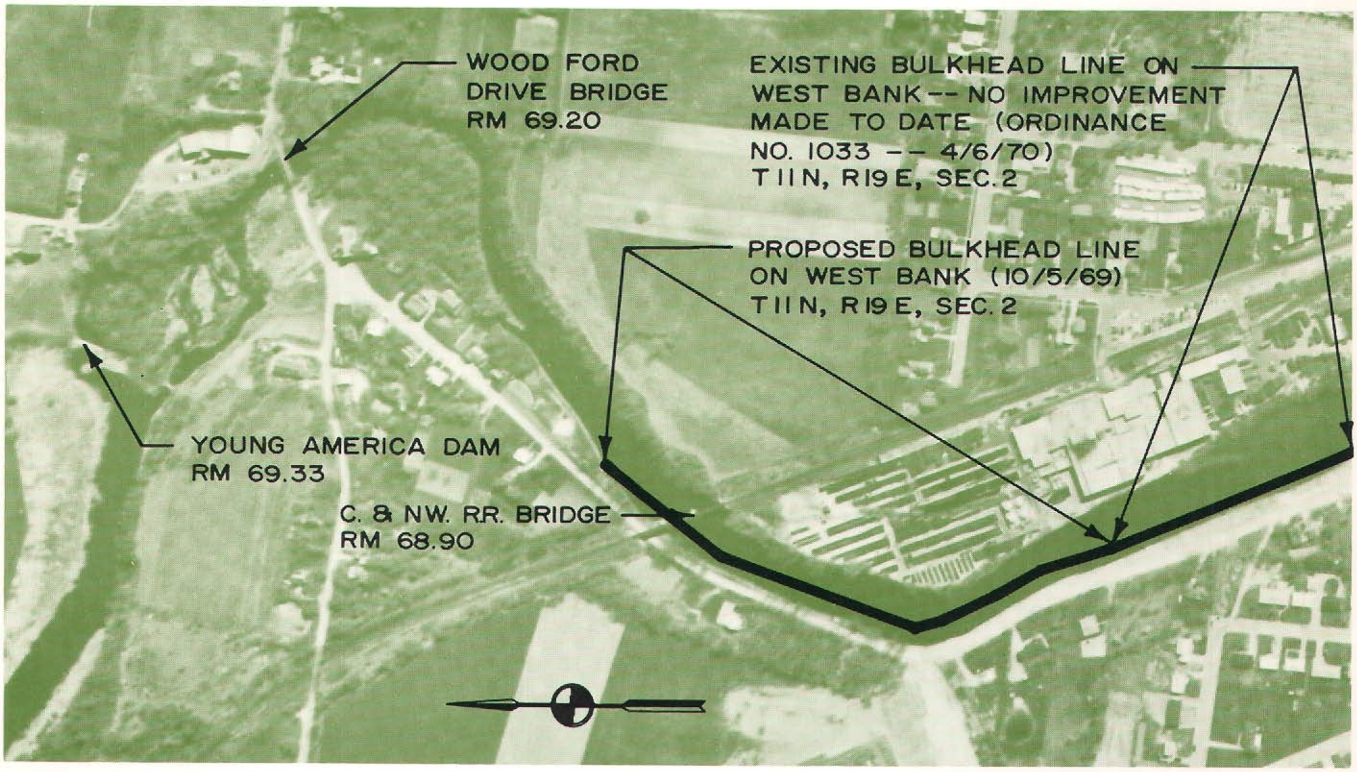
E. PIER ST.
GARBAGE INCINERATOR PLANT
HARBOR ENTRANCE
E. ERIE ST.
HANSEN STORAGE
MILWAUKEE
RIVER
KINNICKINNIC
RIVER
POWER HOUSE
BOILER HOUSE
PUMPING PLANT
AERATION TANKS
CITIES SERVICE OIL CO.
EVINRUDE MOTORS DIV.
HARBOR MARINE, INC.
S. WATER
E. BRUCE ST.
C. & N.W. RY. FREIGHT HOUSE
PURE CARBONIC CO.
BOARD OF HARBOR COMMISSIONERS
CITY OF MILWAUKEE
DOCK LINE MAP NO. 11
NAVIGABLE RIVERS & CANALS
CITY OF MILWAUKEE
CORRECT:
APPROVED:

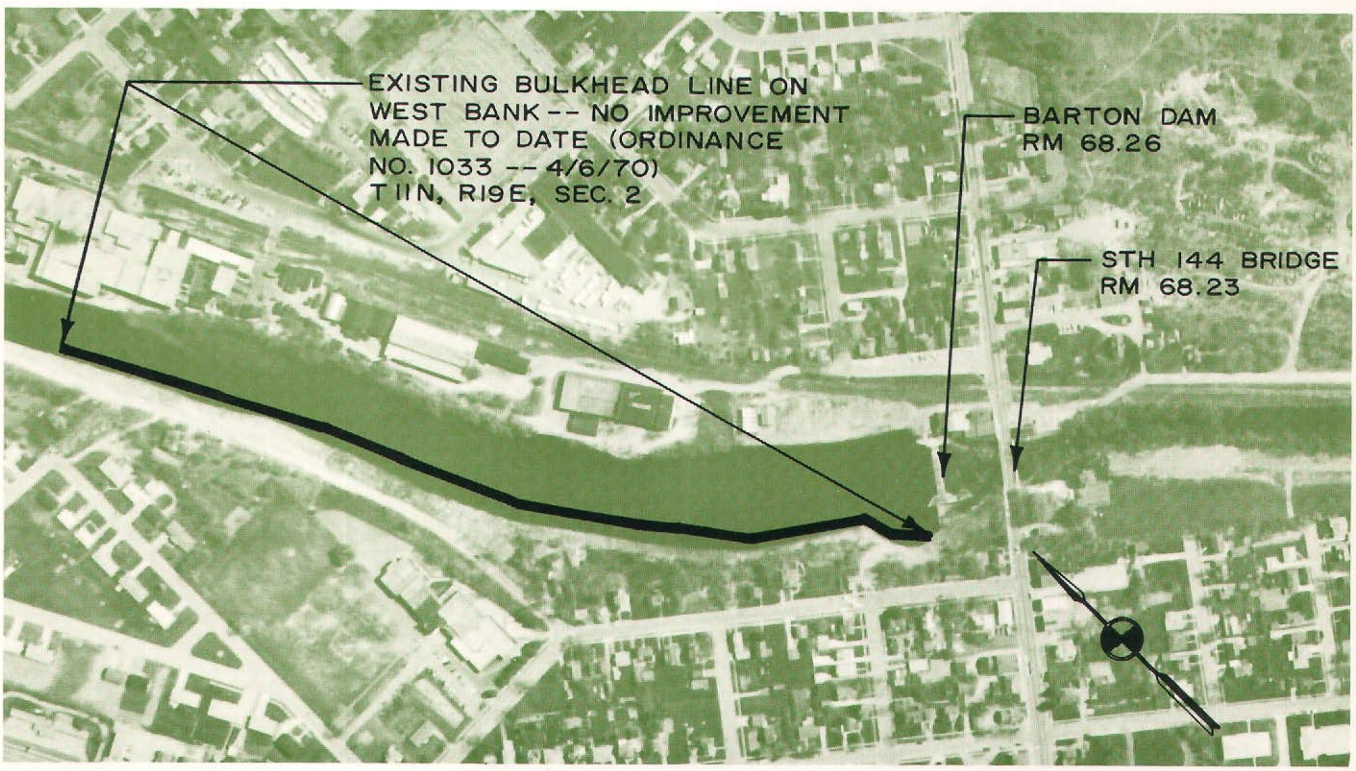


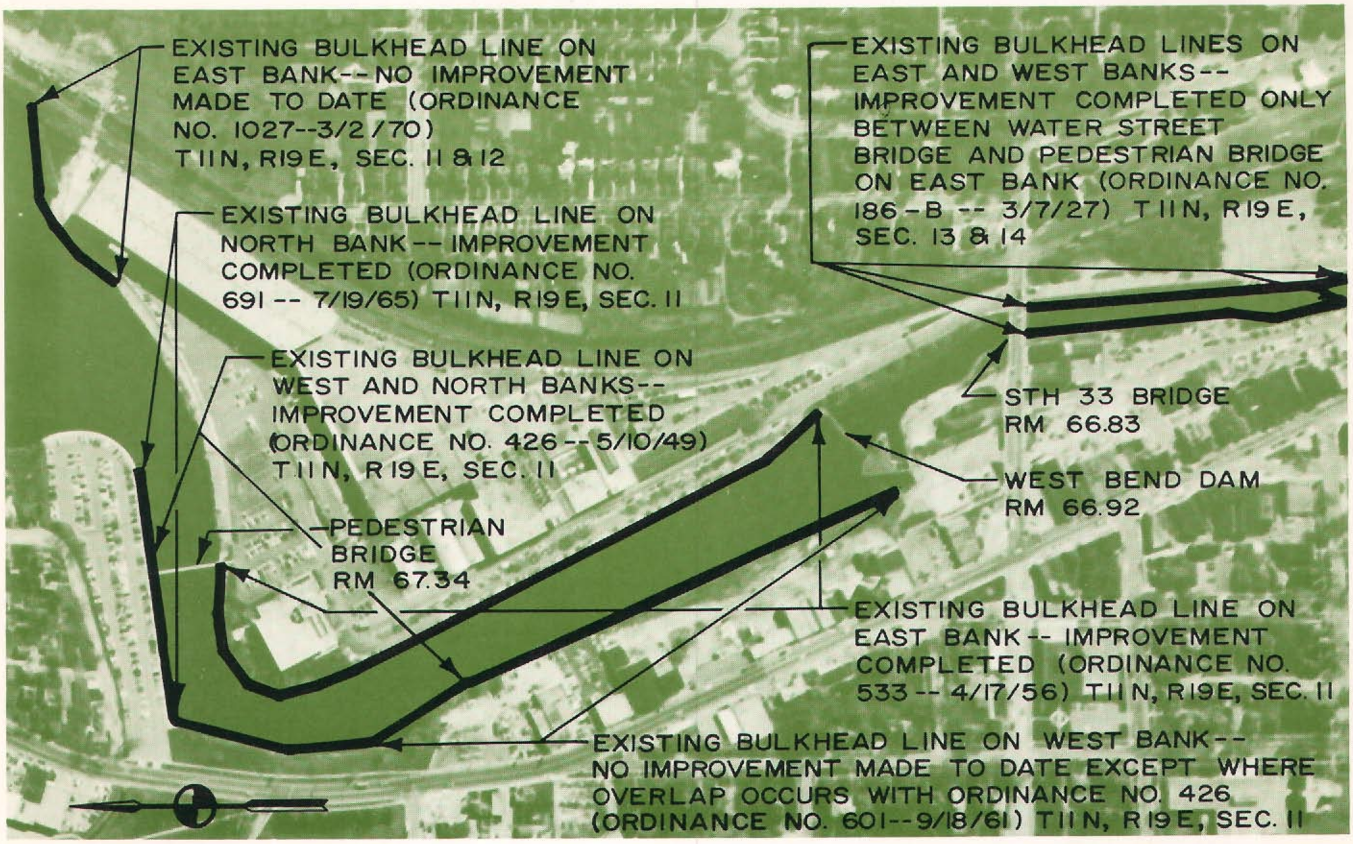
Source: Board of Harbor Commissioners, City of Milwaukee, and SEWRPC.

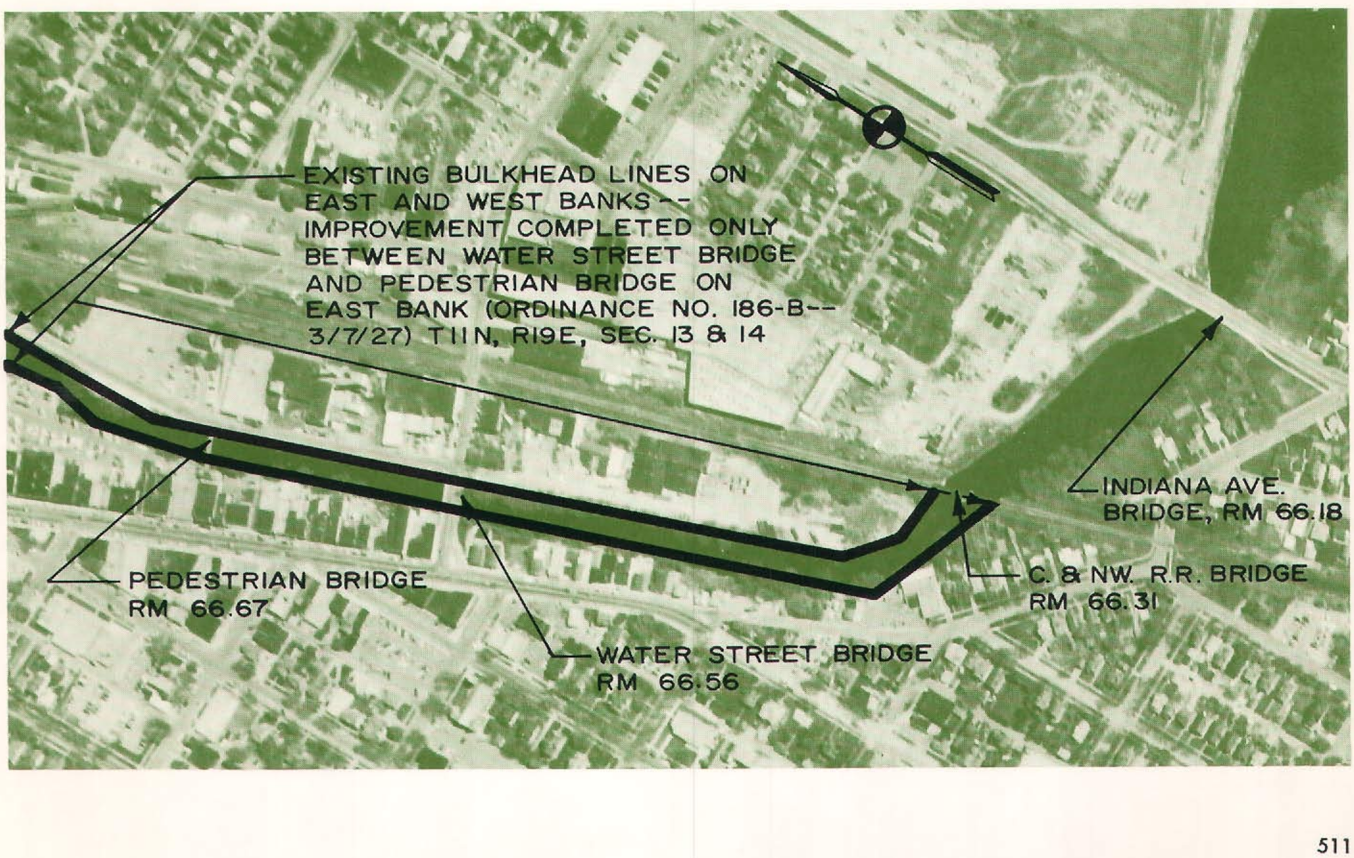
Figure O-2

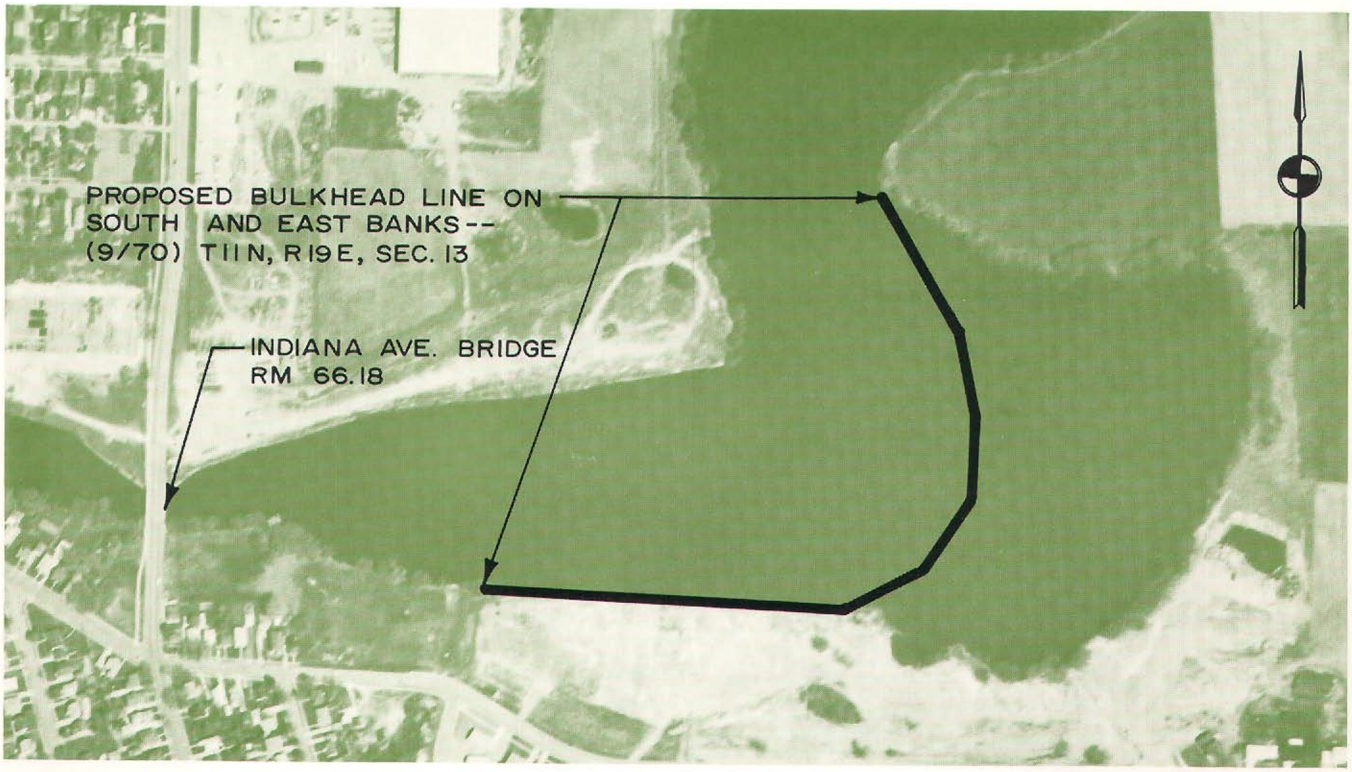
EXISTING AND PROPOSED BULKHEAD LINES ON THE MILWAUKEE RIVER
IN THE CITY OF WEST BEND: 1970

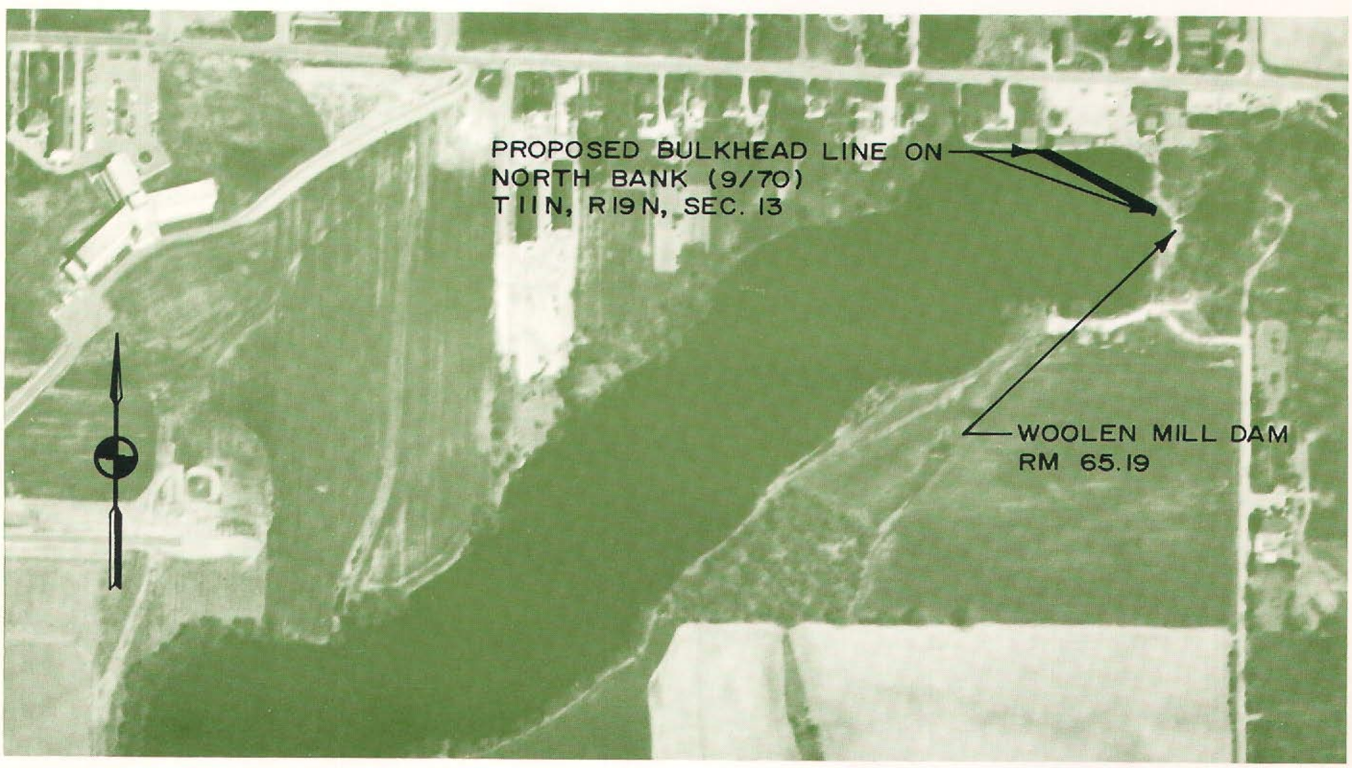





EXISTING BULKHEAD LINE ON EAST BANK--NO IMPROVEMENT MADE TO DATE (ORDINANCE NO. 1027--3/2/70) T11N, R19E, SEC. 11 & 12
EXISTING BULKHEAD LINE ON NORTH BANK--IMPROVEMENT COMPLETED (ORDINANCE NO. 691 -- 7/19/65) T11N, R19E, SEC. 11
EXISTING BULKHEAD LINE ON WEST AND NORTH BANKS--IMPROVEMENT COMPLETED (ORDINANCE NO. 426--5/10/49) T11N, R19E, SEC. 11
PEDESTRIAN BRIDGE RM 67.34
EXISTING BULKHEAD LINES ON EAST AND WEST BANKS--IMPROVEMENT COMPLETED ONLY BETWEEN WATER STREET BRIDGE AND PEDESTRIAN BRIDGE ON EAST BANK (ORDINANCE NO. 186-B -- 3/7/27) T11N, R19E, SEC. 13 & 14
STH 33 BRIDGE RM 66.83
WEST BEND DAM RM 66.92
EXISTING BULKHEAD LINE ON EAST BANK--IMPROVEMENT COMPLETED (ORDINANCE NO. 533--4/17/56) T11N, R19E, SEC. 11
EXISTING BULKHEAD LINE ON WEST BANK--NO IMPROVEMENT MADE TO DATE EXCEPT WHERE OVERLAP OCCURS WITH ORDINANCE NO. 426 (ORDINANCE NO. 601--9/18/61) T11N, R19E, SEC. 11


EXISTING BULKHEAD LINES ON EAST AND WEST BANKS--IMPROVEMENT COMPLETED ONLY BETWEEN WATER STREET BRIDGE AND PEDESTRIAN BRIDGE ON EAST BANK (ORDINANCE NO. 186-B--3/7/27) T11N, R19E, SEC. 13 & 14
INDIANA AVE. BRIDGE, RM 66.18
C. & NW. R.R. BRIDGE RM 66.31
PEDESTRIAN BRIDGE RM 66.67
WATER STREET BRIDGE RM 66.56

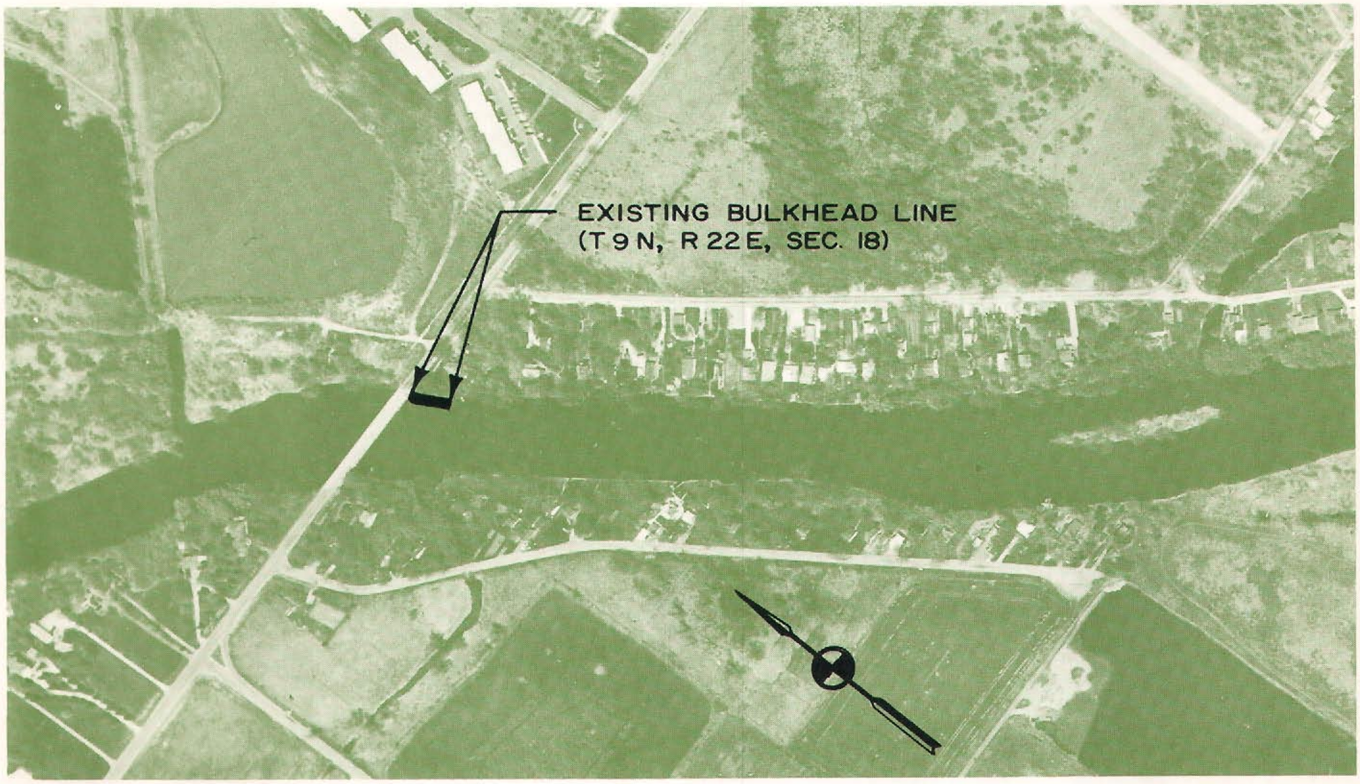




Source: City Engineer, City of West Bend, and SEWRPC.

Figure O-3

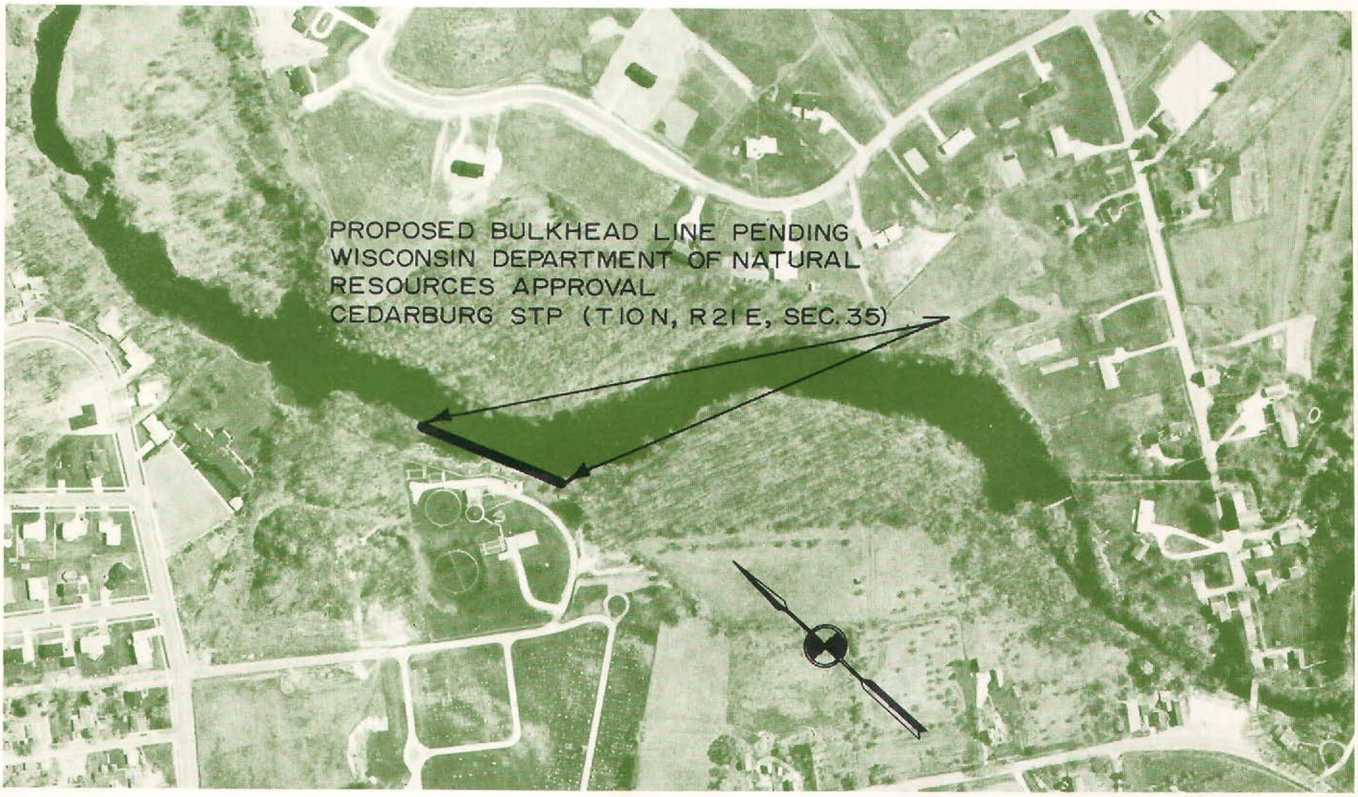
EXISTING BULKHEAD LINE ON THE MILWAUKEE RIVER
IN THE CITY OF MEQUON: 1967



Source: Wisconsin Department of Natural Resources and SEWRPC.

Figure O-4

PROPOSED BULKHEAD LINE ON CEDAR CREEK
IN THE CITY OF CEDARBURG: 1970



Source: Director of Public Works, City of Cedarburg, and SEWRPC.

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Dale Cotter
Assistant District Chief

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