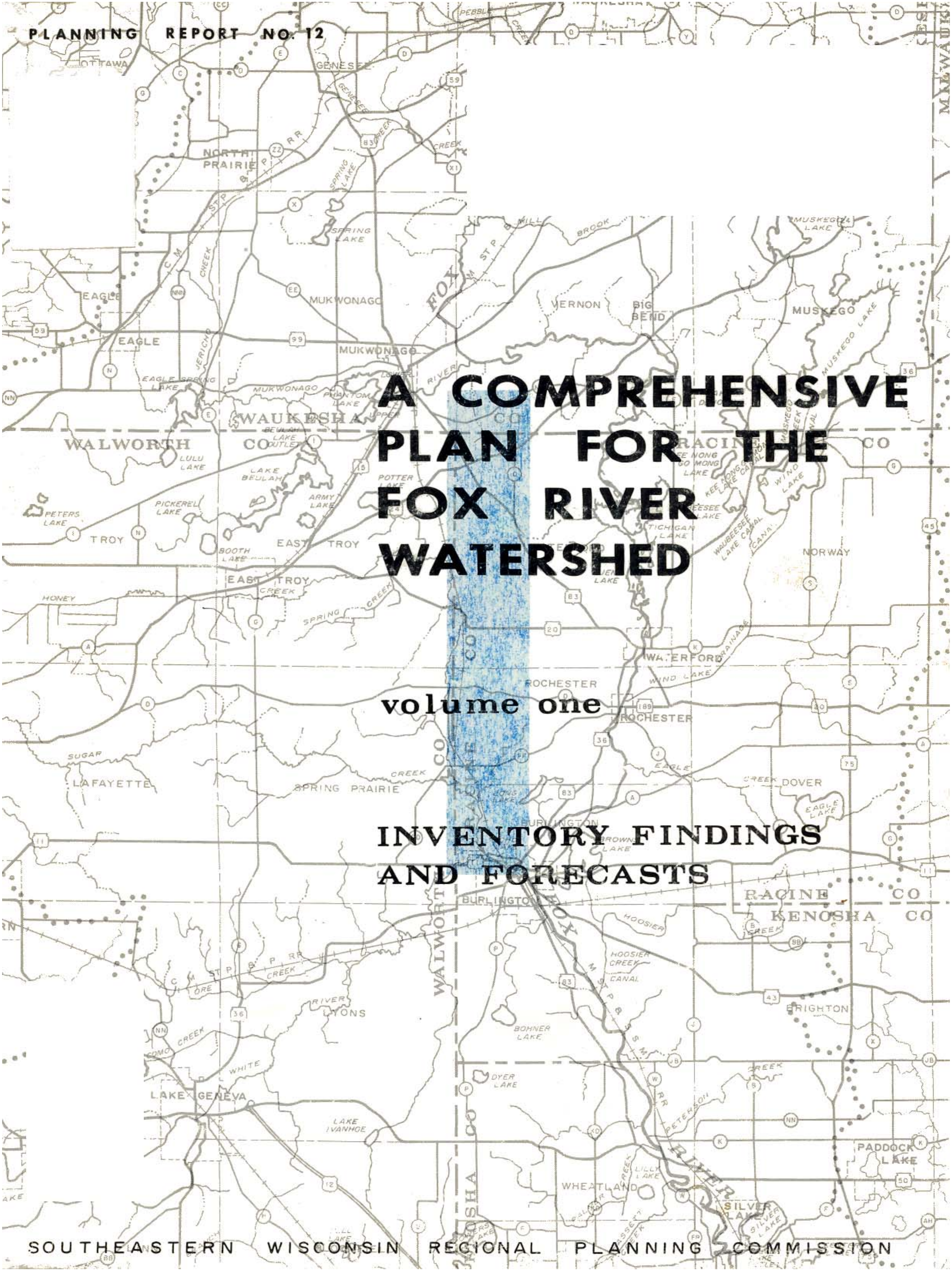
PLANNING REPORT NO. 12



A COMPREHENSIVE PLAN FOR THE FOX RIVER WATERSHED

volume one

INVENTORY FINDINGS AND FORECASTS

SOUTHEASTERN WISCONSIN REGIONAL PLANNING COMMISSION

COMMISSION MEMBERS

COMMISSION STAFF

PLANNING REPORT

NUMBER 12

volume one

A COMPREHENSIVE PLAN FOR THE FOX RIVER WATERSHED

INVENTORY FINDINGS AND FORECASTS

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

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SOUTHEASTERN WISCONSIN REGIONAL PLANNING COMMISSION

916 NO. EAST AVENUE • WAUKESHA, WISCONSIN 53186 • TELEPHONE 542-8083

Serving the Counties of: KENOSHA
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March 27, 1969

STATEMENT OF THE CHAIRMAN

With the approval of the five county boards concerned, the Commission in January 1966 began a three-year comprehensive study of the Fox River watershed in southeastern Wisconsin. The ultimate purpose of this study 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.

The final planning report for the Fox River watershed study consists of two volumes. This, the first volume, presents a summary of the factual findings of the many required inventories completed as a part of that study, 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 of the watershed and thereby provide the basis for the preparation of alternative plans and for the selection, after public hearings, of a final plan from among these alternatives to resolve these problems. 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 herewith transmitted to the governmental agencies operating within the watershed and within the Region for their consideration. Careful review of this volume by all responsible public officials concerned is urged, since out of this report will grow definitive plans and specific recommendations for the resolution of the resource-related problems of the Fox River watershed. During the next few months, many conferences and hearings on the contents of this volume and on alternative plan elements will be held within the watershed. The results of these conferences and hearings and the reactions of public officials and interested citizens will weigh heavily on the effectiveness of the solutions proposed in the final report to the growing problems of the Fox River watershed. 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 C. Berteau
Chairman

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Chapter I

INTRODUCTION

The Fox River watershed study is the second 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 Fox River watershed study and its findings and recommendations.

NEED FOR REGIONAL PLANNING

Regional planning may be 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; impairment of water supply and increasing pollution; underdeveloped sewerage and inadequate sewage disposal facilities; 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 and through the cooperation of all levels of government concerned.

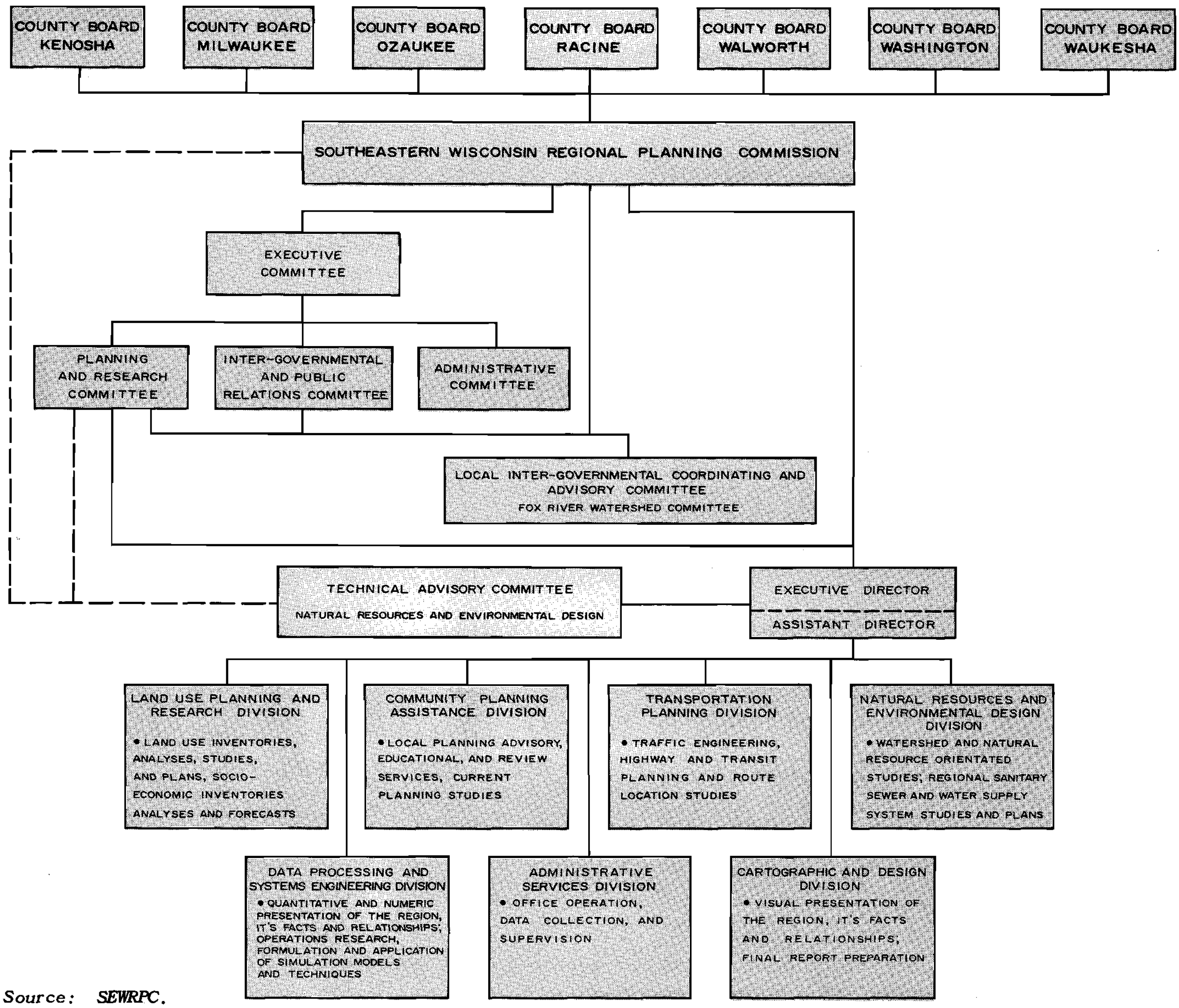
THE REGIONAL PLANNING COMMISSION

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 economic 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 proportioned 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.

FIGURE 1

ORGANIZATIONAL STRUCTURE OF THE SOUTHEASTERN WISCONSIN REGIONAL PLANNING COMMISSION AND STAFF



Source: SEWRPC.

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 developmental 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 level.

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 are within 250 miles of the Region; and over 31 million people reside within this radius.

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 Fox 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. Five 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 are intended to aid in implementing regional as well as local plans and to 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, and, of particular importance to this study, floodplain and shoreland land use regulation. 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, which was 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.

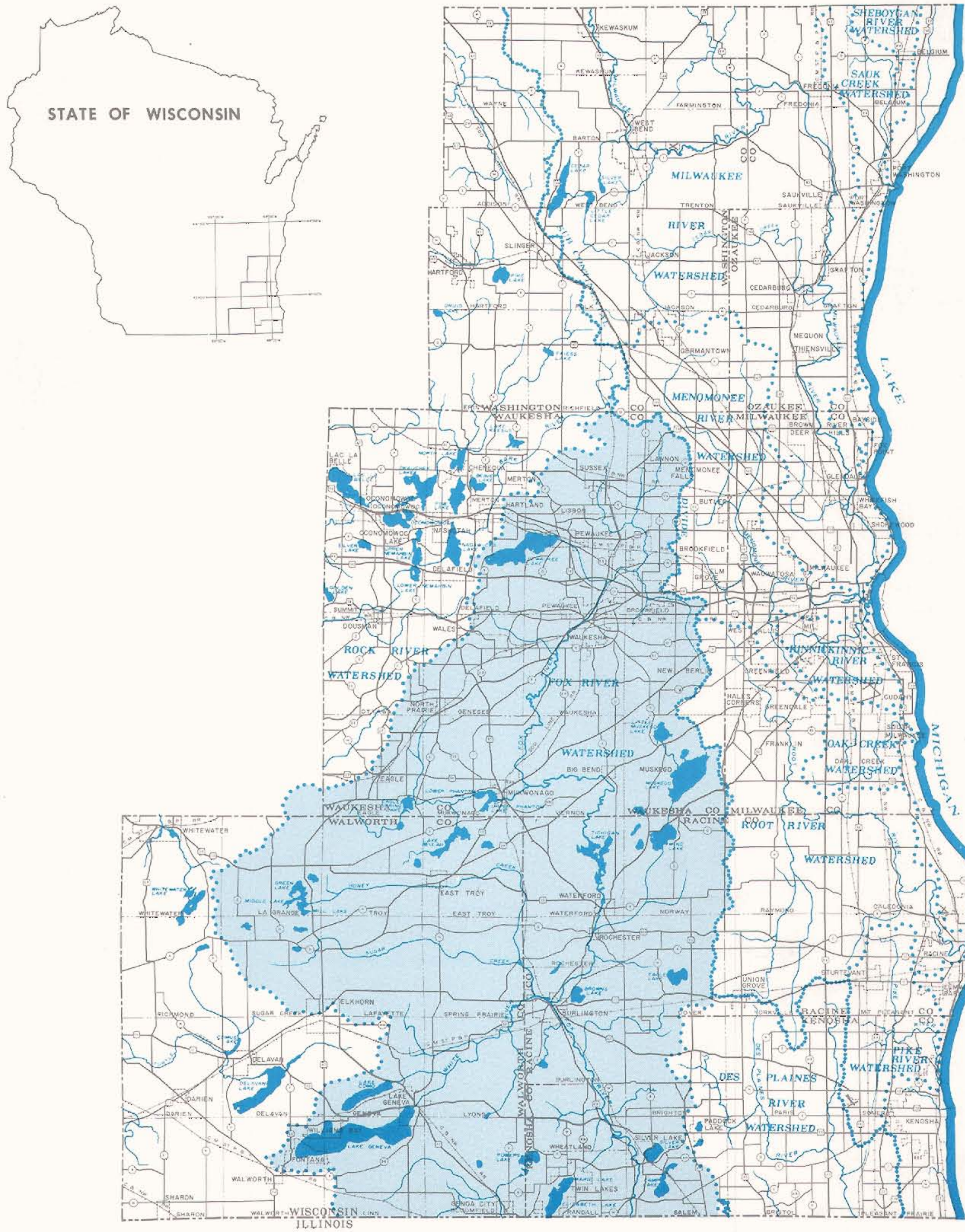
Root River Watershed Study

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 extensions 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 well received to date by the local units of government, and good implementation is anticipated. The recommended plan has been formally adopted by the Milwaukee and Racine County Boards of Supervisors, by the Metropolitan Sewerage Commission of the County of Milwaukee, by the Common Councils of the Cities of Racine and Oak Creek, 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

Map I
LOCATION OF THE FOX RIVER WATERSHED IN THE SOUTHEASTERN WISCONSIN REGION



The Fox River watershed is an integral part of the rapidly urbanizing seven-county Southeastern Wisconsin Region. This Region comprises only 5 percent of the total area of the state but contains over 40 percent of the state's population and over one-half of all the tangible wealth in the state. The Fox River watershed within Wisconsin has an area of 942 square miles and comprises 35 percent of the total 2,689 square mile area of the Region. It is the largest of the 11 major natural watersheds within the Region.

Source: SEWRPC.

Southern Colony Institution have initiated recommended improvements in waste treatment facilities. Finally and most importantly, 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.

THE FOX RIVER WATERSHED STUDY

The Fox River watershed study is the second comprehensive watershed planning program to be undertaken by the Commission. It is, however, the first such study to be conducted by the Commission on a headwater portion of an interstate river basin (see Map 2). In its study of the Fox River basin, the Commission has focused attention primarily on the 942-square mile watershed area which lies within Wisconsin, while cognizant of the interrelationship between this area and the 1,640-square mile watershed area which lies within Illinois. Although the watershed planning area chosen for study by the Commission comprises only 36.4 percent of the total Fox River watershed, this area forms a rational and viable planning unit for the following reasons:

1. The watershed planning area chosen by the Commission comprises the total Fox River watershed area lying within Wisconsin and is, therefore, a jurisdictionally sound unit possessing a community of interest within the southeastern Wisconsin planning region. The Commission was able, therefore, to provide regional planning data previously collected under other regional planning work programs for the entire watershed planning unit, to prepare and adopt a watershed development plan for an intraregional area, and most importantly will be jurisdictionally able to guide the implementation of the watershed development plan.

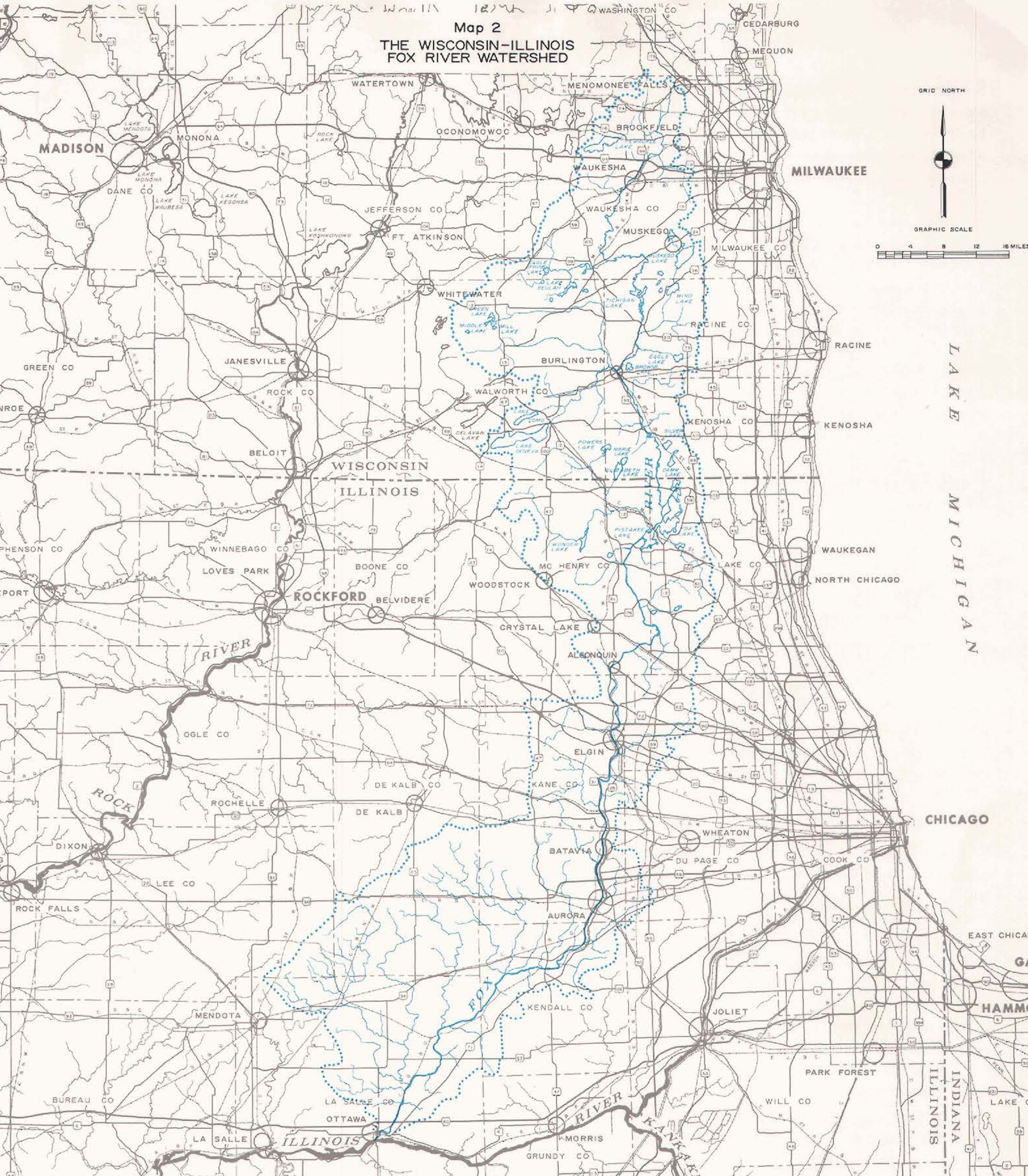
2. The watershed planning area comprises all of the headwater area of the watershed, thus assuring that solutions to the water resource-related problems which emanate from the upper watershed reaches, but are capable of being transmitted downstream, can be effectively resolved within the framework of the watershed study.

3. The planning area is rational and viable in terms of its hydraulic regimen, as a dam exists at Wilmot, Wisconsin, near the Wisconsin-Illinois State line, which results in a sharp break in the hydraulic grade line of the Fox River, thereby terminating the existing and potential backwater effects of any downstream land use or water control facility developments on the Wisconsin portions of the stream.

The Fox 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, decline in floral and faunal diversity, 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. Finally, local public officials and citizens were aroused to the areawide nature of the problems and the urgency of the need for unified action as a result of the unusually severe flood which occurred within the watershed in the spring of 1960. Recognizing the Commission as the logical and best equipped agency to find practical and permanent solutions to these problems, the Waukesha County Board on April 3, 1962, by formal resolution, requested the Commission to undertake a comprehensive study of the Fox River watershed.

In accordance with statutory authority and adopted procedure, the Commission appointed a watershed committee of 39 public officials, technicians, and citizen leaders to assist in the design, execution, and implementation of a comprehensive planning program for the Fox River watershed. Working from November 8, 1962, to August 25, 1964, this committee prepared a prospectus for a comprehensive planning program for the watershed. This prospectus was endorsed by the Commission on December 3, 1964; published; and, in accordance with the advisory role of the Commission, transmitted to the governmental agencies concerned for their consideration and action. All six county boards concerned—Kenosha, Milwaukee, Racine, Walworth, Washington, and Waukesha—formally endorsed the prospectus and agreed to provide the

Map 2
THE WISCONSIN-ILLINOIS
FOX RIVER WATERSHED



The Fox River watershed is an interstate river basin comprising 2,582 square miles of land and water area, 942 square miles of which lie within Wisconsin and 1,640 square miles of which lie within Illinois.

Source: SEWRPC.

local funds necessary for execution of the indicated planning program. The U. S. Department of Housing and Urban Development also endorsed the prospectus and agreed to provide the necessary federal planning funds.

In order to accomplish 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 and the six counties that contain portions of the watershed. Under the contract between the U. S. Department of Housing and Urban Development and the Commission, the latter agreed to complete the necessary planning work in accordance with the prospectus, while the former agreed to provide a Section 701 planning grant in partial support of the study. Under the contracts between the six counties concerned and the Commission, the latter agreed to furnish the necessary planning work; and the former agreed to provide the local funds necessary to support the study. The local study costs, amounting to one-third of the total study costs, were allocated to the respective counties on the basis of each county's proportionate share of the 1963 state equalized assessed valuation in the watershed. The percentage share of the total study costs agreed upon in the contracts were: U. S. Department of Housing and Urban Development, 66.67 percent; Kenosha County, 4.78 percent; Milwaukee County, 0.29 percent; Racine County, 9.20 percent; Walworth County, 5.05 percent; Washington County, 0.01 percent; and Waukesha County, 14.00 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 it fully attained. The prospectus, however, outlined the necessary major work elements, specified a staff organization, established a time schedule, and provided cost estimates. Work on the study began on January 1, 1966.

Study Objectives

The primary objective of the Fox River watershed planning program, as set forth in the prospectus, is to assist in abating the serious water resource-related problems of the Fox 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 and 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 to the floodplains of the Fox River basin.

2. Prepare a plan for water quality management and pollution abatement for the Fox River, 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, for public open-space reservation, and for recreational development.

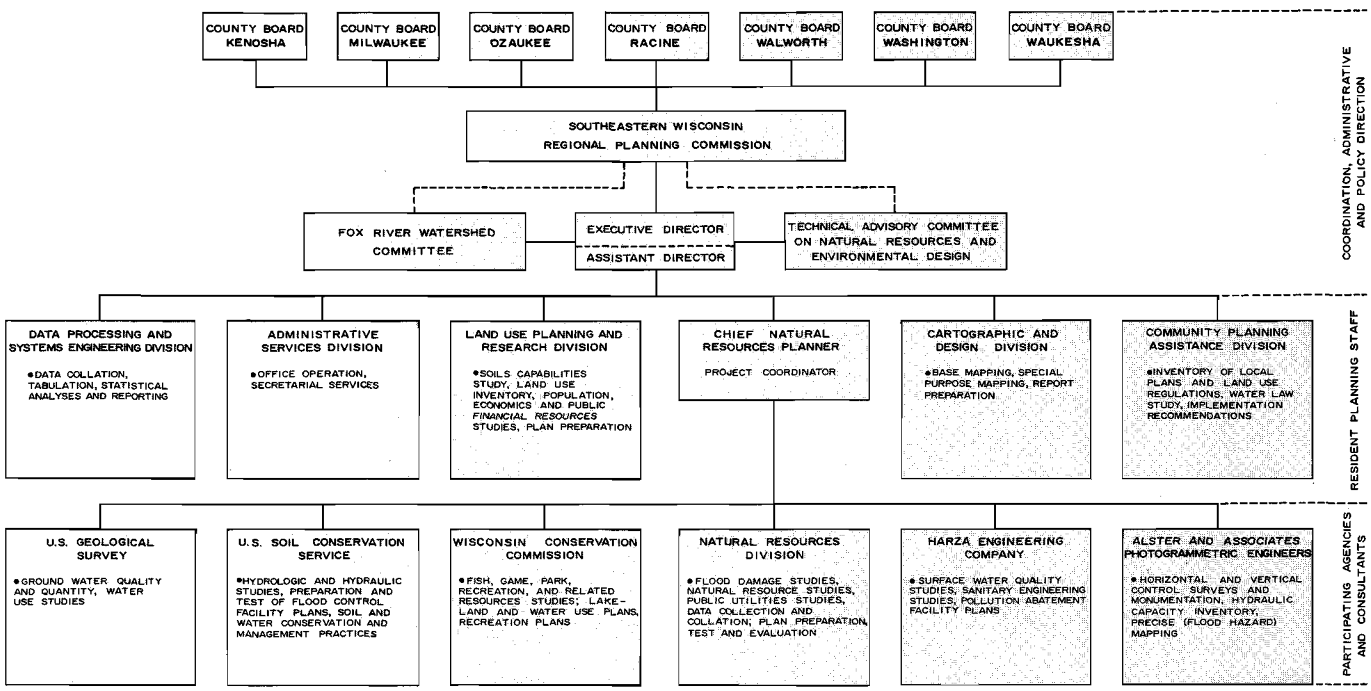
5. Refine and adjust the regional land use plans to the conveyance, storage, and waste assimilation capabilities of the perennial waterways and flood plains of the watershed and to feasible water control facilities and generally to promote the adjustment of land uses in the basin to the surface and ground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

Staff, Cooperating Agency, Consultant, and Committee Structure

The basic organizational structure for the study is outlined in Figure 2 and consists of the cooperating state and federal agency, consultant, and Commission staffs reporting to the Chief Natural Resources Planner as the project coordinator, who reports to the Executive Director. The Executive Director, in turn, reports to the Southeastern Wisconsin Regional Planning Commission. The responsibilities of the cooperating federal and state agency, consultant, and Commission staffs

FIGURE 2

ORGANIZATIONAL STRUCTURE OF THE FOX RIVER WATERSHED STUDY



NOTE: THE U.S. GEOLOGICAL SURVEY, U.S. SOIL CONSERVATION SERVICE, WISCONSIN CONSERVATION COMMISSION, NATURAL RESOURCES DIVISION, AND HARZA ENGINEERING COMPANY ARE RESPONSIBLE IN ADDITION TO THE ABOVE MENTIONED ITEMS FOR THE FOLLOWING WORK ITEMS; STUDY DESIGN, FORMULATION OF STANDARDS, ANALYSIS OF RESOURCE PROBLEMS AND CAPABILITIES, DETERMINATION OF RESOURCE REQUIREMENTS, PLAN SYNTHESIS, TEST AND EVALUATION, AND REPORT WRITING.

Source: *SEWRPC.*

for the conduct of major elements of the planning study are also indicated in Figure 2.

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 assignments; 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 River Watershed Committee. This important committee was established in November 1962, 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. In light of the advisory role of the Commission in shaping regional and subregional development, 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. 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 Fox 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, as well as certain work elements of a natural resources planning nature. These elements included the soils capabilities study; land use inventory; population, economic, and public financial resource studies; flood damage study; public utilities inventory; inventory of local plans and land use regulations; and plan implementation recommendations.

Services of specialists in the disciplines of ground water hydrology, surface water hydrology, hydraulics, recreation, resource conservation, sanitary engineering, surveying, and photogrammetry were necessary to the successful completion of the complex, inter-disciplinary planning program. Contractual agreements were, therefore, executed with the U. S. Soil Conservation Service, the U. S. Geological Survey, the Wisconsin Conservation Commission, the Harza Engineering Company of Chicago, Illinois, and Alster and Associates, Inc., of Madison, Wisconsin. Each of these organizations were 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 the surface water hydrology and hydraulics of the watershed, hydrologic simulation, and surface water-related problems and their solution. The U. S. Geological Survey was responsible for the elements of the study which were related to ground water resources, ground water-surface water relationships, and ground water resource-related problems and their solution. The Wisconsin Conservation Commission was responsible for those elements of the study which were related to recreation, resource conservation, and 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 surface water pollution problems of the watershed and the formulation of alternative recommendations for their solution. Alster and Associates were responsible for the horizontal and vertical control surveys and monumentation within the watershed, the hydraulic capacity inventory, and the precise (flood hazard) mapping.

As the planning effort and this report are both the result of the joint efforts of the Commission, the U. S. Soil Conservation Service, the U. S. Geological Survey, the Wisconsin Conservation Commission, and the Harza Engineering Company, it is difficult to delineate precisely the responsibilities ascribed for certain work elements, the responsibility for which was shared by all study participants. These shared 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; formulation of plan implementation recommendations; and report writing.

The Chief Natural Resources Planner, as the project coordinator, was responsible for the maintenance of inter-staff cooperation and coordination during the study, as well as for directly supervising the operations of the SEWRPC Natural Resources Planning Division. The Executive Director of the Commission, who serves on the Fox River Watershed Committee, administered, and generally directed the study and, as a professional engineer, sponsored the study.

Scheme of Presentation

The major findings and recommendations of the Fox 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. The final 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 tremendous volume of information assembled in the extensive data collection, analysis, and forecasting phases of the Fox River watershed study. Although the reproduction of all of this information in report form is impractical, due to the magnitude and complexity of the data collected and analyzed, all basic data is on file in the Commission offices and is 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 type of data which is 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 development within the watershed.

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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 the 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 the Fox River watershed study. 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 Fox River watershed and the recommended solutions to these problems be properly analyzed and 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. Moreover, drainage and flood control problems are closely related to other land and water use problems. Consequently, floodplain reservation, park and 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. It should be noted that watershed boundaries are subject to change by man's expanding use of land and accompanying changes in surface drainage. Substantial changes in such boundaries, however, are limited and constrained by existing water law. 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 Fox River, must exhibit if it is to form a rational unit for comprehensive water resources planning.

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 three 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. Third, the surface watershed is an integral part of a larger hydrologic system which includes the underground water reservoirs. These reservoirs are affected by influences that extend beyond the watershed boundary.

Important elements of the necessary areawide planning program have been provided by the regional land use-transportation study recently completed 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 about drainage 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, park and public open-space reservation, and water quality and stream pollution. Recognition of the need to prepare such facility plans on a watershed basis, as well as 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 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 Fox 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 development policies and plans; and 2) to provide—through the medium of a long-range plan for water-related community facilities—for the 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 formed the basis for the specific watershed planning process applied by the SEWRPC in that study. These same principles provided the basis for the planning process applied in the Fox 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 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 watershed 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 3 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.

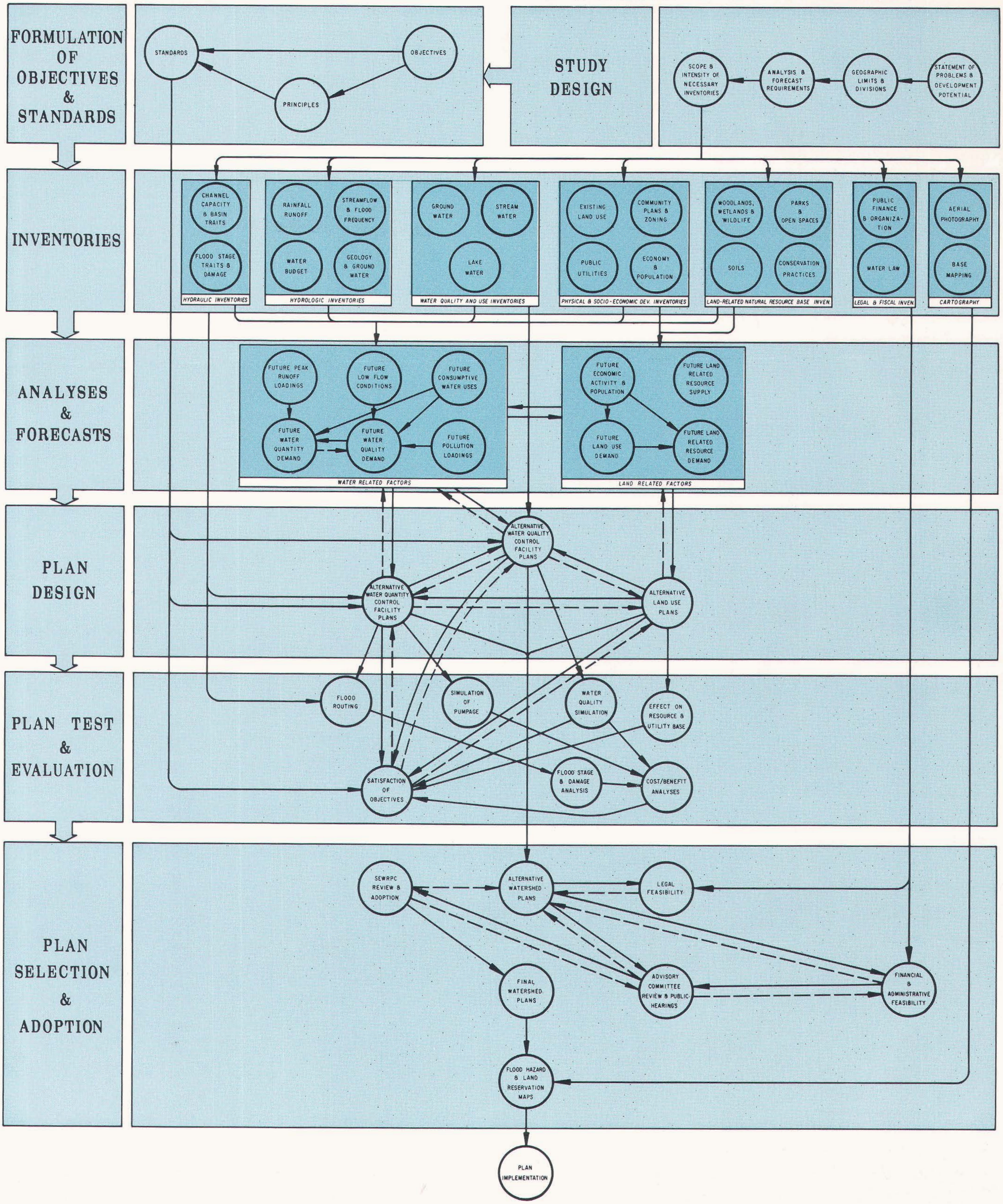
In the Fox River watershed program, the study design was prepared jointly by the staffs of the Southeastern Wisconsin Regional Planning Commission, U. S. Soil Conservation Service, U. S. Geological Survey, Wisconsin Conservation Commission, and Harza Engineering Company and presented to the Fox River 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, more particularly, because it is the objective of the Fox 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-

Figure 3

GENERAL STEPS IN A COMPREHENSIVE WATERSHED PLANNING STUDY



Source: SEWRPC.

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 Fox 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, urban storm water drainage design methodology, and water quality parameters.

Inventory

Reliable basic planning and engineering data collected on a uniform, areawide basis is 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 Fox River study, the most expedient methods of obtaining adequate information of the necessary quality were followed. 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, relationships 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 Fox River watershed study, the necessary forecast period was set as 22 years, both as a very conservative approximation of facility life and as 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 problem 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 to 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 rigorously to several levels of review and evaluation, 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 Fox River watershed study, to develop two alternative land use plans, one representing a refinement of the adopted regional land use plan, 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, 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 Fox 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 for 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 and economic activities, these features may be thought of as the socio-economic base of the watershed. A description of this base is essential to sound watershed planning, for, if such planning is intended to improve the environment within which people live, an understanding of the quality and quantity of the various factors affecting life within the watershed must be achieved.

In order to facilitate such understanding, a description of the socio-economic 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 government 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, composition, and distribution 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 (1963) conditions. The fourth and fifth sections describe the public utility and transportation facility systems within the watershed. A final section summarizes the interrelationships existing between the various components of the socio-economic base of the watershed described as separate elements.

REGIONAL SETTING OF THE WATERSHED

The Fox River watershed, as shown on Map 1, is a surface water drainage unit, 942.37 square miles in areal extent, located in the south-central portion of the Southeastern Wisconsin Region. The watershed is the largest of the 11 major natural surface water drainage units within the Region and comprises 35 percent of the regional land and water area.[1] The watershed is bounded along much of its eastern side by the 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. In Kenosha County the watershed is bounded on the east by the Des Plaines River watershed, also part of the Mississippi River system. Much of the watershed is bounded on the west and northwest by the Kettle Moraine, the unique interlobate deposits that were formed between the Green Bay lobe and the Lake Michigan lobe of the continental glacier. In parts of Walworth and Waukesha Counties, other moraines form the watershed boundary. Finally, the watershed, as it lies within the Region, is bounded on the south by the Wisconsin-Illinois State line. The northern headwater portion of the basin lies in rapidly urbanizing Waukesha County; and the central and southern portions lie in the important agricultural and recreational areas of Kenosha, Racine, and Walworth Counties.

Political Boundaries

Superimposed upon the natural, meandering watershed boundary is a rectangular pattern of local political boundaries, as shown on Map 1. The Fox River watershed occupies portions of six of the seven counties within the Southeastern Wisconsin Region—Kenosha, Milwaukee, Racine, Walworth, Washington, and Waukesha—and portions or all of 9 cities, 19 villages, and 36 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 are coterminous with county boundaries. Six such soil and water conservation districts, which have important responsibilities for the promotion of good soil and water conser-

[1] *Included in the watershed area is a 3.64 square mile area within Jefferson County, Wisconsin, which lies outside the Southeastern Wisconsin Planning Region.*

Table I

AREAL EXTENT OF COUNTIES AND CIVIL DIVISIONS IN THE FOX 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
Kenosha County	278.28	96.46	34.59	10.28
Villages				
Silver Lake . .	1.42	1.42	100.00	0.15
Twin Lakes . . .	5.73	5.73	100.00	0.61
Towns				
Brighton	36.00	20.81	57.81	2.22
Randall.	18.23	18.23	100.00	1.94
Salem.	33.33	26.14	78.43	2.79
Wheatland . . .	24.13	24.13	100.00	2.57
Milwaukee County	242.19	0.47	0.19	0.05
Cities				
Franklin	34.63	0.47	1.36	0.05
Racine County	339.87	164.44	48.38	17.52
Cities				
Burlington. . .	3.04	3.04	100.00	0.32
Villages				
Rochester . . .	0.39	0.39	100.00	0.04
Waterford . . .	1.17	1.17	100.00	0.13
Towns				
Burlington. . .	38.74	38.74	100.00	4.13
Dover.	36.14	31.58	87.38	3.36
Norway	35.72	35.62	99.72	3.79
Raymond	35.37	1.74	4.92	0.19
Rochester . . .	17.53	17.53	100.00	1.87
Waterford . . .	34.63	34.63	100.00	3.69
Walworth County	578.08	341.46	59.07	36.37
Cities				
Elkhorn.	4.05	1.50	100.00	0.16
Lake Geneva . .	3.39	3.39	100.00	0.36
Villages				
East Troy . . .	1.18	1.18	100.00	0.13
Fontana on Lake Geneva .	3.39	3.17	93.51	0.34
Genoa City. . .	0.99	0.99	100.00	0.11
Walworth	1.07	0.12	11.21	0.01
Williams Bay. .	2.79	2.63	94.27	0.28
Towns				
Bloomfield. . .	35.32	35.32	100.00	3.76
Delavan.	32.31	0.60	1.86	0.06
East Troy. . . .	34.81	34.81	100.00	3.71
Geneva	32.75	20.37	62.20	2.17
LaGrange	35.82	28.05	78.31	2.99
LaFayette. . . .	35.11	34.62	98.60	3.69
Linn	34.11	32.09	94.08	3.42
Lyons.	35.98	35.98	100.00	3.83
Richmond	36.17	0.40	1.11	0.04
Spring Prairie.	36.10	36.10	100.00	3.84
Sugar Creek . .	34.98	26.20	74.90	2.79
Troy	35.64	35.64	100.00	3.80
Walworth	30.75	7.27	23.64	0.77
Whitewater . . .	31.87	1.03	3.23	0.11

Table I (Cont'd)

AREAL EXTENT OF COUNTIES AND CIVIL DIVISIONS IN THE FOX 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
Washington County	435.50	0.31	0.07	0.03
Towns				
Richfield	36.34	0.31	0.85	0.03
Waukesha County	580.66	335.59	57.79	35.75
Cities				
Brookfield. . . .	25.34	12.08	47.67	1.29
Delafield	10.17	0.18	1.77	0.02
Muskego	35.47	31.63	89.17	3.37
New Berlin. . . .	36.75	26.93	73.28	2.87
Waukesha.	7.83	7.83	100.00	0.83
Villages				
Big Bend.	0.57	0.57	100.00	0.06
Eagle	0.98	0.94	95.92	0.10
Hartland.	1.76	0.15	8.52	0.02
Lannon.	2.51	2.51	100.00	0.27
Menomonee Falls.	33.50	15.69	46.84	1.67
Mukwonago	1.50	1.50	100.00	0.16
North Prairie. .	0.56	0.56	100.00	0.06
Pewaukee	1.94	1.94	100.00	0.21
Sussex.	1.21	1.21	100.00	0.13
Wales	1.10	0.46	41.82	0.05
Towns				
Brookfield. . . .	7.77	7.56	97.30	0.80
Delafield	23.33	14.86	63.69	1.59
Eagle	35.25	20.33	57.67	2.17
Genesee	34.42	28.87	83.88	3.07
Lisbon.	35.17	22.45	63.83	2.39
Merton.	28.83	1.45	5.03	0.15
Mukwonago	35.29	35.29	100.00	3.76
Ottawa.	36.01	3.14	8.72	0.33
Pewaukee.	31.54	31.54	100.00	3.36
Vernon.	34.90	34.90	100.00	3.72
Waukesha.	31.02	31.02	100.00	3.30
Total		938.73[a]		100.00

[a] *Does not include 3.64 square miles of the watershed which is located in Jefferson County, Wisconsin.*

Source: SEWRPC.

vation practices and for resource management, therefore, have jurisdiction over portions of the watershed. In addition, other special-purpose districts exist within the watershed, including portions of the Metropolitan Sewerage District of the County of Milwaukee, the Western Racine County Metropolitan Sewerage District, and three active farm drainage districts (see Map 3).

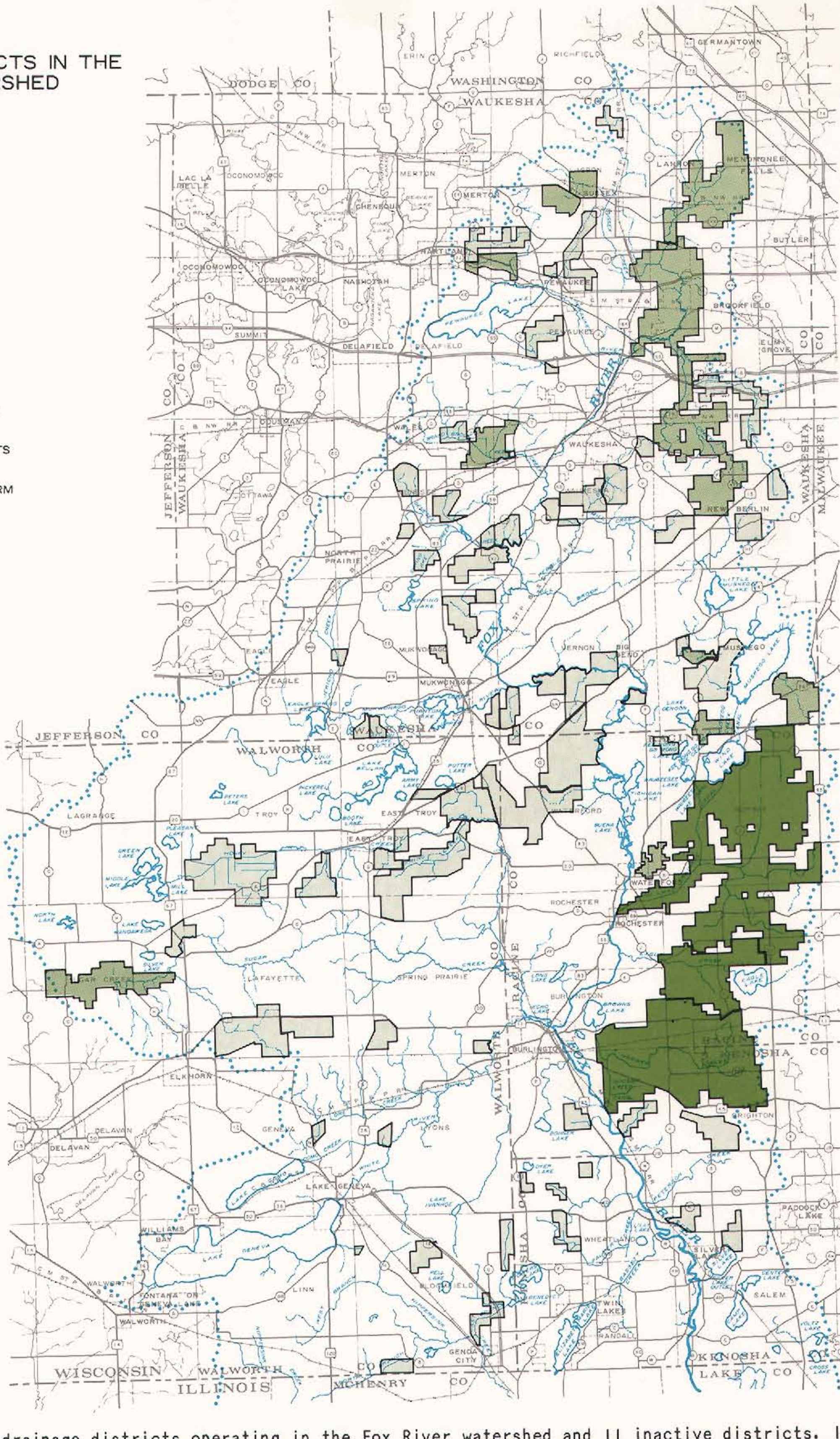
Superimposed upon these local and areawide units and agencies of government are the state and federal governments, certain agencies of which also have important responsibilities in resource conservation and management. These include the Wisconsin Department of Natural Resources, the Cooperative Extension Services of the University of Wisconsin, the U. S. Geological Survey, the U. S. Soil Conservation Service, the Federal Water Pollution Control Administration, the U. S. Public Health 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 and since the ulti-

Map 3

FARM DRAINAGE DISTRICTS IN THE FOX RIVER WATERSHED



There are three active farm drainage districts operating in the Fox River watershed and 11 inactive districts. In addition to these 14 legally constituted farm drainage districts, there are numerous areas in which agricultural drainage improvements have been implemented by individuals or groups of individuals as a private endeavor on an informal basis.

Source: SEWRPC.

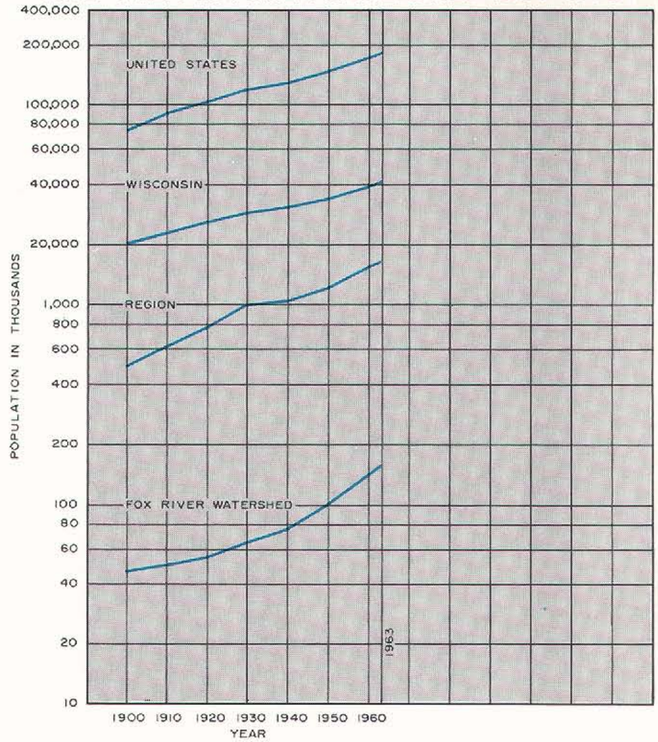
mate purpose of all facilities and services in any community is to meet the needs of the resident population, an understanding of the size, composition, and spatial distribution of this population is basic to planning for future development. Population must also be studied because of the direct relationships existing between population levels and the demand for soil, water, open space, and other elements of the natural resource base. 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 Fox 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 Region. Similarly, the size, composition, and distribution of the population residing within the watershed must be viewed in relation to the population size, composition, and distribution of the Region as a whole.

Population

Population Size: The present (1963) population of the watershed is estimated at 159,500 persons, or about 9.5 percent of the total 1963 regional population of 1,674,000. The population of the watershed has increased steadily since 1850; and since 1940 the rate of population increase has exceeded that of the Region, which, in turn, has exceeded the rate of population increase of both the state and the nation. The trend in population levels within the watershed from 1900 to 1963, along with regional, state, and national trends, is set forth in Table 2 and graphically illustrated in Figure 4. Watershed population growth rates since 1940 exceed those which can be reasonably attributed to natural increase, that is, to an excess of births over deaths, and indicate that migration from other parts of the nation, state, and Region has been a significant factor in the recent rapid population increase.

Figure 4

POPULATION TRENDS IN THE UNITED STATES, THE STATE OF WISCONSIN, THE REGION AND THE FOX RIVER WATERSHED: 1900-1963



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

Table 2

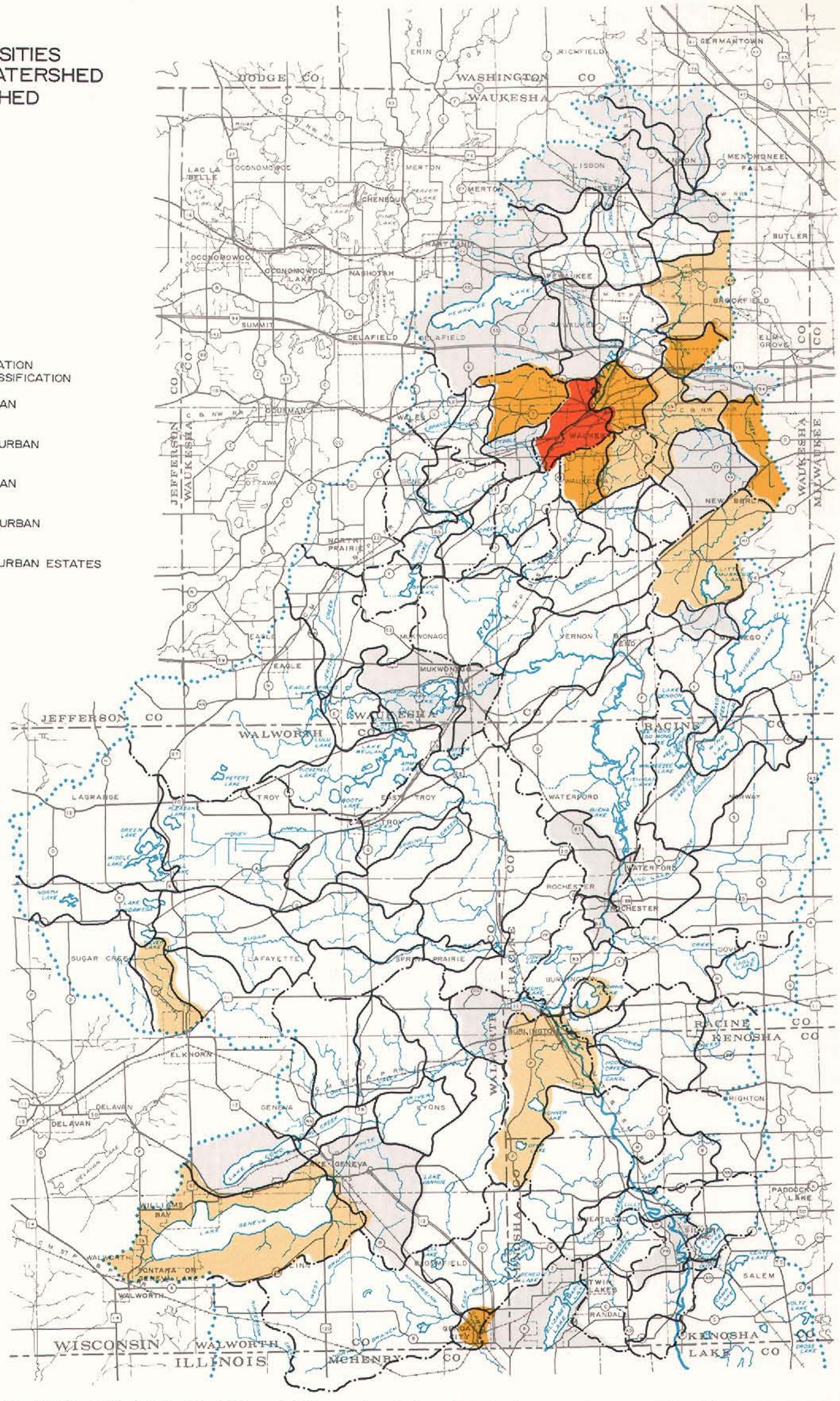
POPULATION SIZE IN THE UNITED STATES, WISCONSIN, THE REGION, AND THE FOX RIVER WATERSHED: 1900 - 1963

Year	Watershed	Percent Increase Over Preceding Decade	Region	Percent Increase Over Preceding Decade	Wisconsin	Percent Increase Over Preceding Decade	United States	Percent Increase Over Preceding Decade	Watershed Population as a Percent of the Regional Population
1900	47,268	--	501,808	--	2,069,042	--	75,994,575	--	9.4
1910	50,151	6	631,161	26	2,333,860	13	91,972,266	21	7.9
1920	54,672	9	783,681	24	2,632,067	13	105,710,620	15	7.0
1930	64,106	17	1,006,118	28	2,939,006	12	122,775,046	16	6.4
1940	75,126	17	1,067,699	6	3,137,587	7	131,669,270	7	7.1
1950	100,061	33	1,240,618	16	3,434,575	9	151,325,798	15	8.1
1960	143,064	43	1,573,620	27	3,952,771	15	179,323,175	18	9.1
1963	159,500	--	1,674,000	--	4,061,000	--	188,616,000	--	9.5

Source: U. S. Department of Commerce, Bureau of the Census; SEWRPC.

Map 4

POPULATION DENSITIES IN THE FOX RIVER WATERSHED BY SUBWATERSHED (1963)



LEGEND

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

Forty percent of the watershed residents live in the rapidly urbanizing headwater area, on only 14 percent of the watershed area. This concentration of population in the headwater area of the watershed is a significant factor contributing to the resource-related problems of the watershed.

Source: SEWRPC.

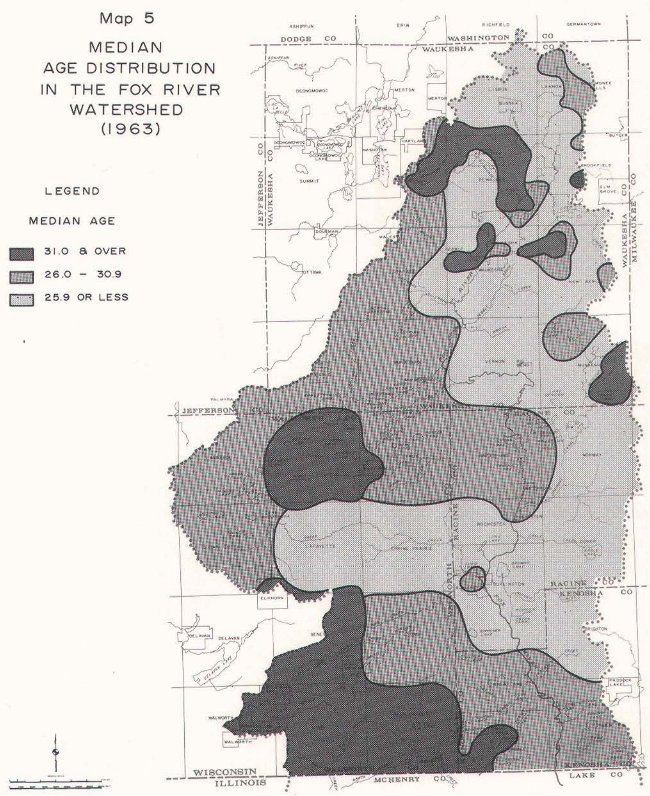
Population Distribution: The Fox River watershed, in common with much of the Region, is becoming increasingly urban, particularly in its headwater area and adjacent to the major surface water bodies.[2] In 1963 about 61 percent of the residents of the watershed lived in incorporated cities and villages, the combined areas of which comprise about 14 percent of the total area of the watershed (see Tables 3 and 4). Forty percent of the watershed residents live within the headwater area, which contains only 14 percent of the total land area of the watershed. The present spatial distribution of the population within the watershed is indicated on Map 4, which shows the average population density by subwatershed. The concentration of population in the headwater reaches of the watershed and surrounding the major water bodies is a significant factor contributing to a number of serious environmental and resource-related problems that will be discussed in detail in subsequent chapters of this report.

Population Composition: The geographic distribution of the resident population of the watershed by median age in 1963 is shown on Map 5. This map indicates a concentration of older people in the major recreational areas of the watershed and in the suburban area surrounding the City of Waukesha. Map 6 shows the geographic distribution of average household sizes in the watershed in 1963. As in the Region as a whole, 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 1963 was 3.54 persons, whereas the average household size for the Region as a whole was 3.41 persons. The average household income in the watershed in 1963 was estimated at $8,680. This compares with a regional average household income in 1963 of $8,322.

The Economy

Increases in the population levels of the watershed are closely related to increases in the amount of economic activity both within the watershed and within the Region, especially in those areas of the Region within ready commuting distance. This is true, not only because much of the population migration into the watershed is dependent upon the availability of jobs within the Region, 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. The rapid population growth in the watershed may, therefore, be attributed basically to increasing economic activity. As shown in Figure 5, employment within the Region, of which the watershed is an integral part, 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 lies in the City of Waukesha and is comprised of 16 of the total of 25 industrial firms within the watershed which employ over 150 persons each. It includes the two largest industries within the watershed—Amron Corporation and Waukesha Motor Company. Other industrial concentrations within the watershed are located in the Cities of Burlington, Elkhorn, and Lake



The median age of the watershed population was only 28 years in 1963 compared to 31 years in 1950, indicating that younger families are moving from the older central cities of the Region into the newer communities of the watershed.

Source: SEWRPC.

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[2] *The headwater area of the Fox River watershed, as defined herein, consists of the land and water areas of the basin lying upstream from the confluence of the Fox River and Pebble Creek. The headwater area has been designated the Upper Fox River subwatershed and is shown on Map 31.*

Table 3

POPULATION IN THE FOX RIVER WATERSHED BY MINOR CIVIL DIVISION: 1963

Civil Division	Population Within Watershed	Percent Of Watershed Population
Kenosha County		
Villages		
Silver Lake	1,100	0.69
Twin Lakes	1,600	1.00
Towns		
Brighton	700	0.44
Randall	1,100	0.69
Salem	3,900	2.45
Wheatland	1,600	1.00
Milwaukee County		
Cities		
Franklin	100	0.06
Racine County		
Cities		
Burlington	6,200	3.89
Villages		
Rochester	500	0.31
Waterford	1,600	1.00
Towns		
Burlington	4,100	2.57
Dover	1,600	1.00
Norway	3,500	2.19
Raymond	200	0.13
Rochester	1,000	0.63
Waterford	3,000	1.88
Walworth County		
Cities		
Elkhorn	2,500	1.57
Lake Geneva	5,300	3.32
Villages		
East Troy	1,500	0.94
Fontana on Geneva Lake	1,300	0.82
Genoa City	1,100	0.69
Walworth	100	0.06
Williams Bay	1,300	0.82
Towns		
Bloomfield	2,300	1.44
Delavan	200	0.13
East Troy	2,400	1.50
Geneva	2,000	1.25
LaGrange	1,100	0.69
LaFayette	1,000	0.63
Linn	1,600	1.00
Lyons	1,900	1.19
Walworth County (Cont'd)		
Richmond	100	0.06
Spring Prairie	1,200	0.75
Sugar Creek	1,500	0.94
Troy	1,100	0.69
Walworth	100	0.06
Whitewater	100	0.06
Washington County		
Towns		
Richfield	100	0.06
Waukesha County		
Cities		
Brookfield	8,700	5.46
Delafield	100	0.06
Muskego	6,900	4.33
New Berlin	9,100	5.72
Waukesha	34,600	21.70
Villages		
Big Bend	800	0.50
Eagle	700	0.44
Hartland	500	0.31
Lannon	1,100	0.69
Menomonee Falls	3,600	2.26
Mukwonago	1,900	1.19
North Prairie	500	0.31
Pewaukee	2,600	1.63
Sussex	1,400	0.88
Wales	100	0.06
Towns		
Brookfield	2,800	1.76
Delafield	2,300	1.44
Eagle	900	0.56
Genesee	1,900	1.19
Lisbon	2,600	1.63
Merton	300	0.19
Mukwonago	1,600	1.00
Ottawa	100	0.06
Pewaukee	6,500	4.08
Vernon	2,200	1.38
Waukesha	4,100	2.57
Total	159,500	100.00

Source: SEWRPC.

Table 4
TOTAL POPULATION AND POPULATION DENSITY IN THE
FOX RIVER WATERSHED BY CITIES, VILLAGES, AND TOWNS: 1963

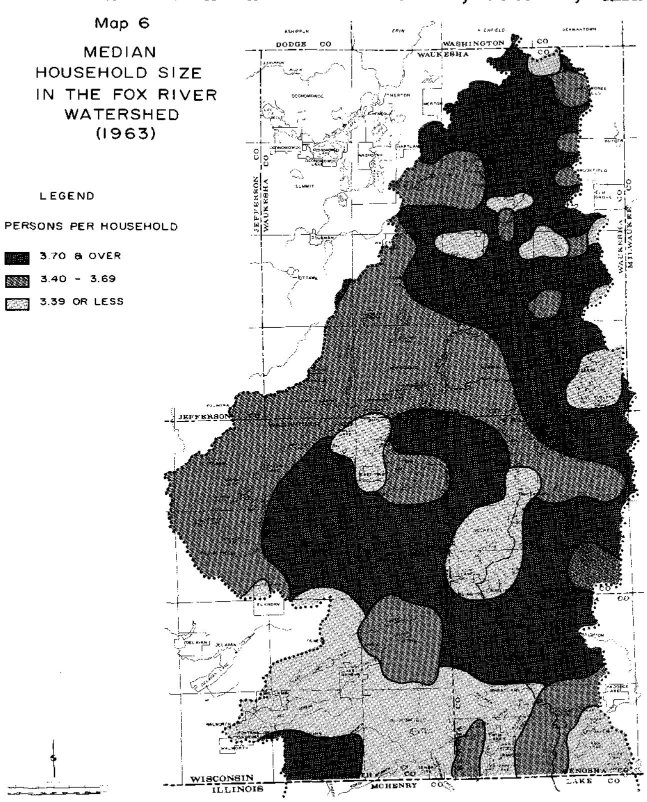
Civil Division	Population Within Watershed	Percent Of Watershed Population	Area Included In Watershed (Square Miles)	Percent Of Area In Watershed	Average Gross Population Density (Per Square Mile)
Cities	73,500	46.08	86.91	9.26	846
Villages	23,300	14.61	42.29	4.50	551
Towns.	62,700	39.31	809.53	86.24	77
Total	159,500	100.00	938.73[a]	100.00	170

[a] *Does not include 3.64 square miles of the watershed which is located in Jefferson County, Wisconsin.*

Source: SEWRPC.

Geneva (see Map 7). Despite these employment concentrations, most of the working population of the watershed, while maintaining residence within the watershed, works elsewhere, primarily in the urbanized areas of Milwaukee, Racine, and Kenosha Counties. Although the watershed contains approximately 9.3 percent of the regional population, it accounts for less than 6 percent of the total regional jobs.

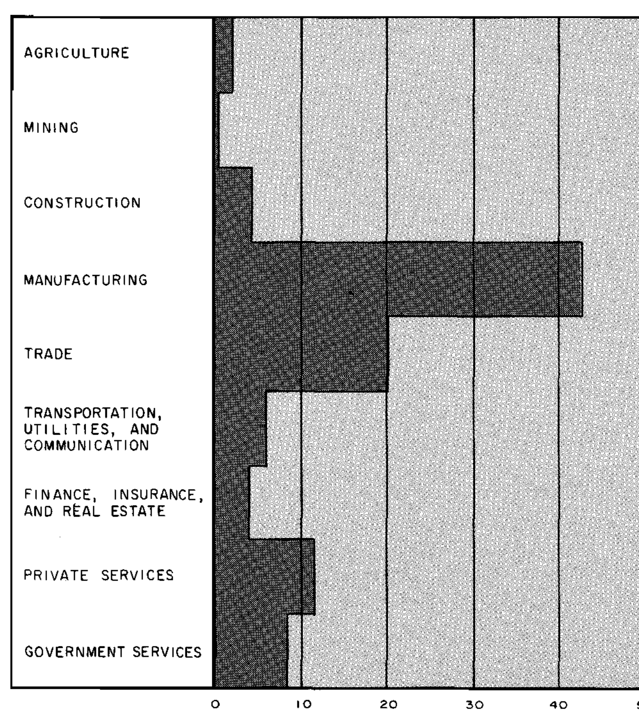
Map 6
MEDIAN HOUSEHOLD SIZE IN THE FOX RIVER WATERSHED (1963)



The median household size within the Fox River watershed averaged 3.58 persons per household in 1963. This compares to 3.40 persons per household for the Region and follows the trend of increasing household size with increasing distance from the larger urban centers of the Region.
Source: SEWRPC.

It is important to note, also, that agriculture is an important component of the economy of the watershed. Although the number of farms in operation,

Figure 5
PERCENTAGE DISTRIBUTION OF TOTAL JOBS IN THE REGION BY MAJOR INDUSTRIAL GROUP: 1963

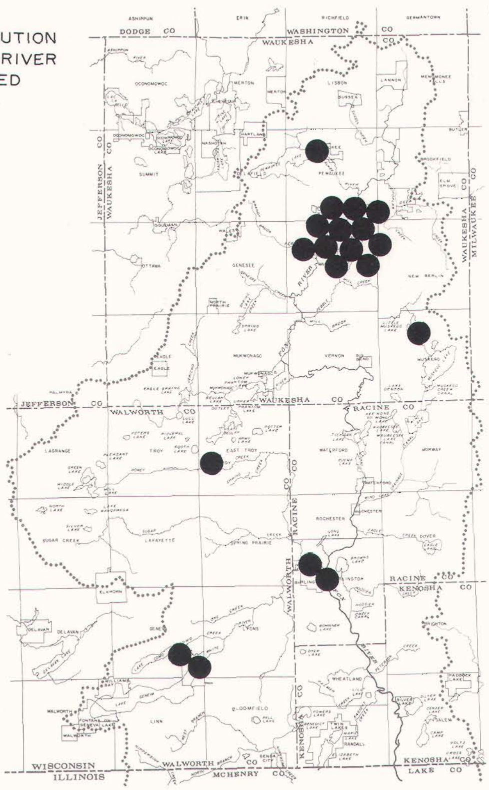


Source: SEWRPC.

Map 7
JOB DISTRIBUTION
IN THE FOX RIVER
WATERSHED
(1963)

LEGEND

● 1,000 JOBS



Employment opportunities within the watershed are, like population, concentrated in the headwater areas.

Source: SEWRPC.

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. As indicated in Table 5, the 1959 to 1964 trend in agricultural indicators for Kenosha, Racine, Walworth, and Waukesha Counties shows a decline in the number of farms from 6,073 to 5,419, or 11 percent; a decline in the number of acres farmed from 809,904 to 768,909, or 5 percent; and the number of farm operators from 5,986 to 5,421, or 9 percent. The average farm size has increased from 133 acres to 142 acres between 1959 and 1964, and the value of farm products sold has increased by more than $10 million from $57 million in 1959 to $67 million in 1964. As indicated in Table 6 , there has been a slight shift in farm product emphasis within these four counties between 1959 and 1964. In 1959 approximately 90 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 88 percent of the total sales of farm products, but the sale of field crops has taken on added importance and the proportionate sales of dairy products decreased. Also, the sale of vegetable products increased proportionately from 3 percent of the total to 4 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 four counties containing the major portions of the Fox River watershed and not to the watershed itself, over 50 percent of the agricultural lands of Kenosha, Racine, Walworth, and Waukesha Counties lie within the Fox River watershed area; and over one-third of the agricultural lands of the

Table 5

AGRICULTURAL INDICATORS IN FOUR SELECTED COUNTIES IN SOUTHEASTERN WISCONSIN: 1959 AND 1964

Indicator	Kenosha County		Racine County		Walworth County		Waukesha County		Total	
	1959	1964	1959	1964	1959	1964	1959	1964	1959	1964
Number of Farms	966	818	1,305	1,193	1,919	1,737	1,883	1,671	6,073	5,419
Acreage Farmed	123,495	114,223	149,391	149,081	306,290	297,600	230,728	208,005	809,904	768,909
Number of Farm Operators . .	952	818	1,274	1,193	1,895	1,739	1,865	1,671	5,986	5,421
Average Farm Size (Acres) .	128	140	115	125	160	171	123	125	133	142
Value of Farm Products Sold (Thousands of Dollars)	9,607	10,995	10,292	14,756	22,125	26,265	14,728	15,274	56,752	67,290
Average Value of Farm Products Sold per Farm (Dollars).	9,888	13,449	7,994	12,380	11,436	15,155	7,754	9,175	9,345	12,417

Source: U. S. Census of Agriculture and SEWRPC.

seven-county Region lie within the watershed. Because of these facts, it is likely that the trends in agricultural indicators within the watershed closely parallel those of the four-county area for which data is 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 soil and water uses and needs of a watershed. Water resource demand can be correlated directly with the quantity and type of land use. Similarly, water resource deterioration parallels directly the quantity and type of land use. The existing land use pattern can best be understood within the context of its historical 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 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[3] and east of the Wisconsin River. Initial urban development occurred along the Lake Michigan shoreline at the ports of Milwaukee, Racine, and Southport (now Kenosha) as these settlements were more directly accessible to immigration from the East Coast through the Erie Canal-Great Lakes route. The settlement of the watershed, which constituted a rich farm hinterland to the three port cities, followed soon afterward. Federal surveyors, after the close of the Black Hawk War of 1832, began to survey and monument the federal lands; and by 1836 the U. S. Public Land Surveys had been completed in southeastern Wisconsin. In 1838 a federal land office was opened

[3] *The Fox River referred to here is located in east-central Wisconsin and discharges to Lake Michigan at Green Bay.*

Table 6

VALUE OF FARM PRODUCTS SOLD BY PRODUCT IN FOUR SELECTED COUNTIES IN SOUTHEASTERN WISCONSIN: 1959 AND 1964

(Thousands of Dollars)

Product	Kenosha County			Racine County			Walworth County		
	1959	1964	Percent Change 1959-1964	1959	1964	Percent Change 1959-1964	1959	1964	Percent Change 1959-1964
Dairy Products	$ 4,109	$ 4,028	- 1.9	$ 3,729	$ 4,476	+16.7	$ 11,992	$ 13,509	+11.2
Livestock Products (not poultry)	2,164	2,351	+ 7.9	1,927	3,384	+43.1	5,565	6,167	+ 9.8
Field Crops	2,116	3,020	+29.9	2,962	3,691	+19.7	3,565	5,329	+33.1
Poultry Products	480	495	+ 3.0	462	1,258	+63.3	594	574	- 3.4
Vegetables	384	622	+38.3	962	1,349	+28.7	272	547	+50.3
Forest Products	182	297	+38.7	205	558	+63.3	109	120	+ 9.2
Fruits and Nuts	172	182	+ 5.5	45	40	-11.1	28	19	-32.1
Total	$ 9,607	$10,995	+12.6	$10,292	$14,756	+30.3	$ 22,125	$ 26,265	+15.8

Product	Waukesha County			Total				
				1959		1964		Percent Change 1959-1964
	1959	1964	Percent Change 1959-1964	Value	Percent Distribution	Value	Percent Distribution	
Dairy Products	$ 7,845	$ 7,295	- 7.0	$ 27,675	48.8	$ 29,308	43.6	+ 5.6
Livestock Products (not poultry)	3,573	3,319	- 7.1	13,229	23.3	15,221	22.6	+13.1
Field Crops	1,730	2,637	+34.4	10,373	18.3	14,677	21.8	+29.3
Poultry Products	927	728	-21.4	2,463	4.3	3,055	4.5	+19.4
Vegetables	282	416	+32.2	1,900	3.3	2,934	4.4	+35.2
Forest Products	239	731	+67.3	735	1.3	1,706	2.5	+56.9
Fruits and Nuts	132	148	+10.8	377	0.7	389	0.6	+ 3.1
Total	$14,728	$15,274	+69.0	$ 56,752	100.0	$67,290	100.0	+15.7

Source: U. S. Census of Agriculture and SEWRPC.

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 wanted 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 Fox River or on major tributaries at natural waterfalls or rapids, where small water-driven 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. By 1840 settlements that were developing around a natural source of water power included Burlington, Eagle, East Troy, Genesee, Geneva, Lyons, Mukwonago, Muskego, Pewaukee, Rochester, Spring Prairie, Waterford, Waukesha, and Wilmot. The 20 mill dams remaining within the watershed today attest to the importance of water power in the early development of the watershed (see Table 7).

The period from 1840 to 1860 was one of rapid settlement of the rural areas 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, particularly within Waukesha and Walworth Counties, even though the crop had to be hauled long distances by wagon over extremely poor roads to markets in the ports of Milwaukee, Racine, and Kenosha. Sheep raising was also important to the agricultural economy of the watershed until about 1880, and Walworth County led the state in wool production. Most of the wool produced was marketed at the major port cities, although considerable wool was used by a large woolen mill established at Burlington. 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 was slow in the watershed, and for many years the only important industries were the many small flour mills located in the villages. The important manufacturing centers lay outside the watershed in the port cities of Milwaukee, Racine, and Kenosha. In the 1880's Waukesha began to develop a distinctive industry of bottling mineral water and carbonated drinks, which helped establish the city's fame as a health spa, the so called "Saratoga of the West." In 1905 at the height of this industry, there were ten firms engaged in bottling mineral water and soft drinks. Waukesha made its most notable industrial progress, however, in the decade extending from 1910 to 1920, when ten manufacturing industries were established within the city, the largest of which was the Waukesha Motor Works.

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 13-year period extending from 1950 to 1963, a 43 percent increase in the population of the watershed was accompanied by a 300 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 centers into the woodlands, the fertile farm lands, and around the many beautiful lakes of the watershed.

Present Land Use

The generalized pattern of present (1963) land use within the Fox River watershed is shown on Map 8 and is summarized in Table 9. Although Map 8 illustrates the still predominately rural character of the basin, it also illustrates the diffused pattern of low-density urban development which has occurred in the headwater reaches and surrounding the major lakes of the watershed. Agricultural land use is still the predominant land use in the watershed, occupying 64.7 percent of the total watershed area. Urban land uses within the watershed presently occupy only 11.4 percent of the total watershed area. Residential development, consisting almost entirely of single-family dwellings, accounts for 45.3 percent of the total urban land use.

Although only 1.1 percent of the watershed area is presently devoted to recreational land use, a high

Table 7

PERTINENT INFORMATION CONCERNING THE MILL DAMS WITHIN THE FOX RIVER WATERSHED: 1967

Dam Name	Location		Purpose Of Original Structure	Date Of Original Construction	Description			
	Lake Or Stream	Town, Range, And Section			General	Type Control	Dam Height (In Feet)	Spillway Elevation[a] (In Feet)
Barstow Street Dam	Sarotoga Lake (Fox River)	6-19-03	Saw and Grist Mill	1836	Manonry and Concrete	Radial Gate	4.2	810.30
Beulah Dam	Beulah Lake	4-18-04	Flour Mill	1840's	Earth and Concrete	None	7.8	808.00
Blott Dam	Linnie Lac	6-20-32	Saw Mill	1837	Clay and Gravel	Stop Log Gate	8.3	814.30
Burlington Dam	Echo Lake	3-19-32	Saw, Wood, and Flour Mill	1835	Stone and Concrete	Radial Gate	4.0	761.60
Cedar Grove Dam	Honey Creek Millpond	4-16-36	Saw Mill	1850's	C.M.P. and Dam Comb.	Wood 2" x 4"	5.6	873.00
Eagle Spring Dam	Eagle Spring Lake	5-17-36	Saw and Grist Mill	1836	Earth, Gravel, and Concrete	Adjustable Boards	7.3	817.10
East Troy Dam	East Troy Millpond	4-18-29	Saw and Flour Mill	1840	Concrete	Removable Boards	11.0	831.20
Genesee Millpond Dam	Genesee Millpond	6-18-27	Grist and Feed Mill	1847	Earth, Gravel, and Concrete	Removable 2" x 6" Boards	3.4	835.10
Geneva Dam	Lake Geneva	2-17-36	Saw Mill	1836	Concrete	Adjustable Boards	9.0	864.30
Hilburn Dam	Honey Creek	4-18-22	Flour Mill	1840	Concrete	Adjustable Boards	8.0	811.40
Honey Lake Dam	Sugar Creek	3-18-03	Grist and Feed Mill	1926	Concrete	Six Adjustable Gates	6.0	770.00
Little Muskego Dam	Little Muskego Lake	5-20-09	Saw Mill	1836	Concrete	Adjustable Boards	8.0	792.00
Lyons Millpond Dam	Lyons Millpond	2-18-10	Saw Mill	1845	Concrete	Adjustable Boards	5.2	796.20
Mill Lake Dam	Lauderdale Lakes	4-16-36	Saw Mill	1840's	Concrete and Steel	None	10.5	884.40
Mukwonago Dam	Lower Phantom Lake	5-18-35	Saw Mill	1848	Concrete	Adjustable Boards	7.3	788.30
Pewaukee Lake Dam	Pewaukee Lake	7-19-09	Flour Mill	1842	Gravel and Concrete	Steel Gate	4.0	852.00
Rochester Dam	Fox River	3-19-11	Grist and Feed Mill	1843	Rock and Concrete	Two 15' Radial Gates	5.0	765.20
Saylesville Dam	Saylesville Millpond	6-18-25	Saw Mill	1856	Stone and Concrete	None	3.4	796.40
Waterford Dam	Fox River	4-19-35	Saw and Flour Mill	1838	Stone and Concrete	None	4.2	773.40
Wilmot Dam	Fox River	1-20-30	Saw Mill	1840	Stone and Concrete	Three Lift Gates	3.5	739.50

[a]*Elevation refered to Mean Sea Level Datum, 1929 Adjustment*

Source: Wisconsin Department of Natural Resources and SEWRPC.

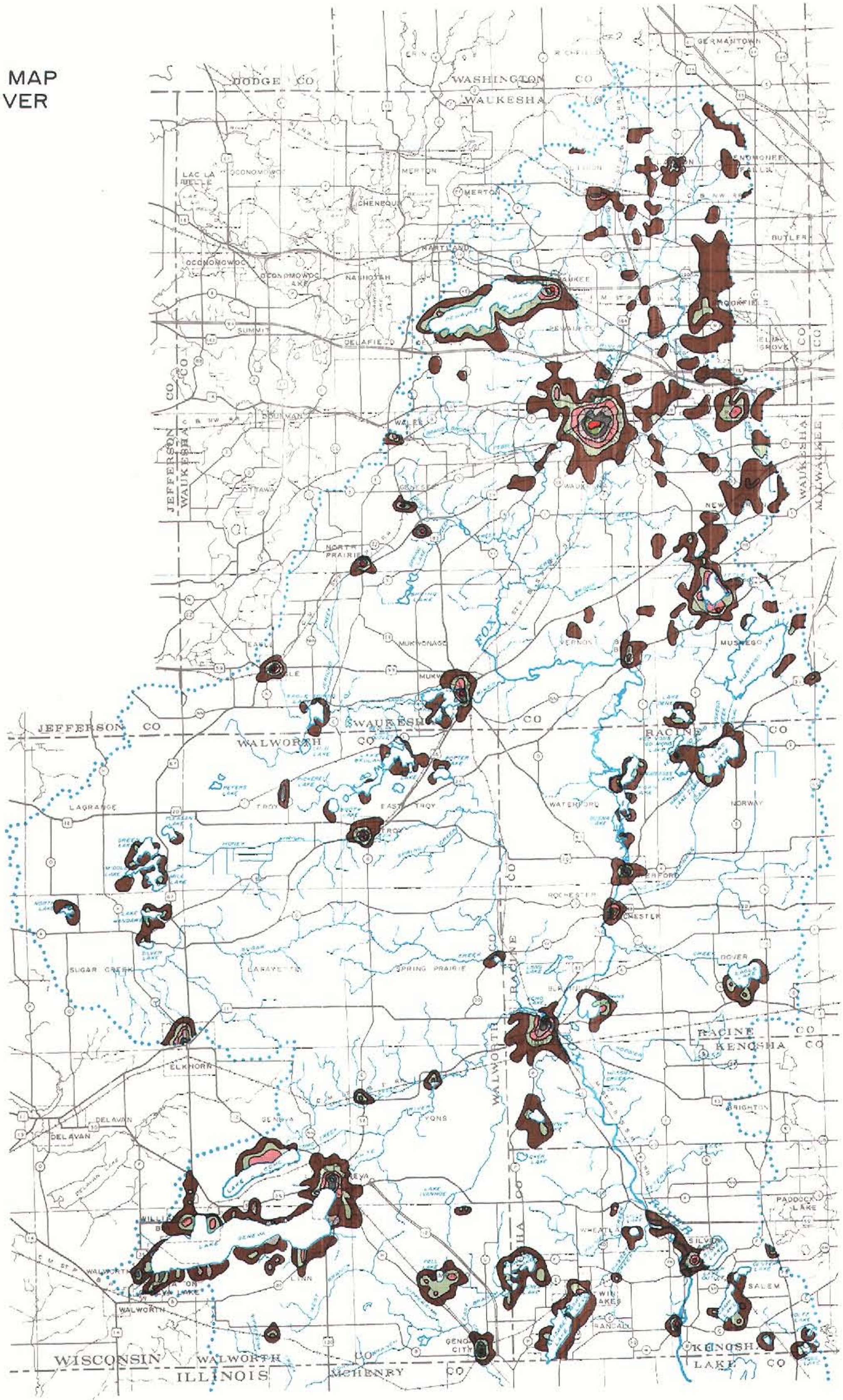
Map 8

HISTORIC URBAN GROWTH MAP FOR THE FOX RIVER WATERSHED (1963)

LEGEND

DEVELOPMENT AS OF:

- 1850
- 1880
- 1900
- 1920
- 1940
- 1950
- 1963



The greatest increase in urban development within the watershed occurred in the 13-year period from 1950 to 1963, when the population of the watershed increased by 43 percent; but land devoted to urban use increased by 300 percent. The influence of the Milwaukee urbanized area and of the inland lakes of the watershed on the development pattern is clearly evident.

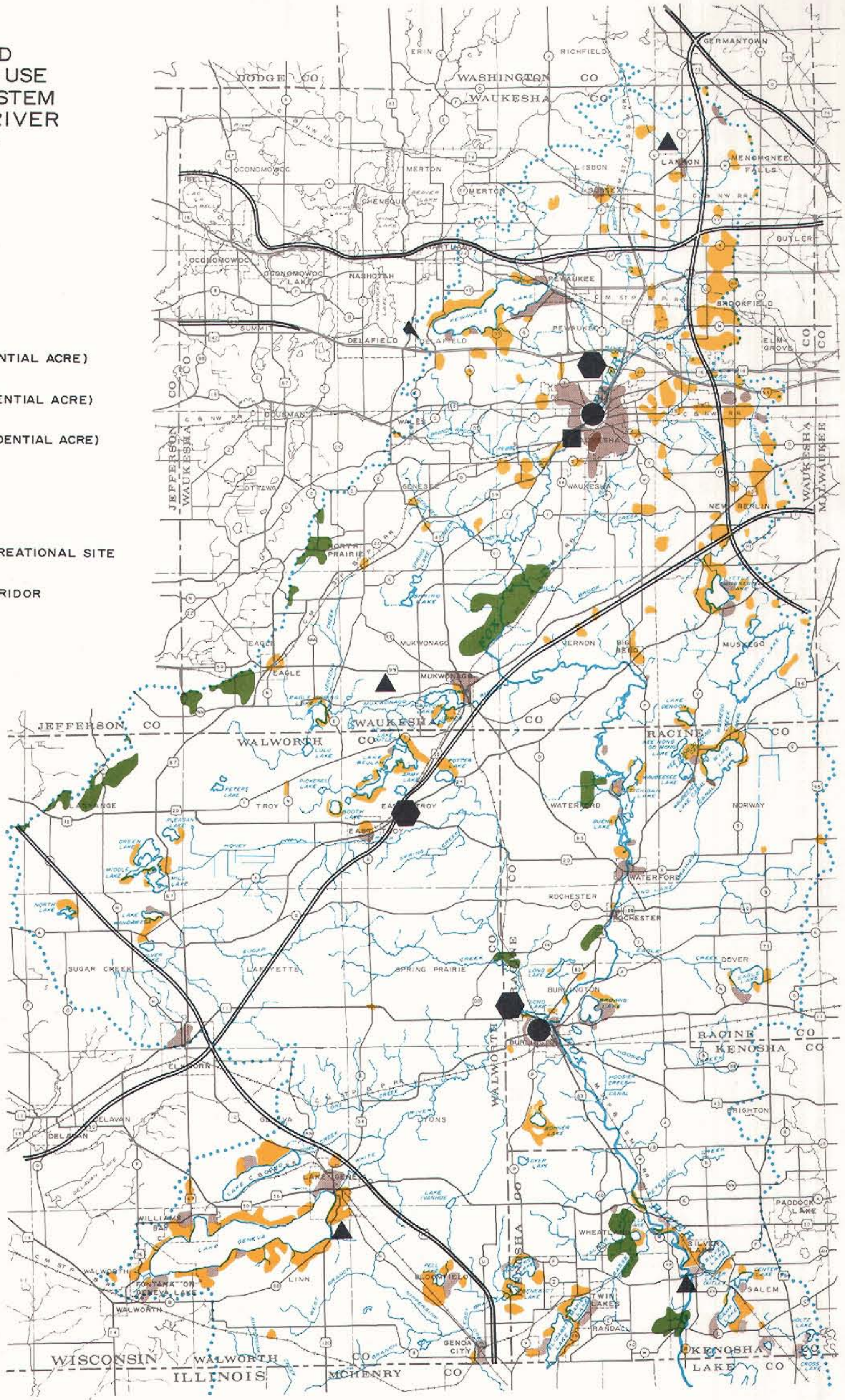
Source: SEWRPC.

Map 9

GENERALIZED EXISTING LAND USE AND FREEWAY SYSTEM FOR THE FOX RIVER WATERSHED (1963)

LEGEND

- LOW DENSITY RESIDENTIAL (0.5 – 7.2 PERSONS PER RESIDENTIAL ACRE)
- MEDIUM DENSITY RESIDENTIAL (7.3 – 22.8 PERSONS PER RESIDENTIAL ACRE)
- HIGH DENSITY RESIDENTIAL (22.9 – 59.2 PERSONS PER RESIDENTIAL ACRE)
- MAJOR RETAIL AND SERVICE
- MAJOR INDUSTRIAL
- PUBLIC AIRPORT
- MAJOR PUBLIC OUTDOOR RECREATIONAL SITE
- PRIMARY ENVIRONMENTAL CORRIDOR
- WATER
- AGRICULTURAL
- PROPOSED FREEWAY



This generalized existing land use map depicts the extent of concentrated urban development within the watershed in 1963. Most of the medium-density and high-density residential areas were developed prior to 1950, with dispersed low-density residential development predominating after 1950. It is significant that 40 of the 45 major lakes within the watershed have low- or medium-density residential development around them.
Source: SEWRPC.

Table 8

SUMMARY OF EXISTING LAND USE IN THE FOX RIVER WATERSHED:[a] 1963

Land Use Category	Area In Acres	Area In Square Miles	Percent Of Major Category	Percent Of Watershed Area
Urban Land Use				
Residential				
Under Development	5,408	8.45	8.0	0.9
Developed	25,256	39.46	37.3	4.2
Subtotal	30,664	47.91	45.3	
Commercial.	1,082	1.69	1.6	0.2
Industrial.	1,176	1.84	1.8	0.2
Mining.	2,909	4.56	4.3	0.5
Transportation and Utilities[b] . .	23,277	36.37	34.4	3.9
Governmental and Institutional. .	2,083	3.25	3.1	0.4
Recreational[c]	6,446	10.07	9.5	1.1
Total Urban Land Use	67,637	105.68	100.0	11.4
Rural Land Use				
Agricultural.	388,848	607.58	72.9	64.7
Open Land				
Water and Wetland	77,741	121.47	14.6	12.9
Woodland.	55,498	86.72	10.4	9.2
Unused Land	11,055	17.27	2.1	1.8
Total Rural Land Use	533,142	833.04	100.0	88.6
Total Land Use	600,779	938.73	--	100.0

[a] *To summarize existing land use as tabulated in the SEWRPC land use inventory, the watershed boundary was approximated by U. S. Public Land Survey quarter-section boundaries, giving a total area for the watershed of 602,666 acres. The difference of 1,887 acres between this approximation and the actual area of the watershed in the Region was distributed by reducing the tabulated area in each land use category on the basis of the proportionate share which each land use category formed of the total watershed.*

[b] *Includes off-street parking.*

[c] *Includes major and neighborhood parks.*

Source: SEWRPC.

potential for development of additional recreational land exists. Water and wetlands are abundant within the basin, comprising 12.9 percent of the watershed area and constituting 43.5 percent of the total regional supply of this land and water reserve. Woodlands comprise 11 percent of the watershed area and constitute 41.7 percent of the total regional supply of this land use.

The existing land uses are summarized in Appendix C by the two major subwatersheds tributary to the existing stream gaging stations located on the main stem of the Fox River at Waukesha and Wilmot.

PUBLIC UTILITY BASE

Sanitary Sewerage Service

Within the watershed the construction of public sanitary sewerage facilities has not 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 (1963), only 32 percent of the developed area[4] of the watershed, only 2.1 percent of the total watershed area, and only 41 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.

Of special significance, and also shown on Map 10, are the areas within the basin in the Cities of Brookfield, Muskego, and New Berlin and the Village of Menomonee Falls which are included in the planned service area of the Metropolitan Sewerage Commission of the County of Milwaukee. Within this service area, which comprises 41.4 square miles, or 4.4 percent, of the total watershed area, sanitary sewage will be exported from the basin across the subcontinental divide.

Map 10 also indicates the location of the 14 municipal sewage treatment plants within the basin. Detailed information on the treatment, loading, and efficiency of these sewage treatment plants is presented in Chapter IX, "Surface Water Quality and Pollution."

Water Supply Service

Public water supply systems serve a somewhat larger percentage of the watershed area than do public sanitary sewerage systems. Presently (1963), 34 percent of the total developed area of the watershed, 2.2 percent of the total watershed area, and 45 percent of the total watershed population are served by public water supply. The existing service areas of public and privately operated water systems are shown on Map 11. The public and privately operated water systems, as well as individual water supplies, all depend entirely upon ground water resources, as no surface water source in the basin is presently utilized for domestic water supply. Considerable information concerning the quality, quantity, sources, and distribution of ground water supplies is presented in Chapter X, "Ground Water Quality and Pollution" and Chapter XI, "Water Supply and Use."

Except for the relatively large public water service areas of the Cities of Burlington, Lake Geneva, and Waukesha, the public and privately owned water service areas are small and scattered and bear little relationship to the existing pattern of urban development. The six separate public and three privately operated water systems within the City of Brookfield typify the non-integrated character of the water service area within the basin.

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.

Two major privately owned electric utilities are authorized within the watershed, which, together with one small municipal utility, provide service to the entire watershed. The major electric utilities are the Wisconsin Electric Power Company, serving approximately 790 square miles of the watershed area, and the Wisconsin Light and Power Company, serving about 150 square miles of the watershed in the extreme southwest corner of Kenosha County and the southern one-third of Walworth County. The City of Elkhorn operates its own municipal electric utility.

As a matter of established utility corporation policy, any major natural gas customer can obtain gas service anywhere within the franchise portions

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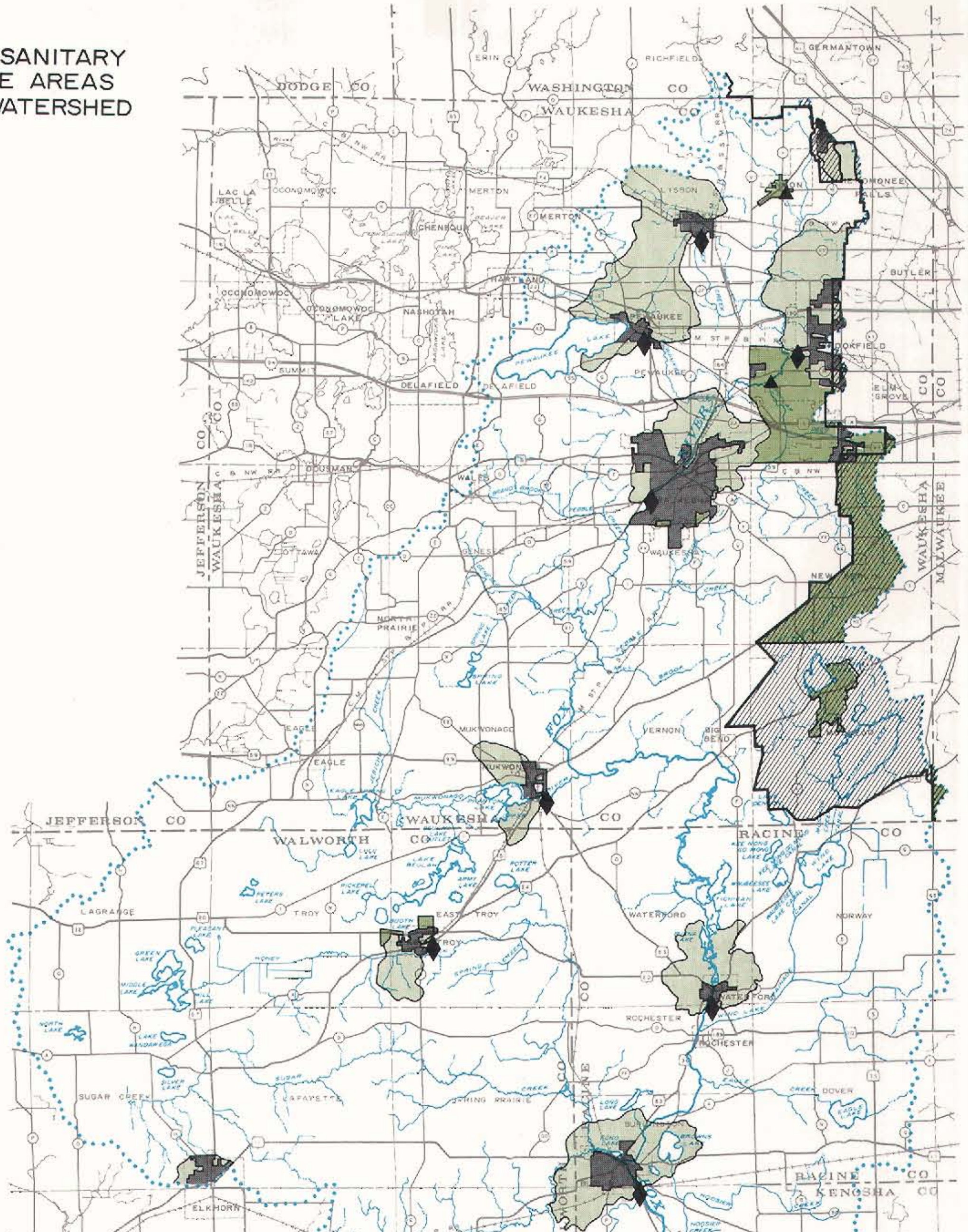
[4] *Developed area is defined for the purposes of this report as including those areas of the Region wherein houses or other buildings have been constructed in relative compact groups or where a closely spaced network of minor streets has been constructed, thereby indicating a concentration of residential, commercial, industrial, governmental, or institutional land uses.*

Map 10

PUBLIC, MUNICIPAL SANITARY SEWERAGE SERVICE AREAS IN THE FOX RIVER WATERSHED (1964)



LEGEND

- EXISTING SANITARY SEWERAGE SERVICE AREA
- PROPOSED SANITARY SEWERAGE SERVICE AREA
- GRAVITY DRAINAGE TO EXISTING TREATMENT FACILITIES
- PLANNED SANITARY SEWERAGE SERVICE AREA WITHIN THE FOX RIVER WATERSHED TO BE SERVED BY MILWAUKEE METROPOLITAN SEWERAGE COMMISSION

TREATMENT FACILITIES

- EXISTING
- PROPOSED

Only about one-third of the present urban development and two-fifths of the population within the watershed are served by public sanitary sewerage facilities, as compared to almost two-thirds within the Region as a whole. Continued urban sprawl within the watershed will tend to further decrease the proportionate area so served and will intensify water pollution and public health problems within the watershed.

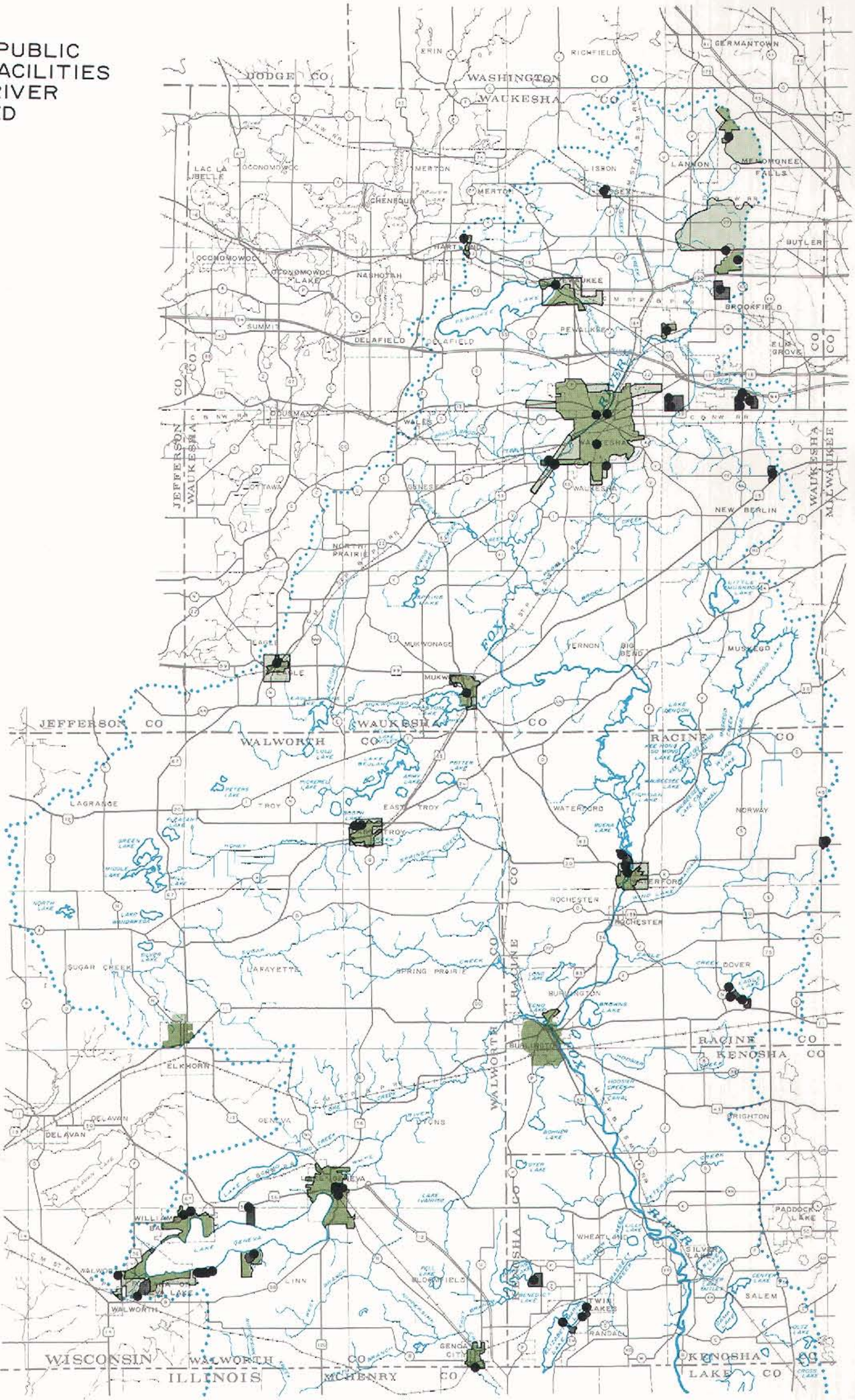
Source: SEWRPC.

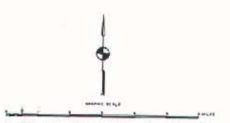
Map 11

PRIVATE AND PUBLIC WATER SUPPLY FACILITIES IN THE FOX RIVER WATERSHED (1964)

LEGEND

- EXISTING WATER SERVICE AREAS (PRIVATE OPERATED)
- EXISTING WATER SERVICE AREAS (PUBLIC OPERATED)
- PROPOSED WATER SERVICE AREAS
- ● EXISTING WELL





Only about one-third of the present urban development and one-half of the population within the watershed are served by public water supply facilities. Ground water is the only source of supply for these facilities.

Source: SEWRPC.

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 Natural Gas Company, the Wisconsin Southern Gas Company, and the Wisconsin Gas Company. No gas utility franchise exists in the watershed within the Town of LaGrange in Walworth County and the Town of Ottawa in Waukesha County.

TRANSPORTATION SYSTEM

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 and connecting the watershed to the Milwaukee, Racine, Kenosha, and Chicago metropolitan centers. Most of the arterial highways presently (1963) carrying over 4,000 vehicles per average week day are either major routes through the watershed or are located within, or radiate from, cities and villages within the watershed.[5]

Intercity bus service is furnished between several communities within the watershed and other urban centers, such as Milwaukee, Beloit, Janesville, and Rockford, Illinois. The Wisconsin Coach Lines of Waukesha serve communities adjacent to STH 59, 36, 24, and 15 and USH 16 and 18. The Peoria-Rockford Bus Lines serve communities along STH 59. Additional service is provided to communities adjacent to USH 12, 16, and 18 by Greyhound Bus Lines.

Rail service in the watershed is limited to freight hauling except for limited commuter passenger train service to Pewaukee from Milwaukee and to Lake Geneva from Chicago. Three major railway lines operate in the watershed: the Chicago and Northwestern Railway Company (C&NW); the Chicago, Milwaukee, St. Paul and Pacific Railroad Company (Milwaukee Road); and the Minneapolis, St. Paul and Sault Ste Marie Railroad Company (Soo Line). In addition, the Village of East Troy operates an electric railway line between East Troy and a junction with the Soo Line at Mukwonago, providing freight service only.

SUMMARY

This chapter has described the man-made features of the Fox River watershed, which together constitute the socio-economic 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 that have particular significance to the comprehensive planning study of the Fox River watershed are summarized in the following paragraphs.

The Fox River watershed is the 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 watershed, although still primarily rural in character, is experiencing a rapid population growth and urbanization. The economic forces that promote this population growth and urbanization are largely centered outside the watershed in the major urban centers of Milwaukee, Racine, and Kenosha. Land areas in the headwaters of the basin and land areas adjacent to major water bodies are undergoing a particularly rapid conversion from rural to urban use. Moreover, recent urban development 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.

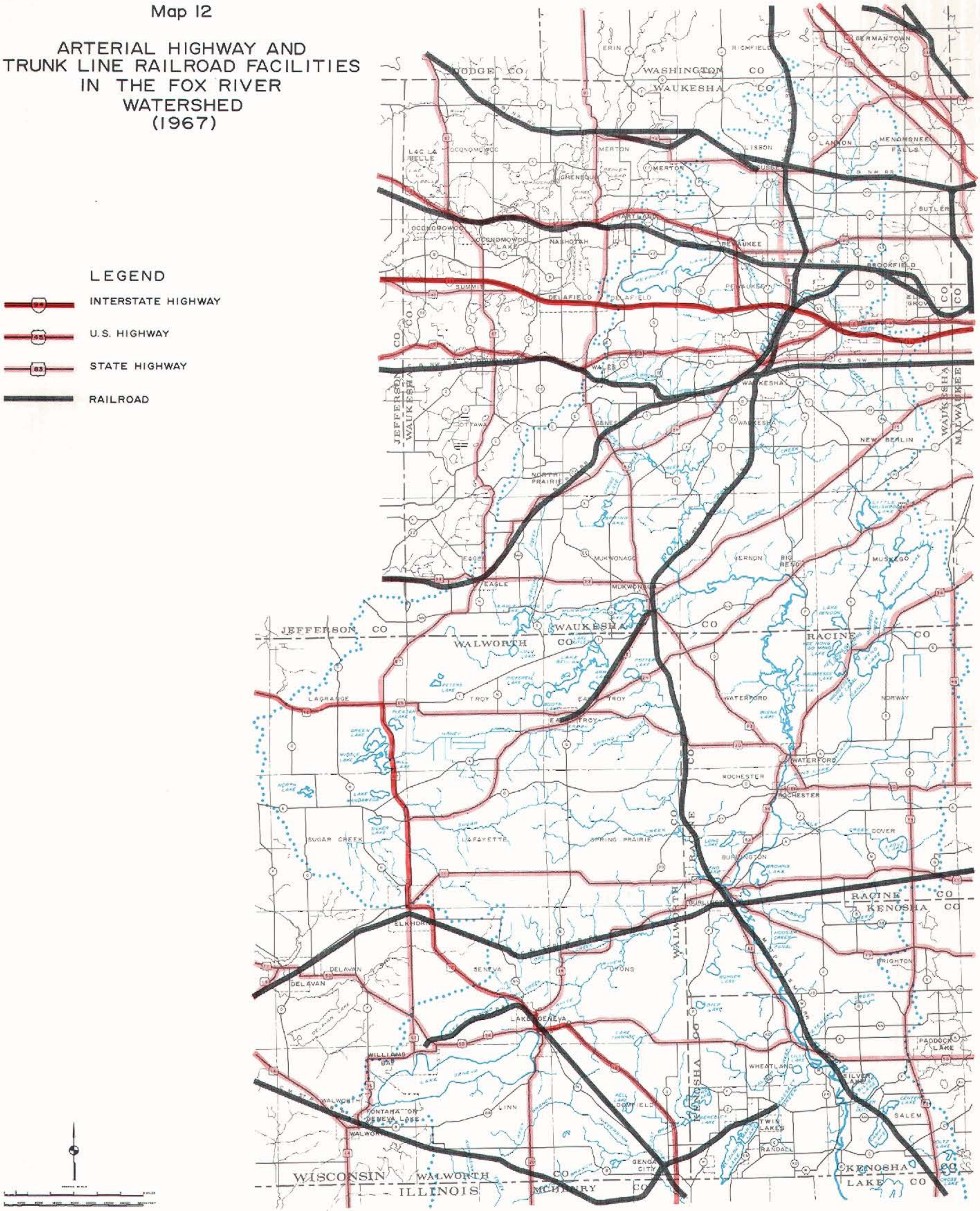
The construction of public sanitary sewer and water facilities has not kept pace with the rapid urban growth in the watershed, necessitating the widespread use of individual private wells and on-site sewage disposal systems (septic tanks). Presently, less than half the developed urban land area of the basin is served by public sewerage and a public water supply.

The extensively developed high-speed, all-weather 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.

[5] *SEWRPC Planning Report No. 7, Volume 1, Inventory Findings - - 1963.*

Map 12

ARTERIAL HIGHWAY AND TRUNK LINE RAILROAD FACILITIES IN THE FOX RIVER WATERSHED (1967)



The watershed is served by a well-developed transportation system, with particularly good linkages to the major urban centers of the Region outside the watershed and to the Chicago metropolitan area.

Source: SEWRPC.

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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 area. 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 their interrelationships, human use and alteration of the natural environment proceeds at the risk of excessive costs in terms of both dollars and destruction of nonrenewable or slowly renewable resources. In this age of high resource demand and accelerating technology, it is especially vital that the resource base be a primary consideration in any areawide planning effort, since these aspects of contemporary civilization make the underlying and sustaining resource base even more vulnerable to misuse and destruction.

CLIMATE

The climate of the Fox River watershed[1] is characterized by extremes in all of the climatic elements common to the latitude and the interior of the North American continent. The climate spans the four seasons, each succeeding one another through varying periods of unsteady transition. Winter, generally beginning in November and lasting through March, tends to be cold, cloudy, and snowy. There is often, however, a short-lived 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, such as Geneva Lake, usually covered with ice by mid-December. 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. Lake and stream ice breakup occurs in late March or early April due to increasing solar radiation. Summers are relatively warm but are marked by occasional hot, humid periods and sporadic cool periods. Typical fall weather may extend from September to November and is characterized by mild, sunny days and cool nights.

Air temperatures within the watershed are subject to large seasonal and yearly variations. Air temperatures lag about three weeks behind the solstices, resulting in July being the warmest month and January the coldest. The number of days with temperatures of 0°F or less has ranged from 2 in 1931 and 1964 to 40 in 1963. The number of days with temperatures of 90° or more has ranged from 2 in 1951 to 36 in 1934. The lowest temperature recorded was -27°F in January 1951. The highest temperature recorded was 109° in July 1936. The mean daily temperature of the hottest month, July, is 72.0°F; and the mean daily temperature of the coldest month, January, is 20.9°F.[2]

The growing season, which is defined as the number of days between the last 32°F freeze in spring and the first 32°F freeze in fall, has averaged about 160 days within the watershed. The average date of the first 32°F freeze in fall ranges from October 8 to October 12.

Precipitation within the watershed takes the form of rain, sleet, hail, and snow. Rainfall ranges from gentle showers of trace quantities to destructive thunderstorms causing property and crop damage, inundation of poorly drained areas, and stream flooding. Averaging 30.62 inches annually at Waukesha, total annual rainfall has been as low as 17.30 inches and as high as 43.57 inches. Approximately 55 percent of the average annual precipitation occurs as rainfall during the growing season. Precipitation in the form of snow is common, however, from late November through March. Maximum and minimum cumulative seasonal snowfall at Waukesha, since the beginning of snow depth measurements in 1955, are 65.9 inches (winter of 1959-1960) and 24.8 inches (winter of 1955-1956), respectively.

Summaries of temperature and precipitation data for the Waukesha, Wisconsin, Weather Station are

[1] *The description of the climate of the watershed is based, in part, upon a regional climatic description prepared by Marvin W. Burley, U. S. Department of Commerce, Weather Bureau, formerly the State Climatologist for Wisconsin.*

[2] *Based on the official weather records of the Waukesha, Wisconsin, Weather Station, 1931-1960.*

presented in Table 9. These climatological summaries closely approximate temperature and precipitation characteristics within the watershed. More detailed summaries of climatological data collected at weather stations within the watershed and the Region have been published in SEWRPC Planning Report No. 5, The Natural Resources of Southeastern Wisconsin.

Winds from the northwest prevail during winter, whereas southwesterly winds prevail during summer. The windiest months are March, April, and November, when the wind velocities average about 14 mph. Wind velocities in the range of 13 to 31 mph occur about 40 percent of the time. Wind velocities exceeding 31 mph occur less than 1 percent of the time.

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

PHYSIOGRAPHY

In general appearance, the Fox River watershed is marked by gently rolling topography interspersed with relatively flat plains, marshy areas, and lakes, many of which are outside the floodplain of the main channel system. The watershed is roughly trapezoidal in shape with its major axis approximately north and south and its minor axis east and west. Its length is about 48 miles, and its average width about 20 miles. On the west boundary, the interlobate morainal deposits of the Green Bay and Lake Michigan glaciers have produced the kettle moraine topography, which has excellent internal drainage and numerous closed depressions that do not contribute directly to surface runoff. There are few lakes in this area.

The northeastern boundary of the Fox River basin forms a major subcontinental, though poorly defined, divide between the Upper Mississippi drainage basin and the Great Lakes-St. Lawrence drainage area. Most of the rest of the watershed boundary is made up of more or less well-defined

Table 9

TEMPERATURE AND PRECIPITATION MEANS AND EXTREMES AT WAUKESHA, WISCONSIN: 1931-1960[a]

Month	Temperature (°F)							Mean Precipitation	Greatest Daily Precipitation	
	Means			Extremes						
	Daily Maximum	Daily Minimum	Monthly	Record High	Date	Record Low	Date	(Inches)	Amount (Inches)	Date
January. . .	29.3	12.5	20.9	62	1-26-44	-27	1-30-51	1.73	2.66	1-24-38
February . .	31.2	14.2	22.7	61	1932[b]	-24	1933[b]	1.29	1.43	2-21-37
March. . . .	40.5	23.1	31.8	80	3-27-45	-14	3- 8-43	2.15	1.92	3-15-43
April. . . .	56.1	34.9	45.5	89	4-30-42	11	4- 3-54	2.57	2.17	4-27-56
May.	68.1	44.7	56.4	101	1934[b]	25	5- 9-47	3.53	3.05	1934[b]
June	78.5	55.1	66.8	101	1934[b]	29	6- 4-45	3.72	4.05	6-22-40
July	84.0	60.0	72.0	109	7-14-36	42	7-11-45	3.39	5.09	7-18-52
August . . .	82.6	59.0	70.8	101	8-24-48	39	8-20-50	3.24	2.42	8- 8-39
September. .	74.2	50.6	62.4	101	9- 1-53	25	9-28-42	2.95	3.35	9- 8-41
October. . .	62.4	40.2	51.3	86	10-20-53	17	10-29-52	2.13	1.83	10- 5-59
November . .	44.8	27.8	36.3	78	11- 1-44	-9	11-24-50	2.37	2.02	11- 9-42
December . .	32.3	17.3	24.8	61	12- 8-46	-19	1933[b]	1.55	1.89	12-26-42
	57.0	36.6	46.8	109	7-14-36	-27	1-30-51	30.62	5.09	7-18-52

[a] *The 30-year period, 1931-1960, is the ''standard normal'' period, which conforms to the World Meteorological Organization standard for climatological normals.*

[b] *Specific day not available.*

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

end moraines of the Lake Michigan glacier. These also have relatively good internal drainage and little wetland area except where the ground water table is high or where the moraine is made up of fine grained materials.

Topography

Most of the Fox River watershed lies within the Niagara cuesta section of the Eastern Ridges and Lowlands physiographic provinces of Wisconsin.[3] Topography in this section is asymmetrical; that is, the eastern border of the watershed is lower in elevation than the western border, as shown on Map 13 and Figure 6. The highest point within the watershed is the crest of a hill in the Town of Linn south of Geneva Lake, an elevation of 1,144 feet above mean sea level. The lowest elevation within the watershed is 739 feet above mean sea level, adjacent to the Fox River at the state line. The maximum relief within the basin is, therefore, 405 feet, although the local relief is generally less than 100 feet.

The bedrock and the overlying glacial deposits together control the topography in the Fox River watershed. The overall gentle slope of the bedrock is reflected in the gradual downward slope of the topography toward the east. The west-facing escarpment of the Niagara cuesta, being buried beneath several hundred feet of glacial deposits, has little effect on topography in the watershed. Glacial deposits are largely responsible for the irregular topography. These deposits are characterized by rounded hills or groups of hills, ridges, broad undulating plains, and poorly drained lowlands (see Figure 6).

The greatest relief in the watershed is found along the range of hills known as the Kettle Moraine, which extends along the border of the watershed from the west end of Pewaukee Lake in Waukesha County to a point about two miles northeast of Whitewater Lake in Walworth County. In places along the Kettle Moraine, the local relief is nearly 200 feet. This complex system of moraines, kames, kettle holes, and drainageways developed along the junction between two adjacent glaciers. The height and prominence of the Kettle Moraine is due partly to the placement of glacial deposits near the crest of the Niagara cuesta. Other important topographic features of the watershed in much of Waukesha County and northeastern Walworth County are drumlins or elongated hills up to 4,000 feet long and 150 feet high. A few scattered drumlins are also located within the watershed in western Racine and Kenosha Counties. Nearly level outwash plains and terraces occur throughout the watershed but exist mostly in north central Walworth County, south central Waukesha County, and along the Fox River below Burlington.

Surface Drainage

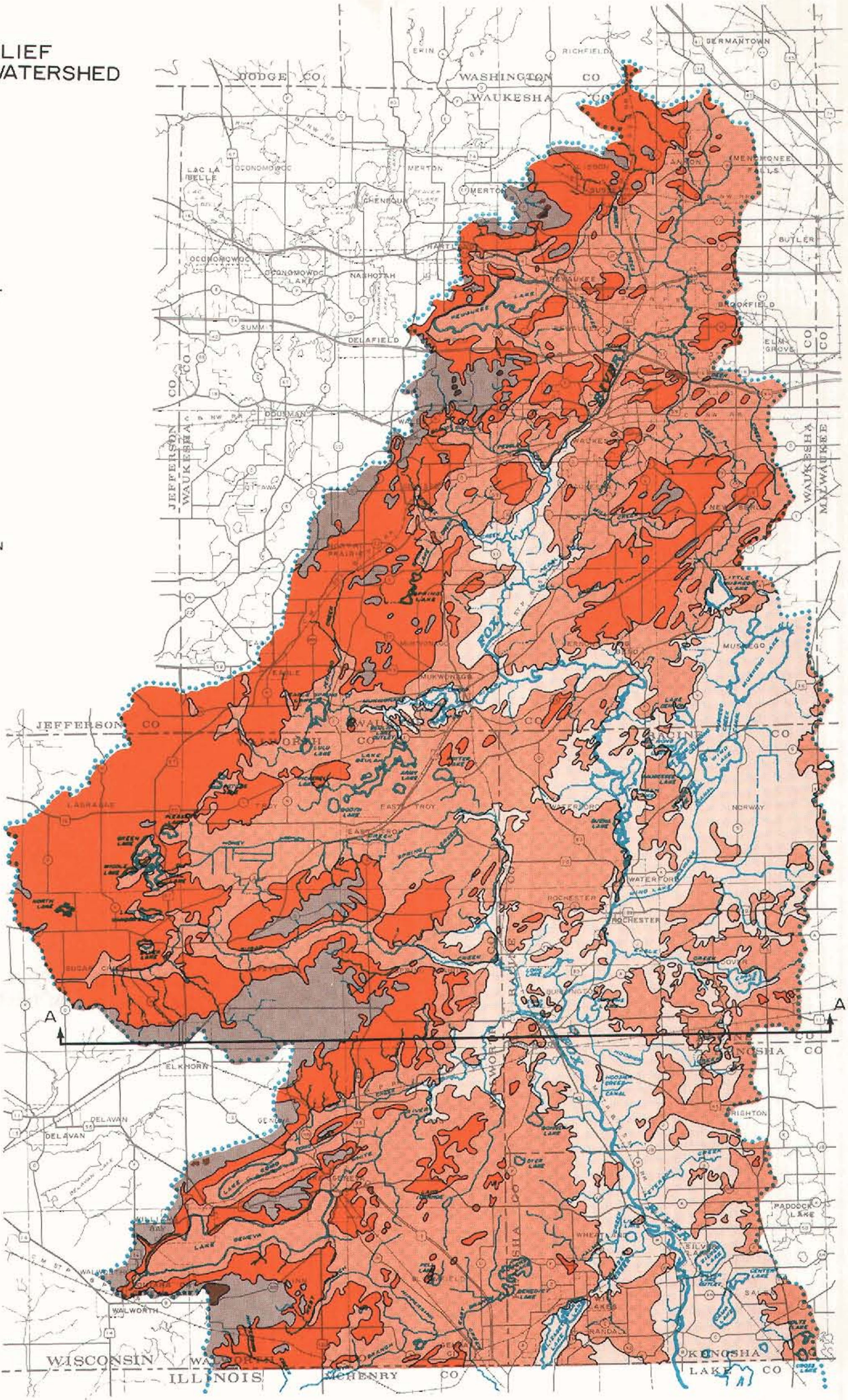
Surface drainage is poorly developed but highly diverse within the Fox River watershed due to the effects of the relatively recent glaciation. The land surface is complex, containing thousands of closed depressions that range in size from mere pits to areas of over eight square miles. Significant areas of the watershed are swampy, and many streams are mere threads of water through the swamps. Some stream courses are, however, controlled by bedrock and preglacial valleys that were cut into the bedrock. Many areas of the basin have disordered or deranged drainage patterns, which occur where preglacial drainage has been covered over and new drainage has not had time to develop. Such patterns are marked by irregular stream courses that enter into, and discharge from, lakes but have relatively few tributaries.

The drainage characteristic known as stream density, or the number of streams within a given area, is an important consideration in river basin studies. The infiltration capacity, or what is commonly referred to as permeability, is probably the most important single factor influencing stream density. It is commonly observed that stream density is greater over impermeable materials than over permeable ones. In fact, areas covered by such permeable materials as sand and gravel may virtually lack surface drainage. Such an area lies within the watershed in the Towns of LaGrange and Troy in north central Walworth County between the Kettle Moraine and the Lauderdale Lakes. Thick sand and gravel deposits in that area absorb the precipitation before it can run off. The low-stream-density pattern suggests, moreover, that this area is an important ground water recharge area. Areas which are underlain by glacial deposits high in silt and clay generally have the highest stream density in the watershed and are characterized by rapid storm runoff and little ground water recharge.

[3] *See Martin, Lawrence, The Physical Geography of Wisconsin, Wisconsin Geological and Natural History Survey, Bulletin No. 36, 1932.*

Map 13

GENERALIZED RELIEF
IN THE FOX RIVER WATERSHED

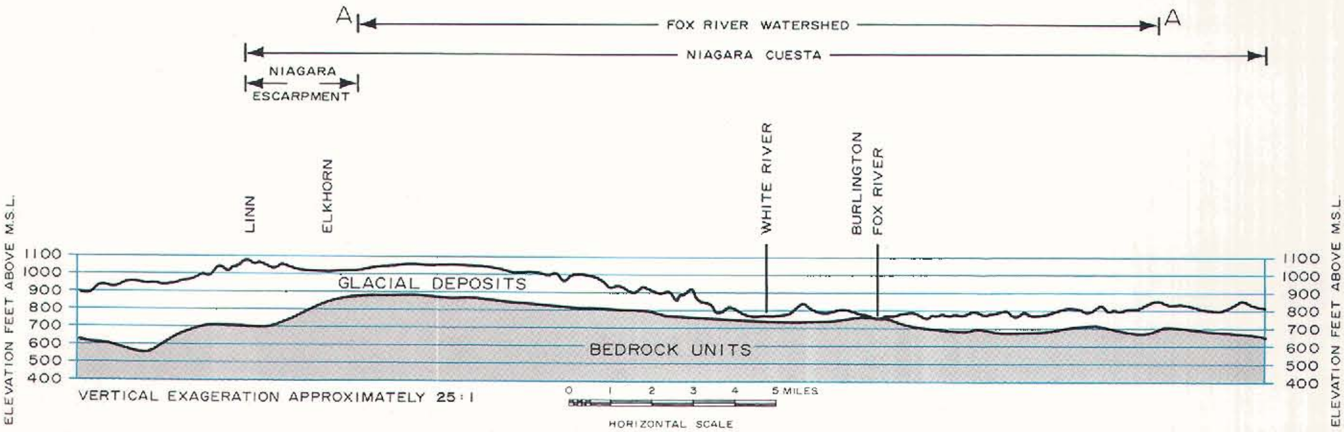


The maximum relief in the watershed is 405 feet; however, local relief is usually less than 100 feet. The surface of the bedrock underlying the watershed slopes gradually downward toward the east, producing an asymmetrical relief pattern, with the western portions of the watershed being generally higher than the eastern.

Source: U.S. Geological Survey

Figure 6

CROSS SECTION THROUGH THE FOX RIVER WATERSHED SHOWING THE EFFECTS OF THE NIAGARA CUESTA AND THE GLACIAL DEPOSITS ON SURFACE TOPOGRAPHY



Source: U. S. Geological Survey.

Table 10

STRATIGRAPHY OF THE FOX RIVER WATERSHED AND THE WATER-YIELDING CHARACTERISTICS OF THE ROCK UNITS

Stratigraphic Unit	Epoch	Representative Thickness Range (feet)	Description	Water-Yielding Characteristics	Ground Water Unit
Alluvium.	Recent	0-50	Clay, silt, sand, peat, muck, marl.	Insignificant; locally will yield water from sand.	Sand and and Gravel Aquifers[a]
Glacial Deposits . . .	Pleistocene	0-450	Till, sand, silt, gravel, peat.	Yields water from sand and gravel. Buried valleys are important.	
Racine Formation . . . Waukesha Formation . . Joliet Formation . . .	Middle Silurian	0-275	Dolomite, white to gray. Some coral reefs. Mostly massive. Crevices and solution channels abundant but inconsistent. Sandy and thin bedded at base.	Important aquifer but variable. Yields water from crevices and solution channels. Yields 5 to 1,500 gpm.	Silurian Dolomite Aquifer[a]
Kankakee Formation . . Edgewood Dolomite. . .	Lower Silurian				
Neda Formation	Upper Ordovician	0-20	Shale and dolomite, red, hematitic.	Yieldś little water to wells. Usually requires casing in wells. Acts as a barrier between shallow and deep aquifer systems.	Aquiclude[b]
Maquoketa Shale. . . .		90-210	Shale, blue and gray, green, and dolomitic. Many beds of shaly dolomite and limestone in upper portion.		
Galena Dolomite. . . . Decorah Formation. . . Platteville Formation.	Middle Ordovician		Dolomite, light gray to blue gray. Massive. Some shale. Sandy at base.	Yields some water from crevices. Not an important source for high-capacity wells.	Sandstone Aquifer[a]
St. Peter Sandstone. .	Lower Ordovician	10-235	Sandstone, fine to medium, white to light gray. Dolomitic and shaly in some places.	Water yielding. Capacity as aquifer varies with permeability and thickness.	
Trempealeau Formation		0-120	Dolomite, pink to gray. Dolomitic sandstone and shale at base. Solution channels abundant.	Water yield generally small, but exceptionally large yields are reported from large crevices.	
Franconia Sandstone	Upper Cambrian	0-130	Sandstone, shale, and dolomite, gray to red.	Water yielding but permeability low. Never developed as sole aquifer.	
Galesville Sandstone		0-100	Sandstone, fine to coarse; mostly medium, white, well-sorted grains.	Yields major quantities of water to wells. Probably most productive in lower portion where it is better sorted and less cemented.	
Eau Claire Sandstone		0-405	Sandstone, fine to medium, light gray to light pink, and dolomitic. Very shaly in upper portion. Shales increase in size and number toward southeast.	Water yielding but permeability low. Never developed as sole aquifer.	
Mount Simon Sandstone		0-900+	Sandstone, white to light gray, fine to coarse, mostly medium. Many beds of shale in some areas. Some dolomite.	Water yielding. Major source of water for high-capacity wells.	
Undifferentiated . . .	Pre-Cambrian		Crystalline rocks: granite, quartzite, slate.	Not water yielding.	Aquifuge[c]

[a] *An aquifer is a relatively permeable water-bearing formation that will yield usable quantities of water to wells.*

[b] *An aquiclude is a water-bearing formation of relatively low permeability that will not yield usable quantities of water to wells.*

[c] *An aquifuge is an impermeable rock unit that is neither water-bearing nor water-yielding.*

Source: U. S. Geological Survey.

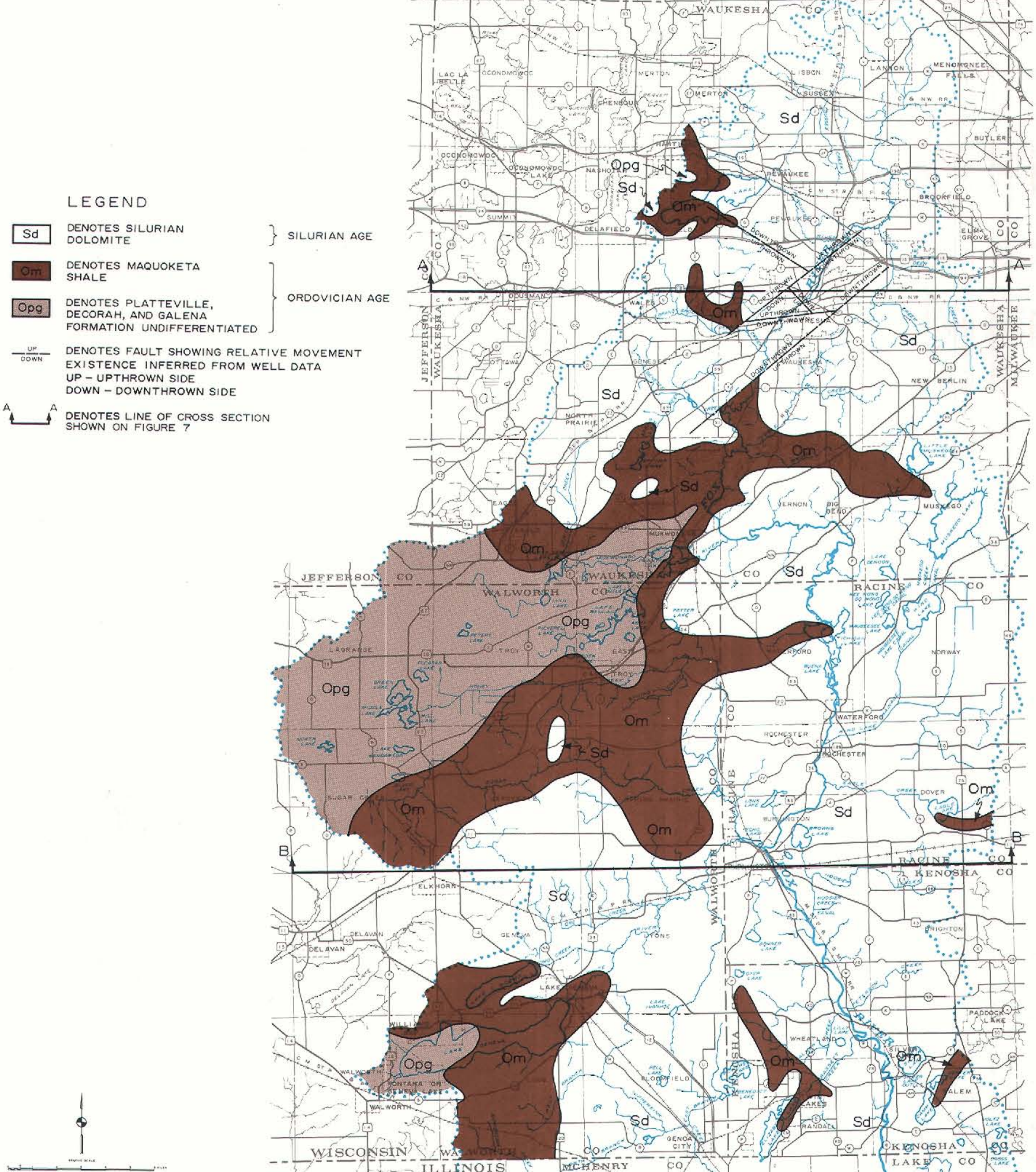
GEOLOGY

Stratigraphy

The rock units from which wells in the Fox River watershed obtain their waters are of prime importance to a comprehensive watershed planning study. These important rock units include sandstone, dolomite, and shale of Cambrian and Ordovician ages, dolomite of Silurian age, and sand and gravel deposits of Pleistocene age (see Table 10). The rocks of Cambrian age, principally sandstone and dolomite, were deposited in shallow seas on an uneven surface of igneous and meta-

Map 14

BEDROCK GEOLOGY
OF THE FOX RIVER WATERSHED

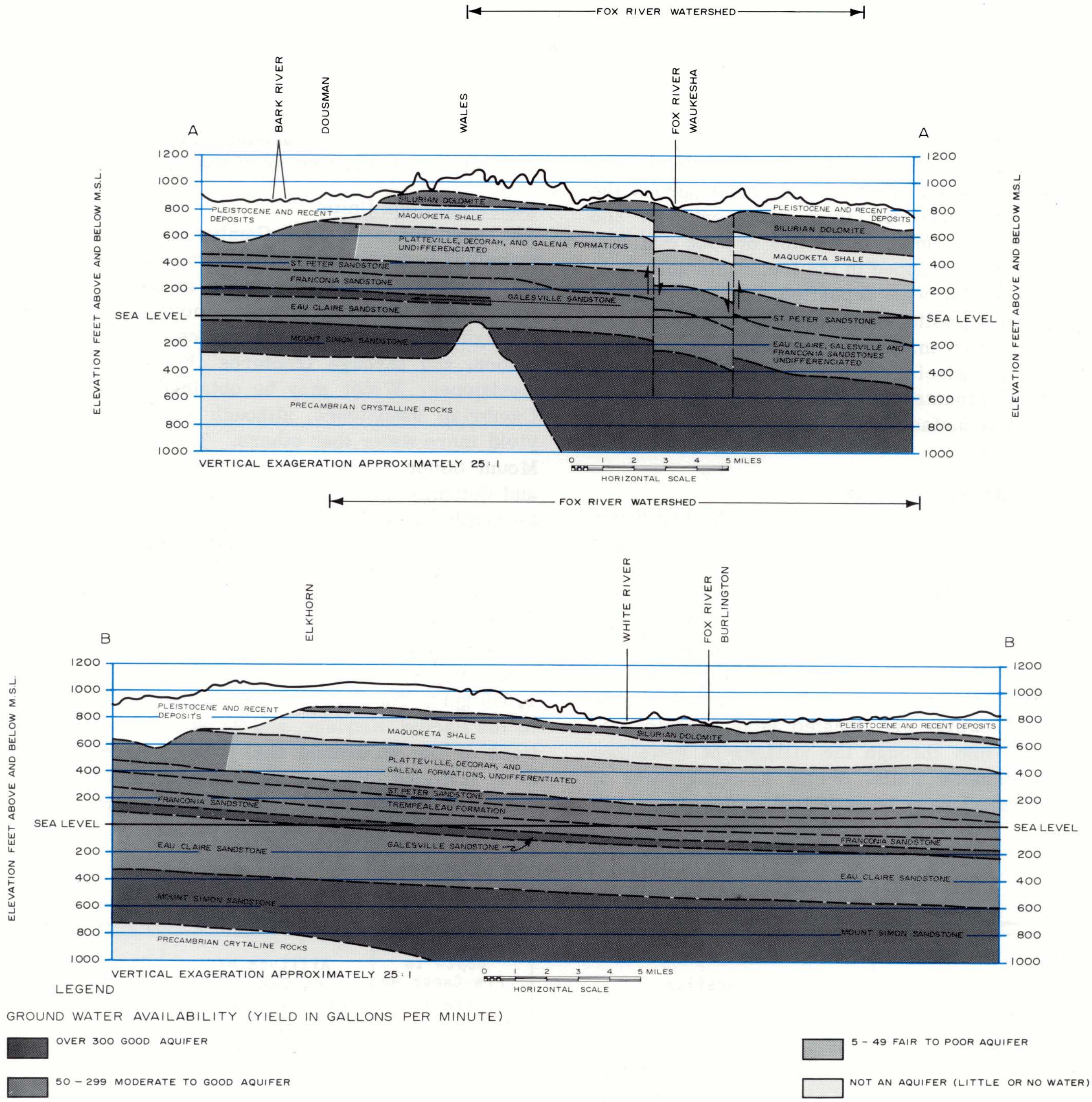


The surficial deposits of the watershed are underlain by sedimentary rock formations, which have varying water-yielding characteristics.

Source: U.S. Geological Survey

Figure 7

STRATIGRAPHIC SECTIONS THROUGH THE FOX RIVER WATERSHED SHOWING THE GENERAL AVAILABILITY OF GROUND WATER FROM THE BED ROCK UNITS



Source: U. S. Geological Survey.

morphic rocks of pre-Cambrian age. Following a period of emergence, an uneven surface was cut across some of the Cambrian rocks. The St. Peter sandstone of Ordovician age was deposited in a shallow sea on the irregular surface. Dolomite and shale of the Platteville, Decorah, and Galena formations (Platteville-Galena unit) and the Maquoketa shale, all of Ordovician age, were subsequently deposited. Dolomite and shale of Silurian and Devonian age were probably deposited in all of the Fox River watershed but have been partly eroded away. The sedimentary rock units dip gently to the east and southeast at slopes of 10 to 40 feet per mile and are of a generally greater thickness in the east and southeast portions of the watershed. The present bedrock geology and stratigraphic sections through the watershed are shown on Map 14 and Figure 7.

Following the deposition of the bedrock, a long period of erosion occurred, which produced a bedrock surface that has a maximum relief of about 530 feet in the watershed. During this erosional period, deep valleys were eroded in the bedrock along the courses of ancient river systems. The ancestral drainage pattern, however, bears almost no relationship with present-day drainage in the Fox River watershed. During the Pleistocene period, continental glaciers advanced across the Fox River watershed from the northeast and transported enormous quantities of rock material which had been trapped in the ice. This unconsolidated material was deposited, as the glaciers melted, in deposits which presently exist as generally unsorted material up to 450 feet in thickness. These glacial deposits are the most important determinants of the present-day, poorly drained land surface of the watershed.

Pre-Cambrian Rock Units

The pre-Cambrian rock units within the Fox River watershed include those crystalline rock units of granite, slate, quartzite, and related types that form the foundation on which the younger rock units are deposited. The pre-Cambrian rock units were formed over 600 million years ago. Only five wells within the watershed are known to reach the pre-Cambrian rock, as shown in Table 11. These wells are located near a northeast-southwest line through the villages of Pewaukee and Menomonee Falls. Wells in other parts of the watershed have been drilled as deep as 2,300 feet without reaching the pre-Cambrian crystalline rock. Knowledge of the depth to pre-Cambrian crystalline rock is important, as this depth marks the lower limit of the major water-yielding rocks of the watershed. In the Pewaukee-Menomonee Falls area, where the crystalline rocks are relatively near the land surface, the deep aquifer is relatively thin and the ground water supply more limited than in other areas of the watershed.

Cambrian Rock Units

The sandstones of late Cambrian age form the principal bedrock aquifer and comprise the major source of water for deep wells in the Fox River watershed. The ground water moves to the wells through interconnected pore spaces, along bedding planes, and through fractures that exist in the sandstones. Water may be obtained from all the Cambrian sandstones, although some rock units yield more water than others. The Galesville and Mount Simon sandstones contain less silt, shale, and dolomite than the other formations and, consequently, yield the largest amounts of water (see Table 10). The Eau Claire and Franconia sandstones yield moderate to small amounts of water. The Trempealeau formation usually yields only small amounts of water, although, where fractures in the rock are large, wells drilled into such fractures may yield quantities of ground water up to 1,000 gpm. The Trempealeau formation is present in the Racine, Kenosha, and Walworth County portions of the watershed but, having been eroded away millions of years ago, is not found in Waukesha, Milwaukee, and Washington Counties.

Table 11

WELLS IN THE FOX RIVER WATERSHED
ENTERING PRE-CAMBRIAN CRYSTALLINE ROCKS: 1967

Owner	Location	Depth to Pre-Cambrian (Feet)	Altitude of Pre-Cambrian (Feet Above M.S.L.)	Pre-Cambrian Rock Type
Highlands Water Co-op	SE 1/4, Sec. 18, T7N, R19E, Waukesha County	1,190	-285	Granite
Village of Menomonee Falls . . .	SW 1/4, Sec. 9, T8N, R20E, Waukesha County	1,375	-481	Quartzite
Village of Pewaukee.	SW 1/4, Sec. 9, T7N, R19E, Waukesha County	1,315	-465	Slate
Sussex Estates Water Co-op	SE 1/4, Sec. 22, T8N, R19E, Waukesha County	1,290	-348	Granite
C. Zimmerman.	SW 1/4, Sec. 25, T5N, R18E, Waukesha County	664	371	Quartzite

Source: U. S. Geological Survey.

Ordovician Rock Units

The St. Peter sandstone of Ordovician age was deposited on a deeply eroded surface cut into the Cambrian rock. The St. Peter unit consists of sandstone intermixed with conglomerate, siltstone, and shale. The sandstone is mostly fine to medium grained, contains much chert and some dolomite fragments, and is dolomitic in places. As a result of this wide variation in lithology, the permeability of the St. Peter formation is generally low. The St. Peter sandstone is, however, an important water-bearing formation.

The Platteville, Decorah, and Galena formations lie on the St. Peter sandstone in the Fox River watershed. They consist mostly of dense dolomite, which is generally thin in the southern portion and massive in the northern portion of the watershed. Water in the Platteville, Decorah, and Galena formations moves through cracks, joints, and solution channels, which are distributed irregularly through the formations. Most wells within these formations yield sufficient water for domestic and other minor ground water supplies, but large ground water supplies for municipal or industrial use generally cannot be obtained from these formations.

The Maquoketa shale, which is a dolomitic shale interspersed within beds of dolomite and limestone, yields little water. The dolomite and limestone beds may contribute small amounts of water to some wells; but, because such formation almost always caves in, it is usually cased off in wells. The Maquoketa shale acts as a seal or a hydraulic barrier between the deep and the shallow aquifers of the watershed.

Silurian Rock Units

Rock units of the Lower and Middle Silurian age are present in about 71 percent of the Fox River watershed. Two formations make up the Lower Silurian strata, the Edgewood dolomite underlying the Kankakee formation. These strata are mostly buff-to-gray dolomite; are silty at the base; and have thin, green shale partings at the top. The Kankakee formation is exposed in quarries near Burlington. Rock units of the Middle Silurian age, known as the Niagaran group, have been tentatively subdivided into the Joliet, Waukesha, and Racine formation. These formations range from clean dolomite to highly silty, clayey, and cherty dolomite, with some thin shale beds, and contain reefs locally. Reefs and associated strata are most characteristic of the Racine formation. The Waukesha and Racine formations are exposed in many places in headwater portions of the Fox River watershed.

The various Silurian strata are not generally differentiated in wells and are referred to by hydrologists as the Silurian dolomite. Well drillers and quarrymen refer to this rock sequence as limerock, lime, limestone, Lannon stone, or Niagara limestone. Ground water occurs in the Silurian dolomite in openings along joints, crevices, and bedding planes that have been enlarged by solution. These open channels are apparently not of cavern size, as in some parts of the Trempealeau formation. However, they do make the very dense dolomite permeable; and all wells in the Silurian dolomite yield at least some water. Crevices seem to be most abundant near the top of the Silurian dolomite, where it forms the bedrock surface; but crevices do occur throughout the formation. For maximum yield wells should be drilled to the base of the Silurian dolomite to take advantage of all crevices.

Pleistocene and Recent Deposits

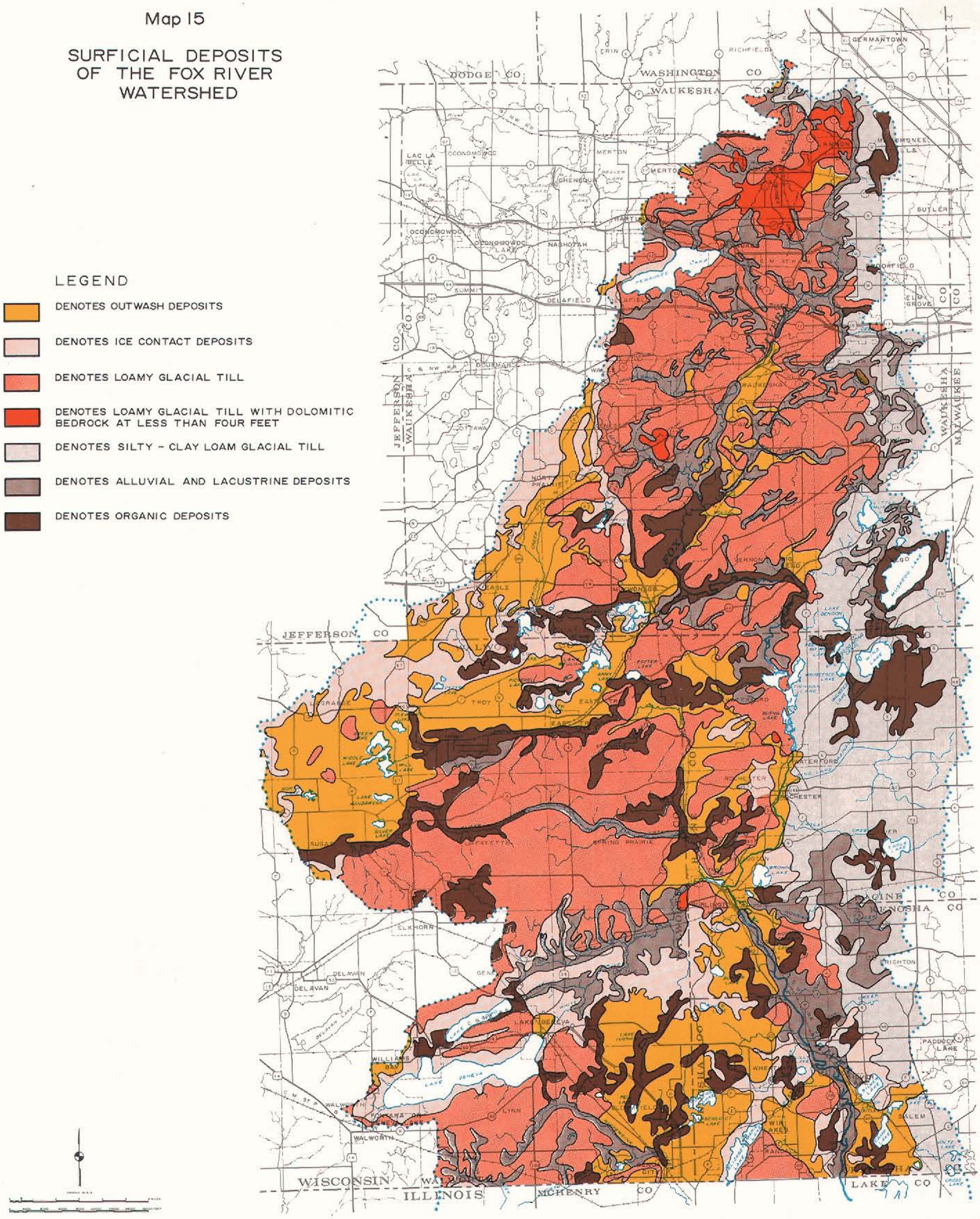
The unconsolidated material at or near land surface is primarily the product of glacial activity during the Ice Age (Pleistocene Epoch). Glaciers have retreated from the watershed so recently that present-day weathering, stream erosion, and drainage patterns have only slightly modified the postglacial landscape. Deposits of Pleistocene and recent age consist mainly of glacial till, ice-contact deposits, outwash, loess, lake deposits and alluvium, and organic accumulations. These sediments, with few exceptions, have not undergone geologic processes to produce a firm, coherent rock, such as sandstone, siltstone, or limestone. Organic alluvial and some lake deposits were formed during the recent time and, where they are present, overlie the older Pleistocene deposits. The generalized distribution of unconsolidated deposits is shown on Map 15, and the thickness thereof is shown on Map 16.

Organic deposits are located in about 3,000 places in the Fox River watershed, according to detailed soils data published by the SEWRPC.[4] The peat and muck that comprise these deposits accumulated in poorly-drained, lowlying areas in the landscape and average about five feet in thickness. The largest organic deposits are located southeast

[4] *SEWRPC Planning Report No. 8, Soils of Southeastern Wisconsin.*

Map 15

SURFICIAL DEPOSITS OF THE FOX RIVER WATERSHED



The topography of the watershed is controlled primarily by unconsolidated materials deposited by glaciers which occupied this Region some 6,000 years ago.

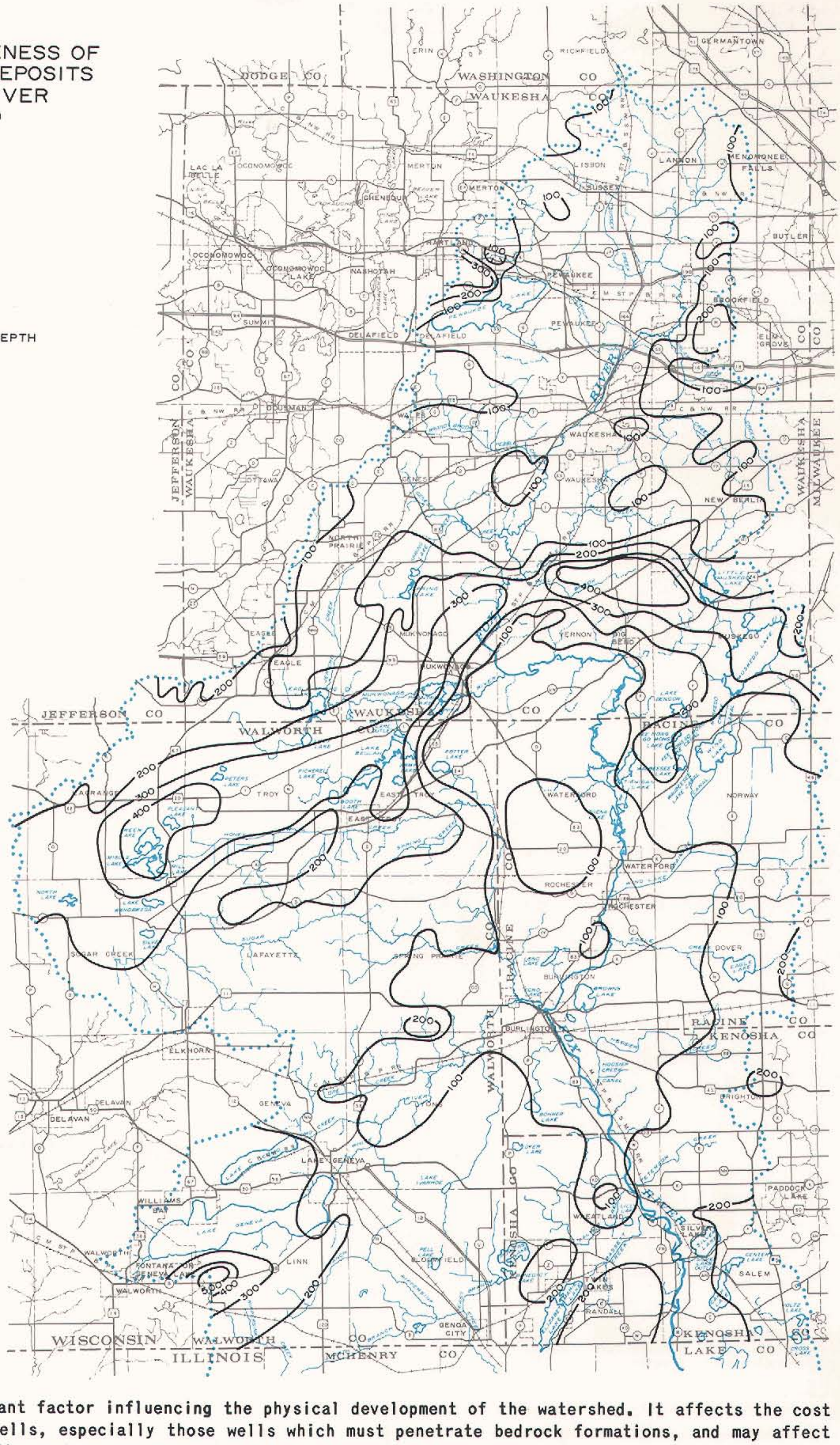
Source: U.S. Geological Survey

Map 16

GENERALIZED THICKNESS OF UNCONSOLIDATED DEPOSITS IN THE FOX RIVER WATERSHED

LEGEND

—100— DENOTES CONTOUR SHOWING DEPTH IN FEET TO BEDROCK



Depth to bedrock is an important factor influencing the physical development of the watershed. It affects the cost of drilling and maintaining wells, especially those wells which must penetrate bedrock formations, and may affect the cost of constructing utility systems and foundations for engineering structures.

Source: U.S. Geological Survey

of Wind Lake, in the headwaters of Sugar and Honey Creeks, along Mukwonago River, in the Vernon Marsh, and in the tamarac swamp in Menomonee Falls.

Glacial-lake deposits and alluvium, consisting of stratified and well-sorted clay, silt, sand, and marl, are generally less than 25 feet thick and crop out in only 11 percent of the Fox River watershed, as shown on Map 15. These deposits are, however, much more extensive than Map 15 indicates, because they are frequently overlain by younger organic deposits or by existing lakes.

Loess is composed mostly of angular silt-sized particles and was deposited by wind during the Pleistocene age. Loess covers all of the unconsolidated material except the organic, glacial-lake, and alluvial deposits.

Outwash deposits were formed by glacier meltwater that flowed upon, within, and beneath the ice and also away from the front of the glacier. The meltwater carried a load of rock debris from the glaciers and, because of loss of velocity, dropped much of this material as abroad sheetlike deposit. Some meltwater followed pre-existing stream valleys and built elongate outwash deposits known as valley trains. Outwash consists mostly of stratified sand and gravel. The size of the materials in the different layers of sand and gravel is likely to differ abruptly from place to place. Outwash deposits in the Fox River watershed cover about 21 percent of the watershed, the largest single areas being located in the headwaters of the Mukwonago River, Sugar and Honey Creeks, and in a broad area south of Burlington.

The outwash deposits are generally excellent sources of ground water, with the well yields dependent upon the saturated thickness and sorting of the sediments. Yields as high as 2,000 gpm can be obtained from properly screened and developed wells that penetrate thick, water-saturated sand and gravel outwash deposits. Frequently, the most useful outwash deposits for water supplies occupy low-lying areas adjacent to perennial streams. Outwash deposits in higher terrain are important as areas of ground water recharge and as sources of building material. Streams flowing through outwash deposits tend to have relatively stable discharge rates.

Ice-contact deposits were formed when a glacier became immobile or stagnant. Many areas of ice-contact drift are characterized by closed depressions that mark the former site of huge blocks of ice that broke loose from a glacier. Rounded hills and knobs of sand and gravel were formed where water plunged into crevasses in the glacial ice. The depressions are called kettles, and the hills are called kames. An elongate kame or a series of overlapping kames is sometimes called a crevasse filling. Such deposits constitute all or a part of an end moraine, such as the well-known Kettle Moraine in the western limits of the Fox River watershed. Generally, the material in ice-contact deposits is not as well sorted as that in the outwash deposits; it may range in size from clay to coarse gravel and boulders and is irregularly bedded. Ice-contact deposits cover about 12 percent of the watershed and occupy areas near outwash deposits.

Ice-contact deposits frequently yield only small quantities of water to wells as such deposits usually have only a few feet of saturation. Silt and clay layers in these deposits may cause the development of perched water tables, which give rise to small springs. Because these deposits are permeable and hold surface runoff, ice-contact deposits are important to ground water recharge.

Glacial till, a mixture of earth materials deposited directly by a glacier, is not layered or bedded and is composed of particles ranging in size from clay to boulders. Till is commonly found as an undulating deposit called ground moraine but may also form rounded, elongate hills called drumlins. Glacial till is the surficial glacial deposit in about half of the watershed, primarily in hills and ridges. In the valleys and along the flanks of many of the hills, it is buried by younger, unconsolidated deposits. Till within the watershed generally ranges from predominantly fine textured in the eastern portion to medium or coarse textured in the western portion of the watershed.

Glacial till generally yields little water, although isolated lenses of sand and gravel may yield small amounts of water to wells. In the past when water needs were more modest, dug wells were used to obtain a few gallons per minute from the glacial till deposits. The low permeability of the finer textured till not only restricts the amount of water that can be pumped from these deposits but also limits the amount of ground water recharge and the absorption of effluent from septic tanks.

Table 12 summarizes the water-yielding characteristics of the unconsolidated deposits of Pleis-

Table 12

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

Unit	General Description	Maximum Thickness (Feet)	Water-yielding Characteristics	Percentage of Surface Area of Watershed
Organic Deposits	Peat and Muck	50	Generally saturated; not used as a source of water for wells. Pits are sometimes dug to expose ground water for use in irrigation.	10
Glacial Lake Deposits (lacustrine) and Stream Alluvium	Clay, silt, sand, and marl; sorted and stratified.	25	Sand may yield small quantities of water.	11
Outwash	Mostly sand and gravel; sorted and stratified.	150	Yield small-to-large quantities of water. Deposits adjacent to perennial streams are most favorable for obtaining large yields.	21
Ice-Contact Deposits	Clay, silt, sand, gravel, and boulders; unstratified to stratified and unsorted to sorted.	100	Yield small quantities of water. Thick sections of sand and gravel in buried valleys may yield moderate-to-large quantities of water.	12
Glacial Till	Clay, silt, sand, gravel, and boulders; unsorted and unstratified	400	Permeability low to very low. Isolated lenses of sand and gravel may yield small quantities of water to wells.	46
Loess	Silt with some clay and a little sand; unstratified. Blankets glacial deposits.	5	Generally unsaturated. Does not yield water to wells.	Approximately 79 percent of the total area of the watershed is covered by this material.

Source: U. S. Geological Survey.

tocene and recent ages in the Fox River watershed.

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 solution or physical removal by wind or water, 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 many kinds of soils in the watershed which have been formed from a variety of parent glacial or glacial-related material and their geographic pattern of occurrence is complex in some places.

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. Department of Agriculture, 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 provided data on the physical, chemical, and biological properties of the soils but also has provided interpretations of the soil properties for engineering, agricultural, conservation, and planning purposes.

Particularly important to watershed planning are the soil suitability interpretations for specified types of urban development. Based upon the interpretations of the soils properties, much of the watershed area exhibits severe or very severe limitations for 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 service on lots one acre or larger in size, as follows:

1. Approximately 279.7 square miles, or 29.8 percent, of the watershed is covered by soils which are poorly suited for residential development with public sanitary sewer service or, more expressly, poorly suited for residential development of any kind. The distribution of these soils is indicated on Map 17.

2. Approximately 528.5 square miles, or 56.3 percent, of the watershed is covered by soils which are poorly suited for residential development without public sanitary sewer service on lots smaller than one acre in size. The distribution of these soils is indicated on Map 18.

3. Approximately 379.2 square miles, or 40.4 percent, of the watershed is covered by soils which are poorly suited for residential development without public sanitary sewer service on lots one acre or larger in size. The distribution of these soils is indicated on Map 19.

It should be noted that the soil 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 capacity, frost heave, and frequent flood overflow.

VEGETATION

Presettlement Vegetation

Historically, vegetational patterns within the watershed were influenced by fire, topography, and the natural drainage characteristics. Historical records, including the original U. S. Public Land Survey, indicate that because of frequent fires set by Indians about 75 percent of the watershed area was either burr "oak openings" or prairies dominated by big bluestem grass and colorful prairie forbs. Areas that were protected from fire by the drainage pattern or local relief developed into mixed hardwood forests. Common species found in the upland hardwood forests included sugar maple, basswood, and oak. Common species found in the lowland hardwood forests included black ash and willow. Studies indicate that "oak openings" were the result of the degradation of prior forest areas by fire. In support of this theory, many original accounts of early settlement explain that, when settlers stopped the use of prairie grass fires, the land not under cultivation reverted to mixed hardwood forests.[5]

Open prairie areas covered a large portion of the watershed. They appeared on a variety of sites ranging from steep, stoney slopes, too dry for trees, to wet meadow areas. Now, however, only widely scattered areas of prairie remain. A few acres of dry prairie with little bluestem grass, birds-foot violet and pasqueflower persist on the southwest exposures of the Kettle Moraine ridges. The wet prairies originally characterized by cord grass, bluejoint grass, and meadow rue have been replaced by canary grass and other exotic pasture grasses tolerant to grazing. Mesic prairies, those neither wet nor dry, were soon cultivated after settlement and became the best cropland. Mesic prairie vegetation includes both the little and big bluestem grasses, prairie dock, and compass plant. Elongated strips of this varied and colorful original vegetation remain along a few railroad rights-of-way and in odd corners of several cemeteries.

Woodlands

Woodlands in the Fox River watershed comprise 67,270 acres, or approximately 11 percent of the land area, as shown on Map 20. Primarily located on ridges and slopes, along lakes and streams, and in wetlands, they provide an attractive countryside resource of immeasurable value. The beauty of the lakes, the streams, and the glacial moraines is accentuated by a variety of upland and lowland hardwoods and conifers. The woodlands have been classified by type into five categories: 1) oak, 2) central hardwoods, 3) lowland hardwoods, 4) upland conifers, and 5) wetland conifer-hardwoods. The oak type is most common and the central hardwoods type next. Most productive for commercial forest products is the lowland hardwoods type, usually established on alluvial soils in bottom lands. It is of interest that the tamarack, which has gradually regressed over the centuries from the upland areas to the wetlands today, is the only tree species growing naturally in the watershed that survived from the original forest that became established as the last glacier slowly retreated. Commercially, the woodlands are poorly-to-moderately well stocked, 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.

Approximately 350 acres of conifers have been planted within the watershed each year over the past 10 years. Plantations consist principally of white and red pine and spruce, trees that add greenery to the countryside during the winter when deciduous species are barren of foliage. The trees within a given plantation are normally the same age, being planted generally by tree planting machines on open land. Most plantations are

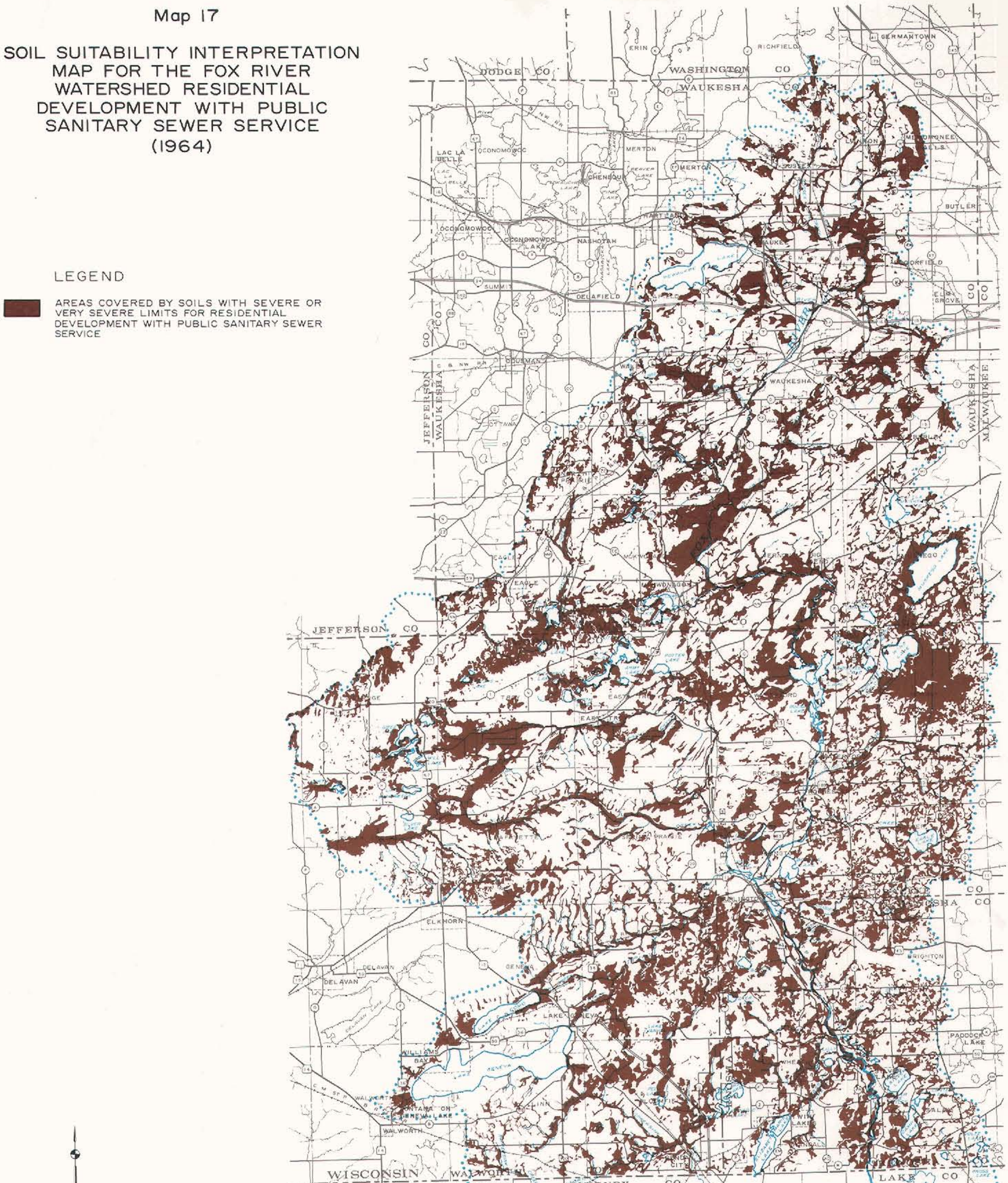
[5] *Curtis, John T., The Vegetation of Wisconsin, University of Wisconsin Press, 1959.*

Map 17

SOIL SUITABILITY INTERPRETATION MAP FOR THE FOX RIVER WATERSHED RESIDENTIAL DEVELOPMENT WITH PUBLIC SANITARY SEWER SERVICE (1964)

LEGEND

AREAS COVERED BY SOILS WITH SEVERE OR VERY SEVERE LIMITS FOR RESIDENTIAL DEVELOPMENT WITH PUBLIC SANITARY SEWER SERVICE



Approximately 280 square miles, or 30 percent, of the watershed are covered by soils poorly suited for residential development of any kind. These soils are especially prevalent in the riverine and wetland areas of the watershed.

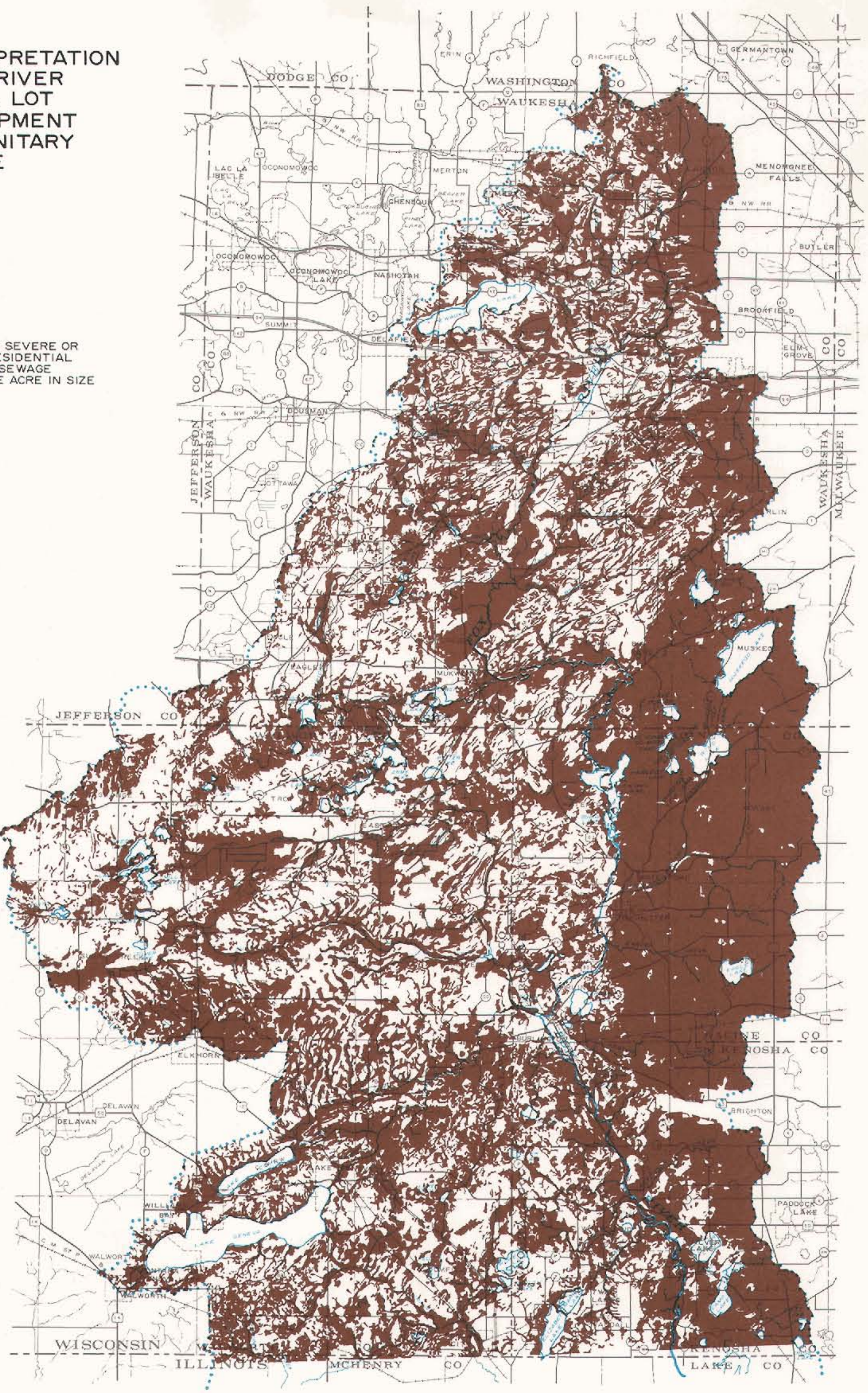
Source: SEWRPC.

Map 18

SOIL SUITABILITY INTERPRETATION MAP FOR THE FOX RIVER WATERSHED SMALL LOT RESIDENTIAL DEVELOPMENT WITHOUT PUBLIC SANITARY SEWER SERVICE (1964)

LEGEND

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



Approximately 528 square miles, or 56 percent, of the watershed 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.

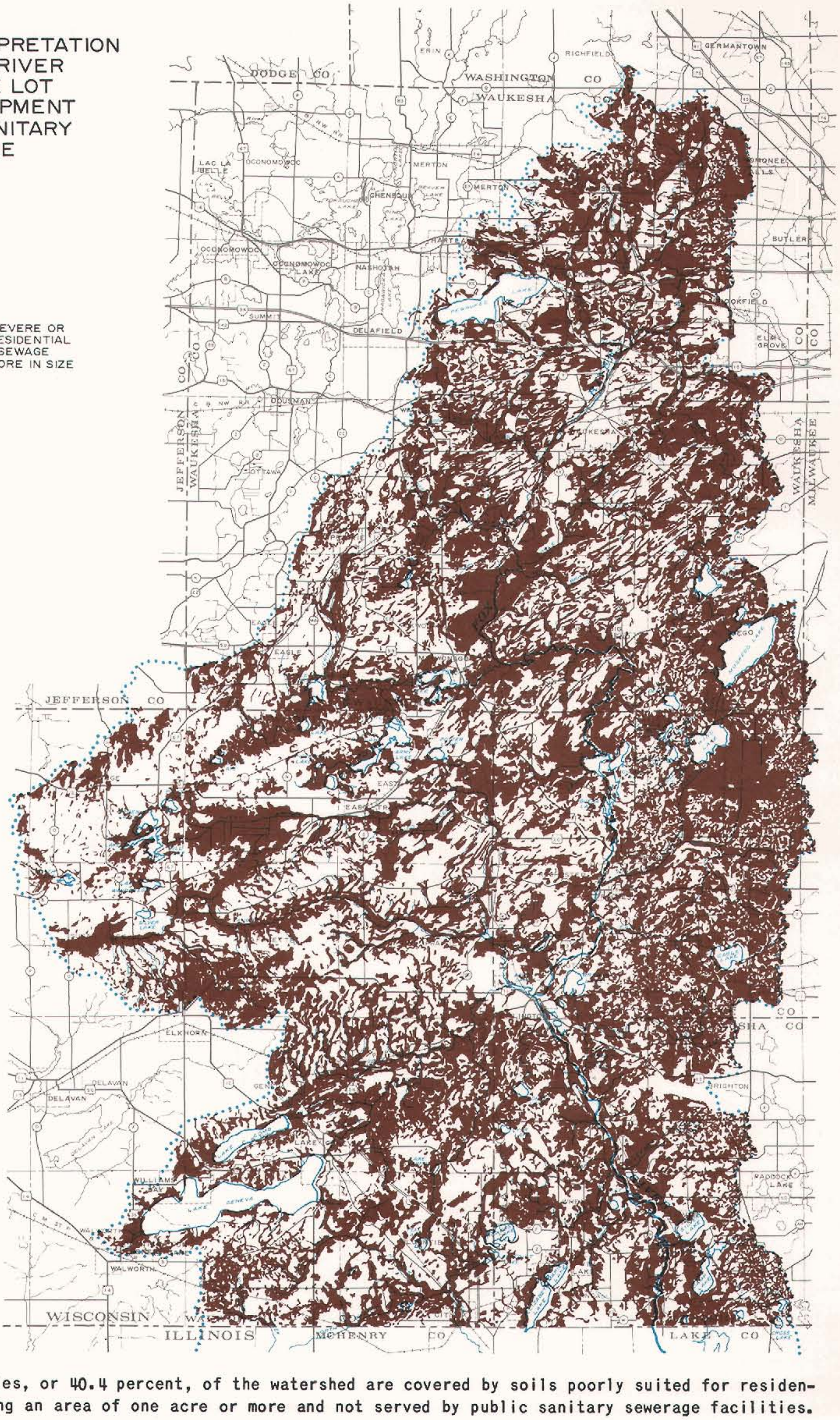
Source: SEWRPC.

Map 19

SOIL SUITABILITY INTERPRETATION MAP FOR THE FOX RIVER WATERSHED LARGE LOT RESIDENTIAL DEVELOPMENT WITHOUT PUBLIC SANITARY SEWER SERVICE (1964)

LEGEND

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



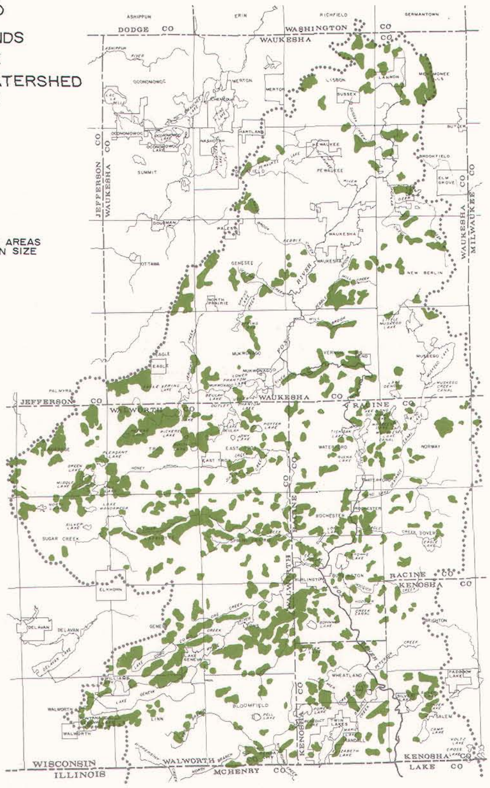
Approximately 379.2 square miles, or 40.4 percent, of the watershed are covered by soils poorly suited for residential development on lots having an area of one acre or more and not served by public sanitary sewerage facilities.

Source: SEWRPC.

Map 20
WOODLANDS
IN THE
FOX RIVER WATERSHED
(1967)

LEGEND

DENOTES WOODLAND AREAS 20 ACRES OR MORE IN SIZE



Woodlands occupy about 11 percent of the total land area of the watershed. These woodlands assist in maintaining unique natural relationships between plants and animals; reduce storm water runoff; contribute to atmospheric oxygen and water supplies; 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 urban development.

Source: Wisconsin Department of Natural Resources.

established on farms by private owners, although a considerable area also has been planted by the state in the Kettle Moraine State Forest.

Currently, natural woodlands are being destroyed at the rate of approximately 350 acres per year. Highway construction, land clearing, and drainage of wetlands are chiefly responsible. Loss of woodlands will be even greater in the future inasmuch as many consist entirely of even-aged old trees with no reproduction or saplings to maintain the stand after the trees mature. Lack of young trees is an unnatural condition established primarily through livestock grazing. This situation, added to the other forces destroying woodlands, will substantially reduce the acreage over the years unless steps are taken to prevent it. Most woodlands in the watershed are not only unmanaged but are also neglected and abused. Approximately 60 percent of the privately owned stands, exclusive of wooded wetlands, are being grazed. Reproduction of the most valuable hardwood species is prevented by livestock grazing; and, thus, the very trees most needed are destroyed by trampling. With no young growth in the stand, the woodland cannot perpetuate itself.

Woodlands in the Fox River watershed, even in their present condition, have many values beyond monetary returns for their forest products. They can serve a variety of uses which are compatible with other uses in the watershed. Conversely, the deforestation of hillsides is contributing to the siltation of lakes and streams, as well as to the destruction of wildlife habitat. Woodlands can and should be maintained for scenic, wildlife, recreation, and watershed protection values. Because of the changes which have occurred within the watershed area during the past few years, it has been necessary to reappraise woodland values. This reappraisal was accomplished during 1967 as a part of the Fox River watershed study. Appraisal was made in terms of contributions of woodlands to the watershed area as a whole, as well as contributions to the owners. The overall primary value of these woodlands has been established as aesthetic and their other significant values, including timber production, as secondary. Of the woodland area, 88 percent has a medium- or high-aesthetic value rating. No direct correlation, however, exists between the various values. A poorly stocked woodland may have a low value for commercial timber production but, at the same time, have superlative scenic value if located where it accentuates the beauty of a lake, stream, or hillside. Strategic location, accessibility, and heavy ground cover are criteria which contribute to the aesthetic value rating of a woodland. An increasing demand for forested areas has arisen, especially those 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 most of the trees when the houses, garages, and driveways were built. If any trees remained, moreover, they usually were seriously weakened through loss of a large portion of their root systems. Woodlands in subdivisions may be appreciably improved through careful management if lots are one acre in size or larger and if architectural and landscape deed restrictions are enforced by control boards.

Wetlands

Wetlands represent a variety of stages in the natural filling of lake and pond basins, as well as floodplain areas. Wetlands are considered herein as areas which have the water table at or near the land surface and are generally unsuited for most agricultural uses requiring cultivation. Wetlands are composed of organic soils, silts, or 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 Wisconsin have been classified by the Division of Conservation, Department of Natural Resources, according to the National Wetland Classification.[6] Under this classification there are seven major classes of wetlands: 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 fur bearers, while drier areas tend to support upland game due to the protection afforded by the ground cover. Shallow-water wetlands are subject to winter freeze and summer drought and, therefore, are considered to be lower in value than the deep-water types of wetlands.

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

In all, 203 wetland units[7] were identified in the Fox River watershed, as shown on Map 21. The drier types comprised 69.0 percent of these, and the wetter types 31.0 percent. This compares with similar estimates in 1958 of 73.0 and 27.0 percent, respectively.

There has been a reduction of about 40 percent of the total wetland area in the watershed since 1939. Most of the loss in wetland area has been the result of its conversion to agricultural uses through extensive drainage ditching. Other reclaimed areas have been developed for urban and recreational uses. There has been a slight increase, however, in recent years of the more desirable deep-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 1939 are shown in Table 13.

Aquatic Vegetation

An aquatic plant survey, involving the 45 major lakes of the Fox River watershed, was conducted during the summer of 1967. Of the lakes surveyed in early summer of 1967, 12 were resurveyed in late August of 1967 to determine if seasonal change in these aquatic plant communities was apparent. The lakes which were resurveyed included Beulah, Camp, Como, Eagle, Ivanhoe, Little Muskego, Lower Phantom, Pewaukee, Rock,

[7] *Wetland units, as used herein, are wetland areas 50 acres or more in size. Smaller areas were inventoried if they were considered to have a high-recreation or wildlife habitat value. Small noncontiguous wetland areas were also inventoried if such areas enhanced a lake, stream, or other nearby recreation area.*

Table 13

SUMMARY OF WETLAND AREA WITHIN THE FOX RIVER WATERSHED: 1939, 1958, AND 1967

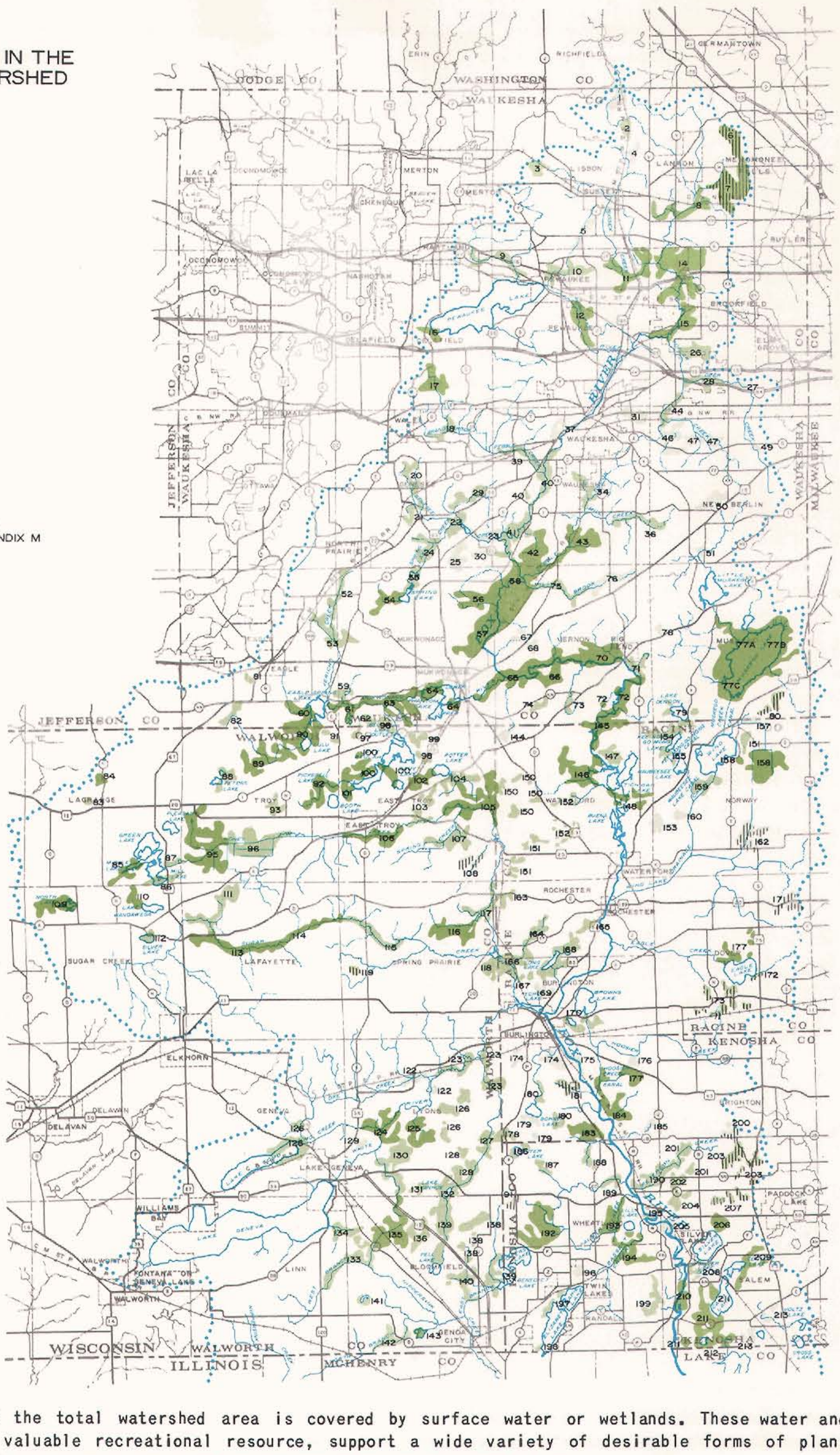
Year	Standing Water Wetlands		Non-Standing Water Wetlands		Total Wetlands	
	Acres	Percent of Total Wetlands	Acres	Percent of Total Wetlands	Acres	Percent of Total Watershed
1939	(NA)[a]	---	(NA)[a]	---	88,800	14.7
1958	16,400	27.0	44,400	73.0	60,800	10.1
1967	16,500	31.0	36,700	69.0	53,200	8.8

[a] *Not available.*

Source: Wisconsin Department of Natural Resources.

Map 21

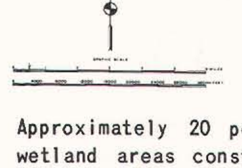
WETLAND AREAS IN THE FOX RIVER WATERSHED (1967)



LEGEND

- DENOTES WETLANDS HAVING PRIMARILY HIGH VALUE
- DENOTES WETLANDS HAVING PRIMARILY MEDIUM VALUE
- DENOTES WETLANDS HAVING PRIMARILY LOW VALUE
- DENOTES PERCHED CONDITION
- 42 NUMBER DENOTES WETLAND UNIT DESIGNATION PRESENTED IN APPENDIX M

NOTE: WETLAND AREAS SHOWN ARE THOSE 50 ACRES OR LARGER



Approximately 20 percent of the total watershed area is covered by surface water or wetlands. These water and wetland areas 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.

Source: Wisconsin Department of Natural Resources.

Tichigan, Waubeesee, and Wind lakes. The primary purpose of the aquatic plant survey was to determine the distribution and abundance of aquatic plants with reference to their possible impact upon man's recreational activities, fish, and wildlife and to establish a record of the present status of aquatic plants for possible future reference. Pondweed (Potamogeton), found in all the lakes, was the most widely distributed genus of aquatic plant. Sago pondweed (P. pectinatus) was observed in over 90 percent of the lakes. Other widely distributed general included musk grass (Chara), water milfoil (Myriophyllum), rush (Juncus), water lily (Nymphaea), cattail (Typha), spatterdock (Nuphar), eel grass (Vallisneria), and waterweed (Anacharis). A complete list of the aquatic plants found in the 45 lakes of the watershed and their relative abundance on a percentage basis is shown in Table 75.

The lakes of the watershed could not be meaningfully grouped into categories of similar aquatic vegetational characteristics. The clearer lakes, however, exhibited more similar aquatic plant characteristics than did the turbid, more fertile lakes. The lakes varied widely in the amount and diversity of aquatic plant matter present. For example, Geneva Lake and Eagle Lake contained very small amounts of vegetation, while Lower Phantom and Pewaukee lakes had so much vegetation over large areas that swimming and boat travel were almost impossible. The wide difference in diversity of plants from lake to lake is well illustrated by Beulah and Lauderdale lakes, which had over 20 aquatic plant genera present in abundance. Waubeesee and Dyer lakes had less than 10 plant genera present and only a few of these in abundance.

The aquatic plants generally exhibited a wide range of depth tolerance. Coontail (Ceratophyllum) and water milfoil (Myriophyllum), for example, were often found in very shallow water, as well as near the maximum depth at which vegetation was found in the lake. Stonewort (Nitella), however, appears to be an exception to this generalization and was only found in relatively clear lakes in water deeper than about 15 feet.

The composition of almost all the aquatic plant stands within each lake remained essentially the same throughout the summer. Some minor exceptions to this were eel grass (Vallisneria), spiny naiad (Najas marina), and slender naiad (N. flexilis). These species apparently start off slowly in June and were sometimes found very abundantly in late August. Rock Lake was the only lake surveyed in the watershed that showed substantial seasonal vegetational changes. Upon resurveying Rock Lake in August of 1967, several large stands of pickerelweed (Pontederia cordata), as well as moderate amounts of eel grass (Vallisneria) and broad leaf pondweeds (Potamogeton) were observed which were not observed in June of 1967.

Two major groupings of algae are present to some degree in all lakes. These are the microscopic floating or weakly swimming plants, commonly referred to as the phytoplankton, and the larger filamentous or massed colonial non-planktonic forms associated with the bottom or with other vegetation. The phytoplankton community is the primary producer of organic matter on which all other forms of life depend directly or indirectly. As the distribution of phytoplankton is at best variable, lake sampling for relative abundance is impractical. Practical indicators of unusually dense phytoplankton communities are reductions in transparency, increases in turbidity, and locally generated reactions to problem situations. Records of chemicals applied for algae control also reflect the latter. The associated, non-planktonic forms are more easily quantified. The abundance of filamentous forms, rather than the particular species present, is the critical value. Algae are abundant in 11 major lakes of the Fox River watershed: Bass Bay of Big Muskego, Pewaukee, Como, Buena, Tichigan, Eagle, Little Muskego, Wind, Camp, Lower Phantom, and Potters Lakes. Phytoplanktonic species represent the abundant form in Bass Bay of Big Muskego, Tichigan, Buena, Como, and Potters Lakes. Filamentous species are abundant in Camp, Eagle, Pewaukee, Little Muskego, Wind, and Lower Phantom Lakes.

WATER RESOURCES

The surface water resources of lakes and streams provide the singular most important natural landscape feature within the watershed and serve to enhance all proximate uses. Their contribution to resource conservation and recreation within the watershed is immeasurable, and they contribute both directly and indirectly to the regional economy. 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 are also the major sources of supply for municipal, industrial, and domestic water users. Indeed,

Table 14

MAJOR LAKES IN THE FOX RIVER WATERSHED

Rank	Name	Acreage	County
1	Geneva	5,262	Walworth
2	Pewaukee	2,493	Waukesha
3	Big Muskego	2,260	Waukesha
4	Como	946	Walworth
5	Wind	936	Racine
6	Tichigan[a]	891	Racine
7	Beulah	837	Walworth
8	Elizabeth	638	Kenosha[b]
9	Eagle	520	Racine
10	Little Muskego	506	Waukesha
11	Silver	464	Kenosha
12	Camp	461	Kenosha
13	Powers	459	Kenosha[c]
14	Lower Phantom	433	Waukesha
15	Browns	396	Racine
16	Eagle Spring	311	Waukesha
17	Green[d]	311	Walworth
18	Marie	310	Kenosha
19	Mill[d]	271	Walworth
20	Middle[d]	259	Walworth
21	North	244	Walworth
22	Buena	241	Racine
23	Denoon	162	Waukesha[e]
24	Potters	162	Walworth
25	Pleasant	155	Walworth
26	Waubeesee	129	Racine
27	Center	129	Kenosha
28	Bohner	124	Racine
29	Long	124	Racine
30	Wandawega	119	Walworth
31	Booth	113	Walworth
32	Spring	107	Waukesha
33	Upper Phantom	106	Waukesha
34	Cross	87	Kenosha[b]
35	Kee Nong Go Mong	87	Racine
36	Lilly	87	Kenosha
37	Pell	86	Walworth
38	Silver	85	Walworth
39	Lulu	84	Walworth
40	Benedict	78	Kenosha[c]
41	Army	78	Walworth
42	Echo	71	Racine
43	Peters	64	Walworth
44	Dyer	56	Kenosha
45	Voltz	52	Kenosha
	Total	21,759	

[a] *Includes the widespread area of the Fox River.*
[b] *Partly contained in Illinois.*
[c] *Partly contained in Walworth County.*
[d] *Part of the Lauderdale Chain of Lakes.*
[e] *Partly contained in Racine County.*

Note: For the purpose of consistent listing throughout the report, the lake name will precede the word Lake.

Source: Wisconsin Department of Natural Resources.

the protection, enhancement, and proper development of these invaluable water resources were among the primary reasons for the conduct of a study of the Fox River watershed.

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 uses with little degradation of the resource. Within the watershed there are 45 major lakes, as listed in Table 14, having a combined surface water area of 21,759 acres and providing a total of 228 miles of shoreline.

The lakes are mostly of glacial origin, being natural, simple, or compound depressions in gravelly outwash, moraine, or ground moraine and sometimes augmented by a low-head dam at the outlet. 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 31 lakes in the watershed of less than 50 acres of surface water area which are considered in this report as minor lakes. These minor lakes have a combined surface water area of 590 acres and provide 29 miles of shoreline. These small lakes generally have few riparian owners and only marginal fisheries and, without stringent restrictions being imposed upon uses thereof, are capable of accommodating little recreational use. In most cases, the value of the minor lakes is largely aesthetic; but these lakes are incapable of retaining this value with any degree of development.

Major Streams: The streams of the watershed, considered herein as major, are the perennial streams, or those streams which maintain at a minimum a small, continuous discharge year-round except under unusual drought conditions. Within the watershed there are approximately 300 lineal miles of such major streams (see 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 of the major streams with the other elements of the planning study.

Ground Water Resources

The Fox River watershed is richly endowed with ground water resources. Ground water is the source of water supply for nearly all industries and for all of the approximately 160,000 people who reside in the watershed. The amount of ground water stored in the rocks beneath the Fox River valley is enormous and is estimated to be 4×10^{13} (40 trillion) gallons. This is enough water to fill the largest lake in the watershed—Geneva Lake—nearly 1,500 times. In addition, ground water contributes approximately 4.5×10^{10} (45 billion) gallons to the flow of the Fox River annually.

Table 15

MAJOR STREAMS IN THE FOX RIVER WATERSHED

Name	Length[a] (Miles)	County
Basset Creek	4.5	Kenosha
Beulah Lake Outlet . .	1.1	Walworth; Waukesha
Brandy Brook	4.8	Waukesha
Como Creek	3.8	Walworth
Deer Creek	7.8	Waukesha
Eagle Creek.	5.5	Racine
Fox River	81.2[b]	Kenosha; Racine; Waukesha
Genesee Creek.	5.5	Waukesha
Honey Creek.	26.8	Racine; Walworth
Hoosier Creek.	3.5	Racine
Hoosier Creek Canal. .	7.5	Kenosha; Racine
Jericho Creek.	6.1	Waukesha
Kee Nong Go Mong Lake Canal.	0.9[c]	Racine
Mill Creek	5.5	Waukesha
Mukwonago River. . . .	16.9[d]	Waukesha
Muskego Creek Canal. .	7.9[e]	Racine; Waukesha
Nippersink Creek . . .	5.2[b]	Walworth
Ore Creek	8.2	Walworth
Pebble Brook	8.0	Waukesha
Pebble Creek	5.0	Waukesha
Peterson Creek	6.5	Kenosha
Pewaukee River	6.4	Waukesha
Poplar Creek	7.5	Waukesha
Silver Lake Outlet . .	0.9	Kenosha
Spring Lake Creek. . .	2.6	Waukesha
Sugar Creek	25.3	Walworth
Sussex Creek.	5.5	Waukesha
Waubeesee Drainage Canal	1.5	Racine
White River	20.0	Racine; Walworth
Wind Lake Canal. . . .	7.3	Racine

[a] *Total perennial stream length as shown on U.S. Geological Survey 7 1/2 minute quadrangle maps.*

[b] *Perennial stream length within Wisconsin.*

[c] *Includes 0.5 mile through Waubeesee Lake.*

[d] *Includes 0.5 mile through Lulu Lake, 1.3 miles through Eagle Spring Lake, and 1.8 miles through Lower Phantom Lake.*

[e] *Includes 2.4 miles through Wind Lake and 1.6 miles through Big Muskego Lake.*

Source: SEWRPC.

The rock units within the watershed differ widely in yield of their stored water. Rock units that yield water in useable amounts to pumping wells and in important amounts to lakes and streams are called aquifers. Three major aquifers exist in the Fox River watershed and, in order from land surface downward, are: 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 aquifer." 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 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 45 major lakes within the watershed, three are 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 within the watershed in order of importance to its fishery include bluegill, largemouth bass, northern pike, bullhead, black crappie, yellow perch, walleye, 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. Pewaukee Lake, however, supports a limited muskellunge population; and Geneva Lake supports a limited population of cisco and trout.

Stream fisheries are very limited in the watershed, with only four major streams—the Fox, Mukwonago, and White Rivers and Nippersink Creek—supporting desirable fisheries. The Fox River from Waterford downstream supports fisheries for walleye, smallmouth bass, channel catfish, white bass, white crappie, and bullhead. Northern pike and bluegill are also present in limited quantities. The remaining three major streams have small populations of panfish and smallmouth bass. In addition, these streams may support northern pike during the spring spawning migration. The minor streams of the watershed support only forage fish population. One exception, however, is a small tributary stream to Geneva Lake which has a fishery consisting of brown trout. Another exception, Palmer Creek, is managed by the State Division of Conservation for trout but is considered only a marginal trout stream.

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, lake fisheries must be supplemented with fish stocking procedures.

WILDLIFE

Since early settlement of the Fox River watershed and the surrounding urbanized area, there has been a sharp decrease in the variety and quantity of wildlife. The extent of this decrease is a controlling factor in appraising the possible value of rehabilitating wildlife populations, along with determining the needs and demands for this type of recreational resource in an urbanized area. The remaining prime wildlife habitat areas within the watershed are shown on Map 22.

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 bordering the kettle moraine. The larger wooded and shrub swamps are also utilized by the deer. It is estimated that there are 1,000 to 1,200 deer within the watershed. 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 more characteristic of the more open woods and countryside. Both require trees of some maturity because the natural cavities in such trees are required for rearing of young and winter protection.

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 50,000; mink at 2,000; raccoon at 5,000; and red and gray fox at 2,500, 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. Lake shores, deep marshes, shallow 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 farm land, 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.

Map 22

WILDLIFE HABITAT IN THE FOX RIVER WATERSHED (1967)

LEGEND

DENOTES EXISTING WILDLIFE HABITAT

A significant area of the watershed is classified as wildlife habitat area. These areas provide an important recreational resource and aid in controlling harmful insects and other noxious pests. Unless consciously protected, these areas will decrease rapidly as urbanization proceeds within the watershed.

Source: Wisconsin Department of Natural Resources and SEWRPC.

Skunks and opossums are common fur-bearers in the watershed; however, their pelts are of little value. Both use woodland areas bordering farm lands 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 found in the watershed include the pheasant, Hungarian partridge, woodcocks, jacksnipe, rail, dabbling ducks, diving ducks, coots, and a variety of geese. Pheasant and Hungarian partridge are upland game birds and provide the best bird hunting. Waterfowl hunting is also excellent as the watershed lies within a major pathway of the "Mississippi Flyway."

The pheasant population within the watershed totals about 40,000, of which 15,000 are roosters. The pheasant population is annually supplemented by the release of state-propagated birds 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 often seen in flocks on snow-covered fields. The ruffed grouse and bobwhite quail have been virtually eliminated within the watershed; however, 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 20,000. Migratory waterfowl populations, both spring and fall, vary greatly. The peak waterfowl population reaches about 150,000 birds annually, while the total migratory passage may be twice this total.

Other species of water-based birds within the watershed include the loon, cormorant, heron, sandpiper, plover, gull, and tern. Fine study and observation areas for these species are provided by the Vernon Marsh Wildlife Area, as well as other less developed wetland areas. Because of the admixture of lowland and upland forest, meadows and agricultural lands, and favorable warm-season climate, the watershed abounds in many other types of birds, including the eagle, turkey vulture, hawks, owls, kingfisher, woodpeckers, swallows, robin, whip-poor-will, and mourning dove. Pest bird species of the watershed may be considered to include the English sparrow, starling, red-winged blackbird, and perhaps the common pigeon.

EXISTING PARKS AND RELATED RECREATION SITES

An inventory of existing parks, outdoor recreation areas, and related open-space sites in the watershed was conducted during 1967. The inventory revealed that there are 358 such sites, totaling 36,312 acres. The percentage distribution of these sites in the watershed by ownership category is shown in Table 16, and the geographic distribution thereof is shown on Map 23. Nearly three-fourths of the total acreage is in public ownership. Ninety percent of that publicly owned land is state-owned, consisting of the large Kettle Moraine forest areas, wildlife areas, and a few small roadside parks. The local government acreage, while small in comparison to the state-owned acreage, consists mainly of intensively used parks and active outdoor recreation areas.

The nonpublic recreation sites, consisting of private, organizational, and commercially operated recreation lands, account for over 58 percent of the sites in the watershed, but only 28 percent of the acreage. Almost one-half of the nonpublic acreage, or 4,618 acres, is owned by organizations that maintain a large number of recreational camps, such as church groups, YMCA's, and Scouts, headquartered largely in the Milwaukee and Chicago metropolitan areas. Nearly 4,000 additional acres are operated on a profit-making, commercial basis.

The SEWRPC has identified specific sites having potential for future public park and open-space use,[8] and the results of the potential park site inventory for the Fox River watershed are summarized in Table 17. Of the 252 sites identified, slightly less than a third were considered to be of high recreational resource value. These high-value sites, however, comprise over one-half of the total delineated potential park site acreage. In general, the study revealed that the Fox River watershed contains much of the best remaining recreational resources in the entire Southeastern Wisconsin Region.

[8] *See SEWRPC Technical Report No. 1, Potential Parks and Related Open Spaces, 1965.*

Table 16

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

Ownership	Sites	Acres	Percent of Public		Percent of Nonpublic		Percent of Total	
			Sites	Acreage	Sites	Acreage	Sites	Acreage
Public								
State.	34	23,618	22.8	90.5	---	---	9.5	65.1
County	14	1,440	9.4	5.5	---	---	3.9	4.1
City or Village. . .	85	1,000	57.1	3.8	---	---	23.7	2.7
Town	16	39	10.7	0.2	---	---	4.5	0.1
Subtotal	*149*	*26,097*	*100.0*	*100.0*	---	---	*41.6*	*72.0*
Nonpublic								
Private.	50	1,636	---	---	23.9	16.0	14.0	4.5
Organizational . . .	50	4,618	---	---	23.9	45.2	14.0	12.6
Commercial	109	3,961	---	---	52.2	38.8	30.4	10.9
Subtotal	*209*	*10,215*	---	---	*100.0*	*100.0*	*58.4*	*28.0*
Total	358	36,312	---	---	---	---	100.0	100.0

Source: SEWRPC.

Table 17

POTENTIAL PARK SITES AND ACREAGE IN THE FOX RIVER WATERSHED BY COUNTY AND VALUE CATEGORY: 1964

County		Site Value			
		High	Medium	Low	Total
Kenosha[a]	Sites	6	13	8	27
	Acres	925	1,680	500	3,105
Racine[a]	Sites	16	24	21	61
	Acres	3,502	2,897	1,625	8,024
Walworth[a]	Sites	31	21	35	87
	Acres	9,370	2,278	1,831	13,479
Waukesha[a]	Sites	24	30	26	80
	Acres	5,762	4,015	2,475	12,252
Total.	Sites	77	88	90	255
	Acres	19,559	10,870	6,431	36,860

[a]*Includes only that portion of the county within the Fox River watershed.*

Source: 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 the natural beauty of the Region and include lakes and streams and their associated floodlands, wetlands, woodlands, wildlife habitat areas, high-relief topography, significant geological forma-

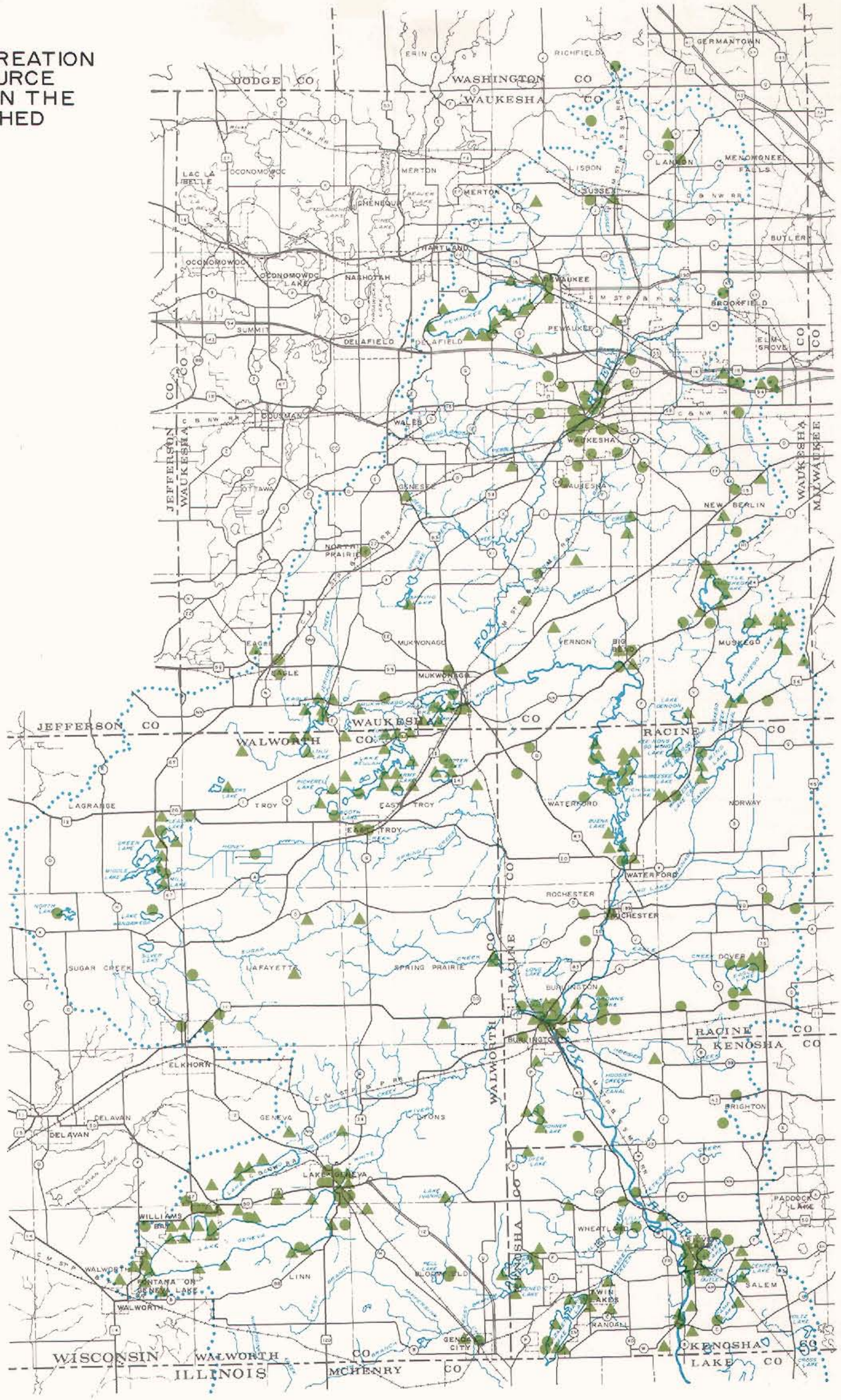
Map 23

EXISTING OUTDOOR RECREATION AND RELATED RESOURCE CONSERVATION SITES IN THE FOX RIVER WATERSHED (1967)

LEGEND

● PUBLIC

▲ NON-PUBLIC



There are 358 outdoor recreation sites in the Fox River watershed totaling 36,312 acres. Nearly three-fourths of the total acreage is in public ownership; but 90 percent of this publicly owned acreage is in state ownership, consisting primarily of forest and wildlife conservation areas.

Source: SEWRPC.

tions, and wet or poorly drained soils. 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.

The delineation of these natural resource and natural resource-related elements on a map of the watershed presents an essentially lineal pattern which has been termed "environmental corridors" by the Commission.[9] Primary environmental corridors, which encompass three or more environmental elements, are shown on Map 24. The primary environmental corridors are found to occupy approximately 198 square miles, or 21 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 river and stream valleys. These primary environmental corridors are more fully discussed in Chapter XII of this report.

It is important to note that the 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, will serve to maintain a high level of environmental quality in the watershed and protect its natural beauty. It is important to recognize that, while the resource values located in the environmental corridors define areas that contain the highest concentration of prime resource values and are, therefore, most suitable for preservation and protection, some areas between these primary corridors also contain similar but isolated resources that merit consideration for preservation and protection on a local level.

[9] *The concept of the environmental corridor was first expressed in Wisconsin in a report entitled Recreation in Wisconsin, State of Wisconsin, Department of Resource Development, 1962.*

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 tends to create severe environmental problems having areawide effects.

SUMMARY

This chapter has described the natural resource base of the Fox River watershed which, together with the socio-economic 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 Fox 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 is 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 young 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 greatly 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. Eighteen stratigraphic units which have a ground water supply significance have been identified from logs of wells drilled in the watershed.

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 develop-

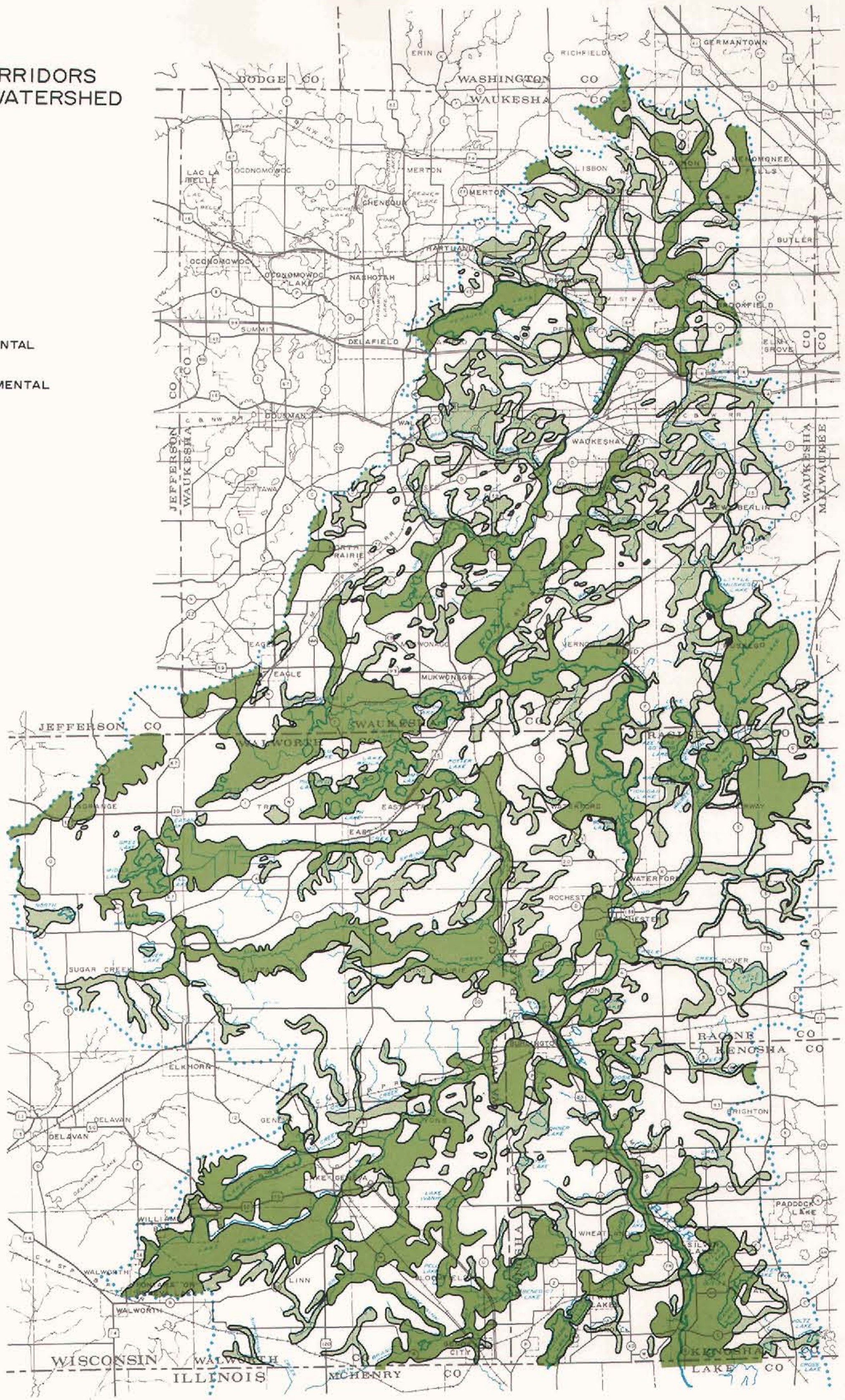
Map 24

EXISTING ENVIRONMENTAL CORRIDORS IN THE FOX RIVER WATERSHED (1967)

LEGEND

DENOTES PRIMARY ENVIRONMENTAL CORRIDORS

DENOTES SECONDARY ENVIRONMENTAL CORRIDORS



Approximately 21 percent of the total area of the watershed lies within primary environmental corridors, which encompass the best remaining forests, wildlife habitat, surface waters, wetlands, and significant topographical and geological features. These corridors must be protected from incompatible development and destruction if the quality of the environment for life within the watershed is to be preserved.

Source: SEWRPC.

ment of additional wildlife habitat, woodland, and outdoor recreational areas.

Very little of the presettlement 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 tiled to provide 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 singularly most important natural resource values in the basin. There are 76 lakes in the watershed ranging in size from 4 acres to 5,262 acres (Geneva Lake) and comprising a total of 22,350 acres of surface water area, or about 4 percent of the total watershed area. Wetlands comprise a total of 53,226 acres or about 0.09 percent of the total watershed area. Approximately 300 lineal miles of perennial streams exist within the watershed. There are three major ground water resources or aquifers in the watershed, which provide nearly all the water supply for industrial, municipal, and private use.

Most of the 45 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 four of the major streams—the Fox, Mukwonago and White Rivers, and Nippersink 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 in the watershed, have diminished in type and quantity due to the complex effects of urbanization and changing land use.

Approximately 6 percent of the watershed area is devoted to parks, outdoor recreation, and related open-space sites, including both publicly or privately owned sites. Potential park sites comprise about 6.0 percent of the watershed area, of which 154 are high-value sites.

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 an essentially lineal pattern of 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 198 square miles, or 21 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.

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Chapter V

HYDROLOGY

INTRODUCTION

The hydrologic regimen of the Fox 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 having varying influence upon the relationship of rainfall to runoff, evapotranspiration, and ground water recharge. The natural channels, with variable slopes and poorly developed drainage patterns, and the numerous kettle lakes and wetland areas 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 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 river system. The Fox River watershed thus is much changed from its natural condition, generally to the overall detriment of the quality and quantity of its water resources. The watershed, however, still retains 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 the 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 and 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 Fox River watershed may vary greatly from time to time. These variations may occur rapidly or slowly and may occur on the land surface, in the ground water systems, or in the atmosphere. 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 Fox 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 lakes and wetlands, in the soil, or on vegetation and is subsequently transpired or evaporated; and the remainder seeps into the ground. Of the water that seeps into the ground, part is retained in the soil; and part continues to move downward and laterally by gravity until it reaches the zone of saturation. Some water is retained in the ground water system, but some 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 Fox River watershed during extended periods of dry weather.

With the exception of the ground water in the deep sandstone aquifer, all of the water on the land surface and underlying the Fox River basin generally remains an active part of the hydrologic system. In the deep aquifer, water is held in storage beneath the nearly watertight 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 in western portions of the watershed, artificial movement through wells and minor natural amounts of leakage through the shale beds provide the only connection this water has with 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 express the total gain or loss of water resources to a watershed over a given time period. The hydrologic budget equates the water gain to a basin from precipitation, surface and subsurface inflow, and increases in surface and ground water storage to the water loss from evapotranspiration, surface and subsurface outflow, and decreases in surface and ground water storage. Quantitative data, however, are normally available for only a few of the many phases of the complex hydrologic cycle. For most watershed areas, including the Fox River watershed, quantitative measurements are compiled for only precipitation and streamflow; and the records of even these phenomena are of a relatively short duration and incomplete.

It is convenient, therefore, to express the hydrologic budget on an average annual basis in a simplified form which includes only the major, measurable 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 Fox River watershed can be developed considering only the surface and shallow ground water supplies. In its simplest form, then, the long-term hydrologic budget for the Fox River watershed may be expressed by the following equation:

$$P = E + R \pm \Delta S$$

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

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

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

ΔS = average annual net change in total surface and ground water storage, expressed in inches of storage[1]

Average annual values of P, E, R, and S for the Fox River watershed were compiled and mapped for the 30-year normal period, 1931-1960,[2] for use in the computation of the simplified hydrologic budget of the watershed, as follows:

P = 31.8 inches per year

E = 25.0 inches per year

R = 6.8 inches per year, and

ΔS = 0 inches per year (see page 7)

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

1. Precipitation: Based upon U. S. Weather Bureau records of weather stations within, and adjacent to, the Fox River watershed, for the period 1931-1960, the average annual precipitation over the watershed ranges from just under 30 inches to over 32.5 inches, as shown on Map 25. The long-term average annual precipitation for the watershed is estimated to be 31.8 inches.

2. Evapotranspiration: The loss of water by evapotranspiration or consumptive use from surface water bodies, plant transpiration, soil moisture, and ground water is an important element of the hydrologic cycle. Some human water uses, such as sprinkler irrigation, also return water to the atmosphere through evaporation processes. In general, evapotranspiration rates are greatest from open water and wetland areas. The geographical distribution of estimated annual evapotranspiration in the Fox River watershed is shown on Map 26. As shown on Map 25, annual water loss by evapotranspiration increases toward the south, primarily due to the slight increase in mean annual temperature and mean annual precipitation. The long-term average rate of annual water loss through evapotranspiration is estimated to be 25.0 inches for the Fox River watershed, or nearly 80 percent of the annual precipita-

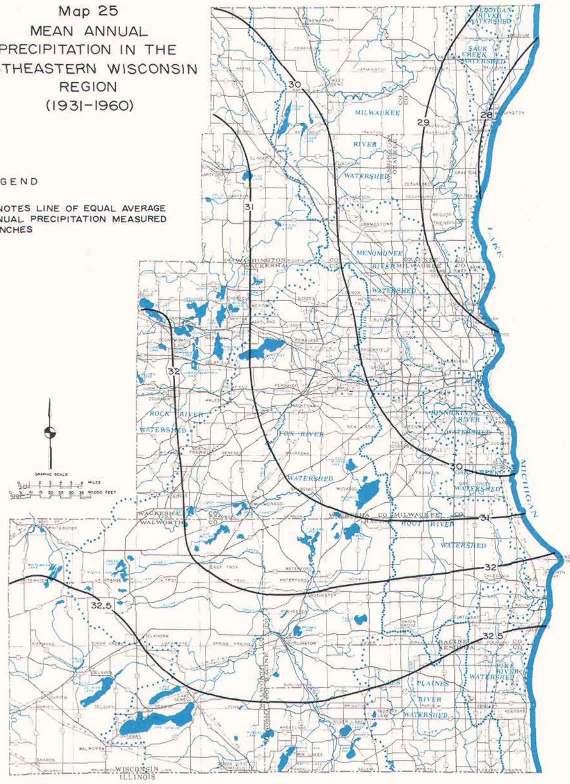
[1] *For consistency of units in the equation, storage is expressed in inches. One inch of net storage change in the watershed equals 51,203 acre-feet or 1,668.5 million gallons.*

[2] *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.*

Map 25
MEAN ANNUAL
PRECIPITATION IN THE
SOUTHEASTERN WISCONSIN
REGION
(1931-1960)

LEGEND

—30— DENOTES LINE OF EQUAL AVERAGE ANNUAL PRECIPITATION MEASURED IN INCHES



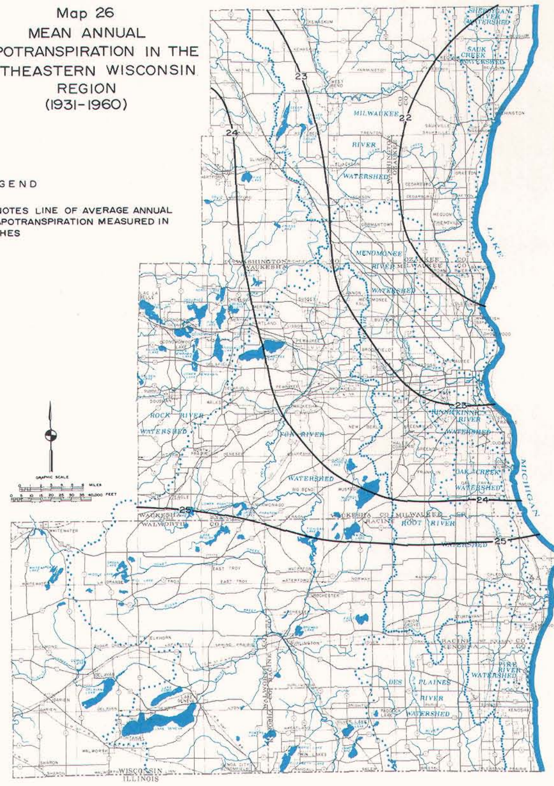
The average annual precipitation in the Fox River watershed is 31.8 inches and ranges from less than 30 inches in the northeastern portion of the watershed to over 32.5 inches in the southwestern portion.

Source: U. S. Geological Survey; U.S. Weather Bureau.

Map 26
MEAN ANNUAL
EVAPOTRANSPIRATION IN THE
SOUTHEASTERN WISCONSIN
REGION
(1931-1960)

LEGEND

—24— DENOTES LINE OF AVERAGE ANNUAL EVAPOTRANSPIRATION MEASURED IN INCHES



Evapotranspiration includes all water returned to the atmosphere through the processes of evaporation and transpiration. Within the Fox River watershed, the estimated long-term average evapotranspiration rate is 25.0 inches per year.

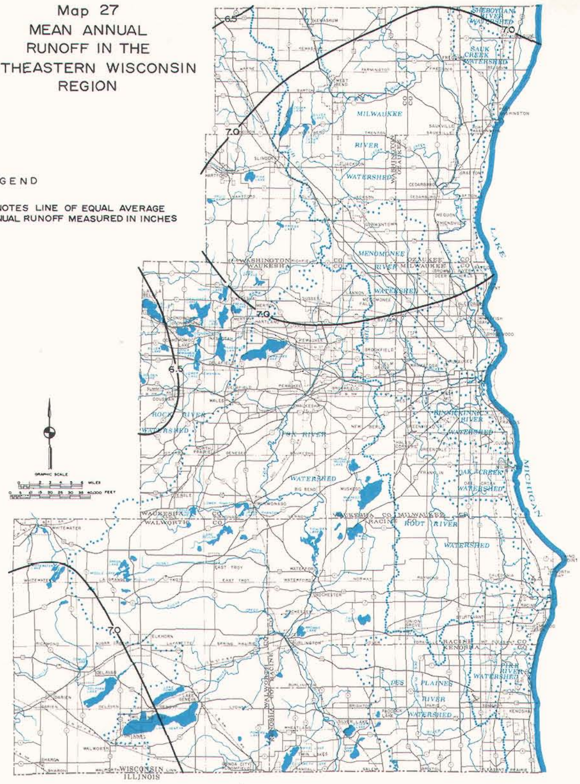
Source: U.S. Geological Survey

tion. Quantitatively, evapotranspiration from the surface area of lakes, streams, and wetlands is nearly equal to the average annual precipitation upon these areas. The quantity of water lost by evapotranspiration from these areas is estimated to be between 35 and 40 billion gallons per year and reaches its maximum rate during the months of July and August.

3. Runoff: Runoff is generally measured as streamflow and is discussed in detail in the surface water section of this chapter. The simple hydrologic budget infers that average annual runoff represents the potentially usable yearly water supply or the theoretical annual "water crop." Certainly the surface runoff is the most easily manageable part of the hydrologic cycle, and it is from this supply that many water needs must be met. Annual runoff from the Fox River watershed is estimated to average 6.8 inches per year, or about 20 percent of the precipitation. The geographic distribution of average annual runoff is shown on Map 27. From this map it can be observed that the annual runoff differs only slightly across the basin. If the annual runoff could be totally managed to produce a uniform rate of streamflow, the streamflow of the Fox River at the Wilmot streamflow gaging station would be a constant 440 cubic feet per second or 283 million gallons per day.[3] This discharge would provide a summertime low flow of about four times the amount usually present. Although complete management of runoff is impractical, these quantities

[3] *The theoretical annual ''water crop'' can be estimated for other drainage areas within the Fox River Watershed or the Region by using Map 27 and the assumption that an average streamflow yield of 0.073 cfs (47,000 gallons per day) would result from each one square mile of area for each one inch of runoff.*

Map 27
MEAN ANNUAL
RUNOFF IN THE
SOUTHEASTERN WISCONSIN
REGION



Runoff is the most readily managed element of the hydrologic cycle. It is estimated that 6.8 inches of water per year run off the land surface of the Fox River watershed.

Source: U.S. Geological Survey

illustrate the theoretical surface water management potential that exists within the watershed.

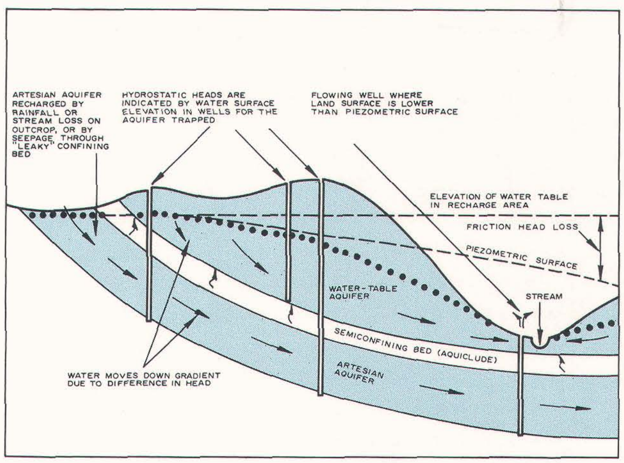
4. Storage: Storage change has been estimated as zero in the long-term hydrologic budget for the Fox River watershed. While fluctuations in the amount of water are constantly taking place in the form of increasing and decreasing streamflow, lake levels, and shallow ground water levels, no significant 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 Fox River valley, although these changes play only a minor role in the hydrologic budget because of the poor hydraulic connection of this aquifer with the shallow aquifer and consequently the surface hydrologic system.

GROUND WATER HYDROLOGY

Water that escapes surface runoff and evapotranspiration processes moves downward from the land surface through the soil and underlying rocks until it reaches the upper most limit of the zone of saturation or the water table. The water levels in shallow wells mark the position of the water table, and the ground water in such wells is said to occur under water table conditions. In places, however, relatively impermeable beds, called aquicludes, prevent vertical seepage of water and may confine the water under pressure. If the water levels in wells drilled through these confining beds rise above the base of the confining bed, the wells are termed artesian wells. Under pressure conditions in an aquifer, a true water table does not exist; however, the static level to which water will rise in a non-pumping well, or an imaginary surface that coincides with the static levels in artesian aquifers, is the artesian pressure surface or the piezometric surface. These basic concepts of ground water hydrology are diagrammatically shown in Figure 8.

Ideal examples of water table conditions are seldom found in nature; and throughout much of the watershed, a combination of water table and artesian conditions exist because a semipermeable strata overlies the aquifer. The occurrence of water under such conditions is termed semi-artesian, and the water level in wells approximates the water table. When water is pumped from the lower, more permeable material, however, the difference in the ability of the two materials to transmit water may be so great that the upper bed assumes the characteristics of a confining bed. An aquifer can receive water by

Figure 8
DIAGRAM ILLUSTRATING THE OCCURRENCE
OF GROUND WATER



Source: U. S. Geological Survey.

leakage through an underlying as well as through an overlying confining bed. Deep aquifers may contain water under artesian pressure sufficient to transmit significant quantities of water, even through many feet of clay, to overlying water-bearing strata.

Both water table and artesian aquifer conditions occur in the Fox River watershed. Water table conditions are normally found only in the shallow sand and gravel aquifers. In many places where permeable sand and gravel occur within less permeable glacial deposits, the wells may actually be artesian; and, in many instances, it is difficult to determine whether a well taps an artesian aquifer without making a pumping test to determine the hydraulic characteristics.

Hydrology of the Sandstone Aquifer

The deep sandstone aquifer underlying the Fox River watershed is the principal source of water for municipal, industrial, and commercial use in the watershed; and, although large quantities of water may be developed from the sandstone aquifer, wells must be drilled to considerable depths. The sandstone aquifer includes all rock units between the top of the St. Peter sandstone and the bottom of the Mount Simon sandstone (see Table 10). The thickness of the sandstone aquifer has a wide range in the Fox River watershed, as shown graphically in Map 28. The thickness of the sandstone aquifer is an important factor in determining its potential for future water development. Where the aquifer is only a few feet thick, as in an area northeast of Waukesha, well yields are much lower than elsewhere in the watershed. In the southeastern portion of the watershed, the aquifer is estimated to be over 2,000 feet thick. Other characteristics of the sandstone aquifer important to watershed planning are shown on Map 28 and Table 10, including the estimated elevation above mean sea level of the top of the St. Peter sandstone and the general availability of ground water from the aquifer, within which the Mount Simon and Galesville units are believed to be the most productive.

As an excellent example of the complex lithology and heterogeneous nature of the sandstone aquifers within the watershed, the log of a major well tapping this formation has been reproduced in Figure 9. This well, the City of Waukesha Merrill Well, located in the northeast quarter of Section 18, Town 6 North, Range 19 East, is one of the deepest wells ever drilled in the Fox River watershed. The lithology of the rock units and the resistivity and hardness of the well water illustrate ground water conditions in the sandstone aquifer. The well, reaching its full depth in the coarse-grained Mount Simon sandstone, was tested for 36 hours at pumping rates up to 1,275 gpm (gallons per minute). Saline water was not encountered in this well at any depth; and, in general, relatively soft water was found in most units of the sandstone aquifer. At the time of drilling, as well as at present, all ground water in the sandstone aquifer occurred under artesian conditions.

Hydrology of the Shallow Dolomite Aquifers

The shallow dolomite aquifers underlying the Fox River watershed and the interconnected glacial deposits are the principal source of water for domestic use by individual residences not connected to a municipal water system. The shallow dolomite aquifers consist of the Silurian dolomite strata and the Platteville, Decorah, and Galena formations where not overlain by the Maquoketa shale. Some creviced limestone and dolomite beds in the upper part of the Maquoketa shale, where present and if water productive, are also included in the shallow dolomite aquifers. Ground water in the shallow dolomite aquifers exists relatively near the land surface; and the aquifers, as already noted, have been developed as important sources of domestic supply and to a lesser extent as industrial, commercial, and municipal supply. Well yields within the aquifers are not predictable, however, and depend upon the size and number of crevices and solution cavities that are tapped. The general availability of ground water from these aquifers is shown on Map 14. Yields from wells range from amounts too small to supply one household to over 1,500 gpm. Nearly all water in the shallow dolomite aquifers occurs under artesian or semi-artesian conditions.

Hydrology of the Sand and Gravel Aquifers

Permeable sand and gravel in the Pleistocene and recent deposits provide water to many shallow wells in quantities adequate for domestic and farm supply. Municipal supplies for the City of Lake Geneva and the Villages of East Troy, Fontana, Genoa City, Hartland, Menomonee Falls, Walworth, and Williams Bay also come from the sand and gravel aquifers.

The availability of water from these aquifers depends upon their thickness and areal extent and is limited by the amount of fine-grained material that is present. Yields over 2,000 gpm have been

Map 28

ELEVATION OF THE TOP AND THICKNESS OF THE SANDSTONE AQUIFER UNDERLYING THE FOX RIVER WATERSHED

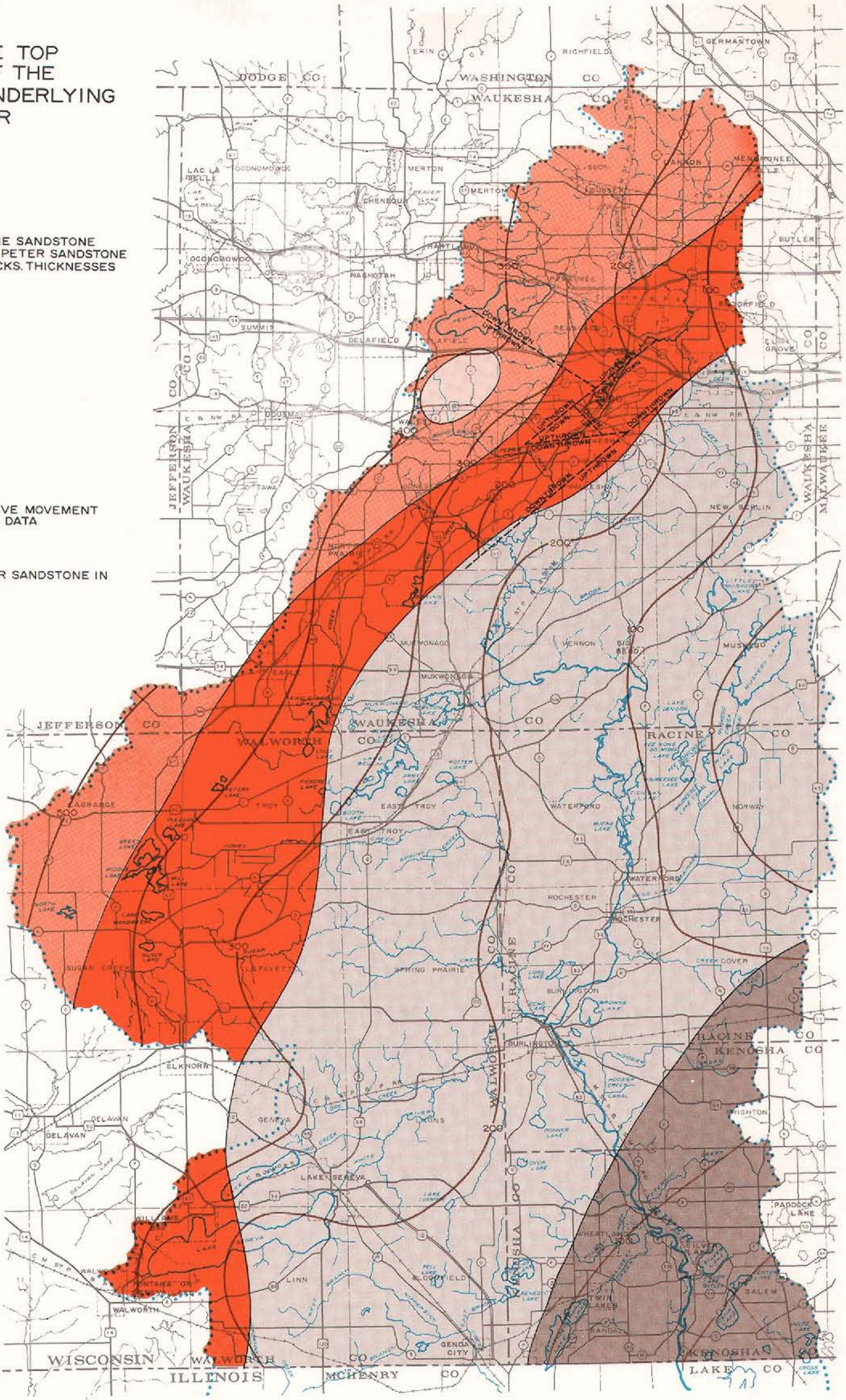
LEGEND

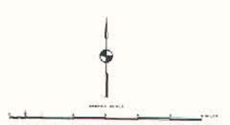
DENOTES APPROXIMATE THICKNESS OF THE SANDSTONE SEQUENCE BETWEEN THE TOP OF THE ST. PETER SANDSTONE AND THE PRECAMBRIAN CRYSTALLINE ROCKS. THICKNESSES IN FEET.

- MORE THAN 2000
- 1500 – 1999
- 1000 – 1499
- 500 – 999
- 0 – 499

UP / DOWN — DENOTES FAULT, SHOWING RELATIVE MOVEMENT EXISTENCE INFERRED FROM WELL DATA
UP–UPTHROWN SIDE
DOWN–DOWNTHROWN SIDE

—100— DENOTES ELEVATION OF ST. PETER SANDSTONE IN FEET ABOVE MEAN SEA LEVEL



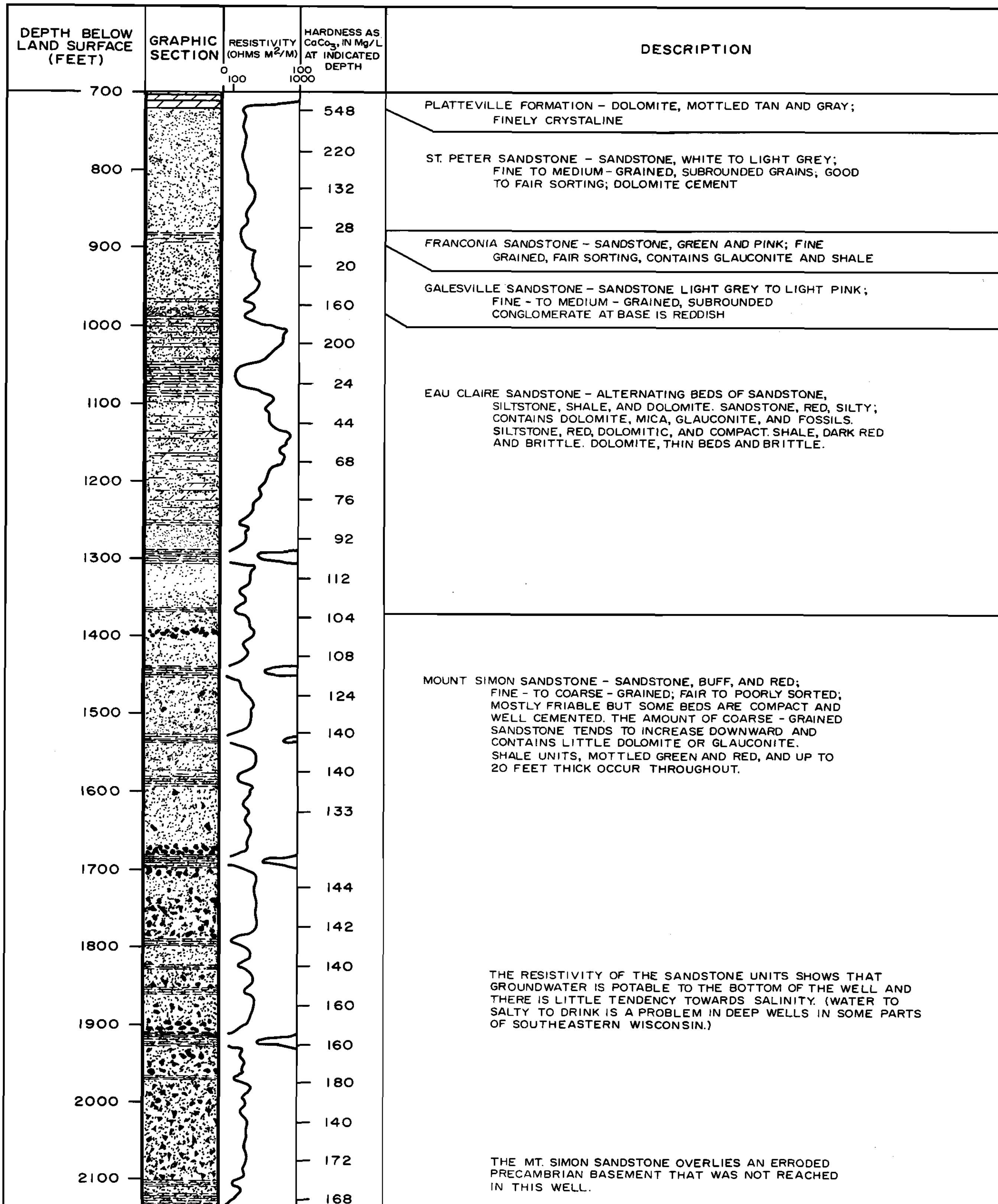


The sandstone aquifer supplies the largest quantity of water used by municipalities and industrial concerns in the watershed. Where the aquifer is only a few feet thick, as in the area northwest of the City of Waukesha, well yields are much lower than elsewhere in the basin.

Source: U.S. Geological Survey

Figure 9

PORTION OF THE LOG OF THE CITY OF WAUKESHA MERRILL WELL SHOWING LITHOGRAPHIC DETAILS, RESISTIVITY, AND HARDNESS OF WATER FROM THE SANDSTONE AQUIFER



Source: U. S. Geological Survey.

obtained from wells in the sand and gravel aquifers within the watershed. Although wells in these shallow aquifers may be cheaper to drill and more economical to operate than wells in the deeper bedrock aquifers, the deeper aquifers, because of the uniform and dependable quality of the water and reliability of the supply, are more extensively utilized as sources of water supply. Due to economic factors, however, the utilization of sand and gravel aquifers for water supply can be expected to increase substantially within the watershed in the future.

Perched ground water conditions occur in the Fox River watershed within sand and gravel aquifers in temporary zones of saturation above, and separated from, the main zone of saturation. These perched water bodies are generally located in small, discontinuous sand and gravel deposits; and, although the perched ground water cannot be considered an important water source, it may provide significant amounts of water to springs and streams during extended dry periods of the year.

Ground Water Recharge

The principal source of recharge to the sandstone aquifer of the Fox River watershed is from percolation through the Platteville-Galena unit in western Walworth and Waukesha Counties. As shown on Map 29, the major recharge area lies largely outside the watershed and partly outside the Region. This recharge area is bounded on the east by the limits of the Maquoketa shale and on the west by the ground water divide which separates eastward and westward ground water movement between the Fox River and Rock River watersheds.

An estimated 12 mgd (million gallons per day) of ground water moves through the sandstone aquifer in the Fox River watershed, representing not only the quantity of water withdrawn from wells within the watershed but also the ground water that is moving toward the Milwaukee and Chicago pumpage centers. The amount of ground water moving into the City of Waukesha pumpage center from the recharge area is estimated at 6.9 mgd. Presently the rate of withdrawal of water from the sandstone aquifer exceeds the rate of recharge, resulting in declines in piezometric levels in the watershed, which average 3 to 4 feet per year. The effect of the declines in water levels upon the future water supply of the watershed is discussed in Chapter XI.

Some recharge of the sandstone aquifer occurs through the Maquoketa shale, which underlies approximately 824 square miles of the watershed. Leakage occurs as a result of large differences in head that exist across the slightly permeable Maquoketa shale. The leakage through this formation is estimated to be between 1 mgd and 2 mgd. Minor amounts of recharge to the sandstone aquifer also occur directly downward from the shallow aquifers through wells open in both aquifers.

The shallow dolomite aquifers and sand and gravel aquifers receive water from precipitation within the watershed area. Recharge takes place most readily where the bedrock or sand and gravel outcrop at the land surface. The major probable recharge areas are indicated geographically in Map 30. The "hill" on the piezometric surface in east-central Walworth County represents the largest such individual recharge area. Smaller, less important, recharge areas are scattered throughout the watershed. The average annual recharge to the shallow aquifers is estimated to be about 3.8 inches of water over the entire ground water basin, or about 12 percent of the annual precipitation. This is equivalent to about 125 mgd over the entire watershed, or about 175,000 gpd per square mile. This recharge rate represents the sustained yield of the shallow ground water resources. The recharge rate varies considerably within the watershed and is much less in areas underlain by glacial till than in areas underlain by sand and gravel.

Ground water pumpage from shallow wells near streams, lakes, or wetlands affects local ground water movement and runoff and directly or indirectly affects streamflow and the stages of lakes and wetlands. Heavy pumping of these wells locally may lower the water table below the stage of the river, lake, or wetland, inducing the movement of ground water toward the wells. These hydraulic conditions, called induced infiltration, are another important means of ground water recharge. The distance of the pumping well from a surface water body, the rate and duration of pumping, and the geologic and hydraulic characteristics of the aquifer within the pumping area determine the magnitude of the effect upon the surface water body.

Ground Water Movement

The general direction of ground water movement through the principal aquifers may be ascertained by inspection and interpretation of the piezometric surface (see Maps 29 and 30). As ground water moves from points of recharge to points of dis-

Map 29

PIEZOMETRIC SURFACE AND RECHARGE AREAS OF THE SANDSTONE AQUIFER UNDERLYING THE FOX RIVER WATERSHED

LEGEND

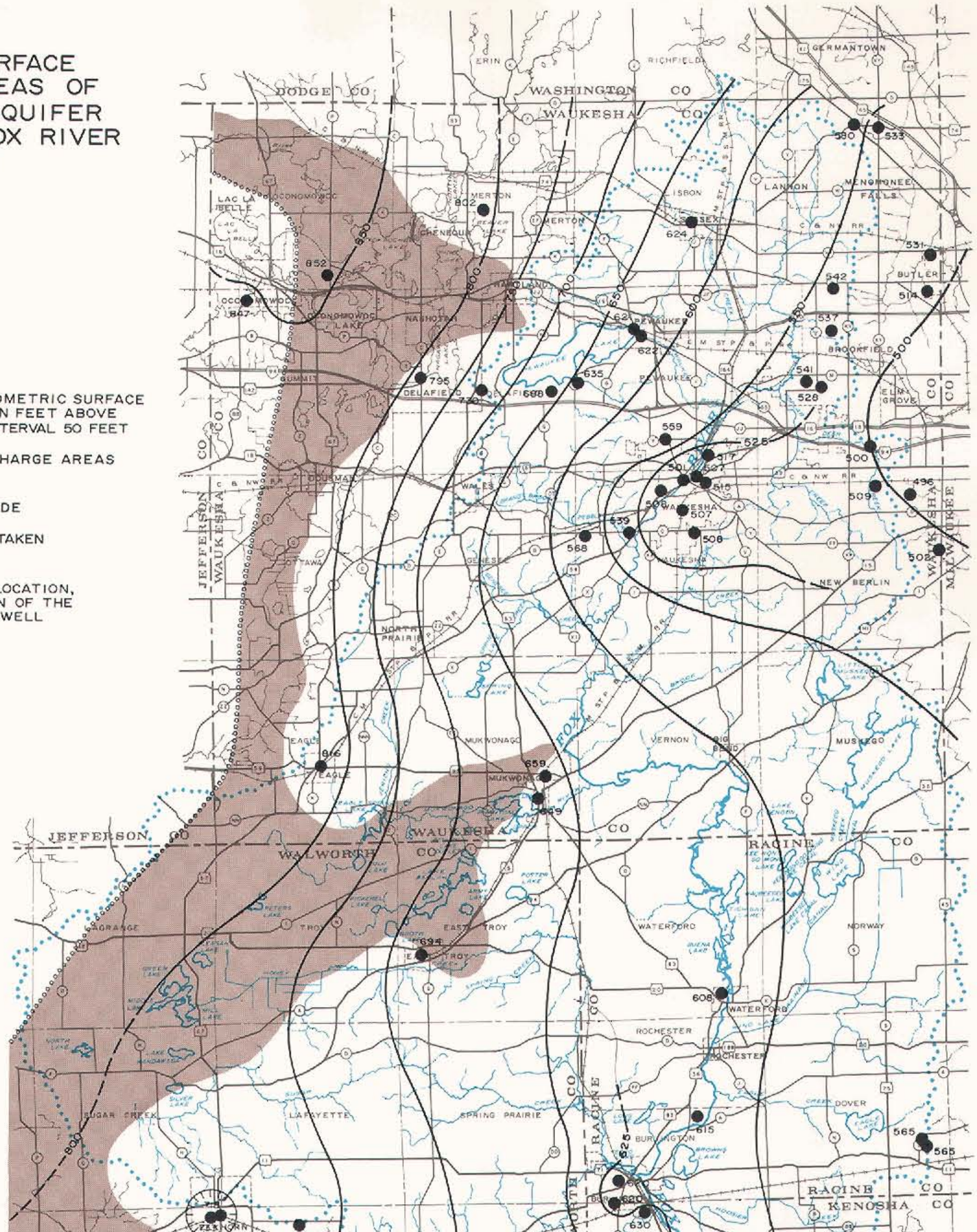
750 — DENOTES ELEVATION OF PIEZOMETRIC SURFACE OF THE SANDSTONE AQUIFER IN FEET ABOVE MEAN SEA LEVEL. CONTOUR INTERVAL 50 FEET

DENOTES GROUND WATER RECHARGE AREAS SANDSTONE AQUIFER

oooooooo DENOTES GROUND WATER DIVIDE

NOTE: GROUND WATER MEASUREMENTS TAKEN SEPTEMBER 1966.

● 508 DENOTES OBSERVATION WELL LOCATION, AND INDICATES THE ELEVATION OF THE PIEZOMETRIC SURFACE IN THE WELL



The pressure levels in the sandstone aquifer underlying the watershed generally decline from east to west indicating that the movement of ground water is generally eastward from the recharge areas located in western Walworth and Waukesha Counties. Areas of high ground water pumpage are indicated by the contours around Waukesha and Burlington.

Source: U.S. Geological Survey

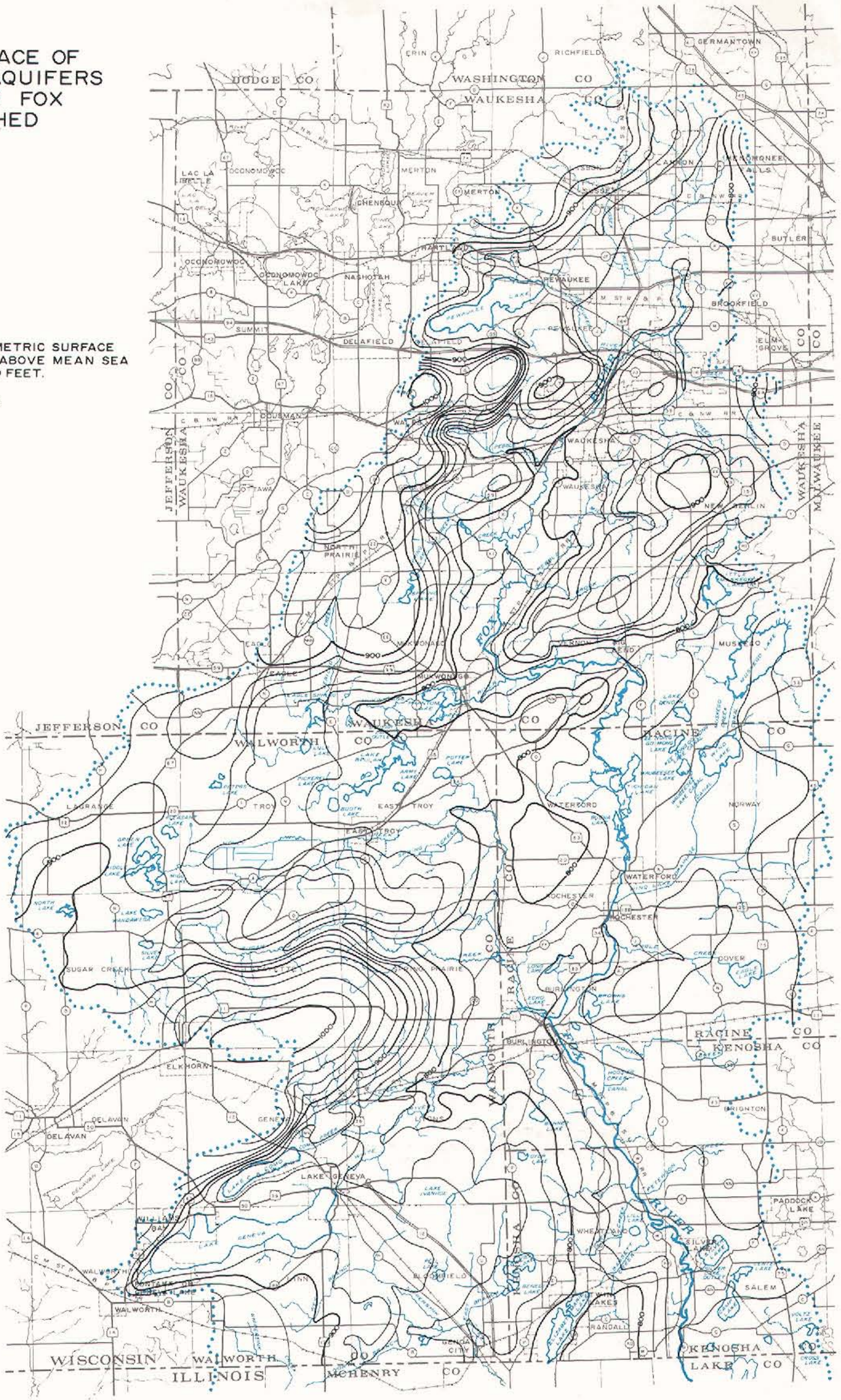
Map 30

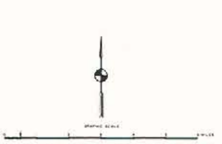
PIEZOMETRIC SURFACE OF SHALLOW DOLOMITE AQUIFERS UNDERLYING THE FOX RIVER WATERSHED

LEGEND

DENOTES ELEVATION OF PIEZOMETRIC SURFACE OF SHALLOW AQUIFER IN FEET ABOVE MEAN SEA LEVEL. CONTOUR INTERVAL 20 FEET.

NOTE : GROUND WATER MEASUREMENTS MADE SEPTEMBER 1966





Water levels in the shallow aquifers stand relatively close to the ground surface. The shallow aquifer, which provides the primary source of supply for both urban and rural residences not connected to a centralized public water supply system, is recharged locally.

Source: U.S. Geological Survey

charge, its general path crosses the piezometric contour lines at right angles. Rates of ground water movement under natural conditions usually are extremely slow. In the Fox River watershed, most ground water moves a few feet or less per day except near pumping wells, which locally increase water velocities. Ground water movement of only a few tenths of a foot per day is common in poor aquifers. Movement of water through the shallow dolomite aquifers, however, may be rapid. Water in the Silurian dolomite aquifer, for example, moved over 1,000 feet in 2 days under natural conditions in the Sussex area of the watershed, as traced with fluoroscein dye during a 1967 sanitary survey by the Waukesha County Health Department.

Streams, lakes, and marshes are the visible surface water expression of the shallow dolomite and sand and gravel aquifers in the watershed. The ground water itself is located a few feet below the land surface along the streams and lakes and about 150 feet below the crests of some uplands of the watershed. The natural gradient of the piezometric surface is nearly always toward streams, lakes, and marshes.

Ground water movement in the sandstone aquifer is from recharge areas to centers of pumpage, generally from west to east beneath the watershed, as indicated by Map 29.

Ground Water Discharge

Ground water within the Fox River watershed discharges both naturally and artificially. It discharges naturally through springs and seepage into lakes, streams, and wetlands and by evapotranspiration processes. Ground water discharges artificially as a result of human activity.

Ground water discharges by seepage where the land surface intersects the water table at springs, lakes, wetlands, and effluent (gaining) streams. The discharge of ground water to selected major streams of the Fox River watershed is shown in Figure 10, which was prepared based on a series of streamflow measurements completed in September 1966 after a three-week period of dry weather. All streamflow, therefore, resulted from ground water seepage and sewage treatment plant discharge. Moreover, even the water from the sewage treatment plants resulted from ground water pumped or infiltrated into the sewerage systems. Inspection of Figure 10 reveals that the flow of the Fox River began below Mill Road in Brookfield and increased rather uniformly as a result of ground water seepage to below the City of Waukesha. The discharge of the City of Waukesha sewage treatment plant doubled the streamflow. For approximately three miles downstream from the Waukesha sewage treatment plant, the flow diminished as water was apparently lost to the ground water system. The recharged water probably either re-enters the channel downstream or will subsequently re-enter the channel at such time as the stage of the river declines.

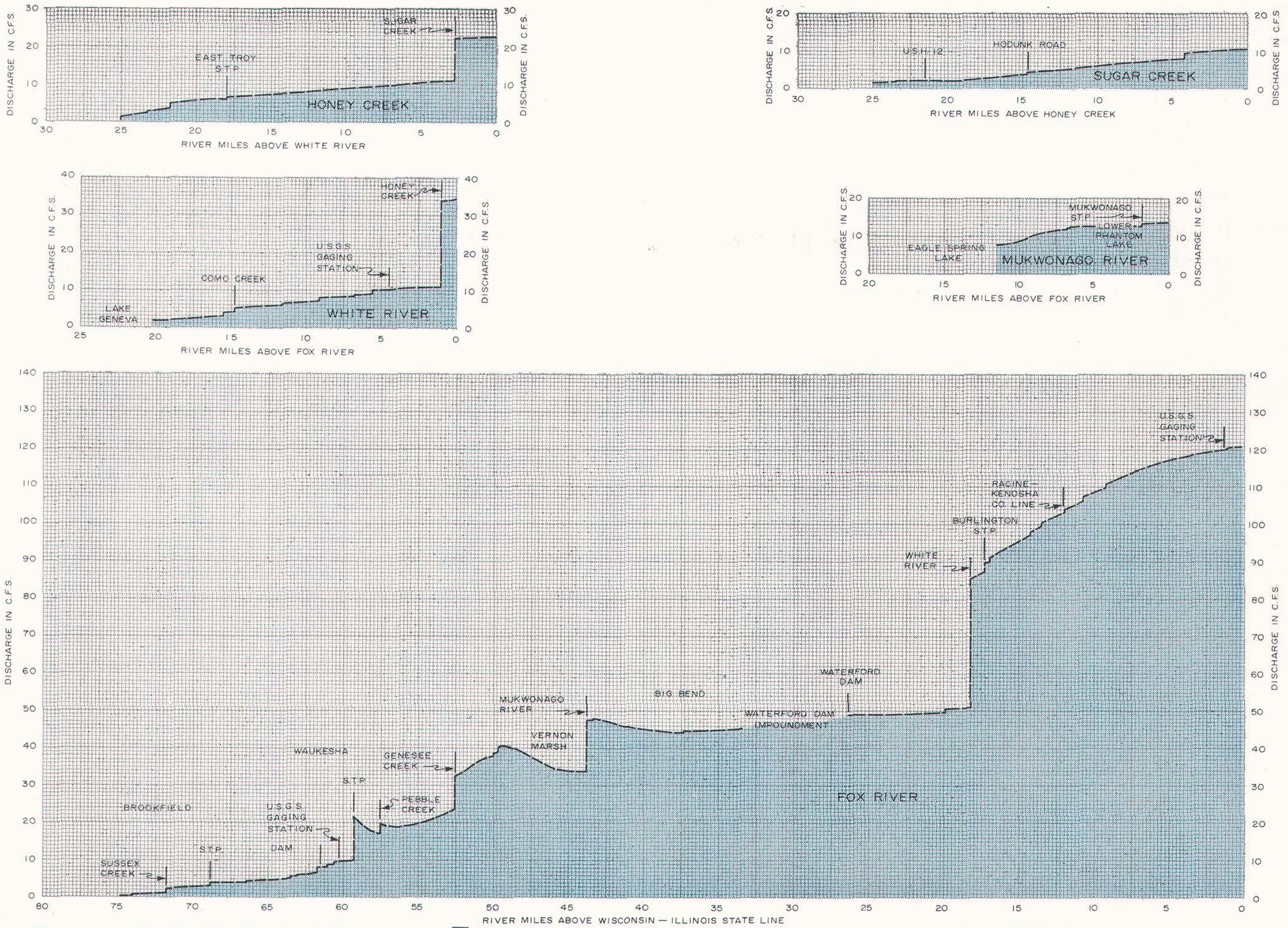
Evapotranspiration probably accounted for the streamflow declines of the Fox River in Vernon Marsh. Very little increase in flow occurred in the Fox River below the Mukwonago River to the point where the White River joins the Fox River at the City of Burlington. At Burlington, the contribution of the flow of the White River represented about 40 percent of the total flow of the Fox River, and nearly all of this contribution resulted from effluent ground water. The flow of the Fox River gained rapidly below Burlington as ground water discharged from the highly permeable sand and gravel deposits that exist along the stream. Similarly, Figure 10 reveals that the flows of the White River, Mukwonago River, Sugar Creek, and Honey Creek increase downstream as a result of ground water discharge into their channels.

The total discharge of ground water and the effluent from treatment plants was about 121 cfs, or 78 mgd, in September 1966, as measured at the Wilmot stream gaging station. The long-term average ground water discharge from the Fox River watershed at Wilmot is estimated to be 240 cfs, or 155 mgd.

Much of the base streamflow of the river system is discharged from springs, the majority of which are located in the westerly portions of the watershed where ground water recharge is high. During a 1958 inventory by the State Department of Natural Resources, six springs within the watershed were found to discharge more than 200 gpm, 12 springs between 100 and 200 gpm, 21 springs between 50 and 100 gpm, and 70 springs between 25 and 50 gpm. During the recharge season, particularly in early spring, numerous small seepage springs form in low places; but these are unimportant with respect to the overall water supply in the watershed. Small seepage springs also appear in low areas where unconsolidated deposits overlie bedrock.

Most artificially discharged ground water in the Fox River watershed is pumped from municipal and private wells. In 1966 the estimated average

Figure 10
DISCHARGE OF MAJOR STREAMS IN THE FOX RIVER WATERSHED
SEPTEMBER 12-14, 1966



Source: U. S. Geological Survey.

daily discharge from wells was about 24.5 million gallons, of which about 10.1 million gallons were withdrawn from the sandstone aquifer. In relatively small quantities as compared to pumped ground water, the ground water of the watershed is also artificially discharged inadvertently in urban areas by infiltration into storm and sanitary sewerage systems and by design in agricultural areas through seepage into drain tile fields and ditches.

Ground Water-Surface Water Relationships

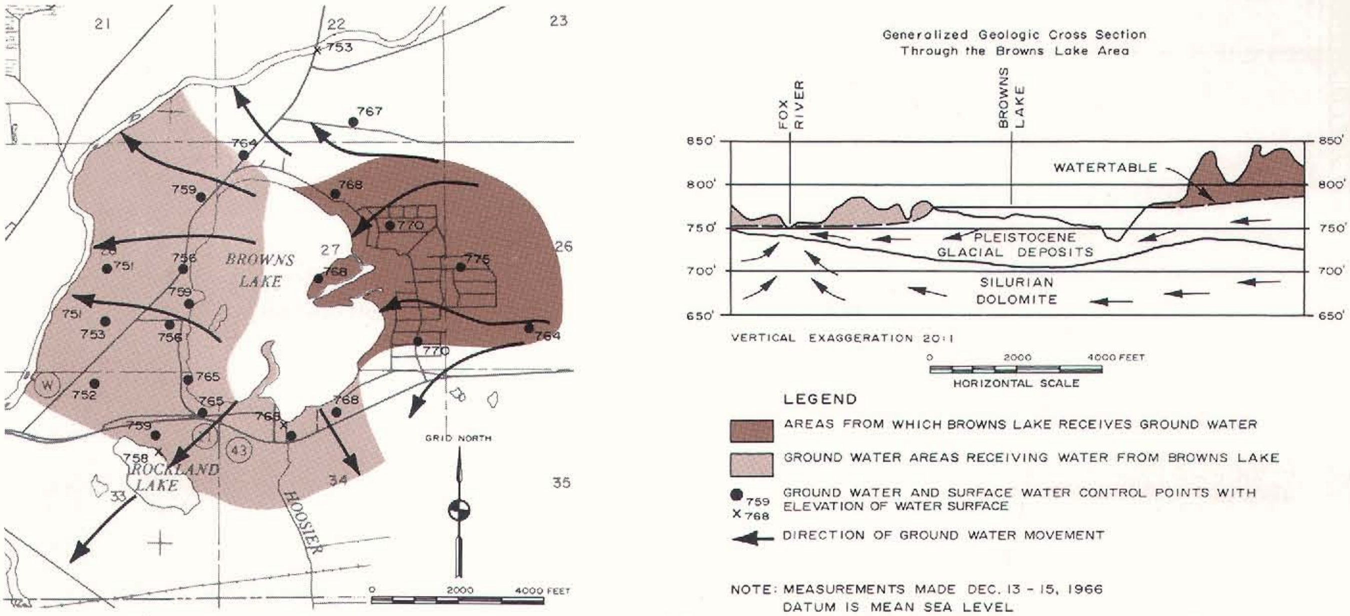
Shallow ground water and surface water are so closely interrelated in the Fox River watershed that neither can be considered an independent source of supply. Changes in precipitation, recharge, evapotranspiration, discharge, drainage, and storage are reflected by changes in the ground water and surface water regimens. Within the watershed it is only the ground water supply of the sandstone aquifer that bears little or no relationship to surface water conditions. In order to understand better the complex hydrologic interrelationships that exist in the watershed, special hydrologic studies involving selected lakes and streams were conducted as a part of the overall watershed planning effort. The results of one such study, involving the hydrologic situation of Browns Lake in Racine County, is summarized in the following paragraphs and diagrammatically shown in Figure 11.

Browns Lake is a kettle lake of glacial origin located in Racine County approximately 2 miles east of the City of Burlington. As shown in Figure 11, the lake level is sustained primarily by ground water inflow from the hilly area on its east side. The source of this ground water is precipitation that has percolated through the sandy glacial deposits. Other sources of inflow into the lake include direct precipitation on the lake surface and surface water runoff into the lake.

Outflow from Browns Lake presents a similar, complex hydrologic situation. By inspection of

Figure 11

GROUND WATER MOVEMENT IN BROWNS LAKE AREA OF THE FOX RIVER WATERSHED



Under normal conditions, Browns Lake discharges part of its water to the shallow ground water aquifer west and south of the lake. This loss, however, is greatly increased when the numerous wells in this same area are in use, thus causing an increase in ground storage capacity resulting in increased discharge of lake water to the shallow ground water system.

Source: U.S. Geological Survey

Figure 11, it is evident that the lake is losing water to the shallow ground water system to the west and south of the lake. The greatest loss of water is induced westerly toward the Fox River which has a normal stage approximately 17 feet lower than that of Browns Lake. It can be observed, therefore, that Browns Lake is simultaneously losing and gaining water with the direction of ground water flow in a general westerly direction. Outflow from the lake also occurs as a result of the evapotranspiration process and intermittently as surface water discharges southerly through its outlet to the Fox River.

By the use of a special hydrologic study, such as that of Browns Lake, it is possible to improve significantly the management of the lake and the protection of its water resources. For example, some of the more readily apparent resource protection measures that might be taken to protect Browns Lake, based on present hydrologic conditions, include:

1. The discouragement of heavy ground water pumpage from shallow aquifers on the north, west, and south shores of Browns Lake, as such pumpage will tend to increase drainage from the lake and thus adversely affect the lake levels.

2. The encouragement of heavy ground water pumpage on the east side of the lake, as no important loss of ground water supply to Browns Lake would be likely.

3. The discouragement of septic tank use on the east side of the lake, as effluent therefrom would probably add nutrients to the lake, which, in turn, would aid the growth of algae and aquatic weeds.

4. The discouragement of the use of the shallow ground water supply on the west and south sides of the lake because of the pollution potential that presently exists.

There are 25 major lakes within the watershed, including Browns Lake, that are simultaneously losing and gaining ground water. These are listed in Table 18. Although the conduct of detailed ground water investigations for each major lake of the watershed was beyond the scope of this study, use of the basic ground water data, including the interpretation of Map 30, was made to determine general ground water-surface water relationships of the lakes. These ground water data were used in the preparation of individual lake use plans and in the formulation of resource measures for their protection. An example of such a lake use plan is included in this report in Appendix D.

Table 18

MAJOR LAKES OF THE FOX RIVER WATERSHED WHICH HAVE COMPLEX GROUND WATER-SURFACE WATER RELATIONSHIPS:[a] 1966

Lake	County	Lake	County
Army	Walworth	North	Walworth
Benedict	Kenosha	Pell	Walworth
Big Muskego	Waukesha	Peters	Walworth
Bohner	Racine	Pleasant	Walworth
Booth	Walworth	Potters	Walworth
Browns	Racine	Powers	Kenosha
Denoon	Waukesha	Silver	Kenosha
Eagle Spring	Waukesha	Silver	Walworth
Kee Nong Go Mong	Racine	Spring	Waukesha
Green	Walworth	Wandewega	Walworth
Lilly	Kenosha	Wabeesee	Racine
Middle	Walworth	Wind	Racine
Mill	Walworth		

[a] *Based upon special hydrologic studies and/or interpretation of Map 30, these lakes were found to be simultaneously gaining and losing ground water.*

Source: U. S. Geological Survey.

QUANTITY OF SURFACE WATER

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

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, 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.

In the watershed the U. S. Geological Survey has operated gaging stations on the Fox River at Wilmot, at Waukesha, and near Mukwonago and on the White River near Burlington. Continuous streamflow records have been obtained at Wilmot since October 1939 and, in cooperation with the Regional Planning Commission and Waukesha County, at Waukesha since January 1963. Near Mukwonago a station was operated during the period April 1927 to August 1930. Discharges have been measured near Burlington on a seasonal basis since August 1964. Other discharge measurements have been obtained by the U. S. Geological Survey at partial record stations and miscellaneous sites since 1958. Stream flow data are published annually by the U. S. Geological Survey in Water Resources Data for Wisconsin.

Ideally, a long continuous streamflow record is required before a representative picture of streamflow can be obtained. Of the stations operated in the Fox River watershed, only the station at Wilmot has a record of sufficient length to represent long-term conditions. This is unfortunate because, in many instances, the flow characteristics exhibited by the Fox River at Wilmot are not typical of the streamflow characteristics of its tributary streams.

The range of variation in daily streamflow quantity is shown in the flow duration curves in Figures 12, 13, and 14. 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 Fox River at Wilmot indicates that 10 percent of the time the mean daily discharge should be greater than

Figure 12
FLOW DURATION CURVES
FOX RIVER
AT WILMOT
1940-1965 WATER YEARS

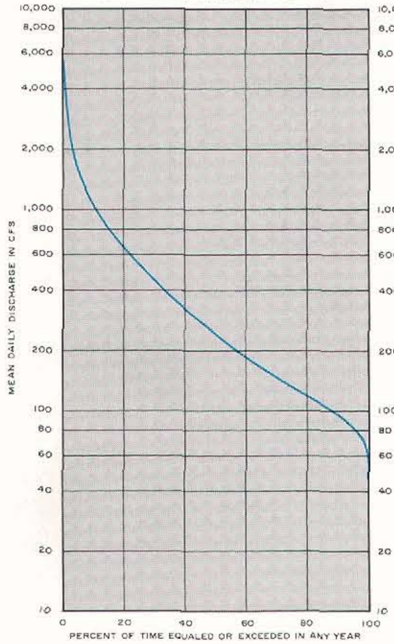


Figure 13
FLOW DURATION CURVES
FOX RIVER
AT WAUKESHA
1964-1965 WATER YEARS

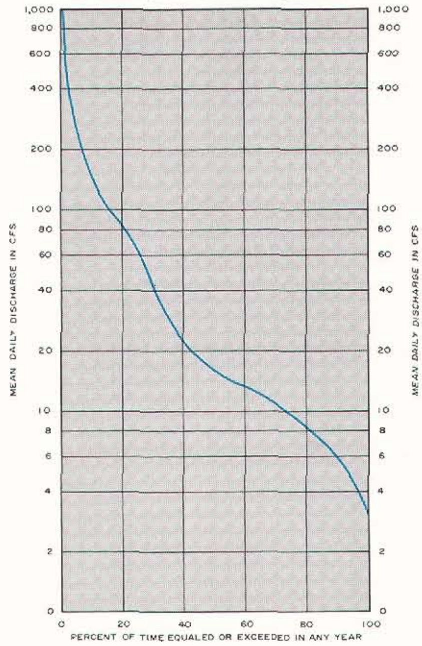
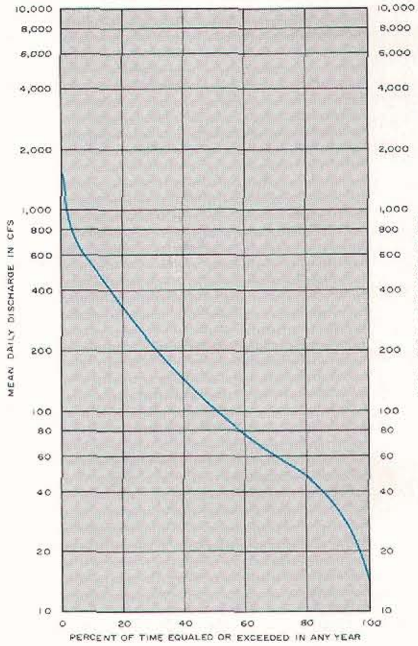


Figure 14
FLOW DURATION CURVES
FOX RIVER
NEAR MUKWONAGO
1928-1929 WATER YEARS



Source: U. S. Soil Conservation Service.

1,000 cfs. 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 duration to include periods of both high and low flow. Curves developed from short periods of record must be used with caution.

The flow duration curve for the gaging station at Wilmot is shown in Figure 12. This curve was developed using a 26-year period of continuous streamflow record and should be indicative of long-term streamflow characteristics. The range of daily discharge, from a maximum of 7,100 cfs to a minimum of 35 cfs, is fairly small when compared to other equivalent sized drainage areas in Wisconsin. This is principally due to the large number of natural lakes and floodplain storage areas in the watershed.

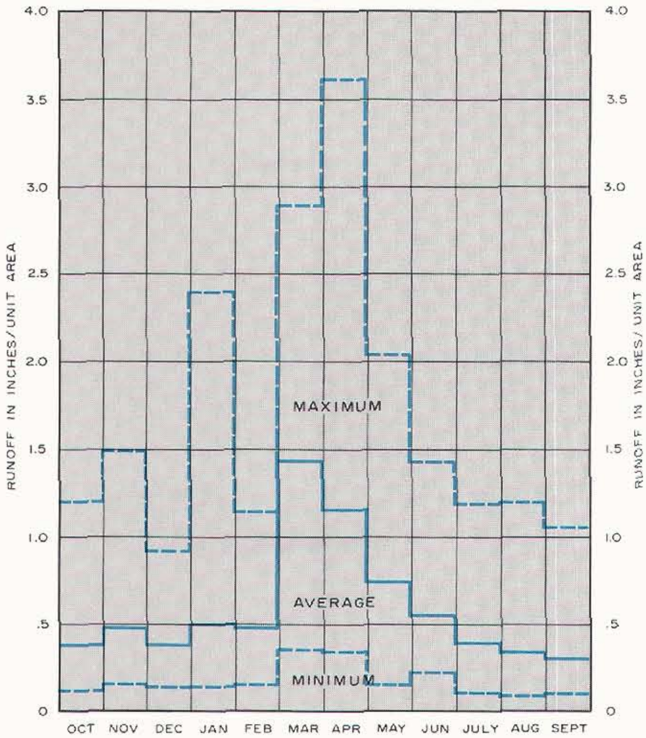
Figures 13 and 14 show the curves developed for the stations at Waukesha and Mukwonago. Two complete water years[4] have been recorded at each of these stations. The records at Waukesha were obtained during years of below average flow, and at Mukwonago the station was operated during a wet period. Consequently, these curves cannot be expected to fully reflect the long-term flow characteristics at the stations.

Streamflow quantity also varies from month to month. The average, maximum, and minimum monthly amounts of runoff are shown for the Wilmot gage in Figure 15. Prolonged periods of high streamflow occur principally in March and April, but all months except December have recorded amounts greater than one inch. One inch of runoff is equivalent to an average monthly flow of about 790 cfs. Minimum monthly amounts generally occur in August and September.

A comparison of annual runoff and annual precipitation is shown graphically in Figure 16. All amounts shown are on a water-year basis. Runoff amounts are those recorded at Wilmot. Precipitation values are an average for the watershed and were developed using the Thiessen method of computing mean areal precipitation. The quantity of annual streamflow is primarily dependent upon the amount of annual precipitation. The influence of other factors, such as land use, when and how the precipitation occurs, and antecedent moisture conditions, however, makes it impossible to establish a direct correlation between annual runoff and annual precipitation. The long-term average annual flow at Wilmot is equivalent to an annual runoff of about 6.9 inches, or about

[4] *''Water Year'' is the 12-month period October 1, through September 30, designated by the calendar year in which it ends.*

Figure 15
MONTHLY RUNOFF FOR
FOX RIVER AT WILMOT
FOR WATER YEARS 1940-1965



Source: U. S. Soil Conservation Service.

21 percent of the average annual precipitation of 32 inches. The maximum and minimum recorded amounts of annual runoff correspond to periods of maximum and minimum annual precipitation. In 1960 the annual flow totaled 16.24 inches, or 39 percent of the annual mean areal precipitation of 41.38 inches. The minimum annual amount of runoff occurred in 1958, when the runoff equaled 2.58 inches, or about 12 percent of the annual mean areal precipitation of 21.78 inches.

A most important characteristic of annual runoff amounts is the probability or frequency of their occurrence. Probability is defined in this instance as the chance of having the annual flow equal or exceed a specified amount. Probability may be expressed as a decimal, a fraction, or a percentage. Frequency is defined as how often an event may be expected to occur in a given period of time. For example, an annual runoff in an amount of such magnitude that it occurred on the average of once in 100 years would have a frequency of 100 years and a probability or chance of occurrence of 1 percent.

The series of annual runoff values was analyzed using a statistical method (Hazen Formula) of probability assignment to establish a relationship between amount and occurrence at the Wilmot gage. The frequency curve resulting from the analysis is shown in Figure 17. The curve indicates that the probability of occurrence of an annual runoff amount equaling or exceeding the 16.24 inches recorded in 1960 is 1.8 percent and that the low of 2.58 inches recorded in 1958 should be equaled or exceeded 98 times in a 100-year period.

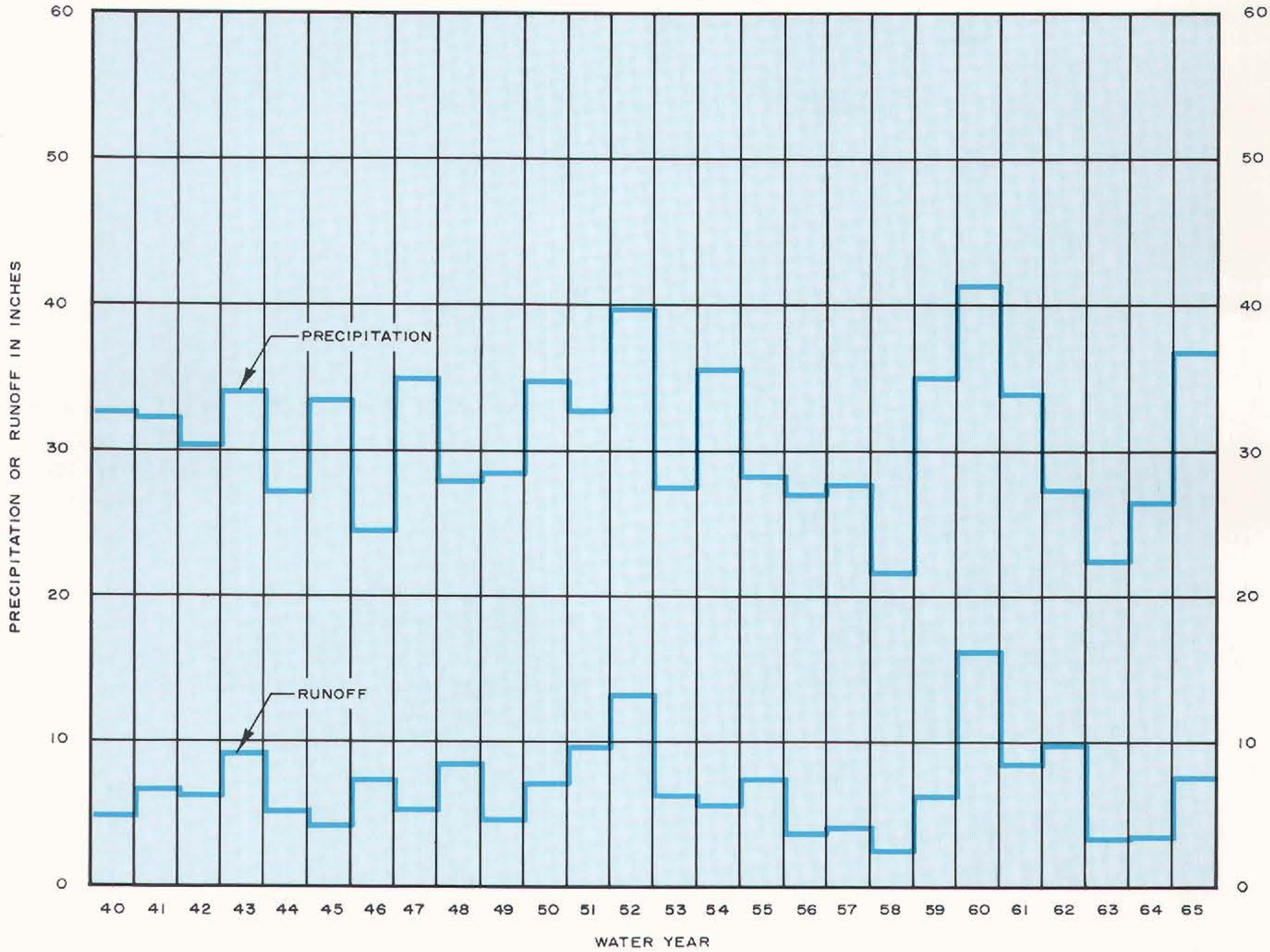
It is not possible to draw precise quantitative conclusions as to the relationship between urban development and streamflow quantity from the hydrologic data presently available in the Fox River watershed. A comparison of inches of annual runoff per inch of annual precipitation for the period 1940 through 1952 and the period 1953 through 1965 indicates no trend. The results, in fact, are identical for both periods. Studies made at other locations, however, indicate that, as urban development continues within the watershed, the quantity of streamflow will probably increase. This increase, however, may be concentrated in periods of flood flow. Streamflow during dry periods may actually decrease. Low flows may also be strongly influenced by increases in sewage disposal plant effluent or by the export of sanitary sewage from the watershed. The trend of runoff changes resulting from urban development can, to some degree, be controlled through proper water management practices based upon a comprehensive watershed plan.

Lake Storage

The total quantity of surface water that is held in major lakes in the watershed is approximately 482,000 acre feet; and the surface area of all major lakes occupies 21,759 acres, or approximately 3.1 percent of the watershed.

Lake levels fluctuate from time to time, responding primarily to variations in precipitation, surface runoff, temperature, and ground water levels. The U. S. Geological Survey has monitored lake levels on North Lake, Silver Lake, Browns Lake, Eagle Lake, and Rockland Lake. Records are available for the period 1936 through 1964 on Browns Lake, Silver Lake, and Eagle Lake. At North Lake measurements have been obtained since May 1937 and at Rockland Lake since 1967. Records of levels at other lakes within the watershed have been obtained from interested individuals and groups.

Figure 16
AVERAGE ANNUAL PRECIPITATION AND RUNOFF
FOX RIVER AT WILMOT
FOR WATER YEARS 1940-1965



Source: U. S. Soil Conservation Service.

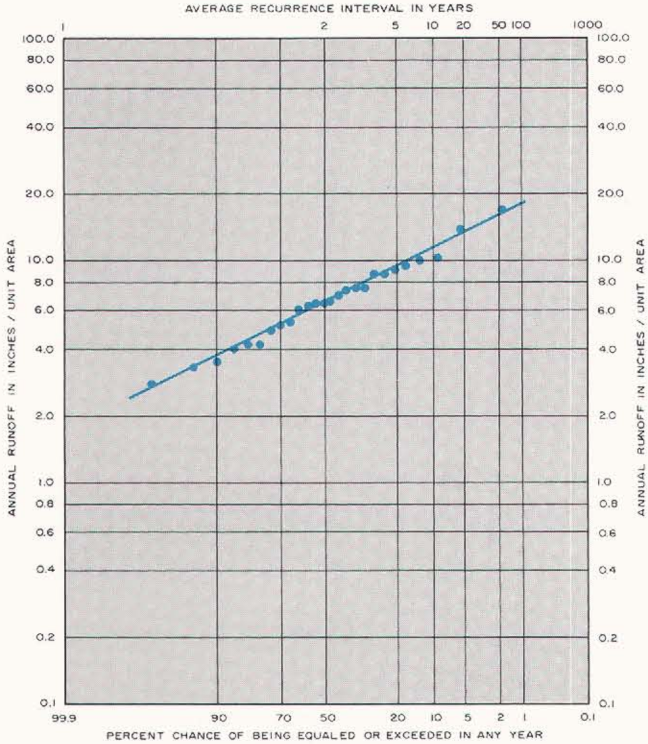
The annual extremes in stage at North Lake are shown in Figure 18. North Lake occupies about 350 acres at high stage and has no surface outlet. Lake levels have varied by more than 7.5 feet during the period of record. The recorded long-term variation in lake level at Browns Lake is 2.6 feet; at Silver Lake, 3.9 feet; and at Eagle Lake, 2.8 feet. High lake levels occur principally in the late winter and spring, usually associated with melting snow. Lower levels persist for most of the remainder of the year, with occasional rises caused by rainfall.

Of the four primary factors that influence the amount of lake storage, only surface runoff and ground water levels are expected to be altered by urban development. The effect of these two variables on lake levels can, like streamflow, be partially controlled through proper water management practices based upon a comprehensive watershed plan.

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, cli-

Figure 17
ANNUAL RUNOFF FREQUENCY
FOX RIVER AT WILMOT
FOR WATER YEARS 1940-1965



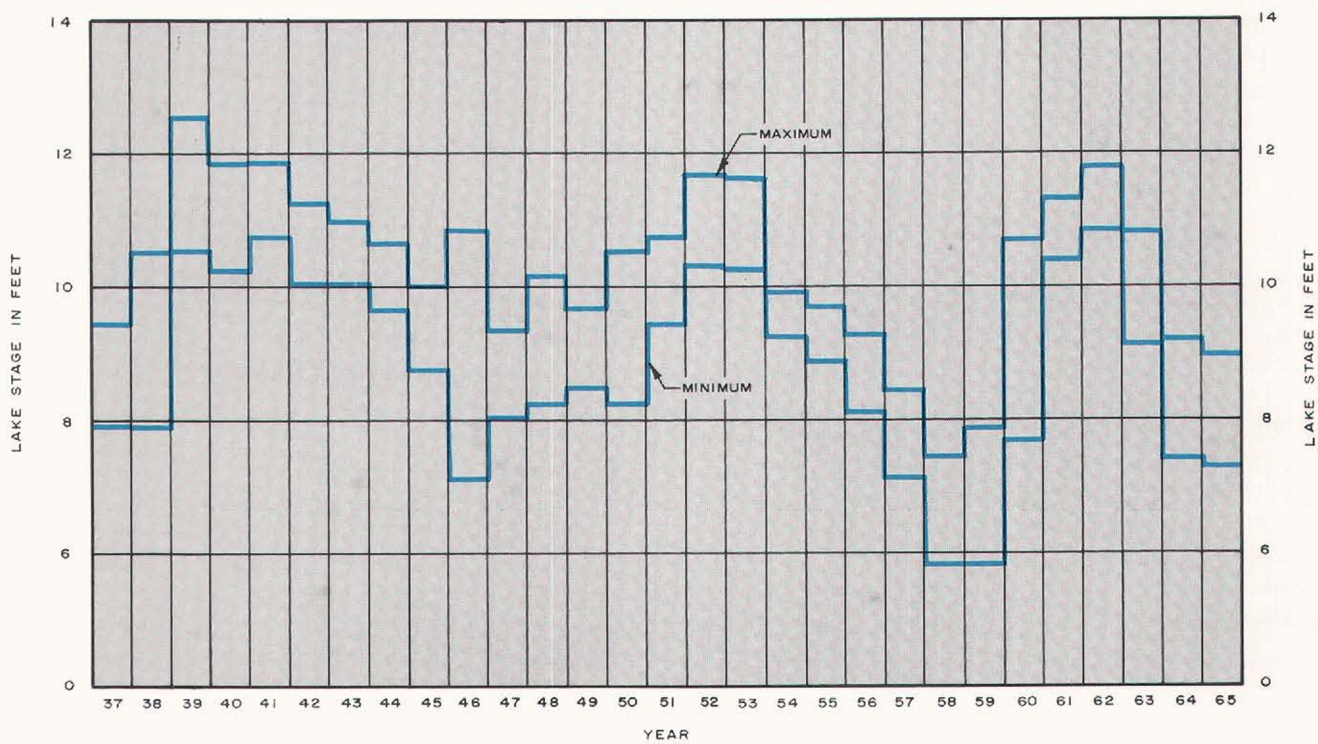
Source: U. S. Soil Conservation Service.

mate, soils, drainage pattern, and topography and such artificial features as water control and other hydraulic structures, artificial drainage and channel improvements, and land use. 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 15 of the 19 hydrologic subwatershed units of the Fox River watershed.

Size and Shape of the Watershed

The Fox River watershed within Wisconsin is a composite hydrologic unit of 19 subwatersheds, which drains in a general southerly direction and is a part of the Upper Mississippi River basin. The watershed is approximately 48 miles long and averages 20 miles in width, with the major axis running in an approximately north and south direction. The total watershed includes 14 subwatersheds having a combined area of 871 square miles, which drain into Illinois through the Fox River near Wilmot, Wisconsin; the Nippersink Creek subwatershed having a drainage area of 45 square miles, which drains into Illinois at Genoa City, Wisconsin, and joins the Fox River in the Chain-O-Lakes Region in Illinois; and four small subwater-

Figure 18
ANNUAL EXTREMES IN LAKE LEVELS AT NORTH LAKE

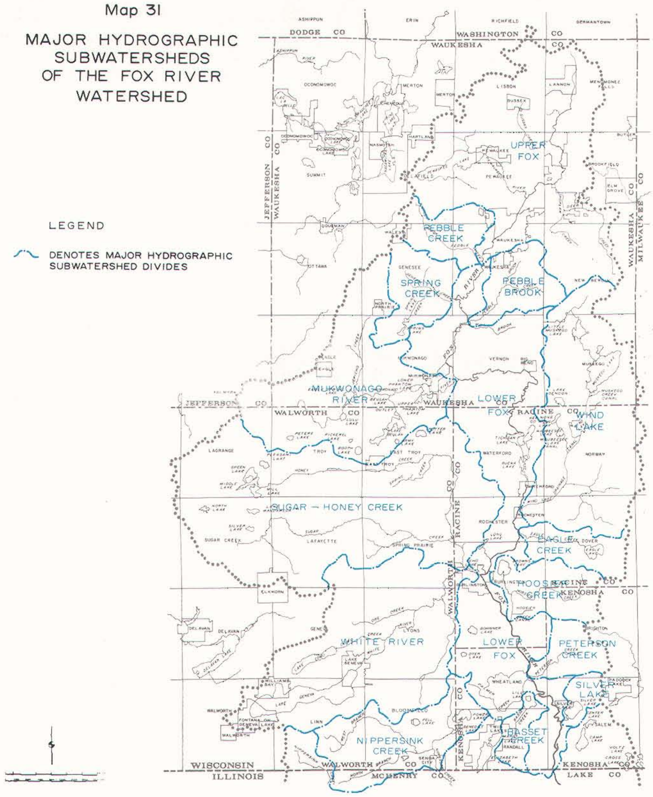


NOTE: LAKE STAGE GIVEN IN FEET ABOVE ASSUMED LAKE LEVEL STAGE DATUM SET BY STATE DEPARTMENT OF RESOURCE DEVELOPMENT; ELEVATION 0.00 OF LAKE LEVEL STAGE DATUM EQUALS ELEVATION 891.68 MEAN SEA LEVEL 1929 ADJUSTMENT.

Source: U. S. Soil Conservation Service.

Map 31

MAJOR HYDROGRAPHIC SUBWATERSHEDS OF THE FOX RIVER WATERSHED



Subwatersheds, representing relatively homogeneous subdivisions of the total watershed, were analyzed for their distinct natural and artificial hydrologic characteristics. This analysis provided a basis for estimating runoff characteristics for each subwatershed and for the basin as a whole.

Source: U. S. Soil Conservation Service.

sheds totaling 32 square miles, which drain directly into Illinois before joining the main stem of the Fox River. The hydrologic subwatersheds of the Fox River watershed and the main stem of the Fox River and its major tributaries are shown on Map 31.

Relationships of Climatic Factors to Runoff

The watershed has a continental climate with four distinct seasons, which results in two distinct surface water runoff distributions. The six-month period from November 1 through April 30 is characterized by snowmelt and long-duration, low-intensity, frontal-type precipitation creating runoff hydrographs with a long-time base, large volume, and relatively low-peak discharges. The six-month period from May 1 through October 31 generally produces hydrographs with a shorter-time base, lower volumes, and relatively high-peak discharges which result from convective thunderstorm-type precipitation generally in association with moisture laden frontal systems. These frontal systems move in a general southwest to northeast direction over the watershed. Typical hydrographs representing the two distinct surface water runoff distributions as gaged at Wilmot, and reduced to a unit graph basis, are shown on Figure 19.

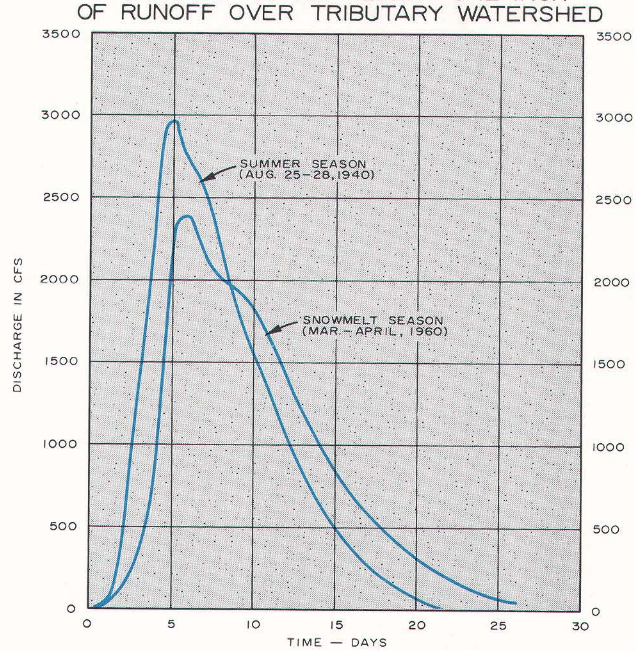
The distributional pattern of precipitation in the watershed results in the lowest values occurring during mid-winter and the highest values during mid-summer. Average annual runoff, however, does not follow this precipitation pattern. Although runoff is directly proportional to precipitation, all other factors being equal, it is inversely proportional to evapotranspiration, which increases during the growing season. This fact, coupled with the accumulative effect of snowmelt, results in 63 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 20).

Relationship of Soils to Runoff

Soils are a product of parent material, climate, organisms, relief, and time. An especially complex pattern of soil types has developed in the Fox River watershed in which glacial action deposited many different kinds of parent material and resulted in a landscape with varied local relief.

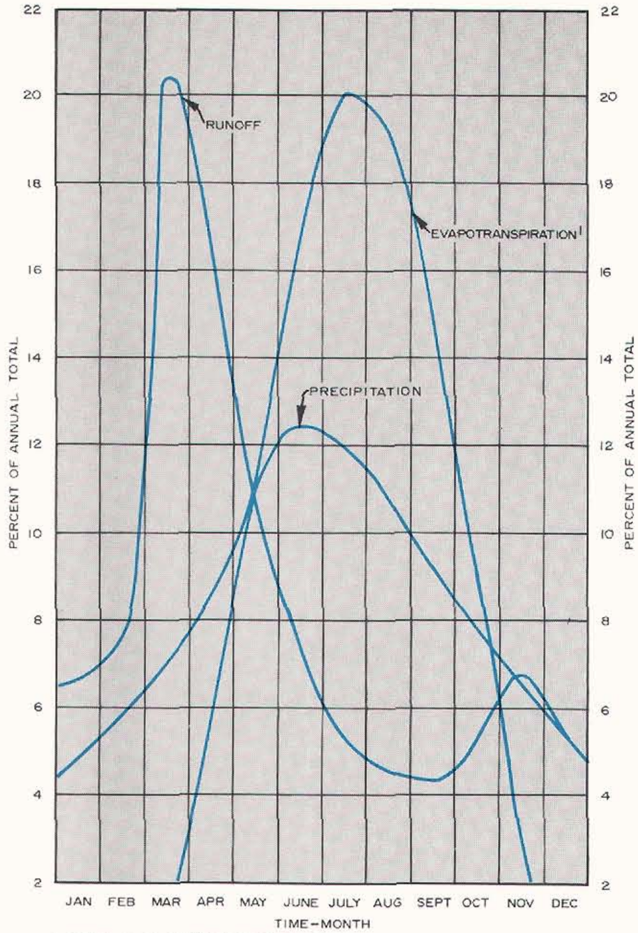
Figure 19

SURFACE WATER RUNOFF DISTRIBUTION FOR THE FOX RIVER AT WILMOT BASED ON LARGEST RECORDED EVENTS, ADJUSTED TO REPRESENT ONE INCH OF RUNOFF OVER TRIBUTARY WATERSHED



Source: U. S. Soil Conservation Service.

Figure 20
SEASONAL DISTRIBUTION OF PRECIPITATION, EVAPOTRANSPIRATION AND RUNOFF IN THE FOX RIVER WATERSHED



[1] BASED ON THE THORNWAITE EQUATION

Source: U. S. Soil Conservation Service.

Soil characteristics which affect surface water runoff include infiltration and transmission rates and, to some degree, moisture retention.

A detailed operational soil survey was completed for the entire watershed in 1966. As a part of that survey, the soils of the Southeastern Wisconsin Region 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. (See SEWRPC Planning Report No. 8, The Soils of Southeastern Wisconsin, pp. 243 to 259.) For the watershed as a whole, approximately 15 percent of the soils belong to Hydrologic Soils Group A, 55 percent to Group B, 10 percent to Group C, and 20 percent to Group D. This corresponds to 15 percent outwash terrace, 35 percent marginal moraine, 40 percent ground moraine, and 10 percent swamp deposits. Thus, for the watershed as a whole, the soils have moderate to moderately slow infiltration and transmission rates when wet, resulting in a moderate to moderately high surface runoff potential. A complete summary of the soil types by subwatershed is provided in Table 19.

Relationship of Drainage Pattern to Runoff

The drainage pattern of the Fox River watershed is basically dendritic, but much of the channel system is greatly 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 many 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 nonclimatic factor determining surface water runoff characteristics in the Fox River basin.

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 76 lakes within the Fox River watershed having a total surface area of 34.9 square miles. Most of these lakes occupy glacial lake basins formed in natural depressions at the time the ice sheets receded. Geologically, most of these lakes are temporary and will eventually be naturally drained when the surface drainage network of the watershed is fully developed.

There are 45 natural lakes of over 50 acres in surface area which have a combined area of 34.0 square miles, or 97.5 percent of the total lake surface area of the watershed. Table 20 sum-

Table 19

HYDROLOGIC SOIL GROUP SUMMARY BY SUBWATERSHED: 1966

Name of Subwatershed	Total Drainage Area (Square Miles)	Hydrologic Soil Group (Frequency of Occurrence)[a]			
		A	B	C	D
Upper Fox River . . .	131.6	m	P	C	C
Pebble Creek	18.0	m	P	m	C
Spring Creek	23.5	m	P	m	C
Pebble Brook	20.2	m	P	m	M
Mukwonago River . . .	91.2[b]	P	M	m	m
Wind Lake	93.5	m	C	M	M
Eagle Creek	15.8	m	M	M	C
Sugar-Honey Creek . .	170.2	C	P	m	C
White River	112.8	m	P	m	C
Hoosier Creek	23.7	m	C	M	C
Peterson Creek . . .	12.6	C	C	M	C
Bassett Creek	8.8[c]	C	P	m	m
Silver Lake	6.4	m	C	M	M
Lower Fox River . . .	142.7[d]	C	P	m	C
Nippersink Creek . .	44.7[e]	C	P	m	m
Total	915.7[f]	C	M	m	C

[a] *0 - 10 percent = Minor (m)*
10 - 25 percent = Common (C)
25 - 50 percent = Major (M)
Over 50 percent = Predominant (P)

[b] *Includes 3.7 square miles in Jefferson County, Wisconsin.*

[c] *Includes 0.1 square mile in Illinois.*

[d] *Includes 0.3 square mile in Illinois.*

[e] *Includes 4.9 square miles in Illinois.*

[f] *Does not include 32.1 square miles within four independent subwatersheds which drain directly into Illinois without contributing streamflow to any major stream in Wisconsin.*

Source: SEWRPC; U.S. Department of Agriculture, Soil Conservation Service.

Table 20

LAKES OF THE FOX RIVER WATERSHED

WITH SURFACE AREAS IN EXCESS OF ONE SQUARE MILE: 1966

Name of Lake	Total Drainage Area (Square Miles)	Surface Area (Square Miles)	Surface Area as Percentage of Drainage Area	Maximum Depth (Feet)	Estimated Volume (Acre Feet)	Subwatershed
Geneva Lake.	28.80	8.19	28.4	135	235,700[a]	White River
Pewaukee Lake. . . .	27.63	3.91	14.2	44	36,900[a]	Upper Fox River
Big Muskego Lake . .	16.60	3.55	21.4	23	13,600[a]	Wind Lake
Wind Lake.	14.51	1.70	11.7	47	10,900[a]	Wind Lake
Como Lake.	8.11	1.65	20.3	9	4,200[a]	White River
Lauderdale Lakes . .	24.07	1.30	5.4	57	12,600	Sugar-Honey Creek
Beulah Lake.	12.76	1.16	9.1	58	11,200[a]	Mukwonago River

[a] *Estimated volume based on mean depth and surface area.*

Source: Data compiled by the U.S. Soil Conservation Service.

marizes pertinent data for the seven lakes within the watershed which have water surface areas of over one square mile. There are no significant natural lakes on the main stem of the Fox River, all of the major lakes being located in the headwater regions of tributaries to the Fox River. All of these major lakes have relatively small surface water drainage areas and a high ratio of water surface to total drainage area. The locations of the lakes tend to give the tributaries a high degree of natural flood control through storage reduction of flood peak flows; but the effect on the main stem, although significant, is decreased considerably by the effect of large uncontrolled tributary drainage areas located downstream from the peripheral lake system. As indicated in Table 21, only 30. 0 percent of the Fox River basin, which exists as a composite hydrologic unit in Wisconsin, flows into natural lakes large enough to modify the discharge hydrographs significantly, even though an unusually high value of 3.6 percent of the entire area is in lake surface.

Another significant natural reduction of flood peaks on the Fox River and its major tributaries is derived from the substantial areas of permanent wetlands. The term permanent wetlands, as used herein, refers to all marshes, swamps, and other poorly drained areas of the watershed which remain saturated most of the year and are unsuitable for agricultural use or for urban use without artificial drainage. Map 21 shows the major areas of swamp deposits which are associated with poorly drained conditions. The amount and distribution of permanent wetlands by subwatershed is shown in Table 22. Study of 7 1/2 minute U. S. Geological Survey quadrangle maps indicates that about 4.2 percent of the Fox River watershed may be classified as wetland area, and nearly all of the area contributing to surface water runoff must

Table 21

PERCENT OF LAKE SURFACE AREA AND LAKE DRAINAGE AREAS BY SUBWATERSHED: 1966

Subwatershed	Total Drainage Area (Square Miles)	Surface Area of Major Lakes[a] (Square Miles)	Total Lake Surface Area[b] (Square Miles)	Drainage Area Tributary to Lakes (Square Miles)	Percent of Total Lake Surface Area To Total Drainage Area	Percent of Tributary Area to Total Drainage Area
Upper Fox River . .	131.6	3.9	4.0	27.6	3.0	21.0
Pebble Creek. . . .	18.0	---	---	---	---	---
Spring Creek. . . .	23.5	0.1	0.2	4.2	1.1	17.7
Pebble Brook. . . .	20.2	---	---	---	---	---
Mukwonago River . .	91.2[c]	2.9	3.4	87.4	3.7	95.8
Wind Lake	93.5	6.8	6.9	49.0	7.4	52.4
Eagle Creek	15.8	0.8	0.8	7.2	5.1	45.1
Sugar-Honey Creek[d].	170.2	2.4	2.7	34.4	1.6	20.2
White River	112.8	9.8	9.9	36.9	8.7	32.4
Hoosier Creek . . .	23.7	0.6	0.7	1.6	2.9	6.9
Peterson Creek. . .	12.6	---	---	---	---	---
Bassett Creek . . .	8.8[e]	0.1	0.2	0.5	1.7	5.7
Silver Lake	6.4	0.7	0.8	5.9	11.9	92.5
Lower Fox River . .	142.7[f]	1.9	2.0	7.0	1.4	4.9
Nippersink Creek. .	44.7[g]	1.1	1.1	5.5	2.6	12.6
Total	915.7[h]	30.5	32.7	267.2	3.4	29.2

[a] *Major lakes include all those that are 50 acres or larger.*

[b] *Total includes all lakes both larger than 50 acres and less than 50 acres.*

[c] *Includes 3.7 square miles in Jefferson County, Wisconsin.*

[d] *Includes 8.3 square miles of internal drainage.*

[e] *Includes 0.1 square mile in Illinois.*

[f] *Includes 0.3 square mile in Illinois.*

[g] *Includes 4.9 square miles in Illinois.*

[h] *Does not include 32.1 square miles within four independent subwatersheds which drain directly into Illinois without contributing streamflow to any major stream in Wisconsin.*

Source: U. S. Soil Conservation Service and the Wisconsin Department of Natural Resources.

eventually flow through at least a portion of these wetland areas.[5]

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. Since the major wetland areas are located on the main stem of the Fox River and the lower reaches of the major tributaries, they have little effect on the flow regimen in the headwater regions of the drainage network but do exert considerable influence on the flow regimen of the Fox River itself, resulting in significant reductions in peak outflows from the City of Waukesha to the state line. Major wetland areas which, due to their size and location, have an important effect on the surface water hydrology on the main stem include the Tamarac Swamp and Capitol Drive areas above Waukesha; the area along the Fox River from the confluence of the Mukwonago River to Waterford, including Tichigan Lake; large areas in the Wind Lake subwatershed; and the Honey Lake region of the Sugar-Honey Creek subwatershed. The Vernon Marsh area, south of the City of Waukesha and through which the Fox River flows, has perhaps the singularly most important effect on streamflow of the main stem of any wetland area within the watershed. This is due to its large areal extent, which ranges in size from 4.5 square miles at low flow to over 7.0 square miles at maximum flood stage, and its naturally constricted outlet. Routings through this marsh, which controls a drainage area of 221.3 square miles, have shown peak discharge reductions of approximately 60 percent for a 50-year snowmelt event and 70 percent for a 25-year rainfall event.

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, as well as other topographically low, flat areas subject to inunda-

[5] *This total does not include the extensive area of rooted, emergent aquatic vegetation within the lakes and streams of the basin, which were inventoried as wetland area, as summarized in Table 13. For the purpose of the hydrologic studies, these areas were inventoried only as surface water acreage.*

Table 22

SUMMARY OF SURFACE STORAGE AREAS BY SUBWATERSHED: 1966

Subwatershed	Total Drainage Area (Square Miles)	Surface Storage Areas (Square Miles)				Surface Storage Areas (Percent of Total)			
		Lake	Wetland[a]	Temporary[b]	Total	Lake	Wetland	Temporary	Total
Upper Fox River. . .	131.6	4.0	2.2	7.8	14.0	3.0	1.7	5.9	10.6
Pebble Creek	18.0	---	0.7	0.7	1.4	---	3.7	3.9	7.6
Spring Creek	23.5	0.2	1.0	1.6	2.8	1.1	4.0	6.8	11.9
Pebble Brook	20.2	---	0.9	1.7	2.6	---	4.4	8.2	12.6
Mukwonago River. . .	91.2[c]	3.4	4.3	2.1	9.8	3.7	4.7	2.4	10.8
Wind Lake.	93.5	6.9	4.7	3.0	14.6	7.4	5.0	3.2	15.6
Eagle Creek.	15.8	0.8	0.5	0.3	1.6	5.1	3.5	1.8	10.4
Sugar-Honey Creek. .	170.2	2.7	5.4	7.0	15.1	1.6	3.2	4.1	8.9
White River.	112.8	9.9	5.1	4.5	19.5	8.7	4.5	3.9	17.1
Hoosier Creek. . . .	23.7	0.7	0.4	1.5	2.6	2.9	1.7	6.3	10.9
Peterson Creek . . .	12.6	---	1.0	0.5	1.4	---	7.8	3.6	11.4
Bassett Creek. . . .	8.8[d]	0.2	0.3	0.4	0.9	1.7	3.4	4.8	9.9
Silver Lake.	6.4	0.8	0.4	0.6	1.7	11.9	6.1	8.9	26.9
Lower Fox River. . .	142.7[e]	2.0	9.6	11.4	23.0	1.4	6.7	8.0	16.1
Nippersink Creek . .	44.7[f]	1.1	1.9	2.8	5.8	2.6	4.3	6.4	13.3
Total	915.7[g]	32.7	38.3	45.8	116.8	3.5	4.2	5.0	12.8

[a] *Determined from marsh symbols on 7½ minute USGS quadrangle maps of the Fox River watershed.*

[b] *Includes floodplains and other areas of temporary surface storage during time of overbank flow.*

[c] *Includes 3.7 square miles in Jefferson County, Wisconsin.*

[d] *Includes 0.1 square mile in Illinois.*

[e] *Includes 0.3 square mile in Illinois.*

[f] *Includes 4.9 square miles in Illinois.*

[g] *Does not include 32.1 square miles within four independent subwatersheds which drain directly into Illinois without contributing streamflow to any major stream in Wisconsin.*

Source: ***U. S. Soil Conservation Service and the Wisconsin Department of Natural Resources.***

tion during periods of overbank flow. The latter may be comprised of marginal areas located around lakes and permanent wetlands with no perceptible 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 retardation effect during times of high stage, especially during the snowmelt season in the spring of the year when storage in the soil profile is least effective. The amount and distribution of temporary surface water storage area is summarized by subwatershed in Table 22, which indicates that the distribution of these areas is fairly uniform throughout the basin, with the largest area occurring in the Lower Fox River subwatershed as a wide floodplain.

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 the flat slopes, under generally full vegetative cover and with long overland flow distances, produce long times of concentration, resulting in low-peak, long-duration runoff contribution to the river channel system. Slopes in the western and southern portions of the watershed, especially in the Sugar Creek and White River areas, are steeper than the average and produce relatively higher peak discharges. Subwatersheds in the northern and eastern portions of the watershed, primarily in the Wind Lake area, have flatter slopes and produce relatively lower peak discharges.

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. The generally flat slopes of the Fox 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 Volume 2. A summary of mean bed slopes is presented in Table 23.

Channel and floodplain hydraulic roughness is still another feature which determines hydrograph shape and stage-discharge relationships. Roughness of the flow cross section, which is represented by the "n" value in the Manning formula, is a function of many factors, including degree of surface irregularity, variation of cross

Table 23

SUMMARY OF OVERLAND AND CHANNEL SLOPES BY SUBWATERSHED: 1966

Subwatershed	Length (River Miles)	Slope (Feet per Mile)	Overland Flow Slopes - Percent	
			Normal Range	Median
Upper Fox River. . . .	47.9	5.2	0.5 - 2.0	1.2
Pebble Creek	9.8	6.3	1.5 - 5.0+[a]	3.5
Spring Creek	8.1	24.8	1.0 - 2.5	2.0
Pebble Brook	13.5	7.9	0.8 - 2.5	1.5
Mukwonago River. . . .	24.1	8.4	0.3 - 2.2	1.1
Wind Lake.	17.6	2.1	0.5 - 2.0	1.0
Eagle Creek.	5.5	6.9	0.2 - 1.0	0.5
Sugar-Honey Creek. . .	52.1	4.6	2.0 - 5.0[b]	3.0
White River.	32.0	6.9	0.5 - 3.5	2.5
Hoosier Creek.	11.0	6.9	0.2 - 1.0	0.8
Peterson Creek	6.5	6.9	0.5 - 1.5	1.0
Bassett Creek.	4.5	11.1	1.0 - 3.0	2.3
Silver Lake.	0.9	18.0	0.8 - 1.8	1.2
Lower Fox River. . . .	60.5	0.9	0.2 - 2.0	1.1
Nippersink Creek . . .	5.2	5.1	1.2 - 4.0	2.4
Fox River Summary			0.8 - 2.6	1.7

[a] *Overland slopes approach 10 percent in some areas of Pebble Creek.*

[b] *Values as low as 0.5 percent exist in some areas of the Sugar-Honey Creek subwatershed.*

Source: U. S. Soil Conservation Service and SEWRPC.

section size and shape, obstructions and vegetation, and must be estimated by experienced engineers on the basis of visual observation. Stream channels and floodplains which provide considerable obstruction to flow have high "n" values and reduced velocity, which results in attenuated hydrographs and higher stages.

Average channel and floodplain "n" values are summarized by subwatershed in Table 24. The values of "n" may change radically 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 floods will be accompanied by unpredictable obstructions consisting of snow, ice, 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 WATERSHED

The preceding discussion was confined to the natural characteristics of the Fox 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 Fox River watershed has been changed significantly by the activities of man. Consequently, a complex of artificial or "unnatural" characteristics has been superimposed over 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 characteristics of a watershed provides him at once with a powerful tool for abating water-related problems if wisely used and a means for further creating severe environmental problems if improperly and thoughtlessly applied. Even intentional acts designed to directly affect the flow regimen, 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. Activities, such as the construction of roads and bridges and changes in land use which are not designed to change the hydrologic regimen do so in an incidental manner. It is, therefore, vitally

Table 24

MANNING FORMULA ROUGHNESS COEFFICIENT AVERAGE "n" VALUES BY SUBWATERSHED: 1966

Subwatershed	Channel		Floodplain		
	Number of Locations	Average "n" Value	Number of Locations	Number of Values	Average "n" Value
Upper Fox River.	42	0.054	45	161	0.076
Pebble Creek	5	0.044	7	24	0.070
Spring Creek	11	0.053	8	36	0.072
Pebble Brook	6	0.054	8	28	0.077
Mukwonago River.	12	0.052	13	48	0.080
Wind Lake.	13	0.045	11	42	0.073
Eagle Creek.	5	0.050	6	18	0.064
Sugar-Honey Creek. . . .	30	0.049	33	70	0.074
White River.	22	0.051	22	74	0.071
Hoosier Creek.	10	0.053	11	40	0.065
Peterson Creek	6	0.059	7	28	0.064
Bassett Creek.	4	0.061	5	16	0.076
Silver Lake.	3	0.050	3	8	0.057
Lower Fox River.	21	0.035	33	92	0.072
Nippersink Creek	4	0.045	5	14	0.079
Total	194	0.050	217	699	0.071

Source: U. S. Soil Conservation Service.

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 considering these separately before analyzing their combined effect upon the watershed. Accordingly, man's activities in the Fox 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 Fox River basin as a whole is treated briefly in the following discussion.

Water Control Structures

The Fox River watershed contains 43 man-made water control structures. 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. Twenty of the water control structures have been constructed at natural lake outlets to regulate and control lake levels for recreational purposes but do provide varying degrees of incidental benefits in the form of flood control and short periods of low-flow augmentation. 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.

The second type of water control structure, of which there are only eight in the basin, was originally built or rebuilt to impound water for recreational and aesthetic purposes. Even the most significant of these, the Barstow Street Dam in the City of Waukesha and Waterford Dam on the main stem of the Fox River, do not have enough storage to materially affect the peaks or durations of surface water runoff hydrographs during the spring runoff period. Except for the Tichigan Lake impoundment above the Waterford Dam, these structure sites have very little potential for flood control due to topographic restrictions.

The third type of water control structure was originally built for water power or water supply. These include low-head mill-pond dams in the western part of the basin and one industrial water supply impoundment dam at East Troy, Walworth County. With the advent of inexpensive areawide electrical power service, these low-head water power developments were abandoned; and the mill ponds 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 surface runoff events. Siltation and topographic restrictions, furthermore, impose serious limitations on these sites for future flood control development.

All water control structures in the Fox 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. Although there are no structures presently existing within the watershed which have been constructed primarily for flood control purposes, the existing dams do provide a very small 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 rather significant reduction in flood peak; but even under natural outflow conditions, flooding would probably not be a serious problem at these locations.

Map 32 shows the location and distribution of these artificial water control structures within the Fox River watershed. A summary of these structures by subwatershed and a brief description of each is given in Table 7.

Channel Improvement

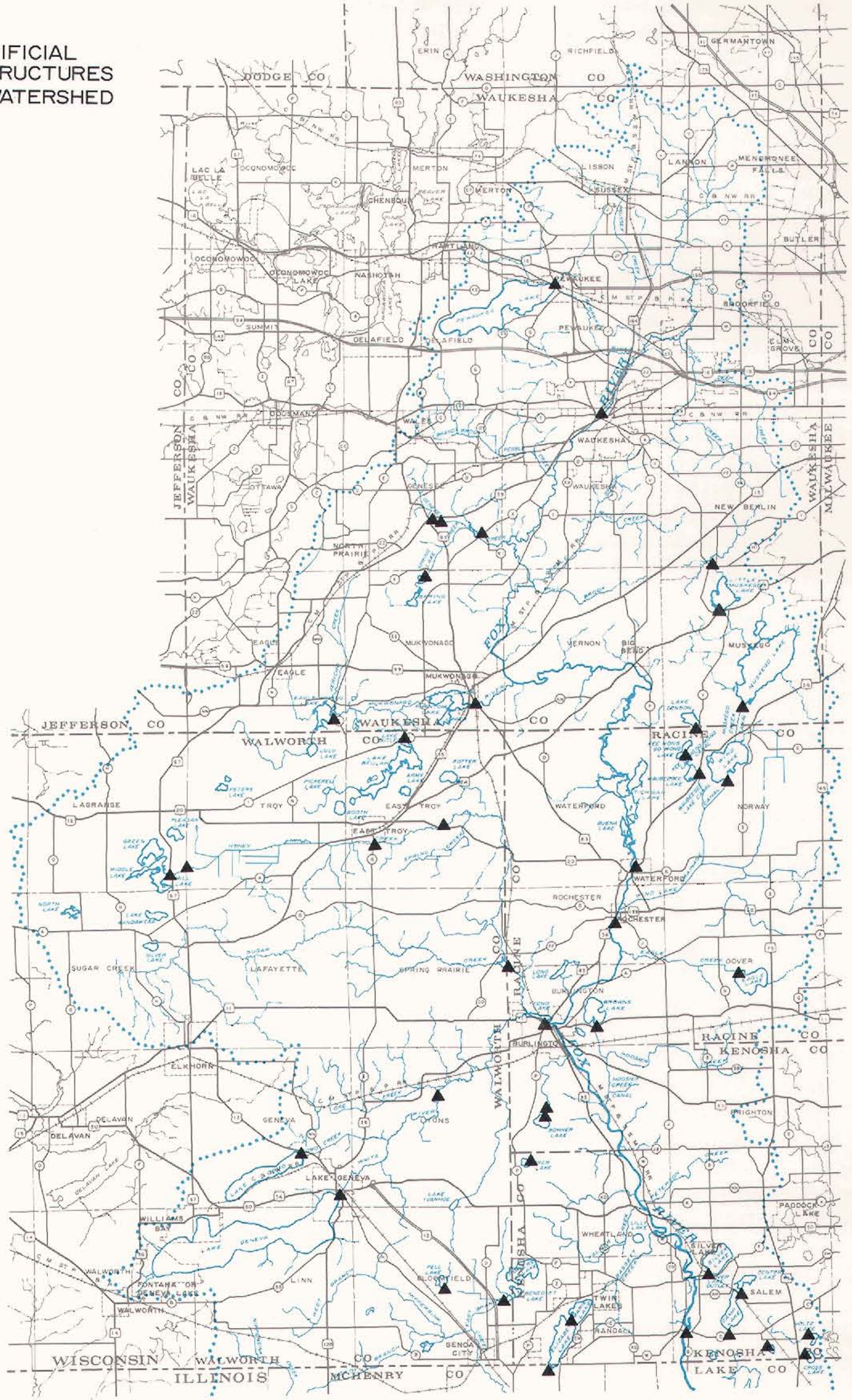
Many miles of the perennial stream system of the Fox River watershed have been intentionally modified by man in an attempt to improve their hydraulic characteristics. Channel improvement may consist of straightening, deepening, increasing the cross-sectional area, improving the horizontal grade line, or diking and generally involves all five phases, all of which result in increased velocity of flow and decreased time of concentration. Large portions of the Fox 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

Map 32

LOCATION OF ARTIFICIAL WATER CONTROL STRUCTURES IN THE FOX RIVER WATERSHED (1966)

LEGEND

▲ MILL DAMS



The 43 existing dams in the Fox River watershed tend to retard streamflow velocity and increase runoff time, thereby serving to decrease the peak rates of discharge.

Source: SEWRPC.

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 about the turn of the last century.

Although small channel improvements have been made in nearly every subwatershed of the Fox River basin, the most intense activity has occurred in the eastern part of the watershed, particularly in the Wind Lake subwatershed. The spatial distribution of channel improvements within the Fox River watershed is shown graphically on Map 3 (Chapter III) and is summarized in tabular form in Table 25. The data in Table 8 are based on measurements taken from 7 1/2 minute USGS quadrangle maps of the basin and include activities through 1960. Detailed tabulations are presented for the entire watershed and for the 15 hydrologic subwatershed areas.

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 reducing stage, although the peak flow rate may actually be increased. 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 thus establishes the need for proper water management practices based upon a comprehensive watershed plan.

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 Fox River watershed as a whole. Because of 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 Wilmot is hardly measurable. Nevertheless, the basic trends indicated previously are very real. In the Wind Lake subwatershed, for example, such activity has made possible the drainage of much valuable farm land, in some cases at the expense of somewhat higher downstream flood peaks. It should be stressed that channel improvement shortens the time of concentration and may cause tributary peaks which would ordinarily coincide to be offset enough to actually decrease the combined discharge rate. Of course, the opposite could also be true, in which case the changed time of concentration[6] may act to increase the combined discharge rate. It is obvious, therefore, that an attempt to generalize on the effect of channel improvement could be misleading and that each project has to be evaluated individually with all of these factors taken into consideration. The effect of channel improvement within the Fox River watershed under present conditions can be generalized only to the extent that most existing projects are confined to the headwater areas or to small tributaries where their influence is generally well dissipated by dominant natural conditions before the discharge enters the main channel system.

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 Fox River watershed have such poor surface drainage under natural conditions that it is necessary to install tile underdrains to permit efficient agricultural operations. The agricultural productivity of certain areas of the watershed, particularly in the northern and eastern parts of the watershed, has been raised from marginal hay and pasture land to highly productive row and truck crop areas through drainage improvements.

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 165 square miles, or 18 percent of the

[6] *See Chapter VII for definition of time of concentration.*

entire watershed area, has been tiled, with over 21 percent of this total lying within the Wind Lake subwatershed. Map 3 shows the spatial distribution of known tile-drained areas within the Fox River watershed basin. These areas are also summarized in tabular form for the entire watershed and for the 15 hydrologic subwatershed units in Table 25. 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 are often required to provide adequate outlets for the agricultural drain tiles.

The effect of artificial drainage on the flow regimen of a watershed is very difficult to analyze since the effect of the drainage is to reduce the surface water storage but to increase temporary soil water storage during the growing season. The net result may be to either increase or decrease the volume of surface water runoff. In spring when ice and snow conditions cause blocking of the drainage courses, there is probably little overall effect on natural flow conditions. Even during the frost-free months, when tile underdrains are fully operable, it would be misleading to generalize on the influence of the drains on the surface water hydrology. It is probable that areas that have been tiled to eliminate poor surface drainage would show an increase in surface runoff,[7] whereas areas that have been tiled to lower a high ground water table would show a decrease in surface runoff due to the increased storage made available in the dewatered soil profile. For the more infrequent high-intensity rainfall events, however, where soil infiltration capacity is a limiting factor, it is doubtful that tiling has any perceptible influence on the surface water hydrology. In any case, tile systems do lower the ground water level more quickly after periods of snowmelt or heavy precipitation, thereby enhancing the economic value of the drained land for agricultural use.

[7] *The increase would be due to tile drain effluent, which is not strictly surface runoff; but since it closely follows surface runoff and can be substantial in quantity, it is reasonable to consider it as a component of runoff from a rainfall event. Under natural conditions, however, percolation and eventual return to the channel system would be so slow that the same water would have to be considered a component of ground water effluent.*

Table 25

SUMMARY OF CHANNEL DRAINAGE IMPROVEMENTS IN THE FOX RIVER WATERSHED: 1966

Subwatershed	Drainage Area (Square Miles)	Channel Drainage Improvement[a]		Artificial Drainage	
		Miles	Miles Per Square Mile	Square Miles	Percent of Drainage Area
Upper Fox River	131.6	81.1	0.62	35.20	26.7
Pebble Creek	18.0	10.0	0.55	2.78	15.4
Spring Creek	23.5	9.8	0.42	4.76	20.3
Pebble Brook	20.2	9.5	0.47	2.76	13.7
Mukwonago River	91.2	11.4	0.12	1.08	1.2
Wind Lake	93.5	79.5	0.85	35.17	37.6
Eagle Creek	15.8	8.0	0.50	6.43	40.7
Sugar-Honey Creek . . .	170.2	60.6	0.36	24.33	14.3
White River	112.8	13.2	0.12	4.42	3.9
Hoosier Creek	23.7	17.4	0.74	19.49	82.2
Peterson Creek	12.6	5.3	0.42	1.81	14.4
Bassett Creek	8.8	---[b]	---[b]	---[b]	---[b]
Silver Lake	6.4	0.3	0.05	0.78	12.2
Lower Fox River	142.7	65.5	0.46	23.51	16.5
Nippersink Creek . . .	44.7	19.3	0.44	2.51	5.6
Total	915.7	390.9	0.43	165.03	18.0

[a] *Channel improvement is based on measurements taken from 7½ minute U. S. Geological Survey quadrangle maps.*

[b] *Negligible.*

Source: *U. S. Soil Conservation Service and SEWRPC.*

Roads, Bridges, and Culverts

There is a total of 251 highway and railroad crossings over the main channel system of the Fox River watershed in Wisconsin. The main channel system is herein defined as the perennial stream network for which hydraulic characteristics have been determined and includes the main stem of the Fox River and its major tributaries as shown on Map 31. The spatial distribution of the main channel system and the location of the crossings are shown graphically on Map 33. The greatest density of bridges and culverts occurs in and near the more heavily populated areas in the Upper Fox River subwatershed. A summary of these structures by subwatershed and a brief description of each is given in Table 7.

The number and type of crossing structures are summarized in tabular form for the entire watershed and for the 15 hydrologic subwatershed areas in Table 26. This tabulation shows that the greatest number of crossings per river mile is 1.67, which occurs in the Upper Fox River subwatershed; and the least number is 0.40 per river mile, which occurs in the Lower Fox River subwatershed. The average distance between crossings for the entire Fox River basin is approximately one mile.

Cultural features imposed upon the watershed by man include roadway and railway crossing embankments, bridges, and culverts. 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. These backwater curves have the effect of reducing 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. 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 a foot.

The backwater effect caused from stream crossings varies considerably from subwatershed to

Table 26

SUMMARY OF STREAM CROSSING STRUCTURES OF THE FOX RIVER WATERSHED: 1966

Subwatershed	Culverts (Span Less Than 20 Feet) Concrete Box	Concrete Pipe	Corrugated Metal Pipe	Bridges Over 20 Feet	Total Crossings	River Miles	Average Distance Between Structures In Miles
Upper Fox River	8	5	10	56	79	45.8	0.58
Pebble Creek	2	0	0	4	6	4.5	0.75
Spring Creek	3	0	2	3	8	6.8	0.85
Pebble Brook	2	2	1	6	11	9.8	0.90
Mukwonago River	4	1	2	5	12	16.9	1.40
Wind Lake	4	0	4	8	16	17.5	1.10
Eagle Creek	0	0	5	0	5	5.5	1.10
Sugar-Honey Creek	0	1	5	31	37	52.0	1.40
White River	1	0	5	26	32	27.8	0.85
Hoosier Creek	3	1	2	3	9	8.7	0.95
Peterson Creek	2	0	2	1	5	4.7	0.95
Bassett Creek	3	0	0	0	3	3.6	1.20
Silver Lake[a]	0	1	3	0	4	0.9	0.25
Lower Fox River	0	0	0	19	19	49.9	2.63
Nippersink Creek[a]	0	0	0	5	5	1.3	0.25
Total	32	11	41	167	251	255.7	1.02

[a] *These are not typical values for the subwatersheds since they include only downstream urban reaches of the channel system.*

Source: SEWRPC

Map 33

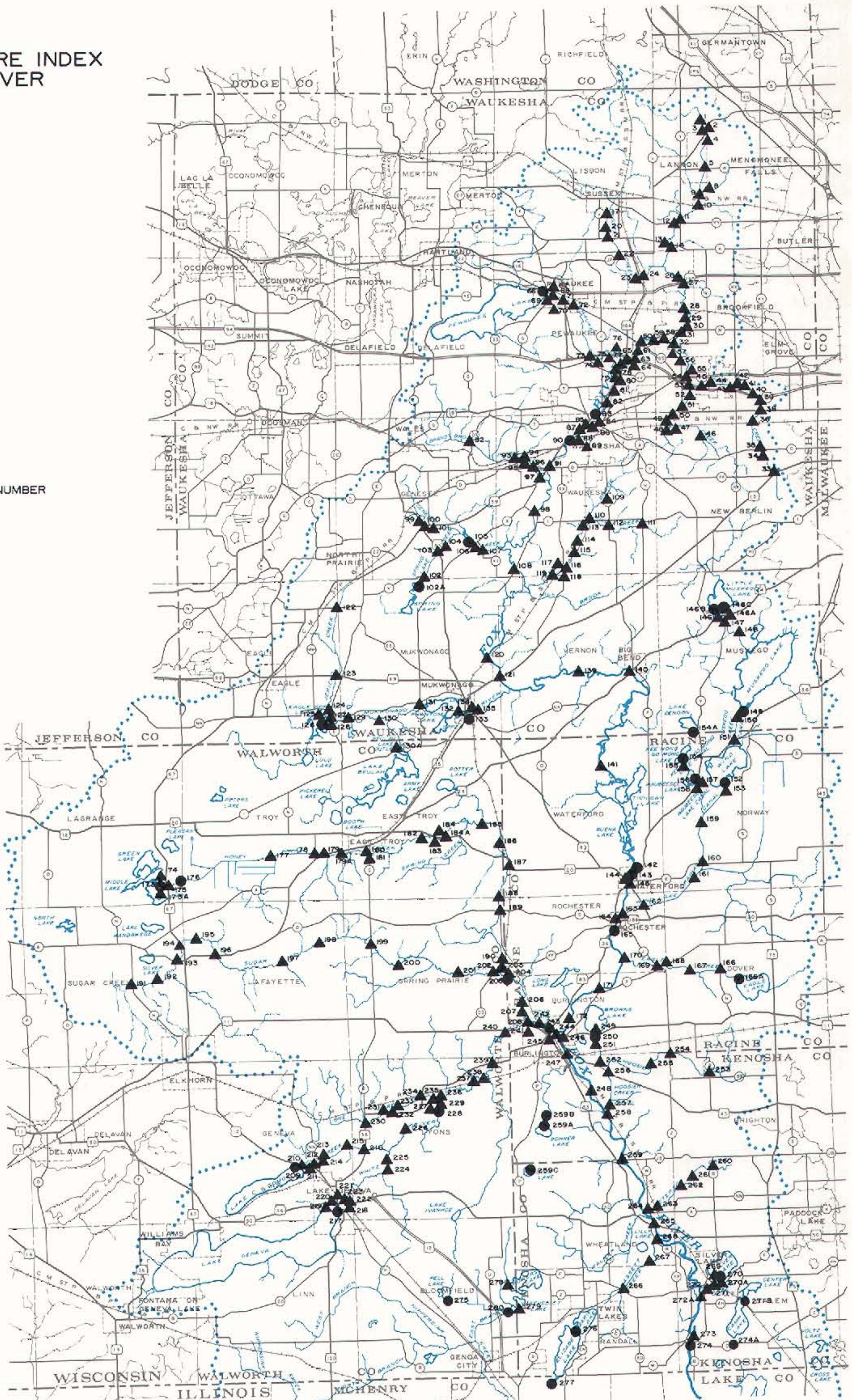
HYDRAULIC STRUCTURE INDEX FOR THE FOX RIVER WATERSHED (1966)

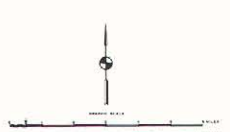
LEGEND

▲ DENOTES CULVERT OR BRIDGE

● DENOTES DAM

92 DENOTES STRUCTURE CONTROL NUMBER





As a part of the hydraulic capacity inventory, the 251 bridges, culverts, and the 43 dams affecting the flow capacity of the Fox River drainage system were surveyed to establish the dimensions and capacity of each structure. In addition a second-order bench mark based upon mean sea level datum was established for each structure.

Source: *SEWRPC.*

subwatershed within the Fox River basin. Where channel slopes are very flat and stream crossings are frequent, as in some areas of the Upper Fox River, bridges and culverts may waste over 50 percent of the potential energy head available to cause flow during a 100-year recurrence interval flood. For the watershed as a whole, the retardation effect is significant, although somewhat overshadowed by the much more significant influence of natural watershed characteristics.

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. Both the rainfall-runoff ratio and the time of concentration of the drainage area are functions of the amount of impervious surface and type of cover. The rainfall-runoff relationship may be expressed as a hydrologic soil-cover complex number[8] 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 of hydraulically rough surface.

The spatial distribution of the existing land uses within the watershed is summarized on Map 9 and in Table 8. About 1 percent of the total area of the watershed is devoted to commercial and industrial uses, which have the highest surface runoff potential; about 4 percent is devoted to transportation, utility, and off-street parking facilities; about 13 percent is in water and wetland; about 65 percent is devoted to agricultural use; about 5 percent is devoted to residential use; about 0.5 percent is devoted to governmental and institutional uses; about 1 percent is devoted to recreational use; about 2 percent consists of "unused" open land; and about 9 percent is in woodland cover, which has 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, surface water runoff may be nearly doubled. 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 Fox River basin, a precise quantitative analysis of the effect of this changed land use 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 in either wetland, prairie, or woodland, all of 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 susceptible to erosion. Both flood peaks and runoff volumes were probably increased by as much as 15 percent. Sedimentation problems increased, and small mill ponds began to silt up.

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

[8] *The 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 VII, ''Estimation of Runoff.''*

Urbanization: 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. 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 on 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 for extremely low-density residential development.

The preceding discussion is valid for summer rainfall events, but major floods in the Fox River watershed are more likely to be associated with snowmelt conditions when the soil is either frozen or saturated and the retention capacity for concurrent rainfall is practically nil. Effectively then, the entire area of the watershed is impervious regardless 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 runoff is less. It can be concluded that flood peaks from urban areas under snowmelt conditions may be either slightly higher or lower than under agricultural conditions; but indications are that they are generally higher, 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.

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 may 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 Fox River basin explained. The general relationships which have been developed for the basin as a whole also apply to the 15 subwatersheds which have been chosen as basic hydrologic units. The hydrologic subwatershed units, which vary in size from 6.4 to 170.2 square miles, were determined on the basis of their hydrologic similitude and generally correspond to the naturally defined watersheds of the major tributaries at their confluence with the main stem of the Fox River. Each subwatershed is homogeneous enough that it can be reasonably considered as having uniform climatic, hydrologic, geologic, and geomorphologic characteristics.

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 of flow to the main stem of the Fox River, beginning with the Upper Fox River watershed, which is the most northerly subwatershed and the headwaters of the basin, and ending with the Nippersink Creek subwatershed adjacent to the Illinois State line.

Upper Fox River Subwatershed

The Upper Fox River subwatershed, which includes most of the City of Waukesha, has an areal extent of 131.6 square miles and is composed of 20 subarea units. The principal bedrock is Silurian dolomite, with a small area in the extreme western part underlain by Maquoketa shale. Ground moraine covers 73 percent of the subwatershed, resulting in many tight subsoils. Hydrologic Soil Type B is predominant; but C and D type soils are common, especially in the eastern part. Surface water storage areas cover 11 percent of the total area; 3 percent is lake surface, nearly all of which consists of Pewaukee Lake; and 2 percent is marsh, with the largest contiguous areas in the Tamarac Swamp and near the Capitol Drive Airport. Floodplain and other temporary storage areas make up the remaining 6 percent of the surface water storage area. Slopes for overland flow are steeper in the western portion than in the east but fall within the range of 0.5 to 2.0 percent. Channel slopes average 5.2 feet per mile, with a mean coefficient of roughness of "n" = 0.054. Compared to the watershed as a whole, the Upper Fox River subwatershed has slightly higher-than-average surface runoff potential per unit area, but a lower peak discharge per inch of runoff.

The Upper Fox River subwatershed includes a natural lake level control structure at Pewaukee Lake and the Barstow Street Dam in the City of Waukesha. Channel improvement to facilitate drainage is the third highest for the watershed, and about 26.7 percent of the area has artificial drainage. There are 79 stream crossing structures on about 46 miles of channel system for which hydraulic characteristics have been determined, giving the Upper Fox River subwatershed the highest representative structure density in the watershed. Twenty-four percent of the area is devoted to urban land use, making it by far the most urbanized area in the Fox River basin. The Upper Fox River subwatershed has been more modified by man's activity than any other subwatershed.

Pebble Creek Subwatershed

The Pebble Creek subwatershed, which contains the western portion of the City of Waukesha, is composed of four subarea units and has an area of 18.0 square miles. The principal bedrock is Silurian dolomite with a small amount of Maquoketa shale occurring in the extreme western part of the subwatershed. Ground moraine is the predominant surficial deposit, covering 72 percent of the surface. Hydrologic Soil Type B is found

Wetlands cover only about 8 percent of the total area, which is less than any other subwatershed. Approximately half of the wetlands is permanent marsh, most of which is in the peat bog area adjacent to the kettle moraine; and the remainder is temporary storage along the channel system. Pebble Creek subwatershed is one of three subwatersheds with no lake storage. Slopes for overland flow are extremely variable but are among the steepest in the entire basin. Channel slopes average 6.3 feet per mile, with a mean coefficient of roughness of "n" = 0.044.

Based on natural flow characteristics, this subwatershed has a surface runoff potential per unit area about equal to the average for the basin; but the peak discharge per inch of runoff is the highest of the 15 subwatersheds, due primarily to the lack of lake storage and the relatively steep overland slopes.

The Pebble Creek subwatershed has no water control structures to modify streamflow, but it does have a rather high ratio of improved channel per unit area. Only about 15.4 percent of the area has artificial drainage facilities. The average distance between stream crossing structures on the main channel is about 0.75 mile. It is the second most urban subwatershed, with 15 percent of the land area devoted to this purpose, of which over half is residential land use. The Pebble Creek subwatershed probably experiences somewhat higher peak discharges as the result of man's activities.

Spring Creek Subwatershed

The Spring Creek subwatershed has an areal extent of 23.5 square miles and is composed of six subarea units. The principal bedrock is Silurian dolomite with perhaps an extremely small area underlain by Maquoketa shale. End moraine covers 71 percent of the subwatershed, resulting in quite variable soils and topography. Hydrologic Soil Type B is predominant, but D type soils are common in association with wetland areas.

in over 70 percent of the watershed, and most of the remainder is D type soils found in association with wetlands.

Surface water storage areas cover 12 percent of the total area; only about 1 percent is lake surface, consisting of three small lakes; and 4 percent is marshland, with the largest areas at Spring Lake and near the mouth of the creek. Floodplain and other temporary storage areas make up the remaining 7 percent. Slopes for overland flow are generally mild and variable, falling within the range of 1.0 to 2.5 percent. Channel slopes average 24.8 feet per mile, with a mean coefficient of roughness of "n" = 0.053. The hydraulic roughness factor for overbank flow averages "n" = 0.072.

Compared to the Fox River watershed as a whole, the Spring Creek subwatershed has a somewhat lower surface runoff potential per unit area; but the peak discharge per inch of runoff is above average. The Spring Creek subwatershed has one mill pond development and two small recreation dams. Improved channel averages about 0.4 mile per square mile of area, with about 20.3 percent of the subwatershed drained artificially by tile systems. Average spacing between stream crossing structures is somewhat less than the watershed average. Urbanization covers only about 7 percent of the area, while 71 percent is used as cropland. Artificial characteristics are probably less of a factor in the Spring Creek subwatershed than for the watershed as a whole.

Pebble Brook Subwatershed

The Pebble Brook subwatershed is composed of five subarea units totaling 20.2 square miles. Bedrock is exclusively Silurian dolomite, which dips toward Lake Michigan. Surface deposits from glaciation are almost exclusively ground moraine, with only about 10 percent of the area covered with other deposits. Hydrologic Soil Type B is the most common, but Type D is a major soil along the channel system and in the lower part of the basin.

Over 12 percent of the total area is classified as wetland, of which 8 percent is temporary storage area and the remainder, permanent marsh, is distributed along the channel system. Despite the relatively high percentage of surface water storage area, there are no lakes in the Pebble Brook subwatershed. Slopes for overland flow are moderate. Channel slopes average approximately 7.9 feet per mile, with a mean coefficient of roughness of "n" = 0.050. The rather marshy nature of the floodplain results in a fairly high floodplain roughness of "n" = 0.077.

An evaluation of natural flow characteristics indicates that this subwatershed has one of the highest surface runoff potentials of the 15 subwatersheds. However, the peak discharge per inch of runoff is typical for the Fox River basin due to the flat slopes and marshy conditions along the channel system, which offset the lack of natural lake storage.

The Pebble Brook subwatershed presently has no water control structures, but its ratio of improved channel per square mile is somewhat higher than the watershed average. Tile systems have been installed in 13.7 percent of the subwatershed to aid drainage. There are 11 stream crossing structures in the 10-mile channel system, resulting in a crossing density somewhat greater than the watershed average. Nearly 15 percent of the area is devoted to urban land use, of which over half is residential. The combined effect of man's activities probably tends to increase flood volumes and peaks within the Pebble Brook subwatershed.

Mukwonago River Subwatershed

The Mukwonago River subwatershed has eight subarea units and an areal extent of 91.2 square miles, which is about 10 percent of the total watershed area. Bedrock consists of all three major formations occurring in the southeastern area of the watershed and includes Silurian dolomite, Maquoketa shale, and Platteville-Galena dolomite, all in significant amounts. Surficial glacial deposits are primarily coarse-grained outwash terraces and end moraine, with only minor amounts of ground moraine and swamp deposits. The Mukwonago River subwatershed is the only subwatershed where the predominant hydrologic Soil Type is A. B soils are common also, but C and D soils are very minor.

Nearly 11 percent of the total subwatershed is classified as surface water storage area, of which approximately 4 percent is lake surface. About 5 percent of the remainder is marshland in association with the lakes and along portions of the Mukwonago River itself. Over 90 percent is controlled by natural lakes, and only 2 percent is temporary floodplain storage area. Overland slopes vary quite widely but generally fall within the range of 0.3 to 2.2 percent. The average channel slope on the Mukwonago River is 8.4 feet per mile. The mean channel roughness coefficient is "n" = 0.052, but the floodplain has the highest average hydraulic roughness in the entire watershed at "n" = 0.080.

The combined effect of the natural flow characteristics would indicate that the Mukwonago River subwatershed has the lowest surface runoff potential, as well as nearly the lowest peak discharge per inch of runoff.

The Mukwonago River subwatershed has two natural lake level control structures and one combination water power and lake level site on Eagle Spring Lake. Improved channel per unit area is much less than the watershed average, and only about 1.2 percent of the subwatershed has artificial drainage facilities. The average distance between stream crossing structures is 1.40 miles, which is much greater than the watershed average. Only about 8 percent of the area is urbanized, most of which is low-intensity residential land use. This subwatershed is probably one of the least modified subwatersheds, with respect to surface water characteristics resulting from man's activity.

Wind Lake Subwatershed

The Wind Lake subwatershed is similar to the Mukwonago River subwatershed in that it consists of eight subareas and accounts for approximately 10 percent of the total watershed area at 93.5 square miles. At this point all similarity ceases, however, since bedrock consists entirely of one major formation, which is Silurian dolomite. Surface deposits left from glaciation are mostly ground moraine, along with significant amounts of end moraine and swamp deposits. Exactly contrary to that of the Mukwonago River subwatershed, the major hydrologic soil type is C. D soils are also very common, but A and B soils are minor.

Surface water storage areas in this subwatershed total nearly 16 percent of the land area. Numerous lakes, including Wind and Big Muskego Lakes, having surface areas in excess of one square mile, account for about 8 percent of the available storage area and effectively control more than 50 percent of the drainage area. The remaining wetland consists of 3 percent temporary storage and 5 percent marshland fairly well distributed throughout the subwatershed. Both overland and channel slopes are very flat, which reduces peaks and increases hydrograph modification. The average channel roughness value of "n" = 0.045 is quite low partly due to channel improvement, while floodplain hydraulic roughness is about average at "n" = 0.073.

An analysis of natural flow characteristics indicates that Wind Lake has the highest surface runoff potential but very low values of peak discharge per inch of runoff. Wind Lake subwatershed has five water control structures, all of which have been constructed to help regulate natural lake levels. A majority of the length of the Wind Lake subwatershed drainage channels have been improved to facilitate the naturally poor drainage characteristics of this area. Underdrains have been installed in about 37.6 percent of the area. The average distance between stream crossings is about 1.1 miles. Urbanization is very near the watershed average at 11 percent, of which slightly less than one-half is residential. Artificial characteristics, primarily in the form of channel improvement and drainage, have probably modified the surface runoff regimen of the Wind Lake subwatershed significantly as compared to strictly natural conditions.

Eagle Creek Subwatershed

The Eagle Creek subwatershed is one of the smaller subwatersheds, consisting of two subareas and having an area of 15.8 square miles. It is underlain exclusively by one major bedrock formation, Silurian dolomite. Surficial glacial deposits consist almost entirely of ground moraine and some end moraine. The major Hydrologic Soil Group is C, although both B and D soils are common.

Slightly more than 10 percent of the total subwatershed is classified as surface water storage area, of which 3 percent is interspersed marsh and less than 2 percent is floodplain and other temporary storage. Eagle Lake, which controls 5 percent of the water storage area and also controls 45 percent of the drainage area accounts for the balance of the wetland. Overland slopes are flatter than the watershed average and fall within the range of 0.2 to 1.0 percent. The channel has a mean slope of about 6.9 feet per mile and a hydraulic roughness of about "n" = 0.050. The average roughness coefficient for areas of overbank flow is "n" = 0.064, making it one of the lowest in the Fox River basin.

The Eagle Creek subwatershed appears to have a rather high surface runoff potential but a peak discharge per inch of runoff relationship which is somewhat lower than the watershed as a whole.

The Eagle Creek subwatershed has one water control structure located at the outlet of Eagle Lake. Channel improvement exceeds the watershed average, but tile underdrains are used on about 40.7 percent of the area. There are five stream crossing structures on the 5.5 miles of channel analyzed. Urban land uses occupy less than 7 percent of the subwatershed, which has the highest percentage of cropland in the Fox River basin. The combined effect of man's activity within the Eagle Creek subwatershed is probably typical of the watershed as a whole.

Sugar-Honey Creek Subwatershed

The Sugar-Honey Creek subwatershed is the largest single subwatershed in the Fox River basin, consisting of 16 subarea units and a total area of 170.2 square miles. Bedrock geology consists of all three major formations, including Silurian dolomite, Maquoketa shale, and Platteville-Galena dolomite. Glacial geology and topography are extremely variable. The northern and western half of the subwatershed is much like the Mukwonago River subwatershed, with very permeable outwash terrace and kettle moraine (Green Bay and Lake Michigan Interlobate Moraine) having good internal drainage and many areas which do not contribute directly to surface runoff. The southern and eastern half is primarily ground moraine and swamp deposits, which have much lower infiltration rates. Soils follow the same pattern, with the southern half having soils which fall into Hydrologic Soil Groups A and B. Soils in the eastern half are primarily classified as B and D.

Somewhat less than 9 percent of the area is open water and wetland, making Sugar-Honey Creek subwatershed next to the dryest subwatershed in the Fox River basin. Less than 2 percent is natural lake surface, of which the Lauderdale Lake system is most significant. About 3 percent is marsh; and 4 percent is temporary storage, most of which is floodplain along the main channel system. Overland slopes are among the steepest in the watershed. Sugar Creek is the most entrenched and has the best defined floodplain of any major tributary in the Fox River system. Channels have an average slope of 4.6 feet per mile and an overall roughness coefficient of "n" = 0.049. Floodplains have hydraulic rough ness values averaging "n" = 0.074, which falls into the median range of the watershed.

Favorable soil conditions and internal drainage areas, which reduce the effective area contributing to surface runoff, give the Sugar-Honey Creek subwatershed one of the lowest surface runoff potentials per unit area. However, other hydrologic factors tend to give the hydrograph a somewhat higher-than-average peak discharge per inch of runoff.

The Sugar-Honey Creek subwatershed has a total of six water control structures, one of which helps regulate natural lake levels, three that were originally built for water power, and two strictly for recreational purposes. There has been considerable channel improvement along the main channel system, but actual tile underdrains have been installed on only 14.3 percent of the subwatershed. Stream crossing structures are less frequent than on any other subwatershed except in the Lower Fox area. Urban land use accounts for only about 5 percent of the area, so that the Sugar-Honey Creek watershed, along with the Peterson Creek subwatershed, is the least urban in character. Nearly 75 percent of the subwatershed is devoted to cropland. Artificial streamflow characteristics probably have less effect on this area than on any of the subwatershed areas.

White River Subwatershed

The White River subwatershed has 11 subarea units totaling 112.8 square miles, or about 12 percent of the entire watershed. Bedrock is primarily Silurian dolomite, but smaller areas of both Maquoketa shale and Platteville-Galena dolomite do exist in the western part. The predominant glacial deposit is end moraine, which gives the subwatershed variable topography interspersed with wetlands. Over 60 percent of the soils are classified as Hydrologic Soil Group B, with A and D soils making up the balance.

Surface water storage areas cover 17 percent of the subwatershed, which is second only to the Silver Lake subwatershed. Almost 9 percent is lake surface consisting of two large lakes, Geneva and Como Lakes, both of which have surface areas much in excess of one square mile (see Table 22). Together these lakes control drainage from about a third of the subwatershed. Marsh and temporary storage areas in about equal portions account for the remaining 8 percent of wetland. Both overland and channel slopes are quite variable though steeper than the average for the watershed. The former ranges from 0.5 to 3.5 percent, while the latter averages 6.9 feet per mile. Channel and floodplain roughness coefficients are typical of the watershed, with values of "n" = 0.051 and "n" = 0.071, respectively.

A combined analysis of natural flow characteristics shows the expected surface runoff potential for the White River subwatershed to be slightly less than average. Peak discharge per inch of runoff is somewhat higher, however.

The White River subwatershed has four water control structures. Two serve as lake level controls; one is used for recreation; and the fourth was originally constructed for water power. Channel improvement has been localized and minor, with less than 3.9 percent of the area drained artificially by tiling. There are 32 stream crossing structures on the main channel system. Urban land use exists in about 13 percent of the area, much of which is recreational land and, therefore, seasonal in nature. The effect of man's activities in the White River subwatershed is probably about typical of the entire watershed.

Hoosier Creek Subwatershed

The Hoosier Creek subwatershed accounts for less than 3 percent of the study area but consists of five subareas totaling 23.7 square miles. The major bedrock formation is exclusively Silurian dolomite. Surface material, which has been transported and deposited by glacial action, consists primarily of ground moraine and older end moraine. There is no one predominant hydrologic soil group within the subwatershed since B, C, and D soils are all present in about equal amounts and even A soils are quite common.

Surface water storage areas account for nearly 11 percent of the total, with 6 percent being floodplain and other temporary storage. Lake surface covers 3 percent but only controls 7 percent of the drainage area. Marsh storage is less than 2 percent. Both overland and channel slopes are relatively flat, with the former ranging from 0.2 to 1.0 percent and the latter averaging about 6.9 feet per mile. Channel and floodplain roughness coefficients are "n" = 0.053 and "n" = 0.065, respectively.

In comparison with the other subwatersheds, this area has a rather high surface runoff potential. However, peak discharge per inch of runoff is average to only slightly higher than average compared to the Fox River watershed in general. The Hoosier Creek subwatershed has a lake level control structure at the outlet of Browns Lake. A very large percentage of channel system has been artificially improved to facilitate natural surface drainage. About 82.2 percent of the area is served by tile drain systems. The average distance between stream crossings is a little less than one mile on the main channel system. About 7.5 percent of the area is devoted to urban land use. Artificial characteristics, especially channel work, has probably had a significant effect on the surface water runoff characteristics of the Hoosier Creek subwatershed.

Peterson Creek Subwatershed

The Peterson Creek subwatershed has an areal extent of only 12.6 square miles consisting of two subareas. The entire region is underlain by the Silurian dolomite formation. The primary surface deposit from glacial action is ground moraine, but end moraine and outwash terrace cover about 30 and 15 percent of the surface, respectively. Soils vary widely with respect to their effect on surface runoff. Hydrologic Soil Group C is the most common, followed by Group D, A, and B in order of prevalence.

This subwatershed has no natural lakes of any significant size, but a poorly defined system results in a higher percentage of permanent marsh than in any other subwatershed. Nearly 8 percent of the surface area is marsh, which is distributed throughout the subwatershed. Less than 4 percent is available for temporary storage. Overland slopes are very flat, and the channel system is poorly defined and irregular. The average hydraulic roughness coefficient for the channel is high at "n" = 0.059, but the floodplain roughness of "n" = 0.064 is lower than the watershed average.

Combined hydrologic characteristics tend to give the Peterson Creek subwatershed higher-than-average surface runoff potential, but the large amount of marsh storage reduces the peak discharge considerably below the watershed mean despite the absence of lake storage.

The Peterson Creek subwatershed has no water control structures, and channel improvement activities are about typical for the watershed at 0.40 mile per square mile of drainage area. Only 14.4 percent of the area has been tiled to improve soil drainage. There are five stream crossing structures on the 4.7 miles of stream channel for which hydraulic characteristics have been determined. This subwatershed, together with the Sugar-Honey Creek subwatershed, are the least urbanized. Only about 5 percent is urban, but a disportionately high value of nearly 0.4 of this is commercial and industrial. Peterson Creek subwatershed is probably one of the least modified subwatersheds.

Bassett Creek Subwatershed

The Bassett Creek subwatershed is a small subwatershed consisting of two subareas totaling 8.8 square miles. Geology consists of Silurian dolomite bedrock covered by glacial deposits, which at the surface are primarily end moraine, along with some ground moraine and outwash terrace. Soils predominantly belong to Hydrologic Soil Group B, although a significant amount of A soils is also present.

About 10 percent of the subwatershed is classified as surface water storage area, of which 5 percent is floodplain and other temporary storage. Approximately 3 percent is permanent marsh concentrated in the lower reaches, and 2 percent is lake surface consisting of Lilly Lake. Overland slopes are somewhat steeper than average, and the main channel has a drop of 11.1 feet per mile. Both channel and floodplain roughness coefficients are rather high, averaging "n" = 0.061 and 0.076, respectively.

A combined analysis of natural flow characteristics indicates a relatively low surface runoff potential, but the peak discharge per inch of runoff is one of the highest in the entire watershed.

The Bassett Creek subwatershed has no water control structures, and both channel improvement and artificial drainage are negligible. Stream crossing frequency is less than one structure per mile, and urbanization accounts for less than 9 percent of the total area. The surface water runoff characteristics of the Bassett Creek subwatershed have probably been modified less by the activities of man than nearly any other area in the Fox River watershed.

Silver Lake Subwatershed

The Silver Lake subwatershed, which has an area of only 6.4 square miles, is the smallest of the 15 subwatersheds. It lies in the region of Silurian dolomite bedrock and has a surficial cover consisting almost entirely of end moraine. Soils fall into a range of three hydrologic soil groups, B, C, and D, in nearly equal proportions.

Silver Lake subwatershed also has the distinction of possessing the largest percentage of wetland area, nearly 27 percent. Silver Lake itself is the dominant feature, giving the subwatershed 12 percent lake surface. The remainder consists of 6 percent well-distributed marshland and nearly 9 percent temporary storage, most of which is contiguous to the permanent marsh. Overland slopes are flat and irregular, and the main channel below the Silver Lake Outlet has an average drop of 18.0 feet per mile. Floodplain roughness below Silver Lake is the lowest for the watershed at "n" = 0.057. Channel roughness, however, is about "n" = 0.050, which is near average.

The dominant influence of Silver Lake, which controls over 92 percent of the drainage area, is responsible for giving this subwatershed the lowest peak discharge per inch of runoff. The surface runoff potential for natural conditions, however, is second only to the Wind Lake subwatershed.

The Silver Lake subwatershed has a natural lake level control structure at the outlet of Silver Lake. Very little channel improvement or artificial drainage has been done. The value of four stream crossing structures per mile is not representative since this is based only on the downstream urban reach of the channel. Less than 10 percent is devoted to urban uses, of which nearly one-third is used for commerce and industry. In view of the overwhelming natural influence of Silver Lake, man's activities have probably had less influence here than elsewhere.

Lower Fox River Subwatershed

The Lower Fox River subwatershed consists of the main stem of the Fox River below the City of Waukesha and includes the area not accounted for by the other subwatersheds above the state line. It is the second largest subwatershed, with 142.7 square miles; and it is divided into 15 subareas. Silurian dolomite is the major bedrock formation for the subwatershed, but small areas near the Village of Mukwonago are underlain by Maquoketa shale. Most of the Lower Fox River flows between low moraine ridges, but each of the other three glacial deposits also occurs over more than 10 percent of the area. Nearly half of the soils are classified in Hydrologic Soil Group B, with most of the remainder being A and D soils in approximately equal proportions.

About 16 percent of the subwatershed is classified as wetland, with approximately half of this being floodplain storage. Nearly 7 percent is permanent marsh, of which a major portion exists as one contiguous unit in the Vernon Marsh. Natural lakes are relatively insignificant. Overland slopes range from 0.2 to 2.0 percent, and the average gradient of the Fox River through the subwatershed is 0.9 feet per mile. Hydraulic roughness coefficient for the floodplain is "n" = 0.072, and for the channel it is "n" = 0.035.

Both the surface runoff potential and the peak discharge per inch of runoff are somewhat lower than the watershed average, based on the combined influence of the natural flow characteristics.

The Lower Fox River subwatershed has three water control structures and nearly a half mile of channel improvement per square mile of drainage area. Underdrains have been installed in approximately 16.5 percent of the area. In the 50 miles of stream channel, there are only 19 crossings, giving the Lower Fox River subwatershed the lowest stream crossing density at an average interval of 2.6 miles. About 9 percent of the subwatershed is in urban land use. Modification of flow characteristics is probably about typical of the watershed as a whole.

Nippersink Creek Subwatershed

The Nippersink Creek subwatershed, which does not join the Fox River in Wisconsin, has an area of 44.7 square miles. Bedrock is exclusively Silurian dolomite overlain by a mantle of end and ground moraine of nearly equal area. The predominant hydrologic soil group is B, but A soils are also common.

Thirteen percent of the area is classified as wetland, of which 6 percent is floodplain and other temporary storage. Lake surface accounts for less than 3 percent, and the remaining 4 percent is permanent marsh. Overland slopes are variable though relatively steep. The channel has a slope of about 5.1 feet per mile and an average roughness coefficient of "n" = 0.045. Floodplain roughness is "n" = 0.079, which is rather high for the watershed as a whole.

An analysis of the combined natural flow characteristics suggests that Nippersink Creek subwatershed is typical of the Fox River watershed with respect to surface runoff potential, but peak discharge per inch of runoff is much higher than for the Fox River basin as a composite unit.

This subwatershed has two natural lake level control structures. Channel improvement exists in localized areas, and artificial drainage has been installed in about 5.6 percent of the area. The number of stream crossings per mile of channel, shown in Table 9, is not typical of the subwatershed, since only the urbanized area around Genoa City is included. About 9 percent of the area is in urban land use. The combined influence of man's activity probably does not vary much from the watershed as a whole.

Other Subwatersheds

In addition to the 15 subwatersheds consisting of 109 subareas, there are four more independent subwatersheds, which drain a total of 32.1 square miles in Wisconsin but do not contribute this runoff to any major channel system within the state. The geographic location of these subwatersheds is shown on Map 39.

SUMMARY

This chapter has described those elements of the complex hydrologic environment of the Fox 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 31.8 inches annually. Surface water runoff and evapotranspiration losses constitute the primary outflow from the basin. The average annual runoff approximates 6.8 inches, while the annual evapotranspiration loss to the watershed totals about 25.0 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 and most productive of the three aquifer systems. Wells tapping this aquifer are sometimes more than 2,000 feet deep and are, 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 is the principal source of water supply for municipalities and large industrial and commercial firms.

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 Fox 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 28-year streamflow record of the Fox River at Wilmot, 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 VI

ANTICIPATED GROWTH AND CHANGE IN THE FOX 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 Fox 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 Fox River watershed within the rapidly urbanizing Southeastern Wisconsin Region is an important factor affecting forecast requirements and methods. Economic activity affecting development within the Fox 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 on the basis of broader regional forecasts of economic activity and employment levels and of population growth.

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, which comprise approximately 7 percent of the total area of the watershed, are particularly important in this respect because it is here that the problems and opportunities arising out of a rapidly changing land use pattern will most affect the other elements of the natural resource base and the quality of the total environment within the watershed. The upland areas of the watershed will also be affected by urban and rural land development, particularly by the conversion of woodlands and prime agricultural lands to urban uses; but the effect upon the total environment will be less than that of urbanization in the riverine areas. The water resource will be 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 demand placed upon the lakes and streams of the watershed and the ability of these lakes and streams to meet water use objectives and standards.

POPULATION AND ECONOMIC ACTIVITY

Several basic methods for preparing population and economic activity forecasts for planning areas are in common use. For each of these methods, a variety of specific procedures and techniques have been developed; and, depending on the use of the forecasts, each method possesses certain advantages and disadvantages. Because the Fox River watershed is an integral part of the Southeastern Wisconsin Region, population and employment growth within the watershed are closely related to population and economic changes in the Region as a whole. Thus, forecasts of future population and economic activity prepared for the Region as a whole, together with an analysis of the historic relationship between population and economic growth in the watershed and in the Region, can provide a basis for the forecast of future watershed population and employment levels. Forecasts for a relatively large area, such as the Southeastern Wisconsin Region, can be prepared with a much higher degree of reliability than for a smaller area, such as the Fox River watershed, and thus provide the best basis for the smaller area forecasts. It was, therefore, decided to derive the necessary population and employment forecasts for the Fox River watershed from regional forecasts by a land use allocation method and then to check these forecasts by the more traditional ratio method.

Population Forecasts

The Commission has prepared population forecasts for the Region to the year 1990, based upon economic, as well as demographic, studies and analyses and using several independent methods. These forecasts estimate the 1990 population level of the Region at 2,678,000 persons, an increase of about one million persons over the 1963 level of 1,674,000 persons.[1] As indicated in Table 27, the population of the Fox River watershed has steadily increased from a level of 47,268 persons in 1900 to 159,500 persons in 1963, an increase over the period of 225 percent. Based upon the allocation of land uses within the watershed, as set forth in the adopted regional land use plan, this level is forecast to increase to 359,000 persons by 1990, or by an additional 125 percent. It should also be noted that the watershed is expected to account for an increasing proportion of the regional population—from 9.5 percent in 1962 to 13.4 percent by 1990 (see Table 27). While this forecast represents a very rapid 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 this projected level to be reasonable, particularly in light of the location of the watershed within the seven-county Region (see Figure 21). The population distribution within the watershed for 1990 is depicted on Map 34 by the overall gross density of each sub-watershed.

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 1963. The average household size within the watershed is expected to decrease from the present level of about 3.54 persons to approximately 3.30 persons by 1990 due, in part, to a decline in the birth rate and, in part, to an increasing rate of household formation. The average household income within the watershed is also expected to parallel the regional income forecasts; that is, to increase

[1] *The forecasts prepared as a part of the regional land use and transportation planning program and the assumptions and techniques employed are set forth in SEWRPC Planning Report No. 7, Volume 2, Chapter III.*

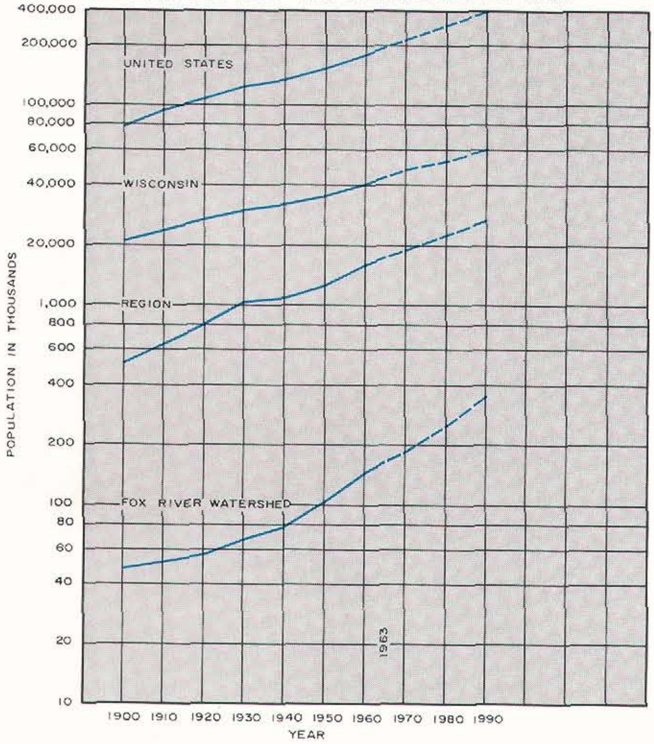
Table 27

POPULATION TRENDS AND PROJECTIONS FOR THE UNITED STATES, WISCONSIN, THE REGION, AND THE FOX RIVER WATERSHED: 1900 - 1990

Year	United States	Wisconsin	Region	Fox River Watershed	Watershed Population as a Percent of the Regional Population
1900	75,994,575	2,069,042	501,808	47,268	9.4
1910	91,972,266	2,333,860	631,161	50,151	7.9
1920	105,710,620	2,632,067	783,681	54,672	7.0
1930	122,775,046	2,939,006	1,006,118	64,106	6.4
1940	131,669,270	3,137,587	1,067,699	75,126	7.1
1950	151,325,798	3,434,575	1,240,618	100,061	8.1
1960	179,323,175	3,952,771	1,573,620	143,064	9.1
1963	188,616,000	4,061,000	1,674,000	159,500	9.5
1970	208,996,000	4,511,000	1,870,000	188,000	10.1
1980	245,313,000	5,176,000	2,223,000	252,000	11.3
1990	288,219,000	5,977,000	2,678,000	359,000	13.4
1963-1990 Percentage Increase	52.8	47.2	60.0	125.1	

Source: U. S. Department of Commerce, Bureau of the Census; SEWRPC.

Figure 21
POPULATION TRENDS AND FORECASTS FOR THE UNITED STATES, THE STATE OF WISCONSIN, THE SOUTHEASTERN WISCONSIN REGION AND THE FOX RIVER WATERSHED: 1900-1990



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

from the 1963 level of approximately $8,700 per household to a 1990 level of approximately $14,000 per household. It is also anticipated that the average resident of the watershed in 1990 will be better educated and have a greater amount of leisure time available to him than in 1963.

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 Fox River watershed, may lie outside the watershed itself. The watershed, and particularly the headwater 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, Racine, and Kenosha urbanized areas. 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 headwater portions of the watershed and in the area surrounding the City of Waukesha. 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 28 , employment opportunities within the watershed are forecast to increase from the 1963 level of 33,500 to a 1990 level of 96,800, an increase of 189 percent.

LAND USE DEMAND

The requirements of approximately 359,000 residents for dwelling space and service facilities will largely determine the amount and variety of each of the various land uses within the Fox River watershed in 1990. If present trends were to continue without regulation in the public interest, it appears likely that the approximately 199,500 new residents which the watershed would gain between 1963 and 1990 will live primarily in residential areas developed at low and medium densities.

An analysis of urban development within the watershed from 1950 to 1963 indicates that about 75 percent of the residential development during this period occurred in the form of low-density development, about 24 percent in the form of medium-density development, and only about 1

Table 28
EXISTING AND FORECAST EMPLOYMENT WITHIN THE FOX RIVER WATERSHED AND THE SOUTHEASTERN WISCONSIN REGION: 1963 AND 1990

Area	Existing 1963		Increment 1963-1990		Total 1990	
	Number	Percent of Region	Number	Percent Change	Number	Percent of Region
Fox River Watershed	33,500	5.2	63,300	188.9	96,800	9.8
Region.	634,900	100.0	349,100	54.9	984,000	100.0

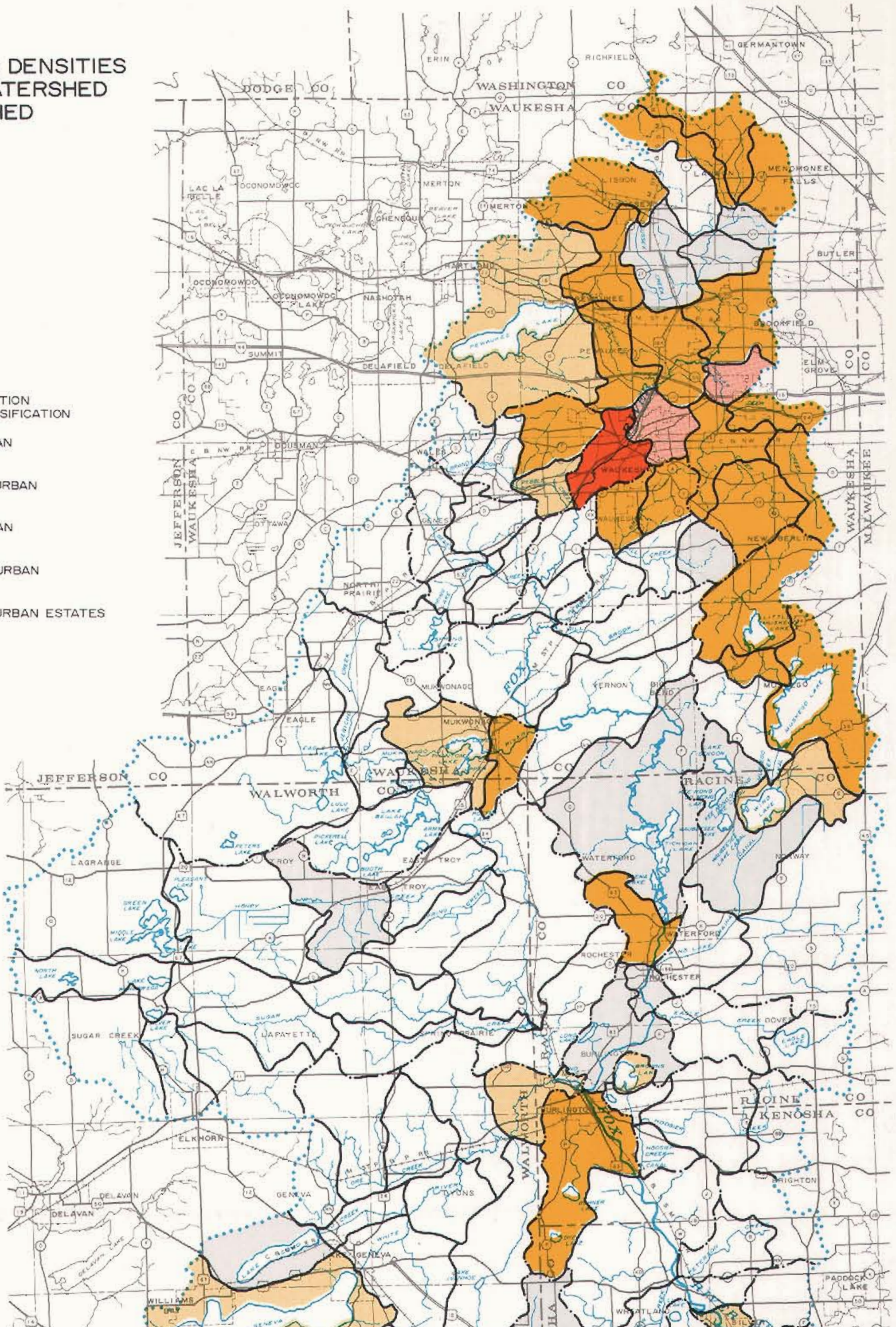
Source: SEWRPC.

Map 34

FORECAST POPULATION DENSITIES IN THE FOX RIVER WATERSHED BY SUBWATERSHED (1990)

LEGEND

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



Population within the watershed is expected to continue to be concentrated in the headwater areas, complicating the flood and water pollution problems.

Source: SEWRPC.

percent in the form of high-density development.[2] The analysis further indicates that, for the Region as a whole, 98 percent of the population resides in households and that the average household size in 1960 was 3.30 persons.

For land use demand forecast purposes, therefore, it was assumed that 98 percent of the population increase in the watershed from 1963 to 1990 would reside in households with an average household size of 3.30 persons. It was further assumed that, if existing trends continue, at least 70 percent of the new households within the watershed would reside in low-density residential areas, that 28 percent would reside in medium-density residential areas, and that 2 percent would reside in high-density residential areas. The slightly greater proportions of medium- and high-density use reflect anticipated changes in this respect as recommended in the adopted regional land use plan. Commercial and industrial land use demand was forecast using existing land use-to-population ratios of 8.3 acres per 1,000 additional persons and 8.1 acres per 1,000 additional persons, respectively. Governmental and institutional land use demand was forecast using a land use-to-population ratio of 11 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 33 percent 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 was forecast for the major land use categories, as shown in Table 29. Comparison with existing land use data indicates that the continuation of present residential land development trends within the watershed would result in an increase in residential land use from 47.91 square miles in 1963 to 106.97 square miles in 1990, an increase of 123 percent. All other urban land uses would increase from 57.78 square miles in 1963 to 94.40 square miles in 1990, or 63.4 percent. This total demand for urban land would be satisfied primarily by conversion of agricultural lands, woodlands, and wetlands, which would collectively decline by 95.68 square miles, or 11.5 percent.

SUMMARY

It is estimated that the population of the Fox River watershed will increase from the 1963 level of 159,500 persons to 359,000 persons by 1990, an increase of about 125 percent in the 27-year period. The level of economic activity, measured at 33,500 jobs in 1963, will increase to 96,800 jobs by 1990, an increase of about 189 percent. It is also anticipated that the population of the watershed will share in the increased levels of income, educational achievement, and leisure, as the Region in general.

If the present trend toward a low-density, highly diffused pattern of urban development is projected to 1990, residential land use will more than double. Accordingly, supporting land uses will increase about 63 percent. In turn, the expansion of urban development within the watershed under forecast conditions would require the conversion of nearly 96 square miles, or about 12 percent of the existing open land resources of the watershed.

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[2] *Low-density residential development is defined as 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 (350-9,999 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 29

FORECAST LAND USE DEMAND IN THE FOX RIVER WATERSHED

Land Use Category	Existing Land Use 1963		Incremental Land Use Demand 1963-1990		Total Land Use 1990	
	Acres	Square Miles	Acres	Square Miles	Acres	Square Miles
URBAN LAND USE						
Residential	*30,664*	*47.91*	*37,800*	*59.06*	*68,464*	*106.97*
Low-density.	24,675[a]	38.56	33,900	52.96	58,575	91.52
Medium-Density	5,740[a]	8.96	3,800	5.94	9,540	14.90
High-Density	249[a]	0.39	100	0.16	349	0.55
Commercial	1,324[b]	2.07	1,656	2.59	2,980	4.66
Industrial	1,297[c]	2.03	1,616	2.53	2,913	4.55
Mining	2,909	4.56	--	--	2,909	4.56
Transportation	22.793[d]	35.61	14,608	22.83	37,401	58.44
Governmental	2,204[e]	3.44	2,753	4.30	4,957	7.75
Recreational	6,446	10.07	2,793	4.36	9,239	14.44
Total Urban Land Use	67,637	105.69	61,226	95.67	128,863	201.37
RURAL LAND USE						
Agricultural	388,847	607.58	--	--	471,916	737.36
Water, Woodlands Wetlands	144,295	225.46	--	--		
Total Rural Land Use	533,142	833.04	--	--	471,916	737.36
Total Land Use	600,779	938.73	--	--	600,779	938.73

[a] *Estimated from 1963 land use inventory information.*

[b] *Includes 242 acres of on-site parking.*

[c] *Includes 121 acres of on-site parking.*

[d] *Include utilities; excludes 484 acres of off-street parking.*

[e] *Includes institutional uses and 121 acres of on-site parking.*

Source: SEWRPC.

Chapter VII

FLOOD CHARACTERISTICS AND DAMAGE

INTRODUCTION

Flooding of the perennial stream system of the Fox 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 by flood-vulnerable urban and rural land uses, together with development-induced changes in the hydrologic regimen of the watershed, has increased flood risks from a nuisance level during predominantly agricultural occupation of the watershed to substantial proportions with urbanization. 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 control, and river engineering, will direct new development into patterns which are compatible with the demands of the river system on its floodplains and seek a mutual adjustment between development and flood needs.

HYDROLOGIC CHARACTERISTICS OF FLOODS

Historic Floods

The Fox River, while having a history of relatively frequent minor flooding, has experienced few major floods in recent times. The two events most readily recalled by residents of the watershed are the floods of March-April 1960 and July 1938. The combination of climatological events which caused the 1960 flood was 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. Studies by the U. S. Weather Bureau[1] indicate that a snow cover with this water equivalent has a 4 percent chance of occurring in March. Temperatures, after having been below normal for most of the month, began to rise on the 27th of March and reached a high of 62°F on the 29th. 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 35, and from this map it was determined that the average depth of rainfall on the watershed during this 24-hour period was 1.5 inches. Seasonal precipitation studies by the U. S. Weather Bureau[2] indicate that a storm of this magnitude has a 5 percent chance of occurring in March. The probability of such rain and snow cover occurring together is the product of their individual probabilities. Therefore, the probability of these two events occurring in combination in late March of any year is 0.2 percent.

These two unusual events combined to produce a peak flood flow of 7,520 cfs at the U. S. Geological Survey gaging station at Wilmot. A discharge of 2,300 cfs was measured at Waukesha; however, it is believed that this measurement was taken after the peak flow had passed. Figure 22 shows the hydrograph of the 1960 flood at Wilmot. Synthesized hydrographs of the 1960 flood event at several other points in the river system are shown in Chapter VIII.

Although the 1960 flood was the highest recorded in the 28 years that the U. S. Geological Survey has operated the gaging station at Wilmot, it was not an event of such rare magnitude or severity in other parts of the watershed. Generally, floods generated by snowmelt are most severe on large rivers. Smaller tributaries are more sensitive to high-intensity rainfalls and generally do not produce record flood peaks as a result of snowmelt.

[1] *Frequency of Maximum Water Equivalent of March Snow Cover in North Central United States*, Technical Paper No. 50, U. S. Department of Commerce, Weather Bureau, 1964.

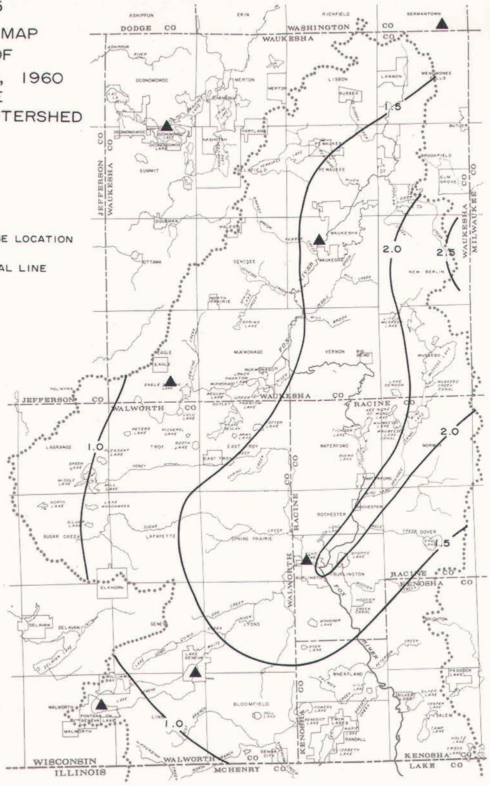
[2] *Rainfall Frequency Atlas of the United States*, Technical Paper No. 40, U. S. Department of Commerce, Weather Bureau, 1961.

Map 35
ISOHYETAL MAP
STORM OF
MARCH 29-30, 1960
IN THE
FOX RIVER WATERSHED

LEGEND

▲ DENOTES RAIN GAGE LOCATION

1.0 DENOTES ISOHYETAL LINE



The severe flood event of 1960 was caused by a 24-hour rainfall over the watershed of about 1.5 inches, as shown, occurring on frozen ground having a snow cover equivalent to 2.8 inches of water. (This resulted in a peak flood flow of 7520 cfs at Wilmot equivalent to a runoff of 2.6 inches over the tributary watershed)

Source: SEWRPC.

The flood that occurred in July 1938 is an example of how portions of the watershed may respond to high-intensity rainfalls. The storm that produced this flood appears to have been centered over the Village of Williams Bay in Walworth County where 6.76 inches of rain were recorded in less than 24 hours. The storm began on June 30 and continued into July 1. The isohyetal map, Map 36, shows that part of the storm which covered the area upstream from the Echo Lake dam in Burlington. A discharge of 4,140 cfs was measured by the U. S. Geological Survey at the outlet of Echo Lake following this storm. The discharge that occurred at the outlet of Echo Lake during the 1960 flood is not known; however, residents of the area upstream from the dam indicate that the 1938 flood was much more severe.

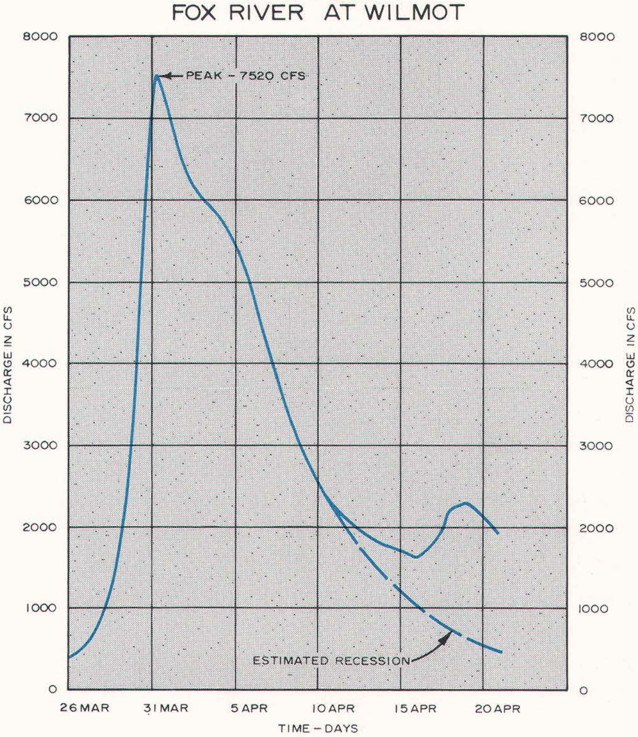
Seasonal Nature of Floods

The record of river discharge obtained since 1940 at the Wilmot dam by the U. S. Geological Survey shows that most floods in the last 28 years have occurred during the late winter or early spring. The date of occurrence of the 28 annual flood peaks is shown in Figure 23. During the 28 years, 16 of the yearly peaks, including the three highest recorded, have occurred in March or April. In 1946 the highest discharge during the year occurred on the 7th of January. Although severe floods are unusual in January, it is not uncommon for sudden thaws to occur at this time of the year and produce minor floods.

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 and not as severe as spring floods. Several factors contribute to this absence of major summer flood events during the 28-year period of streamflow recorded at Wilmot. Summer floods generally result from the rapid rate of runoff that accompanies high-intensity storms. The hydraulic characteristics of the watershed above Wilmot, however, are such that intensive rainfall will not usually produce large flood peaks on the Fox River. This is due to the large amount of natural storage above Wilmot which normally is available

Figure 22

HYDROGRAPH OF THE MARCH-APRIL 1960 FLOOD FOX RIVER AT WILMOT



Source: U. S. Soil Conservation Service and SEWRPC.

Map 36

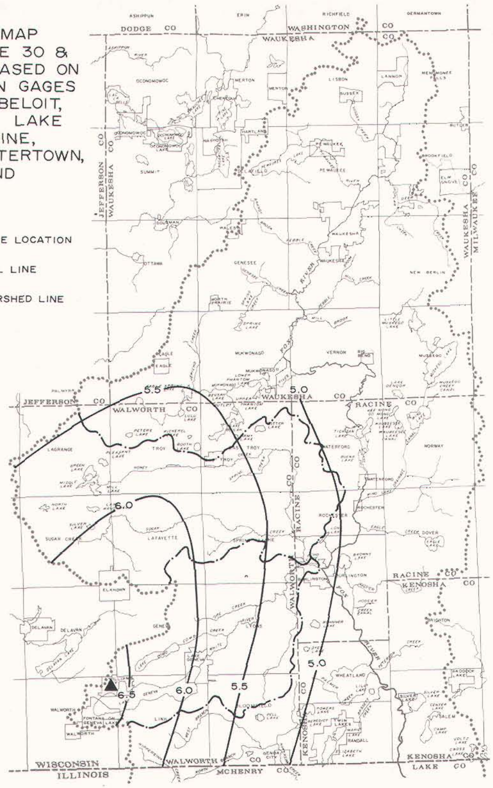
ISOHYETAL MAP
STORM OF JUNE 30 &
JULY 1, 1938 BASED ON
DATA FROM RAIN GAGES
LOCATED AT: BELOIT,
WILLIAMS BAY, LAKE
MILLS, RACINE,
MILWAUKEE, WATERTOWN,
WEST BEND

LEGEND

▲ DENOTES RAIN GAGE LOCATION

5.5 DENOTES ISOHYETAL LINE

DENOTES SUBWATERSHED LINE



Although floods generated by snowmelt are generally the most severe on large rivers, tributaries are more sensitive to high intensity rainfalls. The July 1938 flood on the White River was caused by an estimated 6-hour rainfall of about 6.5 inches centered on Williams Bay. (This resulted in a peak flood flow of 4140 cfs at the outlet of Echo Lake, equivalent to a runoff of 1.2 inches over the tributary watershed-White, Sugar, and Honey Creek watersheds.

Source: SEWRPC.

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, due to normally low seasonal water levels in these natural reservoirs, be available. It appears that such a combination of intensive summer rainfall and full natural storage has not occurred during the period of record at Wilmot. Support for this statement is indicated by the flood damage survey conducted by the SEWRPC. This survey found newspaper accounts[3] of the occurrence of 17 damaging floods of the Fox River in the City of Waukesha since 1868. Twelve of these historic floods occurred during the summer; however, no such summer floods have been experienced since 1941. This period corresponds, almost exactly, to the period of record at Wilmot and indicates that the necessary combination of summer flood-producing events has been lacking over at least a portion of the watershed in recent years. In consideration of the above factors, it must be concluded that the probability of severe summer floods does exist on the Fox River, although no major summer events have been experienced since the stream gage at Wilmot has been in operation.

Flood Frequency

A flood characteristic of vital importance in watershed planning is the frequency at which damaging floods are likely to occur. A long and continuous record of river discharge is the best basis for determining flood frequency. In the Fox River watershed, discharge measurements have been obtained at Wilmot over a 28-year period of record extending from 1939 to 1968. Data from the Wilmot gage were used to establish a relationship between flood magnitude and occurrence at this location, with particular emphasis on determining the probable frequency of the 1960 flood.

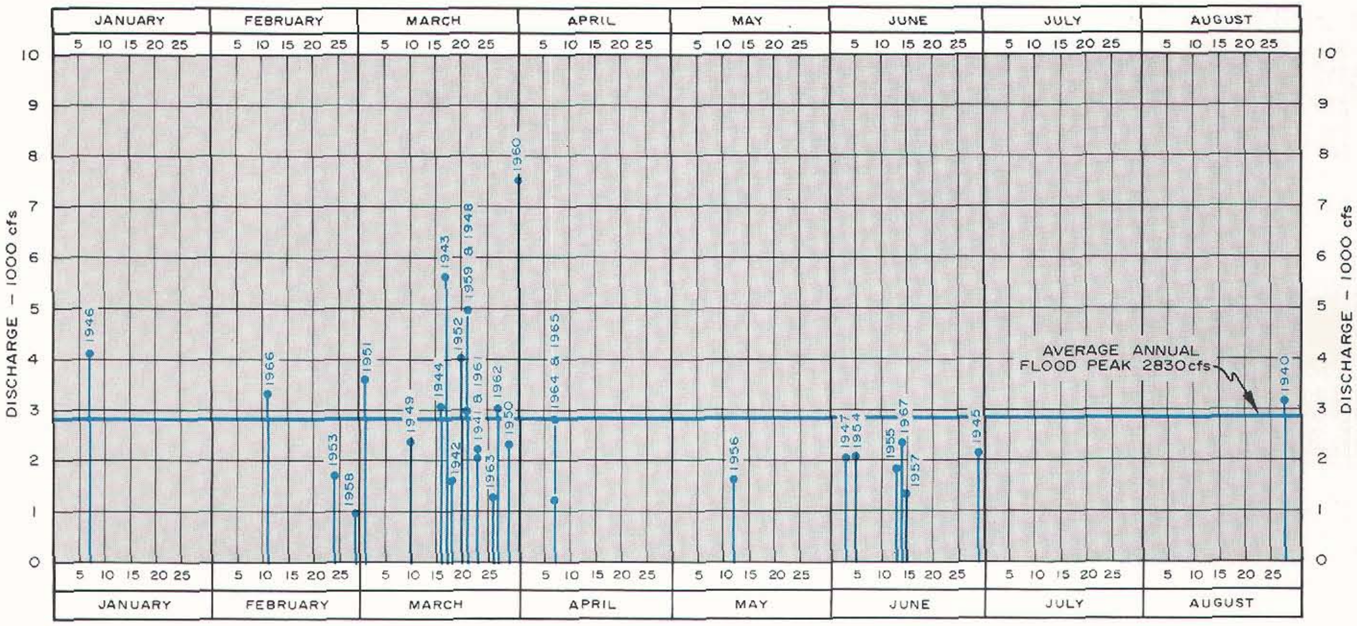
The series of 28 annual peak discharges was analyzed using a statistical method (Hazen formula) of probability assignment.[4] The flood-frequency curve resulting from the analysis is shown in Figure 24. The 28-year period of record available must be considered a relatively short one when attempting to establish the magnitude of the 100-year recurrence interval flood. For this reason, the validity of using the 28-year period of record to represent long-term conditions was checked by a comparison with a similar analyses of flood flows at Algonquin, Illinois, where discharge measurements have been obtained for a 52-year period of record extending from 1916 to 1968. The check was made by comparing the flood-frequency line developed using the Algonquin data for the years 1940-1968 with the line developed using the Algonquin data for the years 1916-1968. The comparison indicated that the slope of the

[3] *Waukesha Freeman.*

[4] *In December 1967 the United States Water Resources Council in its publication "A Uniform Technique For Determining Flood Flow Frequencies," recommended that the Pearson Type III distribution be adopted as a base method for determining flood frequency. In order to establish how well the flood frequency determination, made for this study, compared to the recommended method, the data at Wilmot were analyzed using the Pearson Type III method. The results obtained using the Pearson method were almost identical to those obtained using the Hazen method, as indicated on Figure 25.*

Figure 23

SEASONAL DISTRIBUTION OF ANNUAL PEAK DISCHARGE OCCURRENCES
FOX RIVER AT WILMOT
(1940 — 1967)



Source: U. S. Soil Conservation Service.

flood-frequency line derived from the short-term period should be adjusted slightly upward to better represent long-term conditions. The adjusted line is shown in Figure 24. The adjusted frequency line indicates that the probability of occurrence in any year of a peak discharge equal to or greater than 7,520 cfs recorded in 1960 is 2.7 percent equivalent to a recurrence interval of about 37 years.

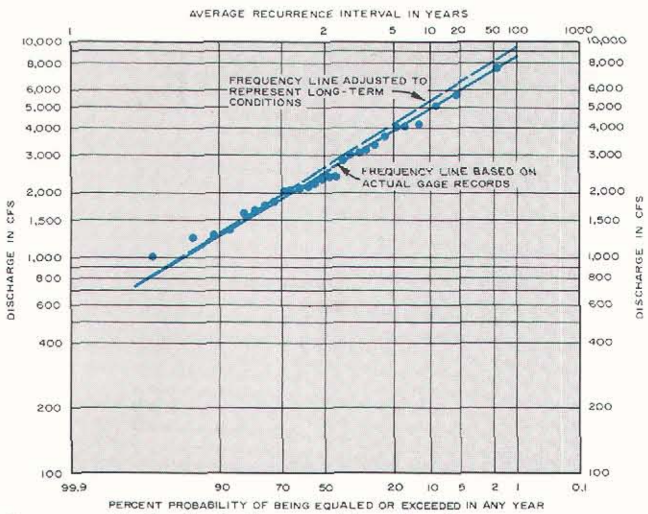
It is important to note that this flood-frequency curve, Figure 24, applies only to one portion of the Fox River system. The curve was used to establish flood-frequency relationships for the main stem of the Fox River between Wilmot and Burlington. Flood-frequency curves for other locations were developed synthetically and indicate that the 1960 flood event ranged from a 10-year recurrence interval on some tributaries to a 50-year event in the Upper Fox River subwatershed. These curves are shown in Appendices E and F.

FLOOD DAMAGE SURVEY

A necessary step in the preparation of sound land use and water control facility plans is a flood damage survey. Such a survey serves to assess the annual monetary risk of flood damage under

Figure 24

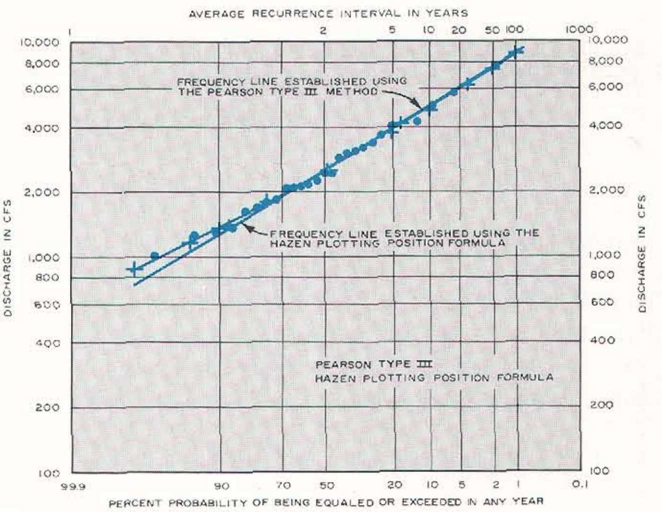
FOX RIVER DISCHARGE-FREQUENCY
AT WILMOT



Source: U. S. Soil Conservation Service.

Figure 25

COMPARISON OF FLOW-FREQUENCY METHODS
AT WILMOT FOR THE FOX RIVER WATERSHED



Source: U. S. Soil Conservation Service.

present land use and flow regimen conditions and provides the basis for forecasting such risks under alternative future watershed development proposals. A flood damage survey was, therefore, conducted in the Fox River watershed by the SEWRPC in the summer of 1966 using personal interview survey techniques. The primary objectives of the survey were to obtain accurate information on actual monetary flood losses and to solicit hydrologic information useful in the hydrologic and hydraulic investigations, such as maximum height of water, time of flood crest, and duration of flooding. The procedures developed by the SEWRPC in the conduct of the Root River watershed planning program were utilized in the flood damage survey of the Fox River. These procedures are in accordance with, and patterned after, established U. S. Army Corps of Engineers and U. S. Soil Conservation Service practices.

Field Survey Operations

The actual field survey operations consisted primarily of on-site personal interviews with farmers, homeowners, and businessmen who had suffered direct or indirect damages from floods in the recent past. 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, leasees, 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 Non-Public Buildings and Grounds. These questionnaire forms are shown in Appendix G. The flood damage data thus collected were divided into three sectors: public property and utilities, agriculture, and residential and commercial.

Because of the relatively large size of the Fox River watershed—942.4 square miles, or 34.9 percent of the entire Region—it was deemed impractical to arrange personal interviews with officials of all the federal, state, and local public and quasi-public agencies within the watershed that might have incurred flood damage costs. Instead, officials of selected agencies were sent letters of inquiry, which 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 Waukesha, Walworth, Racine, and Kenosha Counties; to the chiefs of the police departments of the Cities of Brookfield, Burlington, Lake Geneva, Muskego, New Berlin, and Waukesha; to the Director of the American Red Cross, Milwaukee-Waukesha Chapter; and to the division engineers of all railroads operating within the watershed. Personal interviews were conducted with officials of the State Highway Commission of Wisconsin and of all county highway departments, of all city and village engineering departments, and of 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. A 100 percent sample of damage was thus obtained of the public property and utility sector.

Personal interviews were conducted with 154 farm owners or operators, distributed geographically as shown on Table 30, representing the owners or operators of approximately 95 percent of the probable damaged farm land in the floodplain. The farm owners or operators 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. Results of the interviews were entered directly on the questionnaire forms. Wherever the farm owners or operators were able to reconstruct them, inundation lines were delineated on prints of 1" = 400' scale SEWRPC aerial photographs.

Personal interviews were conducted with 274 homeowners and occupants within the watershed, distributed geographically as shown on Table 31. In the conduct of the survey, three basic categories of residential flood damage were recognized and sampling rate objectives for these established as follows:

1. Inundation from direct overflow of the first (ground level) floor of buildings: 100 percent sample rate.

Table 30

GEOGRAPHIC DISTRIBUTION OF AGRICULTURAL FLOOD DAMAGES
MARCH-APRIL 1960 FLOOD IN THE FOX RIVER WATERSHED

Civil Division	Actual No. of Interviews	No. of Farms Reporting Damage	Probable No. of Farms Damaged	Sampling Rate (Percent)	Total Damage (Dollars)
Waukesha County					
Village of Menomonee Falls	8	0	0	-	$ 0
Town of Brookfield	8	0	0	-	0
City of Brookfield	5	1	1	100	200
Town of Pewaukee	9	0	0	-	0
Town of Waukesha	18	4	4	100	1,325
Town of Vernon	31	4	4	100	500
Town of Mukwonago	10	1	1	100	264
Racine County					
Town of Waterford	11	0	0	-	0
Town of Rochester	3	0	0	-	0
Town of Burlington	27	7	9	78	4,818
Walworth County					
Town of Spring Prairie	2	0	0	-	0
Town of Lyons	8	1	1	100	10
Kenosha County					
Town of Wheatland	9	7	8	88	6,308
Town of Salem	5	2	2	100	8,250
Total	154	27	30	90	$21,675

Source: *SEWRPC.*

Table 31

GEOGRAPHIC DISTRIBUTION OF RESIDENTIAL FLOOD DAMAGES
MARCH-APRIL 1960 FLOOD IN THE FOX RIVER WATERSHED

Civil Division	Actual No. of Interviews	No. of Units Reporting Damage	Probable No. of Units Damaged	Sampling Rate (Percent)	Total Damage (Dollars)
Waukesha County					
Village of Menomonee Falls	2	1	1	100	$ 440
Town of Brookfield	2	1	1	100	980
City of Brookfield	3	1	1	100	1,607
Village of Pewaukee	4	2	2	100	310
Town of Pewaukee	7	4	7	57	2,235
City of Waukesha	67	57	109	52	45,900
Town of Vernon	6	5	5	100	4,298
Village of Big Bend	2	2	2	100	4,393
City of Muskego	1	1	6	17	1,176
Racine County					
Town of Waterford	41	23	68	30	7,710
Village of Waterford	4	3	5	60	800
Village of Rochester	3	2	2	100	230
Town of Burlington	3	0	0	-	0
City of Burlington	37	32	59	54	13,150
Walworth County					
Town of Spring Prairie	6	0	0	-	0
Town of Lyons	4	3	3	100	1,685
Kenosha County					
Town of Wheatland	53	48	86	56	137,340
Town of Salem	18	15	71	21	48,780
Village of Silver Lake	11	9	48	19	32,800
Total	274	209	476	44	$303,834

Source: *SEWRPC.*

Table 32

GEOGRAPHIC DISTRIBUTION OF COMMERCIAL FLOOD DAMAGES
MARCH-APRIL 1960 FLOOD IN THE FOX RIVER WATERSHED

Civil Division	Actual No. of Interviews	No. of Firms Reporting Damage	Probable No. of Firms Damaged	Sampling Rate (Percent)	Total Damage (Dollars
Waukesha County					
City of Waukesha	29	22	22	100	$ 57,561
Racine County					
Town of Waterford	2	1	1	100	1,260
Village of Waterford	6	4	4	100	699
Village of Rochester	2	1	1	100	2,000
Town of Burlington	1	1	1	100	5,450
City of Burlington	10	10	10	100	8,910
Kenosha County					
Town of Wheatland	2	2	2	100	1,650
Town of Silver Lake.	2	2	2	100	250
Total	54	42	42	100	$77,780

Source: SEWRPC.

2. Inundation from direct overflow but limited to basements, lawns, and grounds: 20 percent sample rate.

3. Sewer backup or seepage through walls and floors, resulting in basement flooding: 20 percent sample rate.

In isolated areas containing relatively few damaged properties, a 100 percent sampling rate was set as an objective for all residential damage categories.

Personal interviews were held with 54 owners or managers of commercial properties located on the floodplains, distributed geographically as shown on Table 32. Because of the extreme variability of flood damage susceptibility of individual commercial properties, a 100-percent sampling rate objective was established for this sector.

U. S. Army Corps of Engineers—
Flood Damage Survey

On July 6, 1949, the U. S. Army Corps of Engineers, Chicago District, was authorized by the U. S. House of Representatives to study the flood problems of the Fox River in Illinois and Wisconsin. Funds for the study were not, however, appropriated until fiscal year 1961, so that the Corps initiated a single-purpose flood control study of the Fox River watershed shortly after the disastrous 1960 flood. As a part of this study, the Corps solicited officials of the major flood-damaged Cities of Waukesha and Burlington to conduct house-to-house surveys of urban damages within their communities. A local citizens group, The Fox River Flood Control Committee with Mr. Paul E. Lohaus as Chairman, was also organized to conduct a field survey of agricultural and urban damages along that reach of the Fox River extending from the south limits of the City of Burlington to the state line. This flood damage information, collected by local interests, was presented at a public hearing held by the Corps at Elgin, Illinois, on January 24, 1961, for the purpose of soliciting local views on problems of flooding of the Fox River and possible flood control measures to be taken.

The Corps utilized this locally collected flood damage information as input data to a preliminary evaluation of the economic feasibility of single-purpose flood control projects on the Fox River. The results of this evaluation indicated that channel improvement, levee construction, and flood retention reservoir alternatives lacked economic justification in terms of the potential benefits of single-purpose flood protection. Because of the economic infeasibility of a single-purpose flood control project on the Fox River, the Corps temporarily suspended work on the flood control study and encouraged the Commission to undertake a comprehensive study of the Fox River watershed which would consider areawide land use development patterns and supporting water control facility elements having multi-purpose benefits attributable to recreational use, improved water quality, and increased water supply, in addition to flood control.

In the spring of 1966, upon initiating its comprehensive study of the Fox River watershed, the

Commission requested the Corps of Engineers to provide the flood damage data which had been collected for the Fox River in Wisconsin. This flood damage data, it was believed, would be especially valuable to the study for two reasons:

1. The information was collected shortly following a major flood event in the watershed while memories of the interviewed flood-damagees were still fresh, and therefore, was potentially more complete and accurate than subsequently collected data could be.

2. The rapid turnover of property, which usually occurs in flood damaged areas of a watershed making the reconstruction of costs increasingly difficult with the passage of time after a major flood event, had not as yet occurred. With the passage of time, the former owners of damaged property may no longer be available for interviews or interested in furnishing data, while the new residents may be unaware of past flood damage.

In addition, it was believed that failure to utilize the information collected in a previous flood damage survey could result in needless and costly duplication of effort.

Upon receipt of the Commission request, the Corps of Engineers cooperated fully in furnishing to the study 84 individual flood damage statements concerning the spring of 1960 flood in the watershed, 52 individual statements concerning the spring of 1962 flood in the watershed, and summary flood damage data. This data constituted an invaluable contribution to the Commission flood damage survey.

Evaluation of Flood Damage Survey Results

The field data entered on the personal interview forms and aerial photographs and collected by the letters of inquiry were reviewed immediately after completion of the interviews or receipt of replies to the letters of inquiry and converted into a consistent form suitable for economic analysis. 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. Some of the interviews, however, resulted in information on the actual costs of the damages, whereas, in a few instances, the interviews resulted only in information on the flooding characteristics or on other watershed problems, such as deteriorating water quality and poor drainage.

The individual flood damage forms supplied to the study by the U. S. Army Corps of Engineers were analyzed in the same manner as the SEWRPC interview forms. Upon completion of analysis, these forms were integrated with the SEWRPC interview forms and included as a part of the flood damage survey. In several instances, a flood damagee who had been included in the Corps survey was re-interviewed by the SEWRPC surveyors as a basis for comparison of survey results and to ensure consistency in the evaluation of individual flood damage forms. The results of such comparisons were in all instances excellent and indicated a very high degree of consistency in the results.

Generally, public officials were able to provide accurate costs of damages to public facilities which could be accepted without adjustment. Private-sector cost quotations 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 tables are reproduced in Appendix H. In several 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 for the various depths of inundation.

Many possible sources of error and inaccuracy necessarily 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 could have adversely affected 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 (1966), 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 as they retained little interest in the affected property.

2. A large number of the residences located in certain floodplain areas were vacation

homes owned by persons residing outside of 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 1966). With the passage of over six 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 farm land 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.

COST AND CHARACTERISTICS OF FLOOD DAMAGES

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 terms.

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 any federal agencies which may be asked to assist in the implementation of the recommended watershed plan, the definitions of these four categories of flood losses are defined, for the purpose of the study so as to be consistent with the definitions used by the U. S. Corps of Engineers and the U. S. Soil Conservation Services, as follows:

1. Direct losses are 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 are 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 are 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 are defined as the reduction in 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. Reduced property values, however, are very real considerations along the frequently damaged reach of the Fox River in the Town of Salem, Kenosha County, where homes on the floodplain are difficult to sell and have a real market value considerably less than otherwise equal homes located on upland areas of the town.

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 are 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.

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 and agricultural losses. A summary of these losses in the Fox River watershed is shown in Table 33.

Public-Sector Losses

The costs of flood damages to public property, utilities, and relief agencies were generally accepted as reported in the flood damage survey without adjustment. 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 flood-connected labor charges, only the cost of overtime pay was included.

An important indirect loss accompanying flood closure of streets and highways is the road user detour cost. This cost was calculated on the basis of traffic volume, detour length, time of closure, and the average per mile vehicle operation cost over the normal route and over the detour.[5] The incremental cost of using the detour was taken as the flood loss. The greatest detour cost attributable to a single flood of the Fox River and its major tributaries was $43,185, resulting from the March-April 1960 flood. At the peak of this flood, at least 20 major streets and highways within the watershed were closed to traffic, necessitating traffic detours of one-day duration or longer, as shown in Table 34. The future flood risk of detours has been substantially reduced since the 1960 flood with the completion of IH 94 through Waukesha County and the reconstruction of Capitol Drive (STH 190), both of which are no longer subject to flood closure.

Private-Sector Losses

Residential and Commercial Losses: Damage to the residential sector of the watershed in terms of monetary loss, number of people affected, and intangible damage was by far the most significant result of the spring of 1960 flood. Nearly 500 families in 17 communities were directly affected by this major flood, with damages ranging from basement seepage to the total destruction of a residence.[6] The residential losses incurred as a result of the 1960 flood are summarized in Table 31.

Commercial-sector losses within the watershed from the 1960 flood were also considerable, with 42 commercial establishments reporting damage, as shown in Table 32. The costs of this flood to individual firms reporting damage ranged from a low of $100 to a high of $20,850.

Agricultural Losses: A wide range of agricultural damage has occurred in the watershed from historic floods, 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 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.

[5] *Traffic volume and vehicle operating cost data were derived from data developed under the SEWRPC Land Use-Transportation Study.*

[6] *A home in the Oakwood Point development, Town of Wheatland, Kenosha County, burned to the ground due to a flood-induced electrical fire.*

Table 33

MAXIMUM REPORTED FLOOD LOSS FOR A SINGLE YEAR IN THE FOX RIVER WATERSHED

MARCH-APRIL 1960 FLOOD

Civil Division	Public Sector	Private Sector		Total
		Residential and Commercial	Agricultural	
Waukesha County				
Village of Menomonee Falls . . .	$ 0	$ 440	$ 0	$ 440
Town of Brookfield.	8,805	980	0	9,785
City of Brookfield.	0	1,607	200	1,807
Village of Pewaukee	0	310	0	310
Town of Pewaukee.	0	2,235	0	2,235
City of Waukesha.	24,550	103,461	0	128,011
Town of Waukesha.	0	0	1,325	1,325
Town of Vernon.	0	4,298	500	4,798
Town of Mukwonago	0	0	264	264
Village of Big Bend	0	4,393	0	4,393
City of Muskego	1,000	1,176	0	2,176
Subtotal	*34,355*	*118,900*	*2,289*	*155,544*
Racine County				
Town of Waterford	0	8,970	0	8,970
Village of Waterford	1,084	1,499	0	2,583
Town of Rochester	0	0	0	0
Village of Rochester	0	2,230	0	2,230
Town of Burlington	0	5,450	4,818	10,268
City of Burlington	7,000	22,060	0	29,060
Subtotal	*8,084*	*40,209*	*4,818*	*53,111*
Walworth County				
Town of Spring Prairie	0	0	0	0
Town of Lyons	0	1,685	10	1,695
Subtotal	0	*1,685*	*10*	*1,695*
Kenosha County				
Town of Wheatland	1,000	138,990	6,308	146,298
Town of Salem	0	49,030	8,250	57,280
Village of Silver Lake	0	32,800	0	32,800
Subtotal	*1,000*	*220,820*	*14,558*	*236,378*
Detour Costs.	43,185			43,185
Total	$86,624	$381,614	$21,675	$489,913

Source: *SEWRPC.*

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 other agricultural damage as 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 many of the poorly drained areas of the watershed, farmers were unable to distinguish between crop damage from inundation and localized ponding of water from direct precipitation. In these instances, the reported damage had to be adjusted to exclude costs relating to drainage problems.

A substantial number of farm owners within the watershed have placed floodplain-located farm lands in soil reserve programs administered by the U. S. Department of Agriculture, Agricultural Stabilization and Conservation Service (ASCS).[7] For example, in Waukesha County along the Fox River, 42 farm owners presently have contracts with the ASCS, placing approximately 1,000 acres of floodplain land into soil reserve and conservation practice. 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 risk, however, it was assumed that, under the pressure of increasing population levels, this land would eventually again 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 or calculated. The general formula used to establish monetary crop loss in terms of present dollars is as follows:

Adjusted Monetary Loss =
full probable cash value of original crop -
costs not incurred in cultivation, harvest, and storage +
cost of all operations in producing, harvesting, and storing substitute crop -
market value of the substitute crop

Flood Damage Characteristics In Municipalities

Village of Menomonee Falls and the City and Town of Brookfield, Waukesha County: Historical flood damage has been limited in this reach, which includes the headwaters of the Fox River downstream to Barker Road (CTH Y), 3.0 miles of Poplar Creek, and 3.4 miles of Deer Creek. Public-sector cost of detours has been the largest single flood loss. Eight roads and bridges were closed to traffic during the March-April 1960 flood, resulting in considerable inconvenience and cost. The Davidson Road bridge on Poplar Creek was washed out in this flood, and the road was closed for two weeks while a temporary bridge was constructed. Lannon Road (CTH Y), Silver Spring Drive (CTH VV), Capitol Drive (STH 190), River Road, Town Line Road, North Avenue (CTH M), and Barker Road (CTH Y) were all closed for periods extending from one to three days.

Three residential units in this reach reported flood damages from the spring of 1960 flood, with an average damage cost per unit of over $1,000. This indicates that, if floodplain development should be allowed to continue in this reach, substantial damage may be expected to result from future floods. Only one of 21 farm owners or operators interviewed in this reach reported significant flood damage. A sod farmer north of Capitol Drive (STH 190), however, reported almost con-

[7] *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 crop land from production and instituting conservation measures on land so removed. Farm owners 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. Farm owners 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. The program is presently authorized under the Agricultural Act of 1965, as amended. Farm owners 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.*

Table 34

ROADS AND BRIDGES CLOSED TO TRAFFIC AS A RESULT OF THE MARCH-APRIL 1960 FLOOD IN THE FOX RIVER WATERSHED

Road	Location	Estimated Closure Time In Days
Lannon Road (CTH Y)	Village of Menomonee Falls, Fox River	1
Silver Spring Drive (CTH VV)	Village of Menomonee Falls, Fox River	1
Capitol Drive (STH 190)	Town of Brookfield, Fox River	1
River Road	Town of Brookfield, Fox River	3
Town Line Road	Town of Brookfield, Fox River	2
Davidson Road	Town of Brookfield, Poplar Creek	14[a]
North Avenue (CTH M)	City of Brookfield, Fox River	2
Barker Road (CTH Y)	City of Brookfield, Fox River	3
CTH SS	Town of Pewaukee, Fox River	3
Madison Street (USH 18)	City of Waukesha, Fox River	1
Main Street (STH 59)	City of Waukesha, Fox River	1
Barstow Street	City of Waukesha, Fox River	1
River Road (CTH I)	Town of Waukesha, Fox River	1
Milwaukee Avenue (STH 24)	Village of Big Bend, Fox River	1
Racine Avenue (CTH Y)	City of Muskego, Muskego Creek	1
Woods Road	City of Muskego, Muskego Creek	1
Tichigan Drive	Town of Waterford, Fox River	2
Bieneman Road	Town of Burlington, White River	1
Chestnut Street (STH 11)	Town of Spring Prairie, White River	1
STH 50	Town of Wheatland, Fox River	1

[a] *Bridge failure necessitated closure of Davidson Road for approximately two weeks, until a temporary bridge was installed.*

Source: SEWRPC.

tinuous high water from a recently developed drainage problem.

Village and Town of Pewaukee, Waukesha County: Only minor flood damages have been sustained in this reach in the past, due in part to the flood retention capacity of Pewaukee Lake. The reach includes 3.3 miles of the Fox River and all of the Pewaukee River (6.4 miles). As a result of the spring of 1960 flood, 11 homes located on the floodplains of the Fox and Pewaukee Rivers reported flood damage varying from lawn damage to basement and foundation damages. CTH SS was closed to traffic for one day due to flooding of the Fox River.

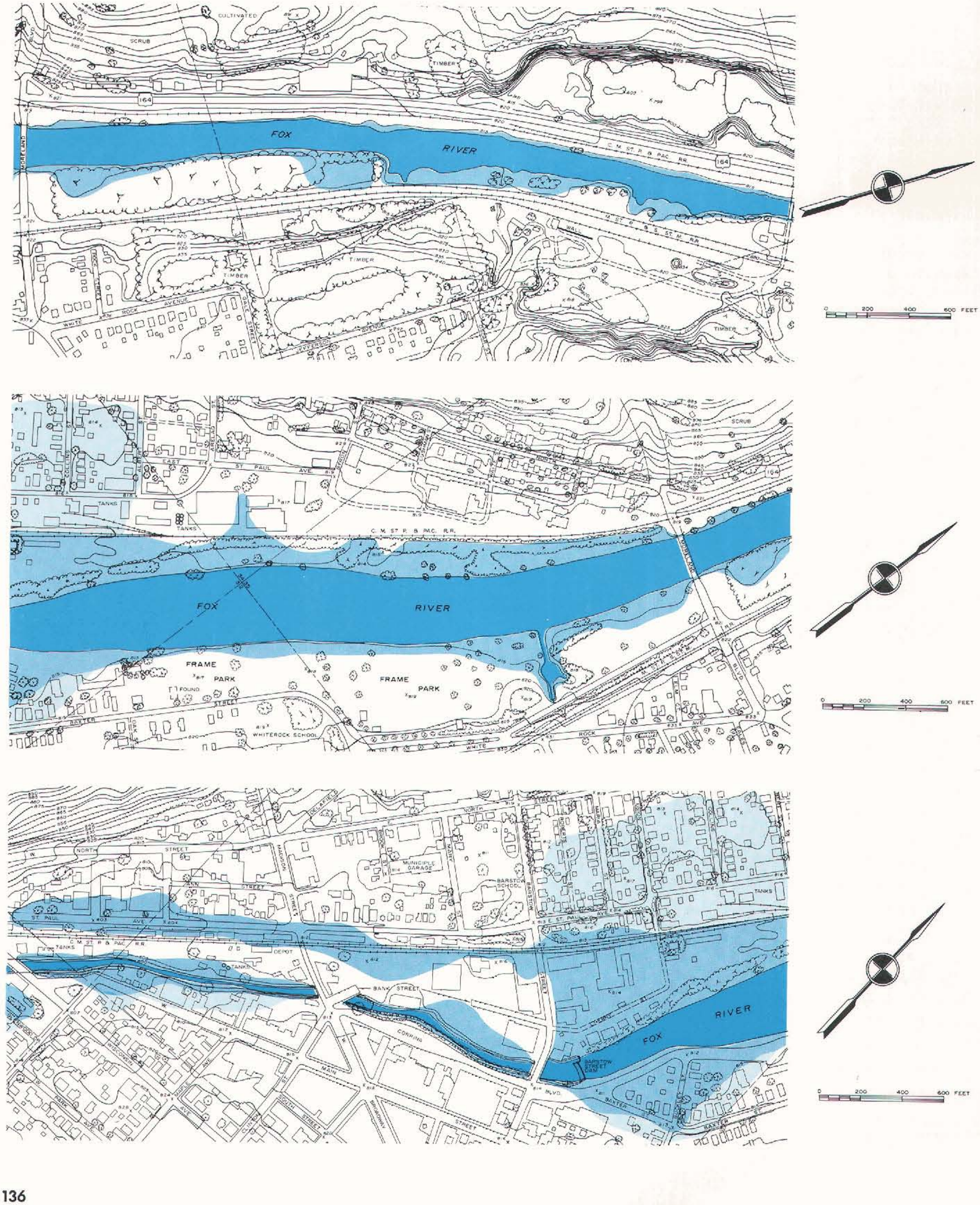
City of Waukesha, Waukesha County: According to historical newspaper accounts,[8] there have been at least 17 damaging floods in Waukesha since 1868, of which 15 were recorded during the 70-year period extending from 1868 through 1940. For a period of 19 years extending from 1941 to 1960, no floods of a damaging nature were recorded. Twelve of the historic floods occurred during the summer and were associated with localized thunderstorms that produced runoff rates in the 126-square mile drainage area north of Waukesha which were in excess of the Fox River channel capacity. The remaining five more devastating floods occurred during early spring thaws. The factors of warm spring temperatures, snowmelt, rains, high runoff rates on frozen ground, and ice jams at the Barstow Street dam, have all combined to cause the most destructive floods in the City of Waukesha.

From the standpoint of monetary losses from flood damage, the March-April 1960 flood was the worst in city history. Approximately 26 percent of the total damage cost of the 1960 flood of the Fox River, origin to state line, can be traced to the four-mile channel reach in the City of Waukesha. This concentration of damage costs places the City of Waukesha as the second most highly damaged reach in the watershed, the most highly damaged reach being the 12-mile Kenosha County reach.

[8] *Waukesha Freeman (1868-1966)*

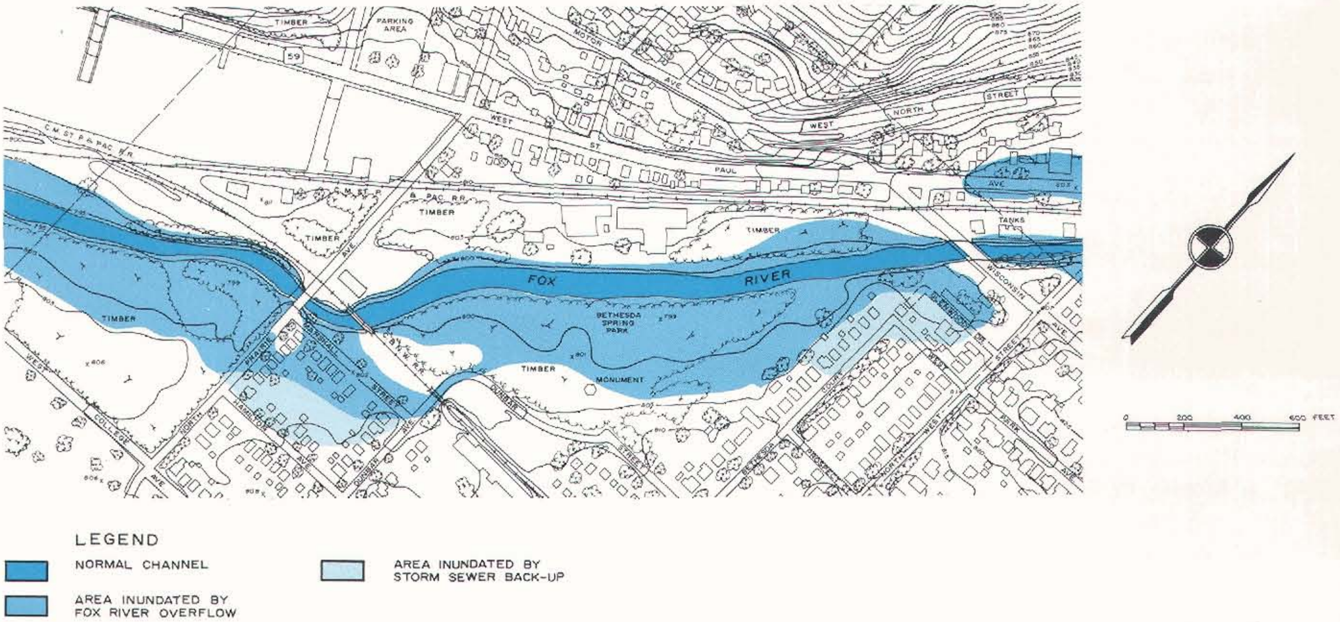
Map 37

FLOOD INUNDATION MAP OF THE CITY OF WAUKESHA FOR THE MARCH - APRIL 1960 FLOOD



Map 37 (Continued)

FLOOD INUNDATION MAP OF THE CITY OF WAUKESHA
FOR THE MARCH - APRIL 1960 FLOOD



The 1960 flood of the Fox River in the City of Waukesha caused over $128,000 damage to public, commercial and residential property. The flooding, though not extensive in area, penetrated into the highly developed sections of the city resulting in high flood damage costs.

Source: SEWRPC.

Of the total damage costs reported in Waukesha for the 1960 flood, 19.2 percent accrued to the public sector, including damage to streets, river structures, and utilities and indirect costs of flood fighting; 35.9 percent to residential losses; and 44.9 percent to commercial losses. Extensive damage occurred in four distinct areas of Waukesha during the 1960 flood, and minor damage occurred along the remaining stream-bank areas (see Map 37).

The first area of concentrated flood damage is comprised of a two-square block area located on the east bank of the Fox River. It is bound by Barstow Street on the south, Corrina Boulevard on the east, Baxter Street on the north, and the Fox River on the west. Eighteen homes and two commercial buildings are contained within this section. At the peak of the 1960 flood, the homes and buildings were surrounded by water. All homes in this area incurred extensive basement and lawn damage plus additional indirect costs of flood fighting, evacuation and relocation, and loss of work. As a safety precaution, utilities were shut off in this section during the flood. Basement damage was due to direct overflow, seepage, and sewer backup. Floodwaters covered most of the municipal parking lot north of Barstow Street and threatened to enter a large department store located east of the lot. The department store had to hire labor and brought in sandbags to fight the rising floodwaters.

The second area of concentrated flood damage is located on the west bank of the river. Forty homes and three commercial firms north of Barstow Street, east of North Street, and south of Albert Street sustained flood damage from direct overflow of the Fox River above the Barstow Street dam, sewer backup, and seepage. Although no residents had to be evacuated, most of the homes were without heat, due to basement flooding, for more than 24 hours. The three commercial firms lost materials that were stocked in their basements or stored out-of-doors. Much of the damaged section is at a lower elevation than the adjacent river bank, thus direct overflow water and storm sewer backup, as well as local run-off water, tends to accumulate in this section.

The third area of concentrated flood damage is located on the east bank of the Fox River between the Wisconsin Avenue and the Prairie Street bridges. This section includes 27 homes, 1 four-family apartment building, and a pattern works. Ten of the homes, the apartment building, and the pattern works were damaged by direct overflow as well as sewer backup and seepage. The remaining homes suffered losses from sewer backup. This damage area is divided by Bethesda Spring Park, which, as an excellent example of a proper use of a floodplain area, sustained only minor damages.

St. Paul Avenue, between Madison Street and Wisconsin Avenue, comprises the fourth major area of concentrated flood damage. Nine commercial firms reported a total of $42,000 in damage costs as a result of the March-April 1960 flood. With the additional damage costs incurred by one apartment building and two homes, the costs incurred in this section amounted to 38 percent of the total damage costs in Waukesha. St. Paul Avenue is lower in elevation than the adjacent river bank, and in 1960 water accumulated to a height of four feet in an automobile sales establishment showroom. Three sources of water combined to cause the damage in this low section, including direct overflow, which found its way down the C. M. ST. P&P railway tracks from the Barstow Street area; sewer backup; and runoff from the hills in the immediate vicinity. Thus, during the 1960 flood, a large amount of water concentrated in the street and surrounding lots until the river level subsided.

Town of Waukesha, Waukesha County: This reach includes 7.6 miles of the Fox River, 3.3 miles of Pebble Creek, 5.2 miles of Pebble Brook, and the entire 2.8 miles of Mill Creek. Of the 18 farm owners and operators interviewed along the Fox River, Pebble Creek, and Pebble Brook in the Town of Waukesha, only four reported flood damages directly resulting from the March-April 1960 flood. Two of the damagees reported costs from flood cleanup and fence repairs. The other two reported that they had lost corn crops that had been unharvested from the previous year. Minor summer floods in July 1964 and September 1965 caused some inundation of pasture and cropland. Farmers reported minor losses to their corn crops and a significant increase in the cost of harvesting these crops on the poorly drained floodplains.

Town of Vernon, Waukesha County: This reach includes 16.7 miles of the Fox River, 2.1 miles of Pebble Brook, and 0.7 mile of the Mukwonago River. Although flooding in this reach has been extensive and common, flood damage has been minimal as much of the floodplain is in conservancy use, including the approximately 5,000-acre Vernon Marsh, which is regulated by the Wisconsin Conservation Commission. Thirty-one farm owners and operators were interviewed; and only four reported historic flood damages, which included loss of fences, equipment damage, clean-up costs, and minor crop losses.

Village of Big Bend, Waukesha County: Approximately 0.5 of a mile of the Fox River borders the southwestern limits of the Village of Big Bend. Flood damage in the village and the unincorporated development just south of the village was principally residential. Seven residential units in this reach of the Fox River suffered flood losses in the spring of 1960. Also, as a result of the 1960 flood, STH 24 (Milwaukee Avenue) was inundated at the Fox River and temporarily closed to traffic.

City of Muskego, Waukesha County: During the spring of 1960, flood runoff into Little Muskego Lake exceeded the combined capacity of its dual spillways; and the lake level rose uncontrolled until the dike was threatened. It was necessary to sandbag the dike to prevent its failure, which would have resulted in disastrous downstream flooding, including possible severe damage to 30 homes located along the Little Muskego Lake outlet directly south of Little Muskego Lake, and would have imposed an additional flood burden on Big Muskego and Wind Lakes. A task force of nearly 100 men, lead by their Town Chairman, Jerome Gottfried,[9] filled sandbags and placed them on the dam to prevent its washout. At least six families had to evacuate their homes, and 12 homes located between the dike and STH 24 were isolated by floodwaters for a period of one day.

Town of Waterford, Racine County: Virtually all flood losses along the 6.5 miles of the Fox River in the Town of Waterford have historically been related to residential damages. An estimated 68 residential units were damaged by the March-April 1960 flood, including 10 units that sustained direct structural damage and 58 units that sustained lawn damage. The Fox River inundated the approach to the Tichigan Drive bridge on the east river bank, necessitating its closure for two days.

Village of Waterford, Racine County: In the spring of 1960, floodwaters damaged five residential units and four commercial buildings along the 1.3 miles

[9] *Mr. Gottfried became Mayor of the City of Muskego when it was incorporated as a fourth class city in 1964.*

of the Fox River in the village, inflicting principally lawn damage and basement flooding. The residential damage occurred above the Waterford dams, with the exception of one damaged home located directly below the east spillway. One building on Fox Isle Park was surrounded by water and sustained minor damage. The remaining commercial damage was concentrated along the floodplain above and below the Main Street bridge. From the effects of this flood, the village incurred costs of labor, material, and equipment principally for protecting the Waterford dams from serious washouts.

Town and Village of Rochester, Racine County: No flood damage was reported along the 2.9 miles of the Fox River in the Town of Rochester from the spring of 1960 flood. The principal losses along the 0.7 of a mile of the Fox River within the Village of Rochester were lawn damage to two homes and damage to the furnishings of a cocktail lounge-restaurant from direct inundation. The conspicuous lack of damage through this reach has been a result of the Fox River being deeply incised with high river banks that afford little floodplain area for urban development.

City and Town of Burlington, Racine County: The City and Town of Burlington cover a 42-square-mile area in the southwest corner of Racine County. The Fox River traces a ten-mile stream course through this reach, with 3.1 miles of channel from the northern township boundary to the city limits of Burlington, 1.2 miles within the City of Burlington, and 5.7 miles below the Burlington City limits southeast to the Racine-Kenosha County line. The White River, a major tributary of the Fox River, drains 275.70 square miles of the southwestern portion of the watershed and joins the Fox River in the City of Burlington. Approximately 2.2 miles of the lower channel of the White River are contained within this reach, including Echo Lake, which is formed by the impoundment above the Burlington Dam.

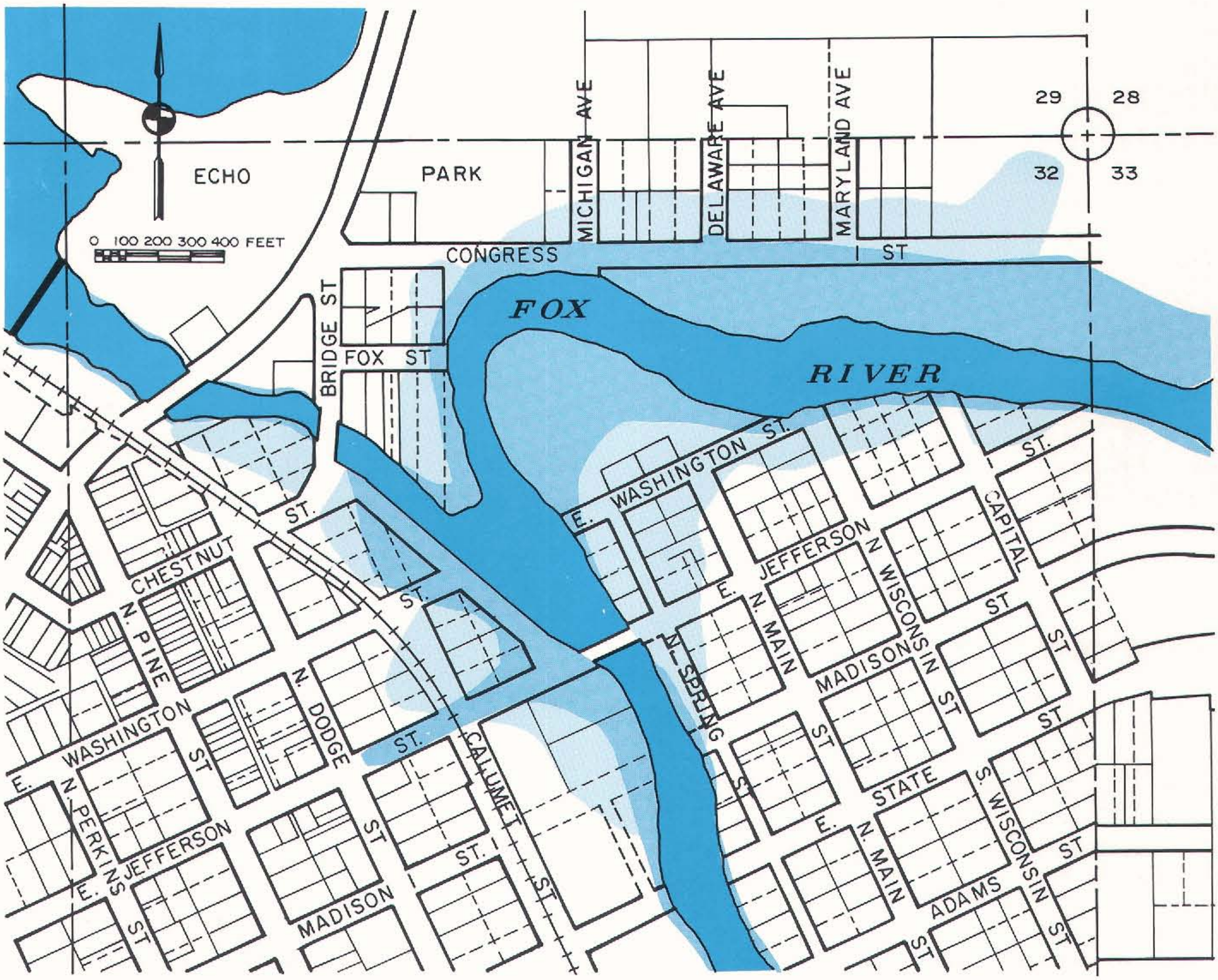
At the present time, most of the floodplain area in the Town of Burlington is under agricultural use, although suburban development has begun north of the Burlington City limits along the Fox River and west of the City of Burlington on the White River. Historically, the summer flood of 1938 probably caused the most extensive flood damage in this reach. Because of the 28-year time lapse since this event, however, it was extremely difficult to reconstruct reasonable damage estimates. The results of the flood damage survey conducted by SEWRPC in the summer of 1966 showed that the flood damage costs during the spring of 1960 flood totaled $5,000 to agricultural property, most of which was structural type damage to fencing, buildings, and equipment, with minor damage to unharvested crops from the previous year. A potential for higher flood damage costs is thus indicated if a flood occurs during the summer growing season.

Flood damage in the City of Burlington has historically been concentrated in two areas (see Map 38). The first area is located on the south side of Echo Lake along Chestnut Street (STH 11). Flood damage costs from direct overflow of the river onto lawns and into basements were incurred by 27 residential units for the March-April 1960 flood. The second area is located at the confluence of the Fox and White Rivers. In the spring of 1960, 32 residential units and 9 commercial firms in this area received damage from direct overflow, seepage, and/or flood-related sewer backup. Public-sector damage costs from the spring of 1960 flood in the City of Burlington were high in both damage areas, as firemen, highway crews, and utility workers spent days pumping water from basements, cleaning and repairing streets, reconstructing a gas main, and replacing and relocating gas meters.

Village of Silver Lake, Towns of Salem and Wheatland, Kenosha County: Historically, this 12-mile reach of the Fox River in Kenosha County has been the most damage-prone area of the watershed. Damaging floods have frequently occurred in the early spring of the year as a result of the combination of snowmelt, spring rains, and high runoff rates from the still frozen ground. Summer floods, associated with thunderstorms and antecedent conditions, have also occurred but less frequently. Particularly susceptible to flooding have been the Oakwood Point development in the Town of Wheatland and the western portion of the Village of Silver Lake, which are located on low-lying areas of the floodplain. Homes located in these two areas, adjacent to the river, have received almost annual spring snowmelt-rainfall flood damage.

Over 48 percent of the total damage costs of the March-April 1960 flood occurred in this reach. Residential losses accounted for 93 percent of the damage costs in the reach, with public, commercial, and agricultural losses accounting for the

Map 38
FLOOD INUNDATION MAP OF THE CITY OF BURLINGTON
FOR THE MARCH-APRIL 1960 FLOOD



LEGEND

NORMAL CHANNEL

AREA INUNDATED BY STORM SEWER BACK-UP

AREA INUNDATED BY FOX RIVER OVERFLOW

Approximately 90% of the flood damage caused by the 1960 flood of the Fox River in the City of Burlington occurred in the heart of the city at the confluence of the Fox and White Rivers. Public and commercial flood damage was the result of direct overflow from the river, whereas residential flood damage was limited in most instances to sewer back up and minor lawn damage.

Source: SEWRPC.

remainder. At least 205 homes in the reach incurred some type of direct or indirect damage as a result of the 1960 flood. The east bank of a three-mile-long portion of this reach, extending from the STH 83 and STH 50 bridge over the Fox River downstream to the CTH F bridge over the Fox River, contains 192 of the total 476 homes that sustained damage in the watershed. Of these homes 124 sustained first-floor damage from direct overflow, and the remaining 68 sustained lawn and indirect damages. Other residential damage occurred in the vicinity of the Wilmot dam.

Public-sector costs of the March-April 1960 flood were the result of flood damage to access roads to the aforementioned homes. Four commercial establishments located in the reach reported minor losses from the 1960 flood. Erosion by the floodwaters was the main cost applied to agricultural damages in this reach.

Walworth County: Damage in Walworth County, attendant to the spring of 1960 flood, was minor with significant losses being incurred by only three residential units located on the floodplain of the White River in the Town of Lyons. A far more significant flood in terms of its damaging effects to Walworth County occurred in July 1938, the characteristics of which were discussed earlier in this chapter. The summer storm caused unprecedented flooding of the White River and Sugar, Honey, and Como Creeks. Reaches of the Fox River south of Burlington in Kenosha County also reached flood stage.

As a result of this storm, the level of Geneva Lake rose a reported 10.5 inches overnight to the second highest historic level,[10] 864.9 feet above mean sea level. All outlet gates of the control structures were opened, yet the lake level continued to rise due to the restricted capacity of the culvert at Willow Street. To bring the lake level under control and to alleviate flooding in the City of Lake Geneva, it was necessary to cut an auxiliary channel across Willow Street.

During the same storm, Como Lake rose to its historic high level of more than three feet above the spillway crest, or 852.5 feet above mean sea level. Considerable inundation of the lakeshore homes and property resulted, and STH 12 east of the lake was closed to traffic.

Railroad service was interrupted within the county by the flood destruction of three bridges located on the C. M. ST. P&P railway line between Elkhorn and Lyons. At least ten highway bridges were washed out from the effects of the flood, including six bridges on Sugar Creek and its tributaries. Due to bridge washouts certain town roads in Spring Prairie Township were closed to traffic for a period of up to six months following the flood.[11]

Private-sector agricultural and urban damages from the July 1938 flood were extremely high within Walworth County; but with insufficient records of losses available and upon the passage of 29 years, the amount of the losses could not be accurately assessed.

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 the sound economic analysis of flood protection measures.

Discharge-Damage Curves

Flood-damage costs generally increase with higher discharges and concomitant higher floodwater elevations, due to greater depth of flooding, greater area of inundation, and greater velocity of floodwaters. The relationship between flood-damage costs and discharge is defined by a discharge-damage curve. Discharge-damage curves representing 1963 land use conditions within the watershed and projected 1990 land use conditions under uncontrolled development of the floodplain areas were prepared for each of nine river reaches along the main stem of the Fox River and the White River from STH 36 to the Burlington Dam. The criteria governing the selection of the river reaches included a relatively uniform character of land use, relatively uniform hydraulic characteristics, and relationship to the location of possible flood control structures.

Flood-damage costs for selected discharges were calculated using the recorded 1960 flood damages

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[10] *Records of the Lake Geneva Water Power and Lake Level Protection Company indicate that the historic high level of Lake Geneva, elevation of 865.1 feet above mean sea level, occurred in June 1908 when the lake was two inches above the 1938 level and 9.5 inches above the spillway crest.*

[11] *Historic accounts of this flood were derived from personal communications with Mr. Wilmer Lean, Walworth County Highway Commissioner, and Mr. George L. Allen, President of the Lake Geneva Water Power and Lake Protection Company; records of the State Highway Commission of Wisconsin; and historic newspaper articles in the Elkhorn Independent, the Geneva Lake News, the Burlington Standard Press, and the Milwaukee Journal.*

as a basis. Cost calculations for the 1963 curves included consideration of the public- and private-sector damage costs at selected discharges greater and lesser than the 1960 discharge. Adjustments were made for increases in damage potential since 1960 due to construction of buildings in the flood plains. Adjustments were also made for the reduction of damage potential since 1960 due to the removal of structures or the supplementation of flood protection measures.

Forecasts of the potential locations of individual structures which might be built in the floodplain by 1990 under uncontrolled land use conditions were made based upon the Unplanned Land Use Alternative—1990, prepared by the Commission as part of the regional land use planning effort.[12] Potential damage to these structures for various discharges was calculated and added to the 1963 damage potential to obtain the 1990 discharge-damage curves for uncontrolled land use development. The discharge-damage curves used in the planning study are shown in Figures 26 through 34.

[12] *See SEWRPC Planning Report No. 7, Volume 3, Recommended Regional Land Use and Transportation Plans--1990, November 1966.*

Damage-Frequency Curves

The frequency of a specific flood damage total can be derived by combining discharge-damage curves and discharge-frequency curves. Flood-frequency relationships for 1963 and 1990 projected uncontrolled conditions were derived from the hydrologic (flood simulation) model described in Chapter VIII. Damage-frequency curves were prepared by plotting the damage associated with a given discharge against the frequency of that discharge. Damage-frequency curves derived for each of the damage reaches for both 1963 land use conditions within the watershed and projected 1990 land use conditions under uncontrolled development of the riverine areas are shown in Figures 35 through 43. The area under each damage-frequency curve is equal to the annual flood-damage risk in that reach. Total annual flood-damage risk along the main stem of the Fox River and along the White River from STH 36 to the Burlington Dam is $76,700 for 1963 conditions and $112,600 for 1990 conditions under projected uncontrolled development trends. Values for individual reaches are shown in Table 35.

It must be emphasized that the annual risk of damage in the Fox River watershed, as computed herein, is conservatively low; that is, it includes

Table 35

PROBABLE FLOOD DAMAGE COSTS
IN THE FOX RIVER WATERSHED
ALL OF THE MAIN STEM OF THE FOX RIVER AND WHITE RIVER FROM
STH 36 TO BURLINGTON DAM

Reach	Location	Average Annual Flood Damage Costs (Dollars)		10-year Occurrence Flood Damage Costs (Dollars)		100-year Occurrence Flood Damage Costs (Dollars)	
		1963[a]	1990[b]	1963[a]	1990[b]	1963[a]	1990[b]
1	Kenosha County Line to State Line	$ 33,900	$ 46,400	$ 96,000	$138,000	$335,000	$522,000
2	City and Town of Burlington[c]	8,200	12,200	23,000	42,000	104,000	174,000
3	Village and Town of Rochester.	700	800	2,000	2,000	13,000	14,000
4	Village and Town of Waterford.	1,000	1,000	1,000	1,000	24,000	25,000
5	Waukesha County Line to Vernon Marsh.	2,700	3,300	8,000	9,000	28,000	62,000
6	Vernon Marsh to City Limits of Waukesha . . .	5,600	9,100	14,000	22,000	19,000	57,000
7	City of Waukesha.	12,700	15,700	24,000	31,000	245,000	295,000
8	Fox River above Waukesha	9,600	21,800	29,000	76,000	58,000	331,000
9	STH 36-White River to Burlington Dam.	2,300	2,300	10,000	10,000	31,000	31,000
Total		$ 76,700	$112,600	$207,000	$331,000	$857,000	$1,511,000

[a] *Based upon SEWRPC Land Use Inventory - 1963.*

[b] *Based upon projection of existing land use development trends.*

[c] *Includes Fox River Area only.*

Source: U.S. Department of Agriculture and SEWRPC.

FOX RIVER WATERSHED FLOOD DISCHARGE-DAMAGE CURVES EXISTING 1963 LAND USE AND PROJECTED 1990 LAND USE UNDER UNCONTROLLED FLOODPLAIN DEVELOPMENT

Figure 26
REACH 1
KENOSHA COUNTY LINE TO STATE LINE

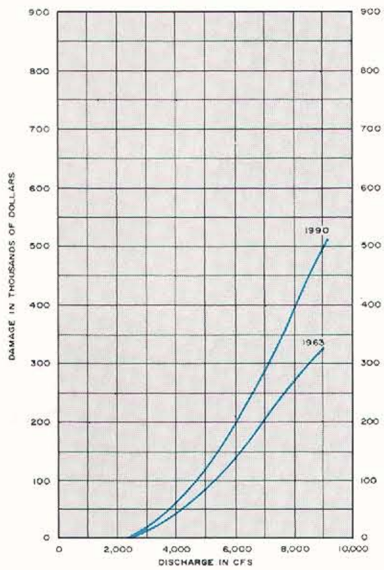


Figure 27
REACH 2
CITY AND TOWN OF BURLINGTON

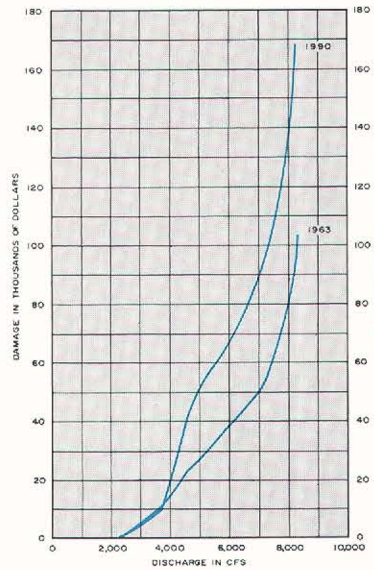


Figure 28
REACH 3
VILLAGE AND TOWN OF ROCHESTER

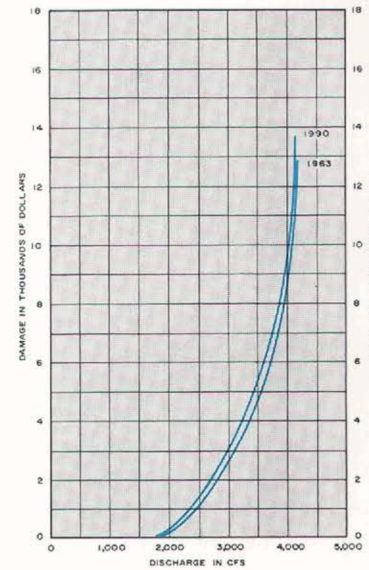


Figure 29
REACH 4
VILLAGE AND TOWN OF WATERFORD

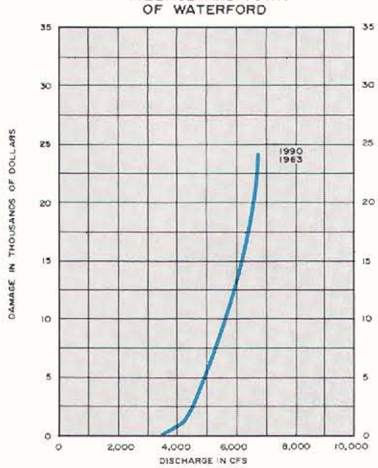


Figure 30
REACH 5
WAUKESHA COUNTY LINE TO VERNON MARSH

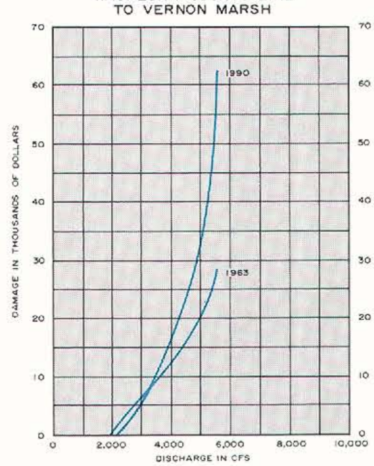


Figure 31
REACH 6
VERNON MARSH TO CITY LIMITS OF WAUKESHA

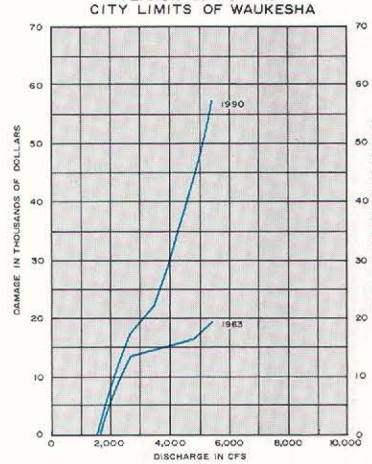


Figure 32
REACH 7
CITY OF WAUKESHA

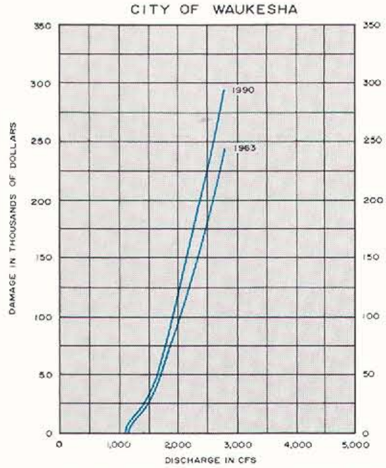


Figure 33
REACH 8
FOX RIVER ABOVE CITY OF WAUKESHA

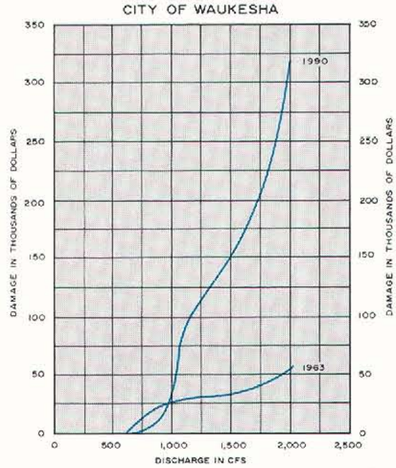
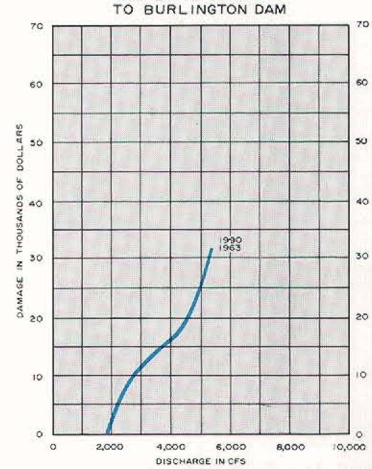


Figure 34
REACH 9
WHITE RIVER: S.T.H. 36 TO BURLINGTON DAM



Source: U. S. Soil Conservation Service.

FOX RIVER WATERSHED FLOOD DAMAGE-FREQUENCY CURVES EXISTING 1963 LAND USE AND PROJECTED 1990 LAND USE UNDER UNCONTROLLED FLOODPLAIN DEVELOPMENT

Figure 35
REACH 1
KENOSHA COUNTY LINE TO STATE LINE

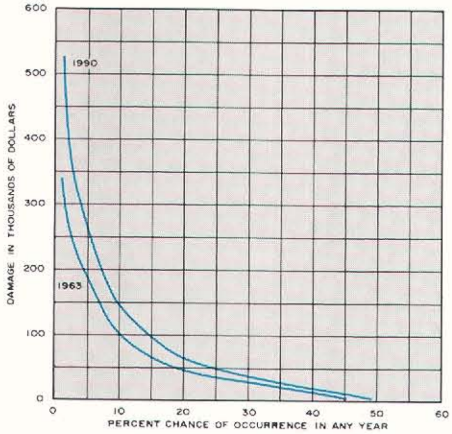


Figure 36
REACH 2
CITY AND TOWN OF BURLINGTON

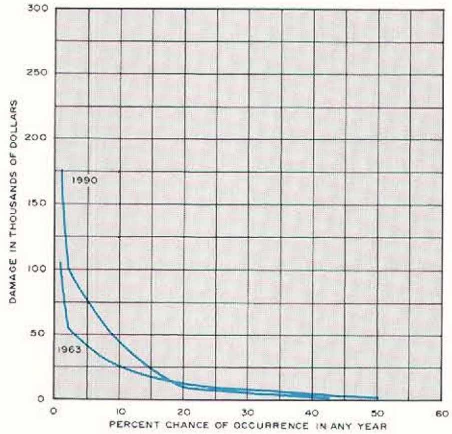


Figure 37
REACH 3
VILLAGE AND TOWN OF ROCHESTER

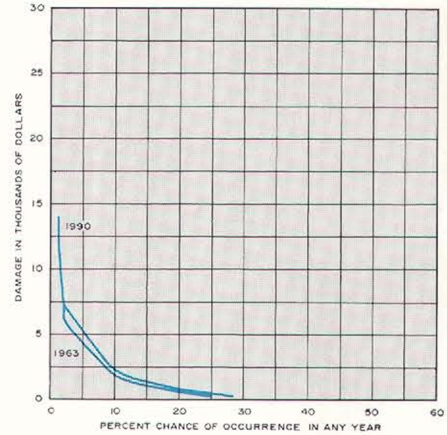


Figure 38
REACH 4
VILLAGE AND TOWN OF WATERFORD

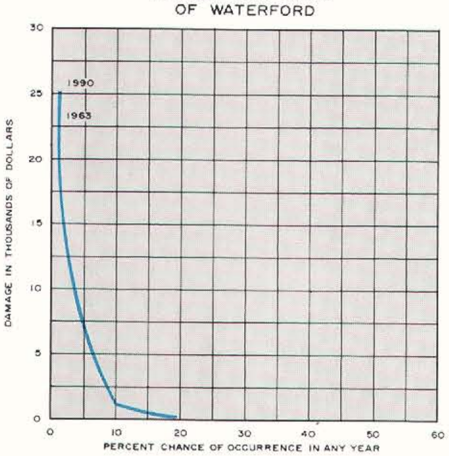


Figure 39
REACH 5
WAUKESHA COUNTY LINE TO VERNON MARSH

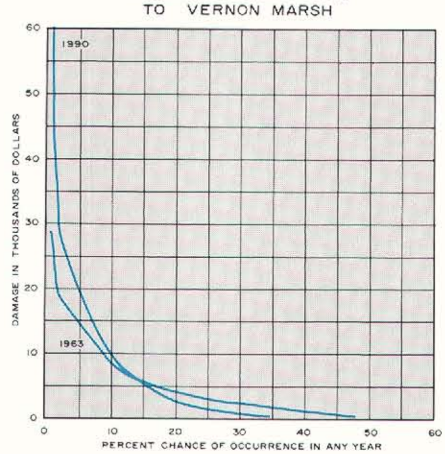


Figure 40
REACH 6
VERNON MARSH TO CITY LIMITS OF WAUKESHA

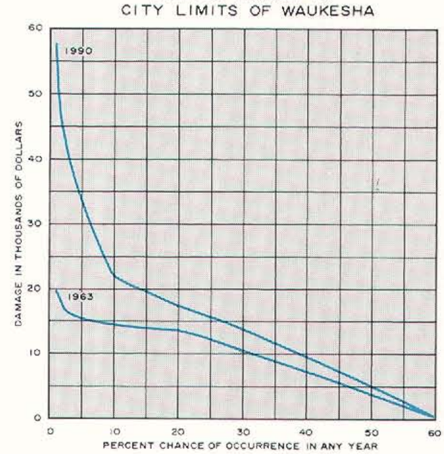


Figure 41
REACH 7
CITY OF WAUKESHA

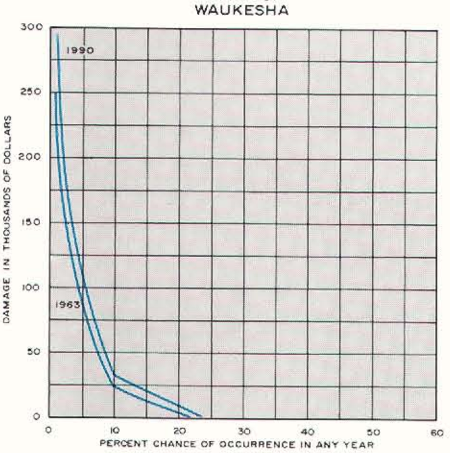


Figure 42
REACH 8
FOX RIVER ABOVE CITY OF WAUKESHA

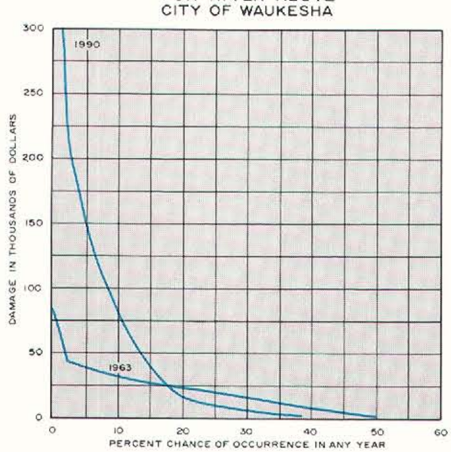
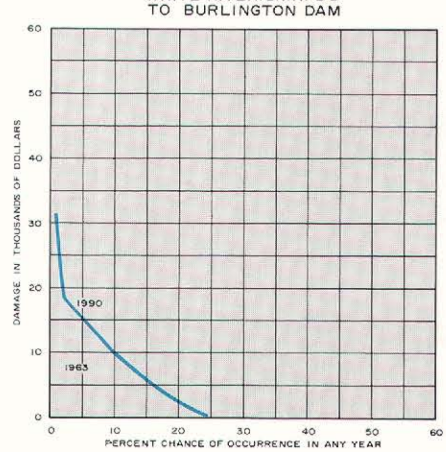


Figure 43
REACH 9
WHITE RIVER: S.T.H. 36 TO BURLINGTON DAM



Source: U. S. Soil Conservation Service.

only the annual risk of damage along the entire length of the Fox River and the urbanizing reaches of the White River through the City of Burlington. Although the damage reaches for which damage-frequency curves were prepared and the annual risk of damage calculated included all those portions of the watershed which sustained significant damage from the major flood of March-April 1960, riverine areas on other major tributaries could sustain damage from a future flood event which might occur under different hydrologic circumstances.

SUMMARY

An understanding of the interrelationships that exist between the flood characteristics of the major stream system and improper urban and rural land use of the riverine areas is fundamental to a comprehensive study of the watershed. This chapter, therefore, has described the hydrologic factors that have contributed to historic flooding of the watershed and the monetary losses that have accrued to the watershed from this flooding, consequent to unnecessary occupancy of the flood plain with flood-vulnerable land uses.

The watershed, while having a history of relatively frequent minor flooding, has experienced only two major floods in recent times, the most damaging of which occurred in March-April of 1960 due to a combination of heavy rainfall and rapid snowmelt. The other significant flood event occurred in the southwestern portion of the watershed in July 1938 as a result of a high-intensity thundershower centered approximately over the Village of Williams Bay.

The SEWRPC conducted a survey of historic flood damages of the watershed in the summer of 1966. The survey included actual on-site interviews with 274 homeowners and occupants, 55 owners or managers of commercial properties, and 154 farm owners or operators. The survey also included an assessment of historic damage to public property through interviews with appropriate public officials. The flood damage survey revealed that the March-April 1960 flood of the Fox River and its major tributaries caused a total of $489,913 in monetary losses, 83 percent of which was loss to private interests and 17 percent to public interests.

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 was calculated. The annual risk of flood damage under 1963 land use conditions was estimated to be $76,700. Significantly, the annual risk of flood damage was estimated to increase to $112,600 by 1990 should the uncontrolled use of the floodplain areas be allowed to continue. Similarly, the projected damage costs of a flood with the same magnitude as the March-April 1960 event would increase from under $500,000 to over $1,100,000 in 1990 under uncontrolled conditions.

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Chapter VIII

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 carried 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 larger and more complex watersheds, such as the Fox 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 hydrologic relationships existing within the watershed to be simulated and the qualitative and quantitative changes that may be expected to be induced upon 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 Fox River watershed study for simulating the present and probable future hydrologic relationships existing within the watershed and the performance of the river system. Since both the amount of water and the pollution loading to be carried by the river system had to be simulated, the models developed and applied in the study are presented in two sections, the first, entitled "Flood Simulation," describing the mathematical models used to simulate the flood flow characteristics of the river system and the second, entitled "Surface Water Quality Simulation," describing the mathematical model used to simulate stream water quality conditions in the river system.

FLOOD SIMULATION

As already noted, the watershed planning process required 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. In the Fox River watershed, stream gaging station records of river stage and discharge have been obtained at Wilmot, on the main stem, for a period of 28 years; near Mukwonago, on the main stem, for a period of 4 years; at Waukesha, on the main stem, for a period of 5 years; and at Burlington, on the White River, for a period of 8 years. Although these direct-flow measurements are extremely valuable to any sound analysis of the behavior of the river system, these measurements have not been obtained over a long enough period of time to represent more than a very small sample of the possible ranges of 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, stream gaging records, regardless of duration, do not provide direct information on river discharge and water levels for stream reaches between or beyond the measuring points. Sound watershed planning, however, requires knowledge of the river system behavior along the entire length of the principal channels. Such information can be practically provided only through flood flow simulation studies.

The term "flood flow simulation," as used in this report, means the representation of the surface water hydrologic 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 hydrological relationships. Inputs to the model include available data on the climate, topography, soils, and land use and on the slope, cross section, and physical characteristics of the various stream channel reaches. Outputs include flood flows, flood frequencies, and accompanying high water surface elevations. The ability of the model to simulate actual flood flows is checked 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 the 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.

Factors that determine the characteristic of flood flows can be separated into three principal groups. One group of such factors relates to the amount of runoff that occurs within the watershed and thus can be used to establish the total magnitude or quantity 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 last 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 U. S. Department of Agriculture, Soil Conservation Service (SCS), has developed a method of flood simulation that follows the steps described above; and this method was used as the basis for constructing the mathematical flood simulation model for the Fox River watershed. The SCS method 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 obstructions as the variables that affect the movement of flood flows through the stream system. The model constructed for the Fox River watershed was used to simulate floods of selected frequency under both present and future land use and water control facility development within the watershed. The model was also used to evaluate the effect of various proposed water control facilities on flood levels and discharges in the river system.

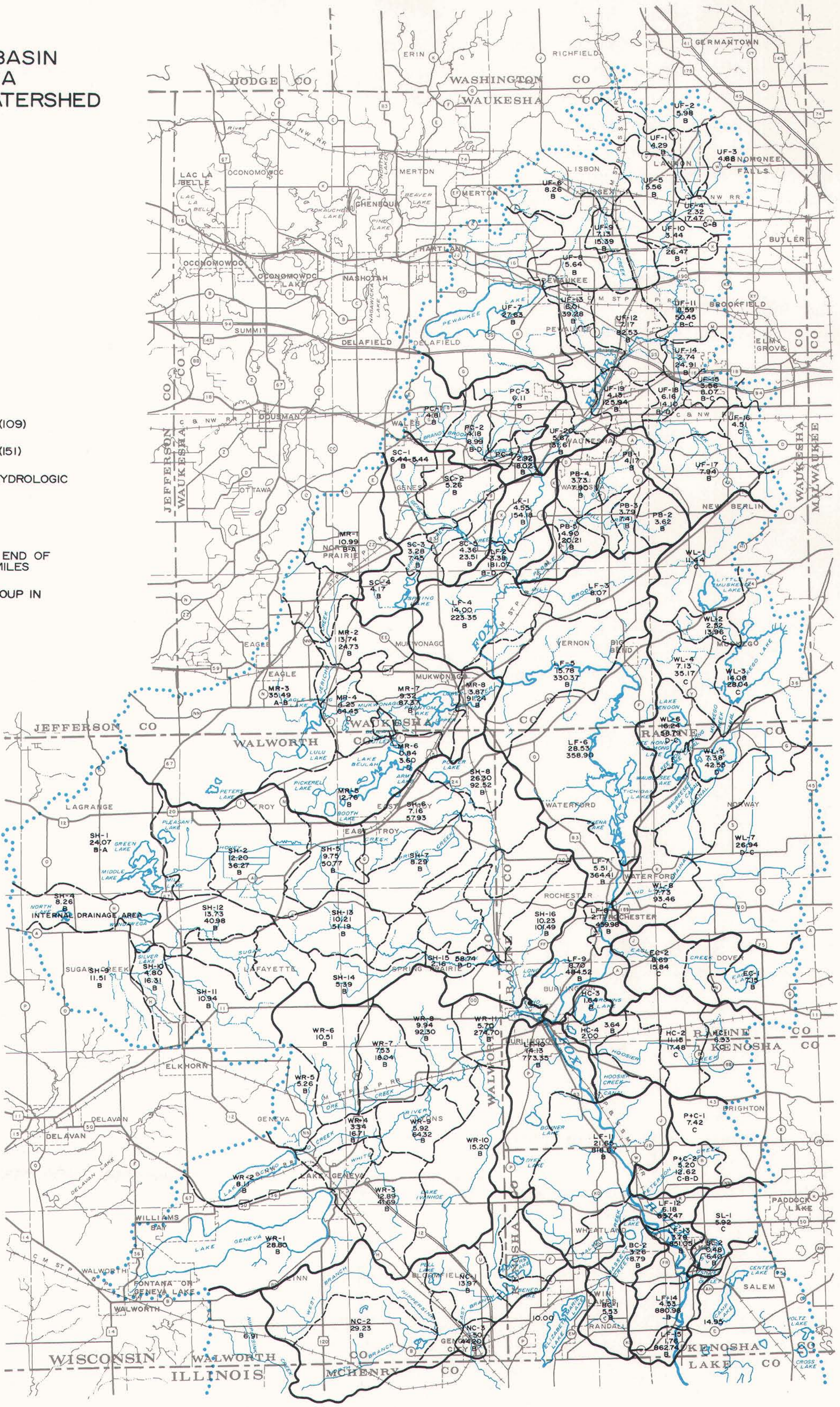
Representation of the Watershed

Delineation of Hydrologic Subareas: In order to provide a manageable basis for the identification and analysis of soil type and land use and treatment, the entire Fox River watershed was divided into 109 hydrologic subareas, ranging from 0.48 to 29.23 square miles in size. The subareas are shown on Map 39 , together with the hydrologic soil group predominant in each subarea. Most of the 109 subareas also provided a unit 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 additional hydrographs should be developed for 151 individual sub-basins. These subbasins are also shown on Map 39 . Sub-basin hydrographs were added to channel flows at junctions of major tributaries; at regular distances along the channel system as determined to be necessary in order to maintain the accuracy of the combined hydrographs; and at all major water control facility structures, such as dams.

Estimation of Runoff: Soil properties influence the process of runoff generation and must be considered in runoff estimation. When runoff from

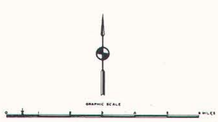
Map 39

HYDROLOGIC SUBBASIN AND SUBAREA OF THE FOX RIVER WATERSHED



LEGEND

- FOX RIVER WATERSHED BOUNDARY
- SUBWATERSHED BOUNDARY (15)
- HYDROLOGIC SUBAREA BOUNDARY (109)
- HYDROLOGIC SUBBASIN BOUNDARY (151)
- NC-3 — HYDROLOGIC SUBWATERSHED AND HYDROLOGIC SUBAREA IDENTIFICATION CODE
- 1.50 — DRAINAGE AREA OF HYDROLOGIC SUBAREA IN SQUARE MILES
- 44.70 — TOTAL DRAINAGE AT DOWNSTREAM END OF HYDROLOGIC SUBAREA IN SQUARE MILES
- B — PREDOMINANT HYDROLOGIC SOIL GROUP IN HYDROLOGIC SUBAREA



These 151 hydrologic sub-basins and 109 hydrologic subareas represent the land areas which were analyzed with respect to soil type, land use, and land treatment as an input to the flood flow simulation model prepared as a part of the Fox River watershed study. The hydrologic sub-basins are divisions of the larger hydrologic subareas which are in turn divisions of the still larger hydrologic subwatersheds. The sub-basins are not numbered.

Source: U. S. Soil Conservation Service.

individual storms is the major concern, as in flood simulation work, 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 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 of the classification of all soils by the SCS 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.

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 were used to identify the predominant soil types in each subarea. All soil types occurring in the Fox River watershed were classified by the SCS into one of the four hydrological soil groups[1] (see Appendix I). This classification, as well as the detailed soils maps necessary to its application, was prepared as an integral part of a detailed operational soil survey of the entire Region conducted by the SCS in cooperation with the Regional Planning Commission.

In view of the availability of detailed soils data for the entire watershed, the SCS Runoff-Curve-Number system was selected as the most suitable method 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 36. 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 vegetation; litter; bare soil; water surfaces; and impervious surfaces, such as roads 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 36, 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 sequency of crop rotations, ranging from good, when 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.

Weighted average runoff curve numbers were calculated 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 1963 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 the various land treatment practices were obtained from the local SCS Work Unit Conservationists. 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

[1] *Refer to* *<u>Soils of Southeastern Wisconsin</u>*, *Planning Report No. 8, June 1966.*

Table 36

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 and Terraced	Poor	66	74	80	82
	Contoured and 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 and Terraced	Poor	61	72	79	82
	Contoured and Terraced	Good	59	70	78	81
Close-Seated Legumes or Rotation Meadows[d]	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 and Terraced	Poor	63	73	80	83
	Contoured and 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. Soil Conservation Service.

urban land use categories are summarized in Table 37. 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 44. These curves were prepared by the SCS using data from gaged watersheds with known soils and cover. The curves indicate the runoff

Table 37

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 square feet and over	0.2- 1.6	0.6- 5.5	350- 3,499	15%
Medium-Density Residential	6,000-19,999 square feet	1.6- 4.6	5.5-15.6	3,500- 9,999	30%
High-Density Residential .	Under 6,000 square feet	4.6-11.4	15.6-39.1	10,000-25,000	60%
Commercial-Industrial. . .					92%

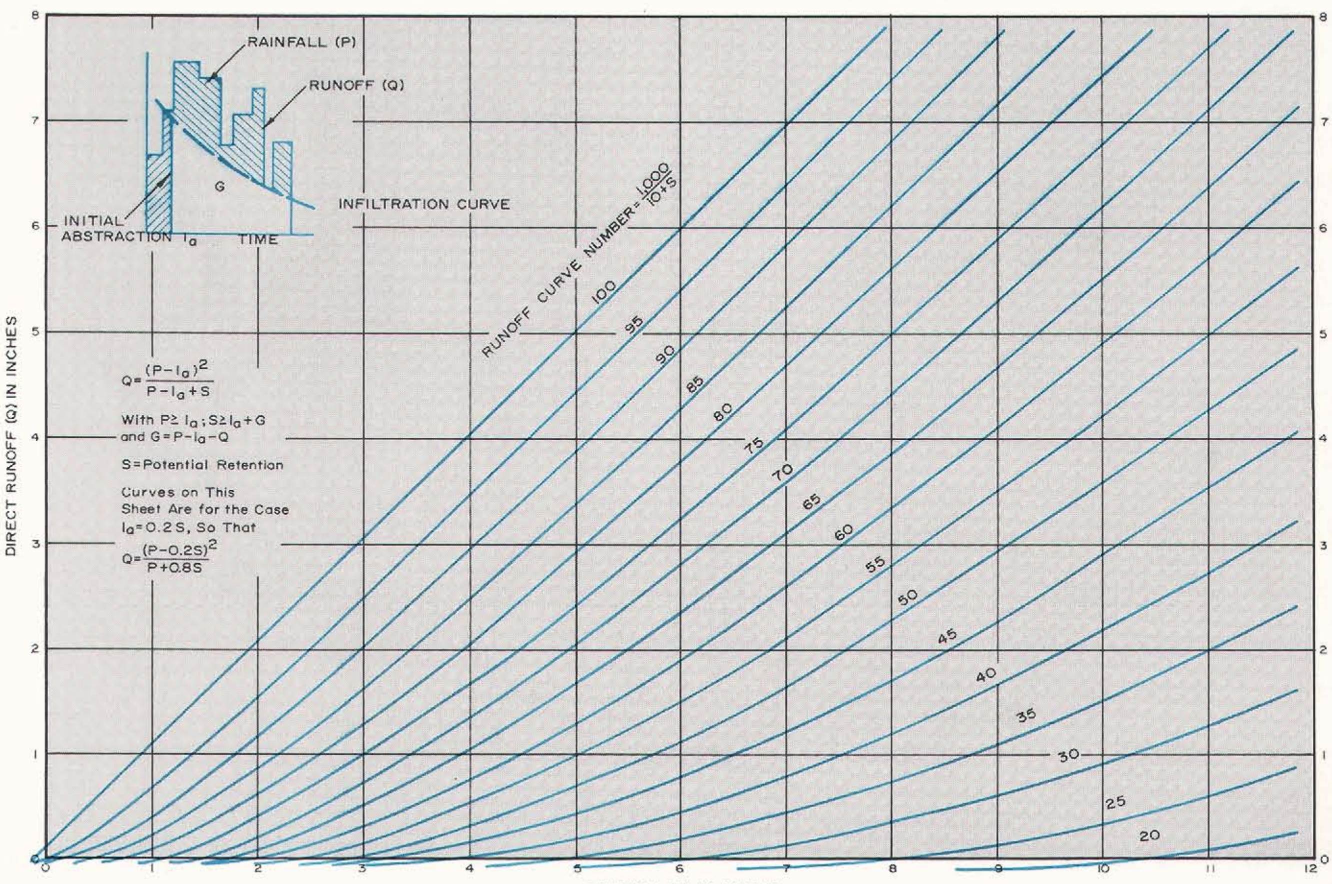
[a] *Net residential area is defined as the area of land actually devoted to residential use within site boundaries and includes the building ground area coverage, together with the necessary on-site yards and open spaces.*

[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.

Figure 44

RAINFALL-RUNOFF RELATIONSHIPS FOR HYDROLOGIC SOIL-COVER COMPLEX RUNOFF CURVE NUMBERS



Source: U. S. Soil Conservation Service.

which may be expected to result from rainfall in a 24-hour period on unfrozen ground and served as a basis for estimating the amount of runoff produced by selected rainfalls.

Time Distribution of Runoff: The pattern of tributary inflow from each of the 151 individual sub-basins was represented by unit hydrographs. The term unit hydrograph is usually defined as the graph of direct runoff over time resulting from one inch rainfall excess (that portion of rainfall which becomes direct surface runoff) generated uniformly over the tributary drainage area at a constant rate during a specified duration. As used herein, however, the term unit hydrograph is defined as the graph of direct runoff over time resulting from a rainfall having a duration equal to 0.4 of the time of concentration of the subarea under consideration. The total rainfall to be anticipated in this duration is derived from the rainfall distribution curve for a 24-hour storm within the watershed.

Preferably, unit hydrographs are derived from streamflow and rainfall records. Practically, however, such records are, because of the costs involved, seldom if ever available for the individual sub-basins of a large watershed; and, therefore, synthetic unit hydrographs must be used. Unit hydrograph characteristics vary with the size, shape, slope, and drainage efficiency of the tributary drainage area. The most significant characteristics are the basin lag, which is the time from the center of mass of rainfall excess to the hydrograph peak, and the peak discharge of the unit hydrograph. Steep slope, compact shape, and an efficient channel network tend to make lag times short and peaks high, while flat slope, elongated shape, and an inefficient channel network tend to make lag time long and peaks low.

The most suitable means of constructing synthetic unit hydrographs is one which takes into account those basin characteristics that most influence the shape of the unit hydrograph and which can be measured, observed, or reliably estimated. The method developed by the SCS makes use of basin area, shape, slope, and overall hydraulic efficiency to determine the time of concentration, from which lag time and unit hydrograph peak discharge can be derived. Time of concentration is defined as the time, from beginning of runoff to arrival at the mouth, of contribution from the hydraulically most distant portion of the basin. Runoff from the most remote part of the basin will occur first as overland flow and later enter a defined waterway and become channel flow. That portion of sub-basin time of concentration spent as overland flow was estimated by multiplying the length of overland flow by an assumed average flow velocity. Velocities used varied from 0.33 to 2.5 feet per second, depending on land surface slope and cover. That portion occurring as channel flow was estimated using channel flow velocities obtained in the hydraulic analysis of the watershed. The flow velocities used were for discharges at or near channel-bank-full stages.

The adjustment of existing rural area concentration times to account for the effects of future urbanization was made by reducing the calculated concentration time in direct proportion to the ratio of assumed hydraulic friction of the drainage systems in urban and rural areas.[2] Hydraulic friction was represented by Manning "n" values, using 0.075 for agricultural areas, 0.050 for partially storm-sewered urban areas, and 0.025 for fully storm-sewered urban areas.

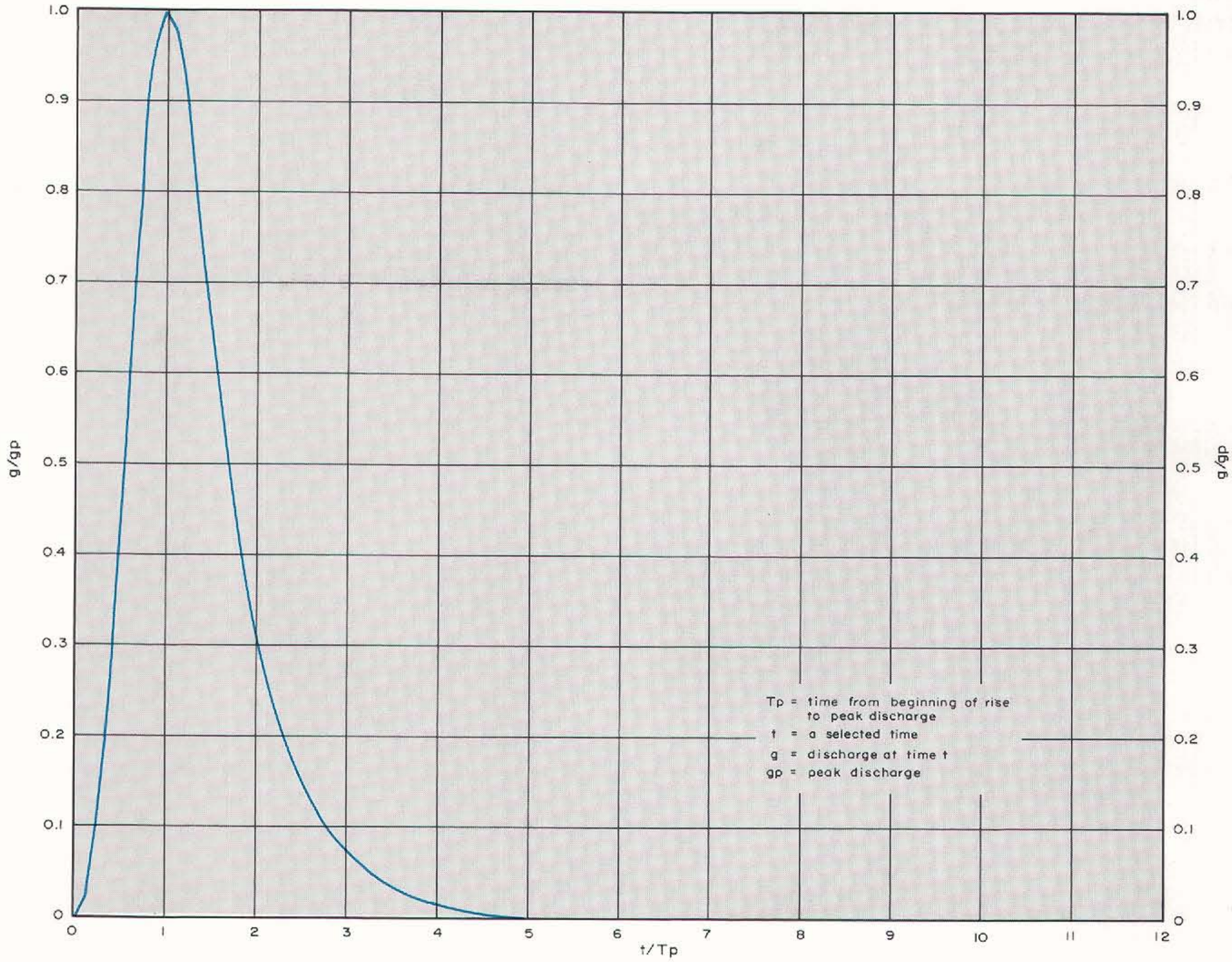
The basic runoff pattern used to construct the unit hydrographs is shown in Figure 45. This dimensionless hydrograph was developed by the SCS by first plotting a large number of actual unit hydrographs for watersheds varying in size and geographical location and then deriving from these an average dimensionless hydrograph. Conversion of the basic dimensionless hydrograph into a unit hydrograph that reflects the effects of subarea characteristics was accomplished by means of the mathematical relationships shown in Figure 46. The relation of lag to time of concentration was established empirically.

The unit storm duration, D, represents the duration of runoff producing rainfall used in the construction of the synthetic unit hydrograph. The relationships shown in Figure 46 indicate that the selected value of D should be smaller than the time of concentration, T_c, since the synthetic unit hydrograph relations are derived for situations wherein peak discharge occurs after the end of the runoff producing rainfall. D must also be chosen

[2] *This approach was developed by the Harza Engineering Company and first applied in the Root River watershed study, as described in SEWRPC Planning Report No. 9, A Comprehensive Plan for the Root River Watershed (July 1966).*

Figure 45

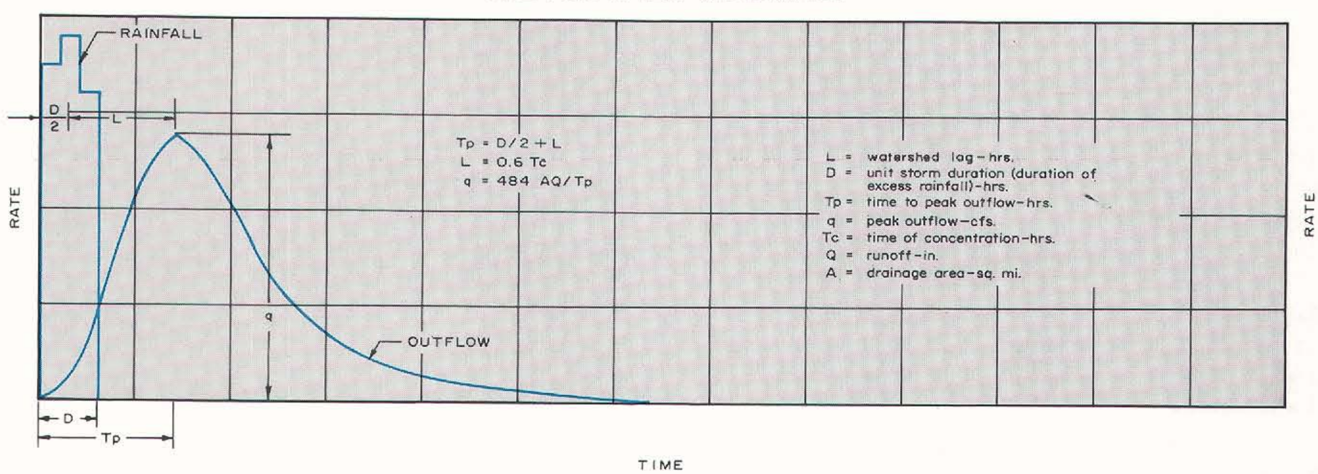
DIMENSIONLESS HYDROGRAPH FOR THE FOX RIVER WATERSHED



Source: U. S. Soil Conservation Service.

Figure 46

SYNTHETIC UNIT HYDROGRAPH RELATIONSHIPS FOR THE FOX RIVER WATERSHED



Source: U. S. Soil Conservation Service.

small enough so that the variation in rainfall during the unit storm duration can be closely represented by an average rate. A unit storm duration equal to 0.4 of the time of concentration of the sub-basin under consideration was used throughout the report.

In addition to the physical characteristics of the subarea, the pattern of runoff is also influenced by the distribution of rainfall within a storm. Figure 47 shows the assumed rainfall distribution used in this report. This storm distribution was selected as representative of an average distribution for the area.

Figure 48 shows how the synthetic unit hydrographs were combined to form a composite storm hydrograph for a subarea.

Flood Movement: 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. The "convex method of flood routing" was selected as the most suitable for use in the Fox River watershed study. The routing equation used is derived from inflow-outflow hydrograph relationships and follows the mathematical theory of convex sets:

$$O_2 = (1-C)O_1 + CI_1$$

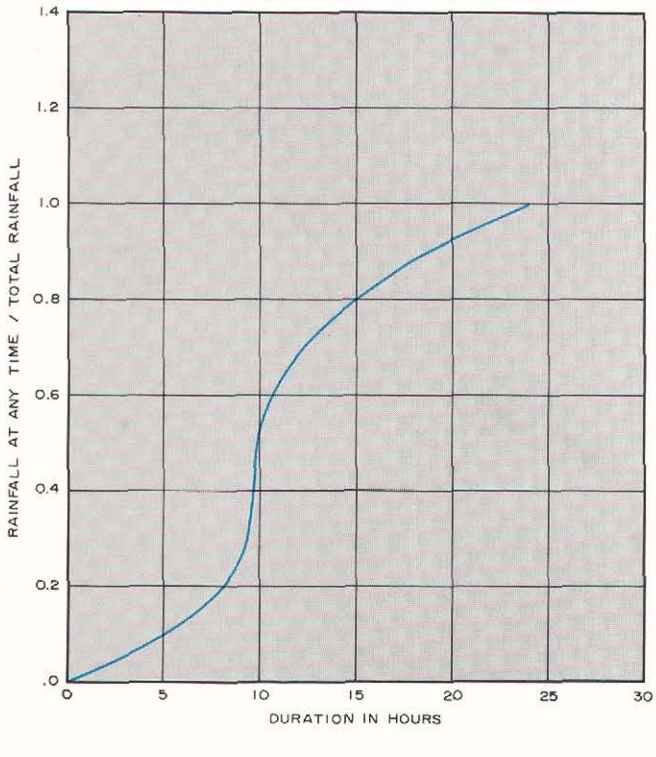
I_1 = inflow in cfs at the upstream end of the portion of the river under consideration (reach length) at time, T_1.

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.

Figure 47

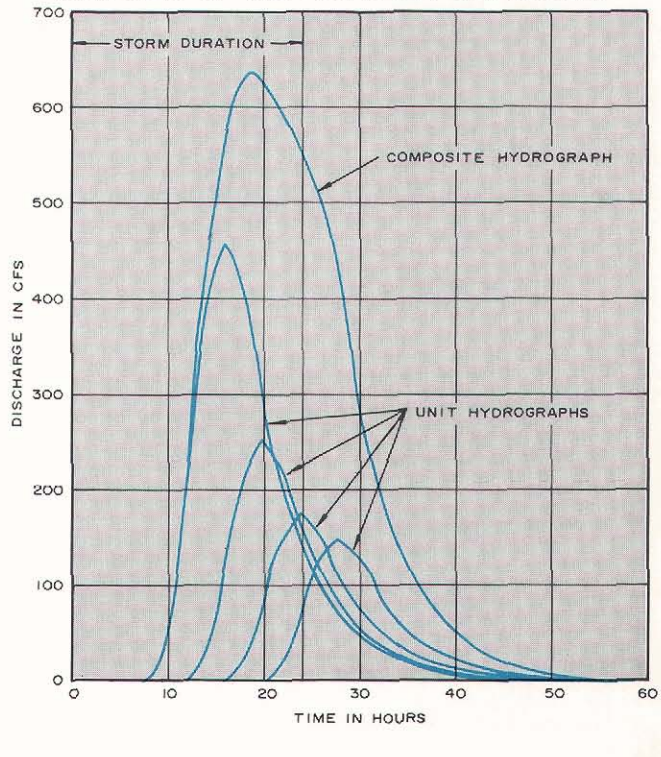
RAINFALL DISTRIBUTION CURVE FOR THE FOX RIVER WATERSHED



Source: U. S. Soil Conservation Service.

Figure 48

COMPOSITE STORM HYDROGRAPH FOR A SUBAREA OF THE FOX RIVER WATERSHED



Source: U. S. Soil Conservation Service.

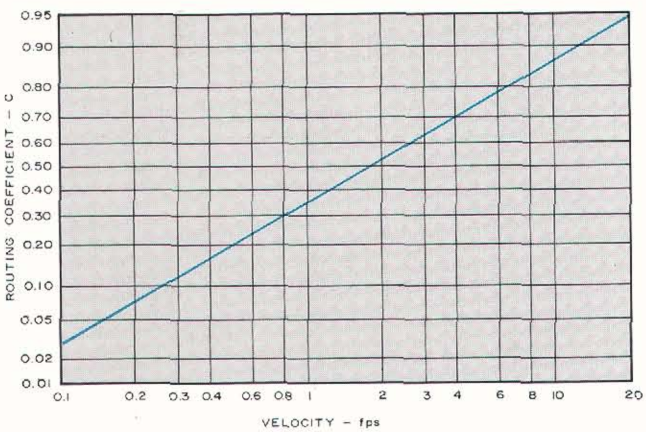
C = a dimensionless routing coefficient that reflects the physical characteristics of the channel.

$T_2 - T_1$ = 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 assumed between velocity and the routing coefficient is shown in Figure 49. The velocity used to establish the routing coefficient is the average of those velocities which are equal to or greater than one-half the peak discharge velocity.

Velocities and corresponding routing coefficients were obtained at 565 locations from stage-area discharge curves that had been prepared as described below under the heading Hydraulic Analysis. Each of the 565 coefficients represents the characteristics of a portion of the river system. Coefficients derived from stage-area discharge curves developed at locations directly upstream from bridges and culverts reflect the ability of these obstructions to modify flood flows. Curves prepared at locations, other than directly above man-made obstructions, indicate the influence of channel characteristics on flood flows.

Figure 49
EMPIRICAL FLOOD ROUTING COEFFICIENT FLOW VELOCITY RELATIONSHIP FOR THE FOX RIVER WATERSHED



Source: U. S. Soil Conservation Service.

In addition to the alterations caused by artificial obstructions and the physical characteristics of the channel itself, flood waves are also modified by man-made water control structures. The ability of such a structure to modify flood flows is dependent upon the hydraulic capacity of its outlet and the storage capacity of the area directly upstream from the structure. The process of determining the modifications made upon a flood wave as it passes through a structure is called reservoir routing. Reservoir routing operations were performed at 30 structure locations in the watershed by the "storage-indication method of flood routing." The general routing equation may be given as:

$$\overline{O} = \overline{I} + \frac{S}{t}$$

$\overline{O}$ = average rate of outflow in cfs during the time interval.

$\overline{I}$ = average rate of inflow in cfs during the time interval, t.

S = change in volume of storage in cfs during the time interval, t.

t = a time interval in hours.

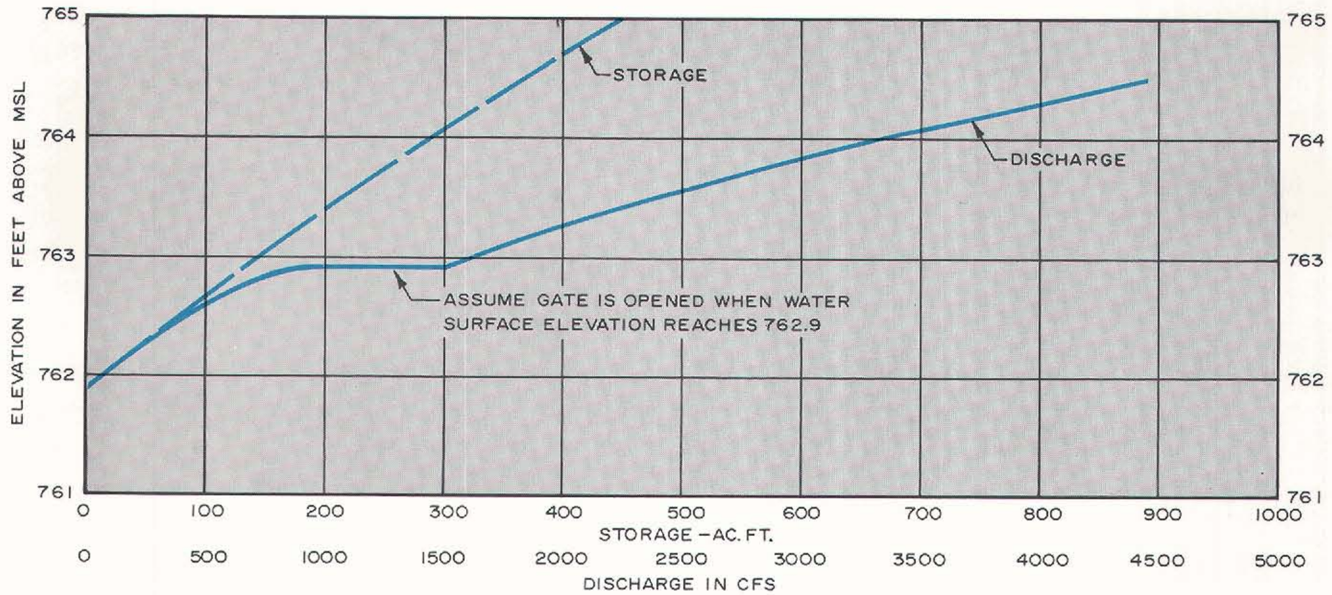
Stage-storage relationships at structure locations were derived from U. S. Geological Survey topographic maps. A typical stage-storage curve prepared under the study is shown in Figure 50 ; all such curves prepared under the study for the Fox River system are on file with the Commission. Stage-discharge relationships were established from measurements of the hydraulic characteristics of the structure and using standard orifice, weir, and pipe flow formulas. Typical stage-discharge curves prepared under the study are shown in Figures 50 through 52.

Operation of the Hydrologic Model: The hydrologic model of the watershed was operated in a sequence of steps similar to that which occurs in nature. Direct runoff amounts were calculated and applied to sub-basin unit hydrographs to obtain sub-basin composite storm hydrographs. The composite subarea hydrographs were routed to appropriate locations where the flow from other subareas was added and the aggregate flow then routed through the channel system. Computations were performed using an IBM-7090 electronic computer. The computer was programmed to carry out the computations in exactly the same manner as they

Figure 50

STAGE-DISCHARGE & STAGE-STORAGE CURVES ECHO LAKE AT BURLINGTON, WISCONSIN: 1966

	WEIR FLOW - $Q = CLH^{3/2}$				GATE FLOW - $Q = CA(2,gH)^{1/2}$; $g = 32.2$ FT./SEC.^{2}				
W.S. ELEV. IN FT. ABOVE MSL	HEAD (H) IN FT.	COEFFICIENT (C)	LENGTH (L) IN FT.	WEIR FLOW Q CFS	HEAD (H) IN FT.	AREA (A) IN FT.	COEFFICIENT (C)	GATE FLOW Q CFS	Q_{TOTAL}
761.9	0	–	–	0	–	0	–	0	0
762.1	0.2	3.3	250	74	–	0	–	0	74
762.5	0.6	3.3	250	380	–	0	–	0	380
762.9	1.0	3.4	250	850	2.9	64	0.72	627	1477
763.5	1.6	3.4	255	1751	3.5	64	0.72	690	2441
763.9	2.0	3.4	255	2454	3.9	64	0.72	726	3180
764.5	2.6	3.4	260	3704	4.5	64	0.72	781	4485



Source: U. S. Soil Conservation Service.

would be done manually so that consistent additional computations can be made manually at any time.

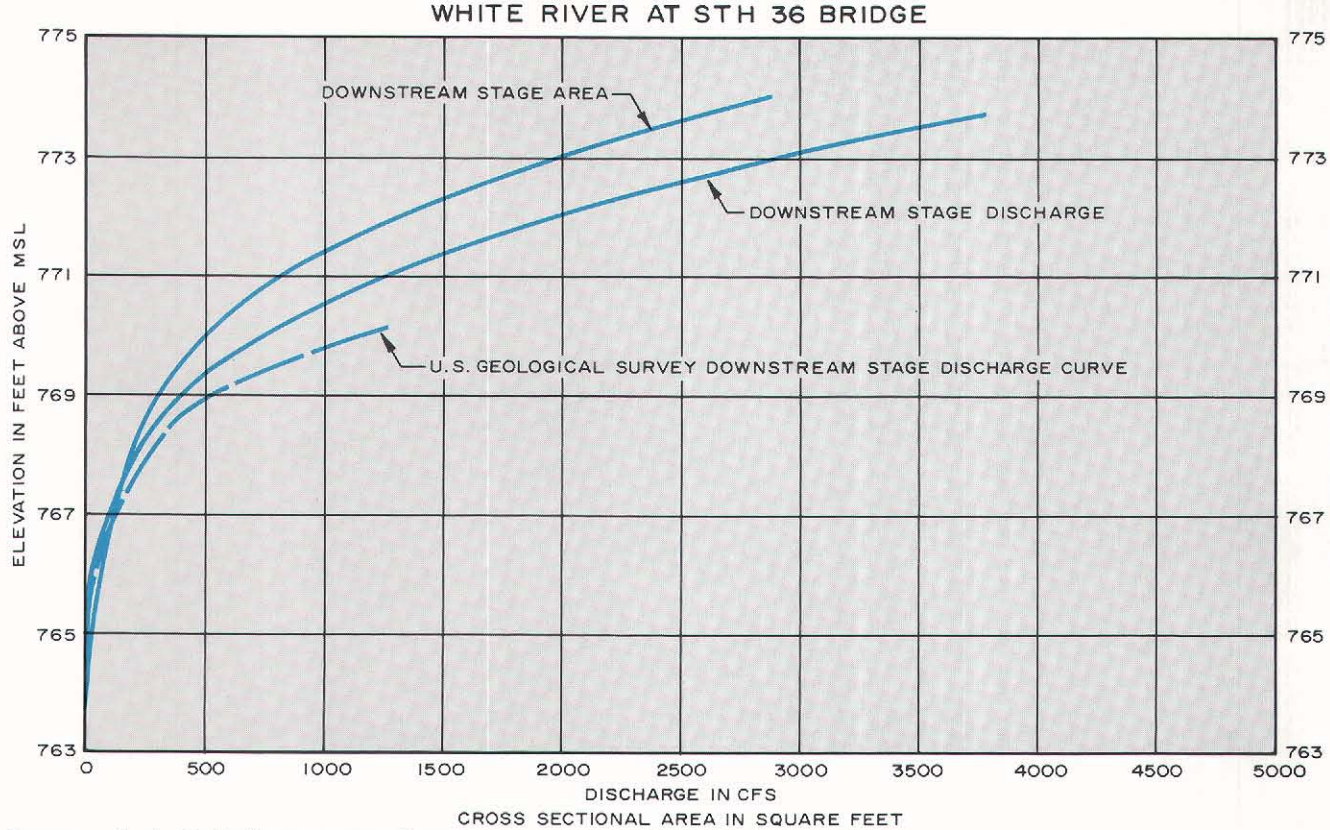
Hydraulic Analysis

The preceding section described the procedures used in the Fox River watershed study to estimate flood discharges. In this section the procedures used to relate the flood discharges to high water surface elevations (stages) is described. Knowledge of present and future stage-discharge relationships is essential to the design and evaluation of many key watershed plan elements. In the absence of actual measurements, stage-discharge relationships must be established using empirical 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 considers both physical characteristics and downstream water levels.

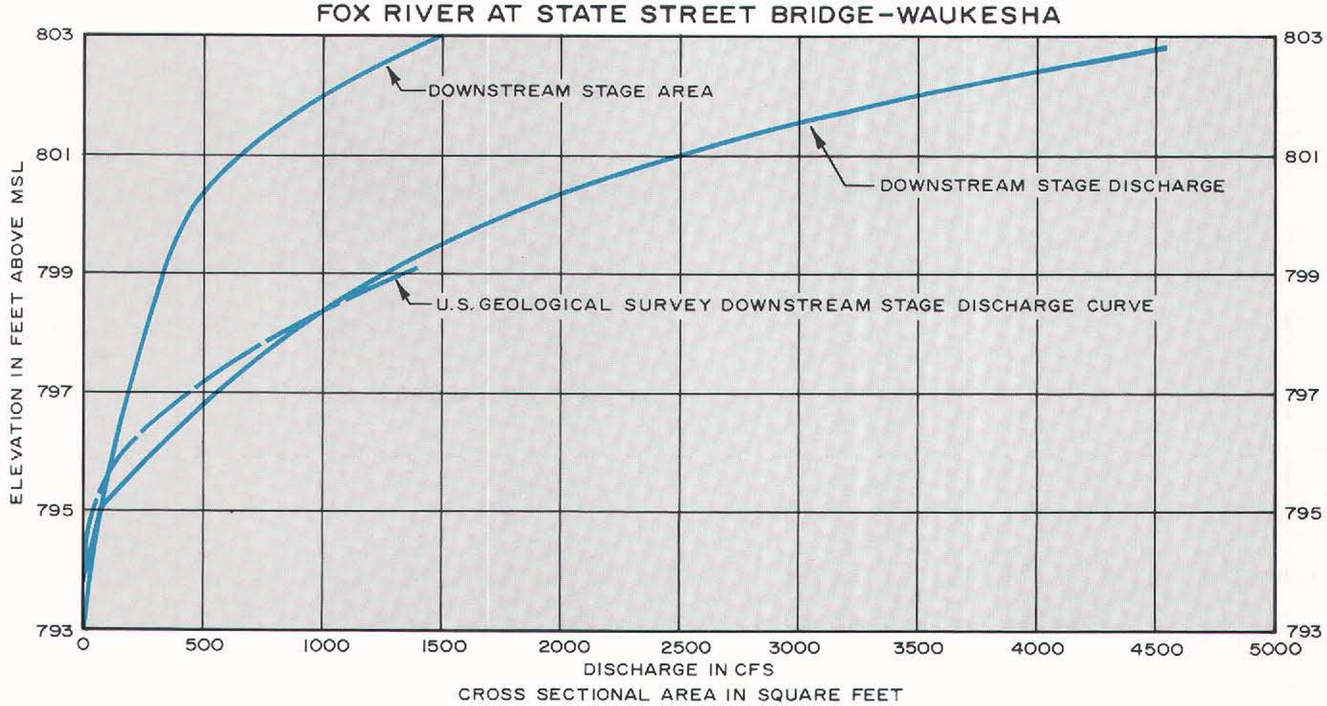
Determination of Channel and Floodplain Characteristics: Channel, floodway, and floodplain size and shape were obtained from cross-sectional drawings of the channel and floodplain prepared by the Commission. In parts of the watershed, topographic maps with a 5-foot contour interval and a horizontal scale of 1" = 200' were used to develop cross sections. In areas where maps of this scale were not available, cross sections were prepared using information obtained from U. S. Geological Survey 7 1/2 minute topographic maps and supplemental field survey data. The field work consisted primarily of determining channel top width and bank elevation. Cross sections of the channel and floodplain were obtained at representative loca-

Figure 51
STAGE-AREA-DISCHARGE CURVES
WHITE RIVER AT STH 36 BRIDGE



Source: U. S. Soil Conservation Service.

Figure 52
STAGE-AREA-DISCHARGE CURVES
FOX RIVER AT STATE STREET BRIDGE-WAUKESHA



Source: U. S. Soil Conservation Service.

tions along the river system and immediately upstream from road or railway crossings. The section obtained on the upstream side of crossings was transposed and also used to represent the size and shape of the channel and floodplain immediately downstream from the crossing.

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 as established by the U. S. Coast and Geodetic Survey.

Channel slopes were estimated using elevations of the channel bottom, which were determined as part of the field survey of structures, and distances between these points of known elevations, as measured on U. S. Geological Survey 7 1/2 minute topographic maps. Generally, this required an assumption that a constant channel slope existed between road and railway crossings. However, where topographic maps indicated a pronounced break in slope between crossings, values were altered to reflect this variation.

Hydraulic friction is a relative measure of the ability of the channel, floodway, and floodplain to 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 cross-section locations. Values were estimated as the sum of the amounts attributable to various factors, as summarized in Table 38. Separate estimates of "n" were made for the channel and for the floodway and the floodplain. Values of "n" used in this study were based on summer or growing season conditions.

Determination of Water Surface Elevations: The procedure used to develop a relationship between water surface elevation and discharge combines the hydraulic relationships established in the Manning formula with the 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. Figure 53 shows the basic relationships established by the two equations. The actual determination of water surface elevations requires a trial and error solution of cumbersome mathematical equations and is not discussed here.[3]

In order to evaluate the effects of downstream water levels on upstream elevations, "backwater" computations were initiated at the Wilmot 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 begun based upon a stage-discharge relationship which was established at the structure.

Figure 50 shows the stage-discharge curve developed for the Echo Lake dam in Burlington. Curves, similar to the one shown, were used at 17 structural locations to establish starting elevations for stage-discharge computations. Many of the 17 structures have facilities, such as gates or flashboards, that can be manually operated to adjust stage-discharge relationships. In this report, it was assumed that gates would be completely opened and flashboards removed when water levels rose within 1.0 to 1.5 feet of the top of the dam.

Bridge and culvert installations raise upstream water levels above downstream levels by an amount equal to the loss of energy that occurs as water passes through the structure. When a bridge was encountered, the change in water surface elevation was calculated using a procedure developed by the U. S. Geological Survey.[4] Briefly, this procedure estimates the total change in surface elevation as the sum of the amounts attributable to flow contraction, skewness, friction, and obstructions. 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 were estimated using standard broad-crested weir formulae.

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[3] *A complete discussion may be found in Supplement A, U. S. Soil Conservation Service Engineering Handbook, Section 5, ''Hydraulics.''*

[4] *''Computation of Peak Discharge at Contractions,'' Geological Survey Circular 284, by C. E. Kindsvater, R. W. Carter, and H. J. Tracy, U. S. Department of the Interior (1953).*

Table 38

CHANNEL FRICTION COMPONENTS

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

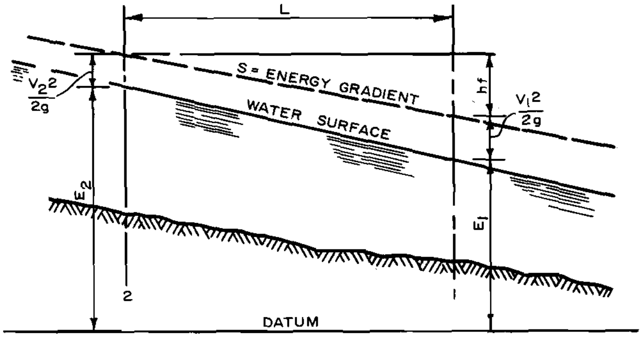
[a] *Equivalent straight line length measured along thread of channel.*

[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.''

At all cross sections, a water surface elevation was determined for each of six selected discharges. These six discharges were selected to best define the rating curve for each cross section with no particular regard for flood frequency occurrence except an attempt was made to define a rating curve beyond the anticipated 100-year flood level. Sample channel cross sections, computation of n value, and stage-area-discharge curves are shown in Figures 54 and 55. In order to reflect the variation in discharge that occurs between two cross-section locations, discharge values were assumed to be directly proportional to the size of the drainage area above the cross section. This means that a higher discharge was assumed to be occurring at the same instant at the

Figure 53
ENERGY RELATIONSHIPS FOR OPEN CHANNEL FLOW



$E_2 = E_1 + V_1^2/2g + hf$

LEGEND

E = WATER SURFACE ELEVATION - FT.
L = LENGTH BETWEEN CROSS SECTIONS 1 & 2 - FT.
Q = DISCHARGE - CFS
A = CROSS SECTIONAL FLOW AREA - SQ. FT.
V = Q/A = VELOCITY - FPS
g = ACCELERATION OF GRAVITY - FPS/SEC
hf = S x L = ENERGY LOSS BETWEEN POINTS 1 & 2 - FT.
S = SLOPE OF THE ENERGY GRADE LINE - FT./FT.
(RATE OF ENERGY LOSS)

THE RATE OF ENERGY LOSS BETWEEN POINTS 1 & 2 IS ASSUMED TO BE THE AVERAGE OF THE RATE OF LOSS, AS DETERMINED BY THE MANNING FORMULA, AT POINTS 1 & 2.
THE MANNING FORMULA FOR THE RATE OF LOSS AT ANY POINT IS:

$$S = \left(\frac{nQ}{1.486AR^{2/3}}\right)^2$$

Q = DISCHARGE - CFS
n = HYDRAULIC FRICTION FACTOR
A = CROSS SECTIONAL FLOW AREA - SQ. FT.
R = HYDRAULIC RADIUS - FT.
S = RATE OF ENERGY LOSS - FT./FT.

Source: U. S. Soil Conservation Service.

next downstream cross section when a water surface elevation was established at a cross section. Stage-discharge curves were drawn using the six established points for each cross section. Figures 51 and 52 show stage-dishcarge curves that are typical of those developed. Actual measurements of stage and discharge have been made by the U. S. Geological Survey at these same two locations, and these curves are also shown.

Method of Computation: Stage-discharge relationships were established at 589 locations in the 260 miles of channel length studied. This number includes the curves developed on the upstream and downstream sides of 217 bridge or culvert installations and 178 representative channel and floodplain sections. The computations were performed using an IBM-650 electronic computer. The computer was programmed to carry out the computations in exactly the same manner as they would be done manually so that consistent additional computations can be made manually at any time. In addition to performing stage-discharge computations, the computer was programmed to calculate cross-sectional flow areas at each cross section and to determine the number of acres inundated between cross sections for each specified discharge. Cross-sectional flow areas were used in the flood routing procedure, and area inundated values were used in the flood damage evaluation.

CALIBRATION OF THE HYDROLOGIC MODEL

Since general theoretical and empirical relationships were used to construct the hydrologic model, it was necessary to calibrate the model to the specific characteristics of the Fox River watershed. A number of suitable calibration standards were fortunately available within the watershed for this purpose. These included stage-discharge records at Wilmot, Mukwonago, and Waukesha on the main stem of the Fox River and at Burlington on the White River and high water elevations at various locations along the entire stream channel system for the 1960 flood event and some for the 1938 flood event.

In order to provide the best possible basis for model calibration, the actual flood event used for such calibration 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.

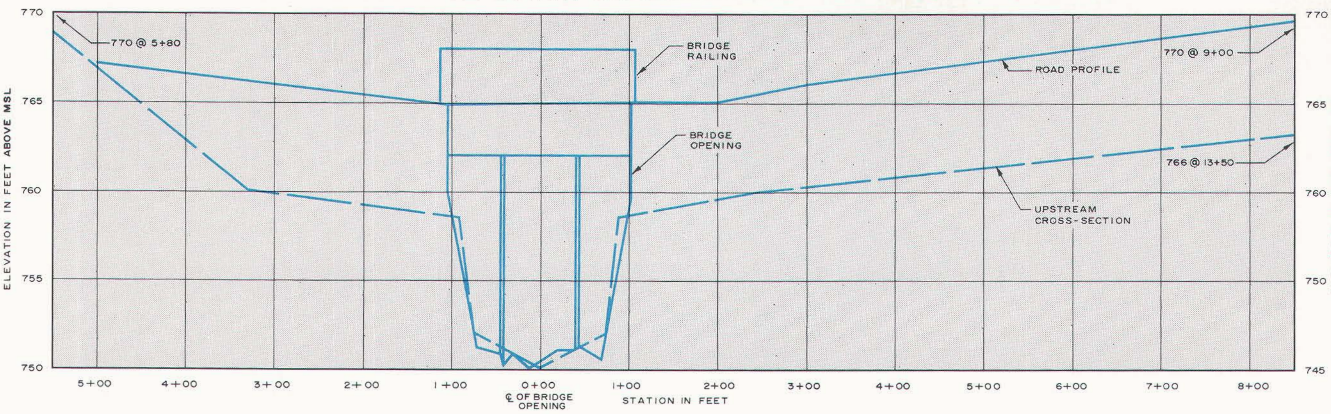
5. A number of high water marks and other documented flood data should be available.

6. The magnitude of flooding should be of an infrequent nature, preferably in excess of 10 years, and having 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

Figure 54

STAGE-DISCHARGE CURVE CALCULATIONS-FOX RIVER AT C T H W



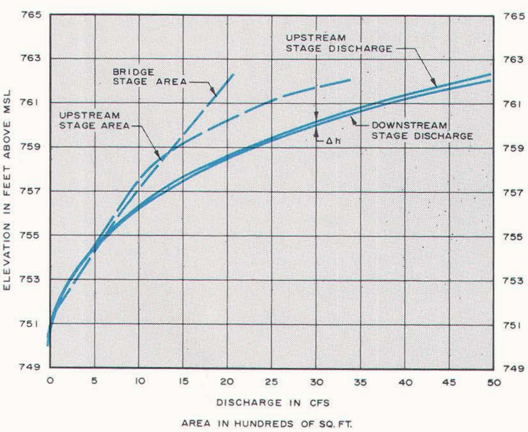
CALCULATION OF UPSTREAM FLOW

$$Q = 8.02 C A_3 \sqrt{\frac{\Delta h}{1 - \alpha_1 C^2 (A_3/A_1)^2 + 2 g C^2 (A_3/K_3)^2 (L + L_W K_3/K_1)}}$$

UPSTREAM CROSS SECTION PROPERTIES

CHANNEL $\frac{1.486}{N} = \frac{1.486}{0.035} = 42.46$ LEFT FLOOD-PLAIN $\frac{1.486}{N} = \frac{1.486}{0.065} = 22.86$ RIGHT FLOOD-PLAIN $\frac{1.486}{N} = \frac{1.486}{0.55} = 2.702$

	CHANNEL					LEFT FLOODPLAIN					RIGHT FLOODPLAIN						
ELEV	A_1	W.P.	R	$R^{2/3}$	K	A_1	W.P.	R	$R^{2/3}$	K	A_1	W.P.	R	$R^{2/3}$	K	TOTAL K_1	TOTAL Q
750	0			0.00	0												0
751	37	72	0.51	0.64	1,000												45
752	150	153	0.98	0.99	6,342												125
753	302	155	1.95	1.56	20,028												250
754	458	160	2.87	2.02	39,342												450
755	618	164	3.77	2.42	63,657												675
756	782	168	4.65	2.78	92,571												950
757	950	173	5.50	3.12	125,800												1,300
758	1122	177	6.63	3.43	163,228	0			0	0	0			0.00	0		1,750
759	1298	180	7.23	3.74	206,224	20	97	0.21	0.35	160	13	65	0.20	0.34	120	206,504	2,275
760	1474	180	8.21	4.07	254,910	182	246	0.74	0.82	3,410	121	161	0.75	0.83	2,700	261,020	2,900
761	1650	180	9.19	4.39	307,650	433	264	1.64	1.39	13,810	378	353	1.07	1.05	10,700	332,160	3,700
762	1826	180	10.17	4.69	364,310	706	284	2.49	1.84	29,720	821	540	1.52	1.32	29,200	423,230	4,700



BRIDGE PROPERTIES

BRIDGE $\frac{1.486}{N} = \frac{1.486}{0.025} = 59.44$

ELEV	A_3	W.P.	R	$R^{2/3}$	K_3
750	0			0.00	0
751	42	39	1.08	1.05	2,620
752	184	135	1.36	1.23	13,450
753	337	149	2.26	1.73	34,650
754	497	156	3.18	2.16	63,800
755	664	178	3.73	2.41	95,120
756	839	191	4.39	2.68	133,650
757	1021	201	5.09	2.96	179,640
758	1209	211	5.73	3.20	229,960
759	1405	222	6.33	3.42	285,600
760	1608	232	6.93	3.63	346,900
761	1814	238	7.62	3.87	417,300
762	2020	247	8.18	4.06	487,500

VARIABLES IN DISCHARGE CALCULATION

R = HYDRAULIC RADIUS, FT.
A_1 = CROSS SECTIONAL AREA OF UPSTREAM SECTION, SQ. FT.
A_3 = CROSS SECTIONAL AREA OF BRIDGE SECTION, SQ. FT.
C = COEFFICIENT OF DISCHARGE[1]
g = GRAVITATIONAL ACCELERATION, FPS/SEC.
Δh = DIFFERENCE IN WATER SURFACE ELEVATION BETWEEN UPSTREAM SECTION AND BRIDGE, FT.
K_1 = TOTAL CONVEYANCE OF UPSTREAM SECTION
K_3 = CONVEYANCE OF BRIDGE SECTION
L = LENGTH OF ABUTMENT, FT.
L_W = DISTANCE FROM BRIDGE TO UPSTREAM CROSS SECTION, FT.
Q = DISCHARGE, CFS
α = VELOCITY - HEAD COEFFICIENT
N = MANNING ROUGHNESS COEFFICIENT
WP = WETTED PERIMETER
H = DIFFERENCE IN ELEVATION BETWEEN UPSTREAM WATER SURFACE AND ROADWAY

[1] FROM "COMPUTATION OF PEAK DISCHARGE OF CONTRACTIONS," GEOLOGICAL SURVEY CIRCULAR 284, BY C. E. KINDSVATER, R. W. CARTER, AND H. J. TRACY, US. DEPARTMENT OF INTERIOR, 1953.

Source: U. S. Soil Conservation Service.

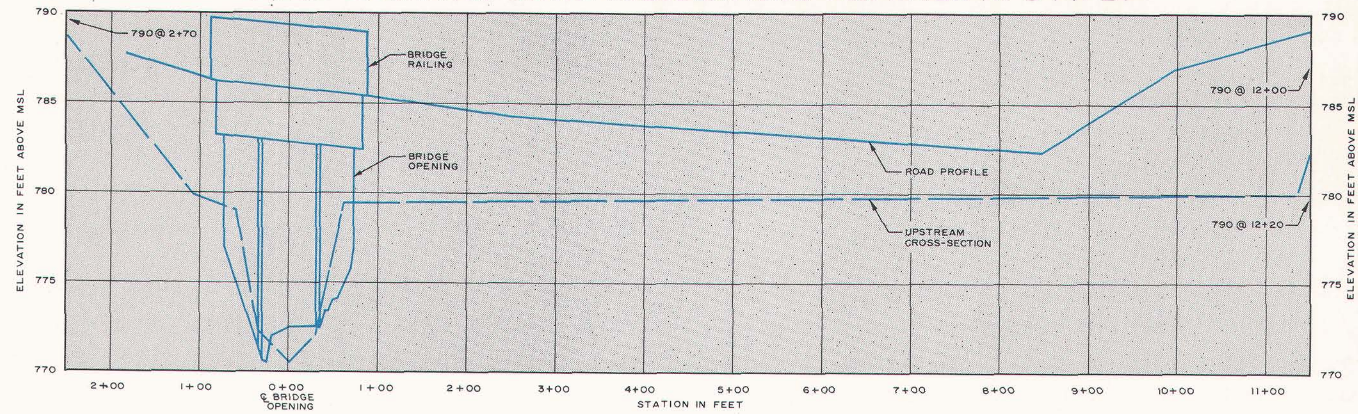
hydraulic information was available to define precisely the physical characteristics of the drainage network, it would then be theoretically possible to duplicate exactly the historic flood event simply by adjusting the variable hydrologic input to the simulation model. Once this was accomplished, the model would be fully calibrated and could be used with a very high degree of confidence to synthesize possible future 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.

Since the 1960 flood event did not fully meet all of the foregoing criteria, a regional flood analysis was also carried out as a further check on the ability of the model to simulate accurately the performance of the river system. This statistical approach served to reduce the chance sampling error inherent in any calibration of the model against a specific flood event at the few isolated locations along the river system for which a full range of necessary data were available. It thereby provided an excellent independent check on the model.

In the model calibration, the hydraulic inputs to the model, 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. Certain hydrologic inputs, including tributary drainage

Figure 55

STAGE-DISCHARGE CURVE CALCULATIONS-FOX RIVER AT S T H 24



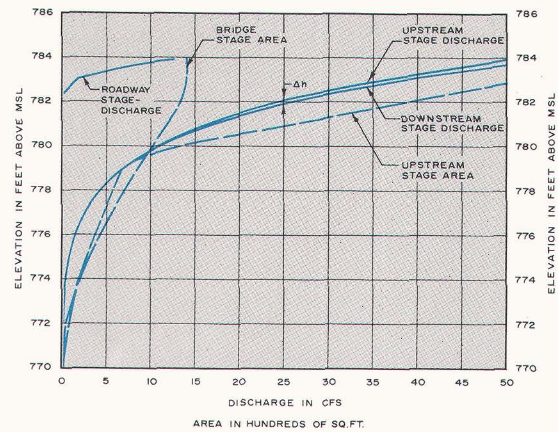
CALCULATION OF UPSTREAM FLOW

$$Q = 8.02 C A_3 \sqrt{\frac{\Delta h}{1 - \alpha C^2 (A_3/A_1)^2 + 2gC^2 (A_3/K_3)^2 (L + L_W K_3/K_1)}} + 3.1 C_R H^{3/2} R_R L_R$$

UPSTREAM CROSS SECTION PROPERTIES

CHANNEL $\frac{1.486}{N} = \frac{1.486}{0.040} = 37.15$ LEFT FLOOD-PLAIN $\frac{1.486}{N} = \frac{1.486}{0.060} = 24.77$ RIGHT FLOOD-PLAIN $\frac{1.486}{N} = \frac{1.486}{0.085} = 17.48$

ELEV	A_1	W.P.	R	$R^{2/3}$	K	A_1	W.P.	R	$R^{2/3}$	K	A_1	W.P.	R	$R^{2/3}$	K	TOTAL K_1	TOTAL Q
770	0				0											0	0
771	7	18	0.24	0.38	100											100	0
772	48	61	0.79	0.86	1,525											1,525	5
773	112	69	1.63	1.39	5,775											5,770	15
774	185	78	2.38	1.78	12,250											12,250	25
775	265	85	3.10	2.13	20,950											20,950	70
776	355	95	3.75	2.41	31,850											31,850	140
777	452	103	4.40	2.68	45,070											45,070	250
778	559	112	5.00	2.92	60,700											60,700	420
779	673	120	5.60	3.15	78,820	0				0	0				0	78,820	680
780	811	146	5.60	3.15	94,220	12	52	0.23	0.37	110	440	1100	0.40	0.54	4,150	98,480	1,050
781	957	147	6.50	3.49	124,070	57	57	1.00	1.01	1,430	1,540	1100	1.40	1.25	33,570	159,070	1,600
782	1103	147	7.50	3.84	157,120	117	69	1.69	1.42	4,130	2,648	1115	2.38	1.78	82,510	243,760	2,400
783	1249	147	8.50	4.16	193,200	193	83	2.34	1.76	8,380	3,761	1117	3.37	2.25	147,570	349,150	3,600
784	1395	147	9.51	4.48	232,200	293	106	2.78	1.98	14,360	4,873	1120	4.36	2.67	226,970	473,530	5,050



BRIDGE PROPERTIES

BRIDGE $\frac{1.486}{N} = \frac{1.486}{0.015} = 99.06$

ELEV	A_1	W.P.	R	$R^{2/3}$	K_3
770	0				0
771	4	11	0.36	0.50	200
772	19	37	0.51	0.64	1,200
773	80	135	0.59	0.71	5,600
774	176	138	1.27	1.17	20,400
775	292	157	1.86	1.51	43,800
776	423	176	2.41	1.80	75,265
777	567	193	2.94	2.05	115,200
778	717	202	3.55	2.33	165,265
779	867	209	4.14	2.58	221,330
780	1017	217	4.69	2.80	282,400
781	1167	224	5.22	3.01	347,733
782	1317	231	5.71	3.20	416,865
783	1377	203	6.79	3.59	489,330
784	1377	203	6.79	3.59	489,330

FLOW OVER ROADWAY

ELEV	LGTH	H	$H^{3/2}$	R_R	C_R	Q
782		0				
783	117	0.7	.59	.89	0.8	150
784	285	1.7	2.22	.81	0.8	1270

VARIABLES IN DISCHARGE CALCULATION

- R = HYDRAULIC RADIUS, FT.
- A_1 = CROSS SECTIONAL AREA OF UPSTREAM SECTION
- A_3 = CROSS SECTIONAL AREA OF BRIDGE SECTION
- C = COEFFICIENT OF DISCHARGE[1]
- g = GRAVITATIONAL ACCELERATION, FPS/SEC.
- Δh = DIFFERENCE IN WATER SURFACE ELEVATION BETWEEN UPSTREAM SECTION AND BRIDGE, FT.
- K_1 = TOTAL CONVEYANCE OF UPSTREAM SECTION
- K_3 = CONVEYANCE OF BRIDGE SECTION
- L = LENGTH OF ABUTMENT, FT.
- L_W = DISTANCE FROM BRIDGE TO UPSTREAM CROSS SECTION
- Q = DISCHARGE, CFS
- α = VELOCITY - HEAD COEFFICIENT
- N = MANNING ROUGHNESS COEFFICIENT
- L_R = LENGTH OF OVERFLOW (ACTUAL LENGTH IS CONVERTED TO A LENGTH THAT WOULD PRODUCE AN EQUIVALENT RECTANGULAR FLOW AREA)
- H = DIFFERENCE IN ELEVATION BETWEEN UPSTREAM WATER SURFACE AND ROADWAY
- R_R = CORRECTION FOR SUBMERGENCE[2]
- C_R = A COEFFICIENT - .80 TO .90 FOR ROAD AND HIGHWAY FILLS
- W.P. = WETTED PERIMETER, FT.

[1] FROM "COMPUTATION OF PEAK DISCHARGE OF CONTRACTIONS," GEOLOGICAL SURVEY CIRCULAR 284, BY C.E. KINDSVATER, R.W. CARTER, AND H.J. TRACY, U.S. DEPARTMENT OF INTERIOR, 1953.

[2] FROM "DROP SPILLWAYS," SOIL CONSERVATION SERVICE ENGINEERING HANDBOOK SECTION II, U.S. DEPARTMENT OF AGRICULTURE, 1952.

Source: U. S. Soil Conservation Service.

area, time of concentration, runoff distribution, and runoff volume, were then determined from careful analysis of topographic, soils, and land use maps and of weather and stream gaging records. A trial model run was then made to attempt to duplicate the 1960 rainfall-snowmelt flood event.

The results of the initial model run were found to reproduce reasonably well the actual hydrograph characteristics and high-water marks recorded for the 1960 rainfall-snowmelt flood. Generally, however, the synthetic hydrograph bases were found to be too short and the discharge peaks too high, which suggested some modification of the model inputs. Further analysis indicated a reduction in contributing drainage area was necessary to adjust for the many small areas of depression drainage existing in the kettle moraine area of the watershed. It was also apparent that some travel time and time of concentration values would have to be increased. These adjustments were made on the basis of experienced engineering judgment after careful analysis of the recorded and synthesized hydrographs at Wilmot, Waukesha, and Burlington, as well as of available high-water level information at other locations along the channel system. A second model run was performed after incorporation of the appropriate changes and the synthesized relationships again checked against the 1960 event. The second run was found to fit closely the existing data, and it was concluded that any further attempts at refinement were unwarranted and that the model was adequately calibrated.

Hydrograph Shape

One of the best model calibration standards available is the 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. 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, storage, infiltration, and channel geometry are essentially constant, the shape of hydrographs from different flood events caused by similar hydrologic conditions are also similar. This is the essence of the unit hydrograph theory and the fundamental basis for the flood simulation technique used in the Fox 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 that cause flooding.

Actual hydrograph shapes always vary somewhat from one flood to another, owing to differences in the conditions that 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. A regional analysis of flood events in the southeastern part of the state, including the Fox River, indicated that only two hydrograph shapes would have to be studied in order to determine the most critical conditions for the entire basin. Generally, in smaller subwatersheds, summer rainfall events were found to produce the highest peak discharges, while in larger subwatersheds the spring snowmelt-rainfall events were found to produce the floods of highest peak discharges. It was, therefore, necessary to check both summer rainfall and spring snowmelt-rainfall flood events in order to determine which controlled in any particular channel reach.

Comparisons of the final adjusted synthesized hydrographs to recorded streamflow hydrographs at U. S. Geological Survey (USGS) stream gaging stations are shown in Figures 56 to 60. These have been adjusted to a unit volume of one inch of rainfall excess in order to facilitate visual comparison of hydrograph shape and the peak-to-volume relationship. The comparisons between the recorded and the synthesized unit streamflow hydrographs indicated that the model simulated the stream behavior very well despite a slight tendency for the synthesized peaks to be somewhat higher than the recorded peaks. By far the largest variation between recorded and synthesized peak discharge was observed at the Wilmot gage, as shown in Figure 59. It was not, however, considered desirable in the model calibration to attempt to match the peaks because the unit hydrograph, based on recorded events at Wilmot, was derived from relatively minor floods; and it has been found that unit hydrographs required to reproduce major flood hydrographs quite often have peak discharge ordinates from 25 to 50 percent higher than those computed from records of minor floods. This is probably due principally to differences in the areal distribution of rainfall and difference in hydraulic relations. If the volume of rainfall-excess during major floods was concentrated in the lower portion of the basin, the peak runoff would be proportionally higher.[5] Since the probability of rainfall-excess being concentrated in the lower portion of the basin increases as the basin size increases, it is reasonable to expect the largest variation in peaks to occur at the Wilmot gage and to decrease as the drainage area decreases.

Rainfall-Runoff Relationship

In order to synthesize flood events resulting from excess rainfall, the hydrologic model must include some means of determining what portion of the total rainfall will contribute to surface runoff. As already noted, the SCS has developed a system of empirical runoff curves for this purpose, based on soil type, soil cover, land treatment, and antecedent precipitation. Recorded rainfall and runoff records for the Fox River watershed were used to check the results of the application of the SCS runoff curve procedure. After a careful analysis of all 28 years of runoff records at the Wilmot

[5] *See: Civil Works Investigations, Project 152, Unit Hydrographs, Part 1, Principles and Determinations, U. S. Army Engineering District, Corps of Engineers, Baltimore 3, Maryland, 1963.*

Figure 56

COMPARISON OF SYNTHESIZED AND RECORDED HYDROGRAPH – FOX RIVER NEAR MUKWONAGO, WISCONSIN (Rainfall Event)

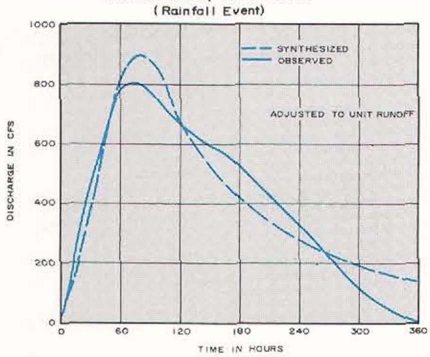


Figure 57

COMPARISON OF SYNTHESIZED AND RECORDED HYDROGRAPH – FOX RIVER NEAR MUKWONAGO, WISCONSIN (Snowmelt Event)

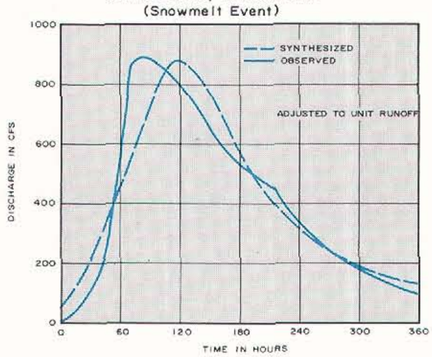


Figure 58

COMPARISON OF SYNTHESIZED AND RECORDED HYDROGRAPH – WHITE RIVER NEAR BURLINGTON, WISCONSIN (Rainfall Event)

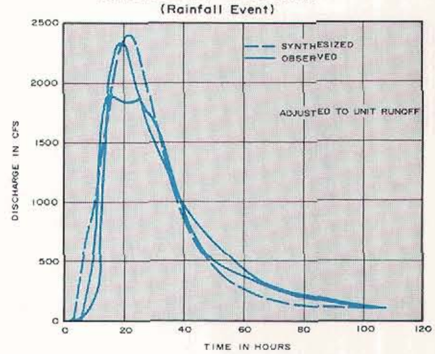


Figure 59

COMPARISON OF SYNTHESIZED AND RECORDED HYDROGRAPH FOX RIVER AT WILMOT (Rainfall Event)

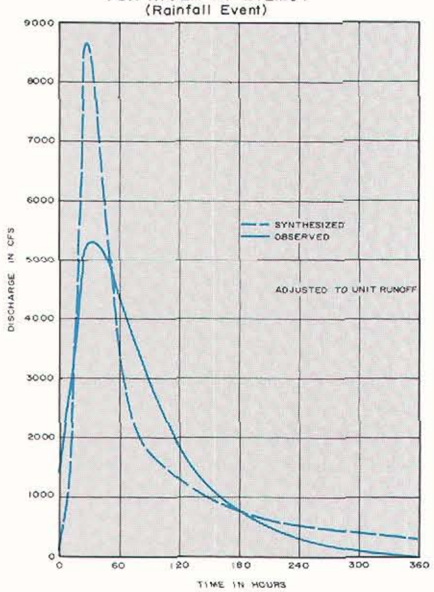
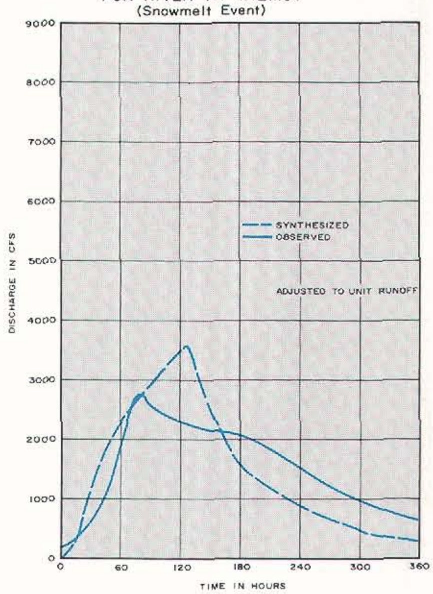


Figure 60

COMPARISON OF SYNTHESIZED AND RECORDED HYDROGRAPH FOX RIVER AT WILMOT (Snowmelt Event)



Source: U. S. Soil Conservation Service.

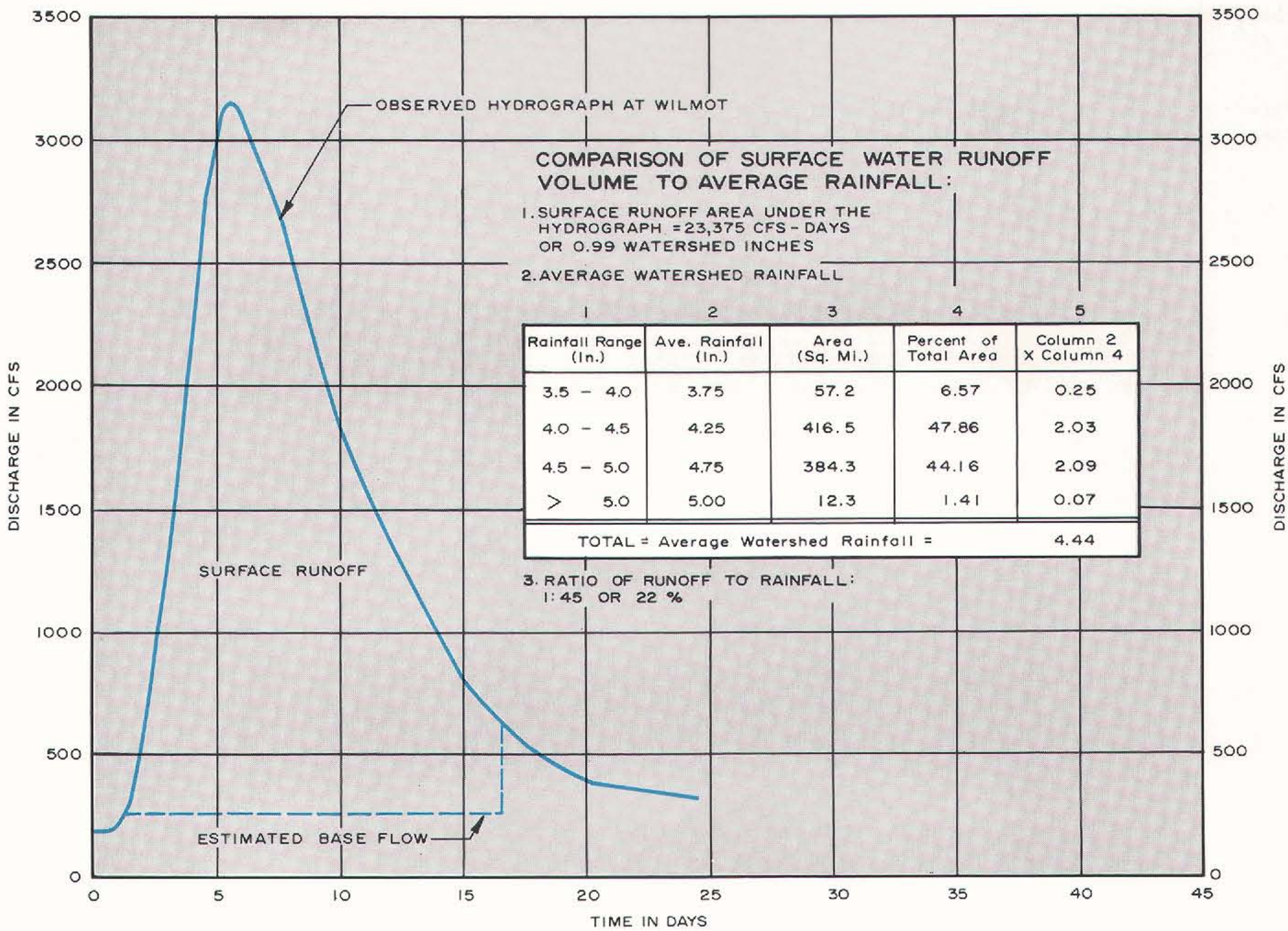
gage, a 15-day surface runoff base time was selected and the largest summer runoff event for each year determined. Surface water runoff volume, expressed in inches of depth over the entire tributary watershed, was computed for each annual event. Rainfall records from the U. S. Weather Bureau Climatological Data were used to construct isohyetal maps of the rainfalls which produced several of the largest summer floods corresponding to the period of record at the Wilmot gage. Average rainfall volume in inches over the entire tributary watershed was computed and compared to the surface runoff measured at the Wilmot gage. Figure 61 shows the results of one such determination.

Actual rainfall-runoff relationships were also compared to computed values based on the SCS runoff curve number procedure. The results of several such checks are summarized in Table 39. Although variation exists between the actual and computed values, the comparison was considered quite satisfactory considering the nature of the phenomena involved.

The historic flood damage survey finding that 12 of 17 damaging floods that have occurred in the Waukesha area of the watershed since 1868 have occurred during the summer is an indication that severe rainfall flooding can occur within the Fox River watershed. It is also an indication that the

Figure 61

SAMPLE RUNOFF – RAINFALL COMPARISON, FOX RIVER AT WILMOT, STORM OF AUGUST 25, 1940



Source: U. S. Soil Conservation Service.

Table 39

COMPARISON OF COMPUTED AND OBSERVED RAINFALL-RUNOFF RELATIONSHIPS

Date of Rainfall	24-Hour Average Rainfall (Inches)	Five-Day Antecedent Rainfall (Inches)	Corresponding Soil Moisture Condition	Runoff Curve Number	Surface Runoff (Inches)	
					Computed	Observed
June 22, 1940	4.25	0.64	I	55	0.63	0.66
Aug. 25, 1940	4.44	0.18	I	55	0.71	0.99
July 18, 1952	3.35	1.10	I and II	64	0.63	0.80

Source: U. S. Soil Conservation Service.

period since 1940 has been unusual in terms of antecedent moisture conditions prior to major rainfall events. Based on this observation, it was determined that the model should be programmed to use normal soil moisture, or Condition II, for developing average rainfall-runoff relationships.[6]

An additional indirect check on the rainfall-runoff relationship was conducted by comparing volume-frequency curves based on both synthesized and observed values at Wilmot. The synthesized 10- and 100-year runoff volumes determined by the SCS runoff curve number procedure were used to draw a synthetic volume-frequency curve. This was compared to the actual volume-frequency relationship based upon the annual series of summer flood volumes previously computed at the Wilmot gage. The results are shown in Figure 62 and are considered to provide a good check.

As a check on the representativeness of the volume-frequency relationship at Wilmot, additional volume-frequency curves were computed and drawn for five other stream gaging stations located in areas surrounding the Fox River watershed. Graphical volume correlation curves were plotted for each of the five gages against the

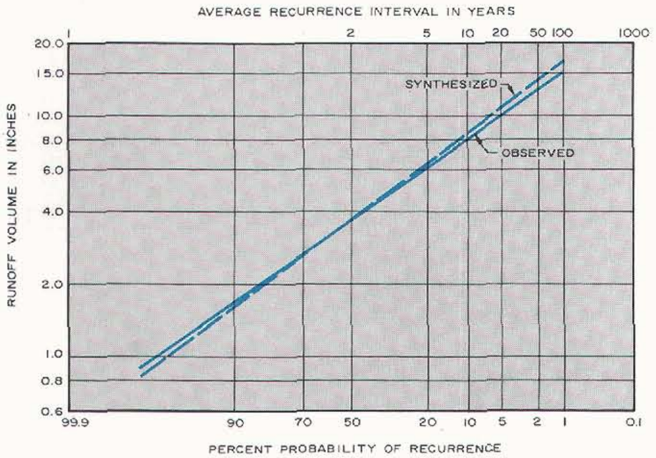
---

[6] *Rainfall-runoff relationships determined by the SCS RUNOFF CURVE NUMBER procedure are a function of the five-day antecedent rainfall. Condition II is the normal or average condition and, for the growing season is considered to total 1.4 to 2.1 inches. Condition I is dryer than normal and has the lowest runoff potential, while Condition III is a nearly saturated condition with a very high runoff potential.*

Figure 62

COMPARISON OF SYNTHESIZED AND OBSERVED VOLUME-FREQUENCY RELATIONSHIPS, FOX RIVER AT WILMOT, WISCONSIN

(Rainfall Event)



Source: U. S. Soil Conservation Service.

Wilmot gage. Although the resultant point scatter and consequently the standard error of estimate were rather large in some instances, the regression lines indicated that the experience at the Wilmot gage could be considered representative of the Region and that there was no statistical justification for modifying the summer volume-frequency line.

Regional Analysis

One of the purposes of the hydrologic model was the generation of peak discharge-frequency relationships at dams, bridges, and other critical points on the Fox River watershed stream network. Because of the importance of these relationships to plan design, an independent check on the slope of the frequency line and on the peak discharge values resulting from application of the model was made using a multiple correlation technique developed by the U. S. Geological Survey.[7] The method develops the magnitude of the mean annual flood by using basin parameters, which include drainage area, slope, lake and reservoir surface area, and a geographical factor. The magnitude of floods of other specific recurrence intervals can then be obtained from a composite frequency curve, which expresses the ratio of floods of various recurrence intervals to the mean annual flood. Figures 63 through 74 show the results of these checks. At least one flood frequency relationship for each subwatershed was checked, except for those subwatersheds having drainage areas of less than 20 square miles, which is beyond the lower limit of applicability of the USGS Method.

Three curves are shown for each location checked. In each case, the peak discharge-frequency line, designated "Model," was obtained by application of the flood simulation model, while the line designated "USGS" was obtained by a rigid application of the USGS regional flood analysis method. In nearly every case, the latter values were found to be considerably higher than the hydrologic model would indicate, especially as the drainage area approached the lower limit of applicability of 20 square miles. A third line, designated the "USGS Modified," was obtained by application of the USGS method, but with the percentage

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[7] *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.)*

Figure 63
DISCHARGE-FREQUENCY
UPPER FOX SUBWATERSHED
AT STRUCTURE NO. 89, WAUKESHA GAGING STATION

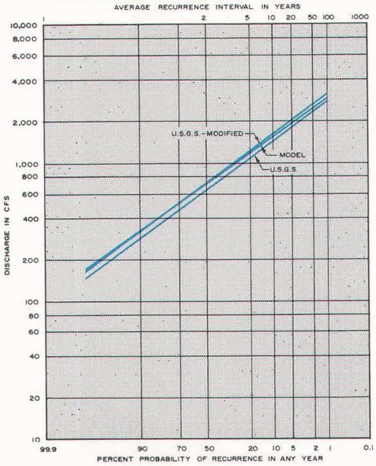


Figure 64
DISCHARGE-FREQUENCY
PEBBLE CREEK SUBWATERSHED
AT STRUCTURE NO. 97, STH 59

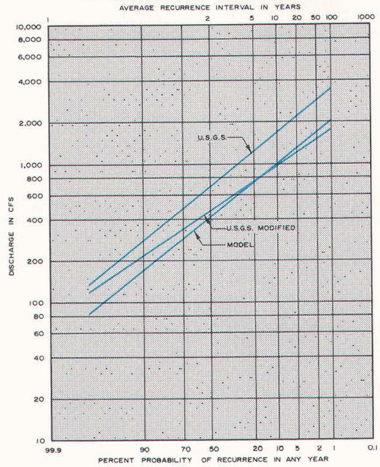


Figure 65
DISCHARGE-FREQUENCY
SPRING CREEK SUBWATERSHED
AT STRUCTURE NO. 107, CTH XI

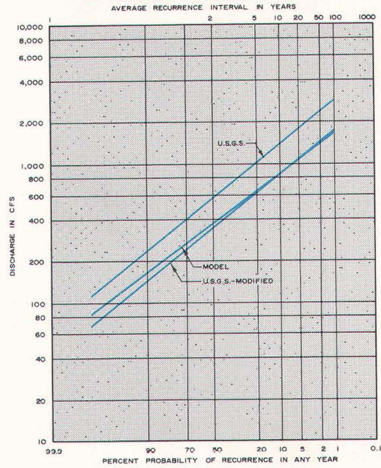


Figure 66
DISCHARGE-FREQUENCY
PEBBLE BROOK SUBWATERSHED
AT STRUCTURE NO. 119, SOO LINE RR. (Sec. 33, T. 6 N., R. 18 E.)

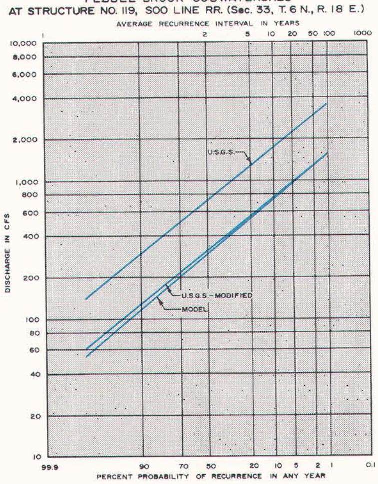


Figure 67
DISCHARGE-FREQUENCY
MUKWONAGO RIVER SUBWATERSHED
AT STRUCTURE NO. 131, CTH I

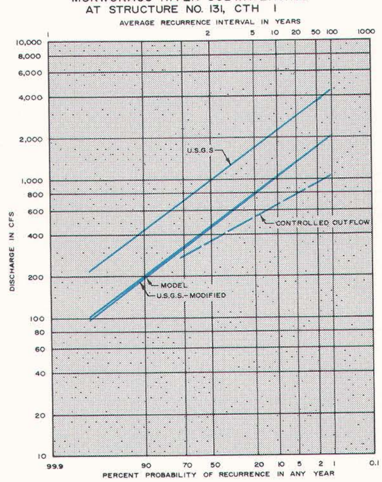


Figure 68
DISCHARGE-FREQUENCY
JERICHO CREEK SUBWATERSHED
AT STRUCTURE NO. 123, STH 99

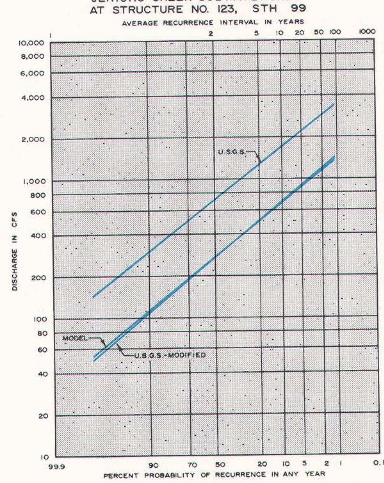


Figure 69
DISCHARGE-FREQUENCY
WIND LAKE SUBWATERSHED
AT STRUCTURE NO. 162, STH 20

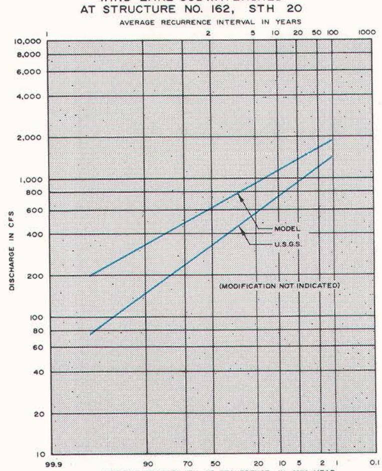


Figure 70
DISCHARGE-FREQUENCY
HONEY CREEK TRIBUTARY
AT STRUCTURE NO. 188, CTH D

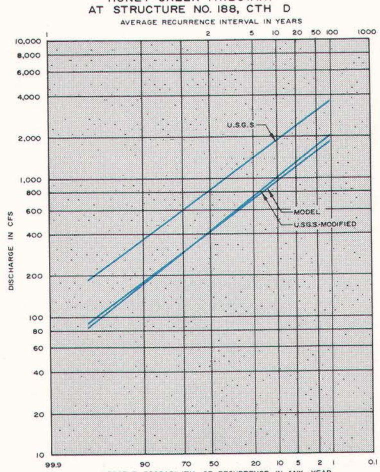
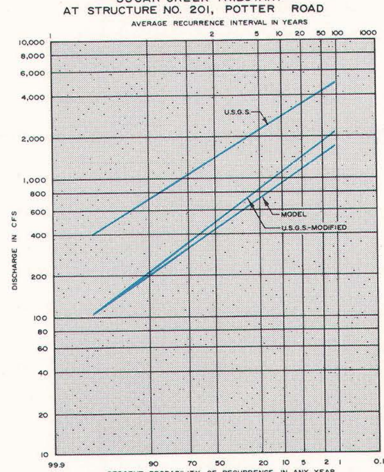


Figure 71
DISCHARGE-FREQUENCY
SUGAR CREEK TRIBUTARY
AT STRUCTURE NO. 201, POTTER ROAD



Source: U. S. Soil Conservation Service.

Figure 72
DISCHARGE-FREQUENCY
SUGAR-HONEY SUBWATERSHED
AT STRUCTURE NO. 206, SPRING PRAIRIE RD.

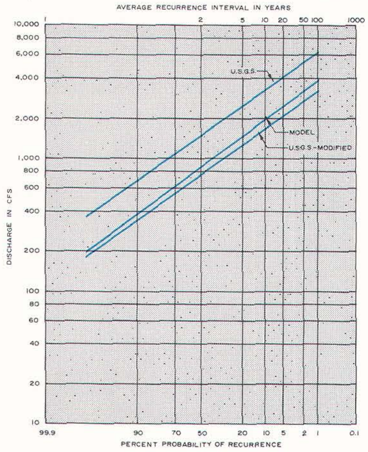


Figure 73
DISCHARGE-FREQUENCY
WHITE RIVER SUBWATERSHED
AT STRUCTURE NO. 240, STH 11

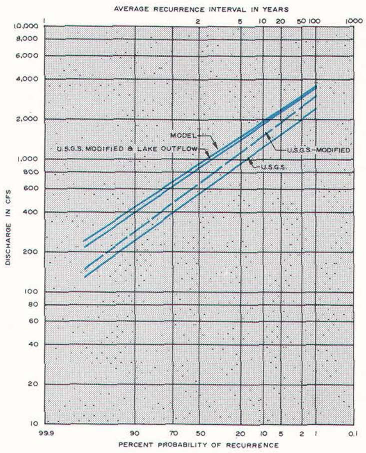
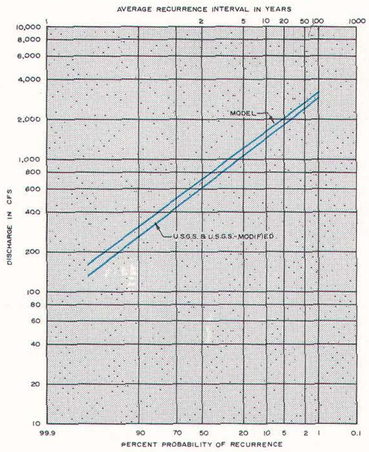


Figure 74
DISCHARGE-FREQUENCY
NIPPERSINK CREEK SUBWATERSHED
AT STRUCTURE NO. 278, CTH B



Source: U. S. Soil Conservation Service.

of lake and reservoir surface area systematically modified to reflect the attenuating effect of permanent marsh areas within the tributary drainage area. Marsh areas located on the stream channel system were weighted at 50 percent of equivalent lake surface areas, while peripheral or upland marshes were weighted at 25 percent of equivalent lake surface areas. Other minor modifications included the use of a single geographical factor throughout the watershed and some reduction in lake effect when less than 20 percent of the contributing area was controlled. The modifications in the USGS Method were arrived at after careful study and consultation with the USGS personnel who helped develop the method. The USGS procedure, as modified, provided a very close check on the simulated values, with both the magnitude and slope of the frequency lines being very close to those generated by the model. This was considered to constitute a significant check on the model calibration.

Simulation of the 1960 Flood

The March-April 1960 flood within the watershed was simulated using the hydrologic model, not only to calibrate the hydrologic model but also to assist in establishing the frequency of this event at locations within the watershed other than Wilmot. Climatological conditions leading to the 1960 flood were described in Chapter VII of this report. The flood was caused by unusually high snowmelt occurring concurrently with an unusually heavy rainfall for that time of year. Measurement of the snow cover at the U. S. Weather Bureau Station in Milwaukee showed a water equivalent of 2.8 inches on the ground immediately prior to the flood. Rapidly rising temperatures, coupled with an average rainfall depth of 1.5 inches, resulted in a surface water runoff volume of 2.60 inches during a 15-day period at the USGS stream gaging station at Wilmot.

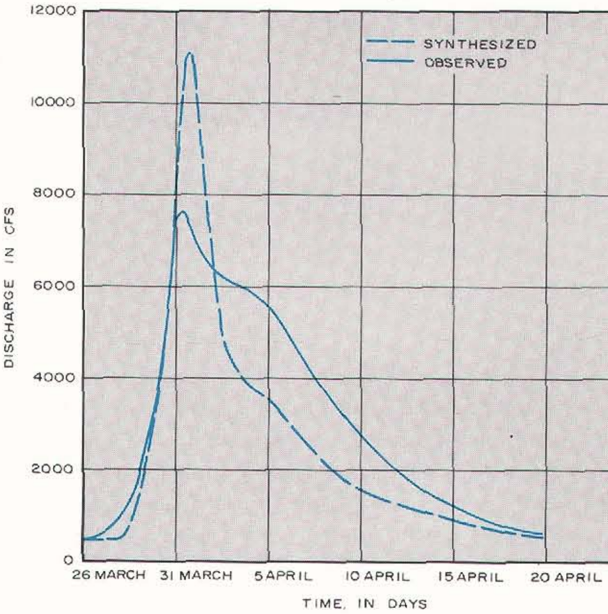
In synthesizing the 1960 flood, it was assumed that the snowmelt runoff component of the flood would be the same in all subwatersheds of the total basin. This assumption was justified by the balancing effect of the long period of snow accumulation and the general areal uniformity of melting temperatures. The reconstructed isohyetal map of rainfall over the watershed, as shown on Map 35, Chapter VII of this report, indicates that the rainfall depth ranged from less than one inch in parts of the Sugar-Honey Creek subwatershed to over two inches in the Wind Lake area. This distribution of rainfall was used in the simulation of the flood.

Even though there was a combined snowmelt-rainfall runoff potential of over four inches on the entire watershed, only 2.60 inches of surface runoff was actually recorded at the Wilmot gage during the 15-day runoff base period from March 28 through April 12, 1960. Part of the difference may be attributed to the hydraulics of the watershed itself. Even under frozen or saturated soil conditions, significant amounts of water that start as surface runoff are temporarily detained in lakes and marshes and do not contribute to direct surface runoff as measured at Wilmot. Other important factors reenforcing this attenuation include the numerous small areas of depression drainage, the permeable ground water recharge areas within the watershed, and the increased infiltration potential due to the mild slopes and low-flow velocities generally existing within the watershed.

After a few minor changes in the inputs were made, based upon the analysis of a trial model run, the synthesized hydrograph at Wilmot was considered to be in satisfactory agreement with the actual observed hydrograph. A comparison of the actual and synthesized surface water runoff hydrographs at Wilmot, as shown in Figure 75, indicates that the synthesized hydrograph has a somewhat higher peak and a more rapid recession than the observed hydrograph. This difference, though quite apparent, was not considered significant since further analysis indicated that the most significant cause of the observed discrepancy was due to the flat channel slopes and the high degree of interrelationship between tributary stage-discharge curves and stage on the main stem. The Wind Lake subwatershed is perhaps the best example of this situation, in which the elevation of the floodwaters on the main stem of the Fox River function as a retarding obstruction to the water flowing from the Wind Lake Canal. This means that, for a given stage on the Wind Lake Canal, discharge into the Fox River becomes a function of the stage on the river rather than of the hydraulic characteristics of the canal. During times of peak stage on the main stem, there may

Figure 75

COMPARISON OF SYNTHESIZED AND RECORDED HYDROGRAPHS FOR THE MARCH–APRIL 1960 FLOOD OF THE FOX RIVER AT WILMOT



Source: U. S. Soil Conservation Service.

be little or no discharge from the Wind Lake Canal, causing the water to be temporarily stored and released after the stage on the main stem starts to recede. This would result in a lower peak and a sustained recession in the observed hydrograph at Wilmot.

After the hydrologic model had been calibrated to reproduce a satisfactory hydrograph of the 1960 flood at Wilmot, the synthetic flood profile was checked at all other locations in the watershed where historic high-water marks were available or could be obtained by indirect methods. In general, synthesized high-water elevations were found to be within less than one foot of actual recorded elevations. This was determined to be a most satisfactory tolerance considering the degree of accuracy inherent in the historic high-water marks themselves.

Additional checks on stage-discharge relationships were available at two locations in the watershed: at Waukesha on the main stem of the Fox River and at Burlington on the White River. These were all locations at which the U. S. Geological Survey either maintains or had maintained stream gages and for which actual measurements of stage and discharge were available. Figures 51 and 52 show the comparison of the synthetic and measured stage-discharge curves for the two locations. Both of these checks were reasonable and indicated that the synthesized curves tended to be conservative in any deviations from the measured values. These two checks, coupled with the check at Wilmot, provided us with good comparisons.

The model was used to determine hydrographs for the 1960 flood at various other locations in the watershed after satisfactory agreement between the synthesized and recorded hydrographs had been obtained at Wilmot. A number of synthesized hydrographs for the 1960 flood are shown in Figures 76 through 78.

Development of Synthetic Floods

When the hydrologic model was considered to be in satisfactory agreement with actual measured flow characteristics in the watershed, the calibrated model was used to develop synthetic flood flows and frequencies. Two types of future floods, those produced by melting snow and those produced by rainfall, were synthesized, each for a 100-year and a 10-year recurrence interval. Additional frequencies were determined from a flood frequency line developed for the location

Figure 76
SYNTHESIZED HYDROGRAPH
MARCH - APRIL 1960 FLOOD
FOX RIVER AT WAUKESHA STRUCTURE NO. 89
WAUKESHA GAGING STATION

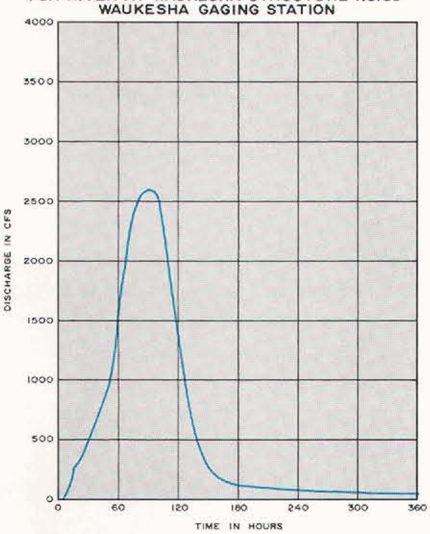


Figure 77
SYNTHESIZED HYDROGRAPH
MARCH - APRIL 1960 FLOOD
FOX RIVER AT BURLINGTON ABOVE
ECHO LAKE, NEAR STRUCTURE NO. 172

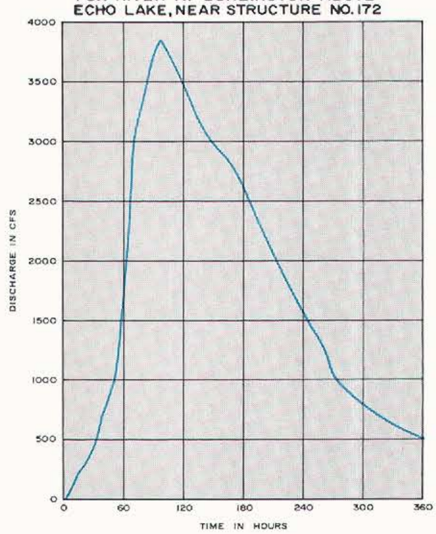
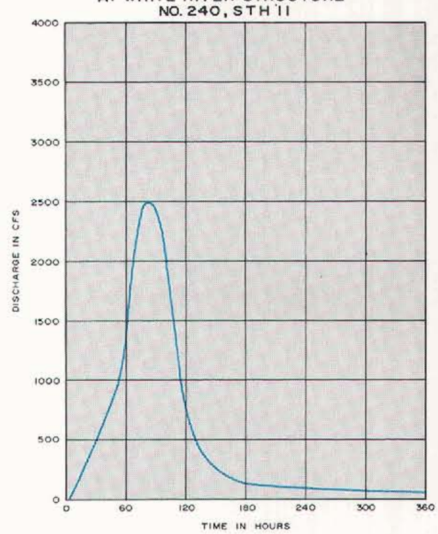


Figure 78
SYNTHESIZED HYDROGRAPH
MARCH - APRIL 1960 FLOOD
AT WHITE RIVER STRUCTURE
NO. 240, STH 11



Source: U. S. Soil Conservation Service.

from this data. 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. Map 40 indicates those portions of the river system in which the model applications indicate that the major floods may be expected to be either rainfall events or snowmelt events.

Synthesis of Snowmelt Floods: 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 melt, 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. Treatment of the other variables in the flood simulation is described below. Soils were assumed to be frozen during the melting period, and all hydrologic subareas were assigned a runoff curve number of 100 (impervious soils) to adjust the model to these conditions. The rate of snowmelt runoff, used in the synthesis of snowmelt floods, is shown in Figure 79. In developing this rate, the average melt potential in the watershed in late March and early April was first established, using long-term average daily temperatures and the following equation:[8]

$$M = KD$$

M = Potential snowmelt in inches per day.

K = A dimensionless constant that varies with watershed and climatic conditions. A value of 0.08 was used for the Fox River watershed.

D = The number of degree-days for a given day. A degree-day is defined as a 24-hour period having an average temperature one degree above 32° F.

Maximum and minimum temperatures, as found in the U. S. Weather Bureau Climatological Data, were averaged to get daily average temperatures; and the duration of melt was selected as the length of time to produce 2.5 inches of runoff. The volume of snowmelt runoff used to synthesize selected snowmelt floods was established from an analysis of actual winter and spring flood volumes as measured at Wilmot. In the analysis the volume of runoff for the largest flood of each year that occurred during the period December 1 to April 30 was computed. The volume of runoff that

[8] *The duration of melt was selected as the length of time required to produce 2.5 inches of runoff.*

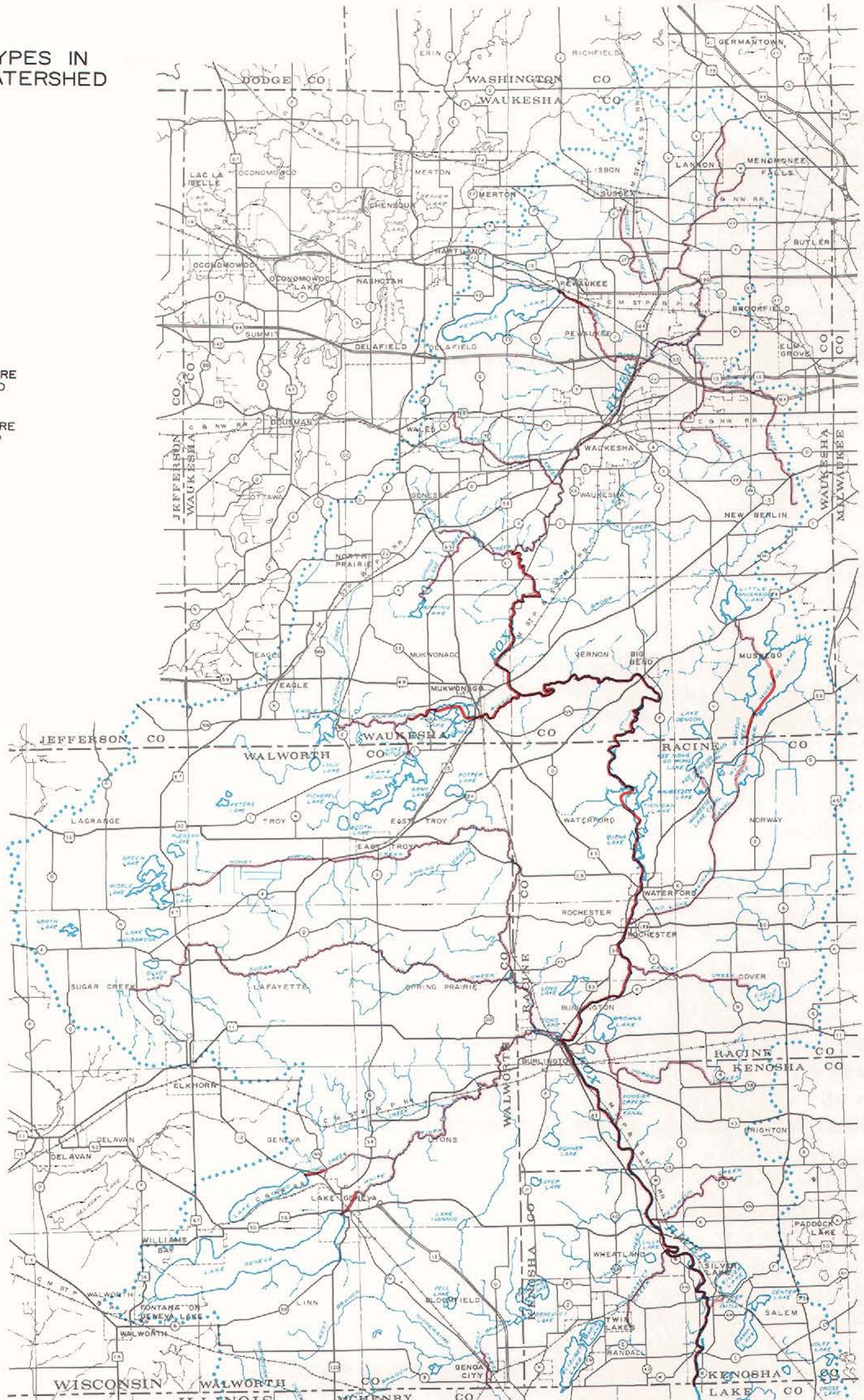
Map 40

MAJOR FLOOD TYPES IN THE FOX RIVER WATERSHED

LEGEND

DENOTES STREAM REACHES WHERE SNOWMELT MAY BE EXPECTED TO PRODUCE MAJOR FLOODS

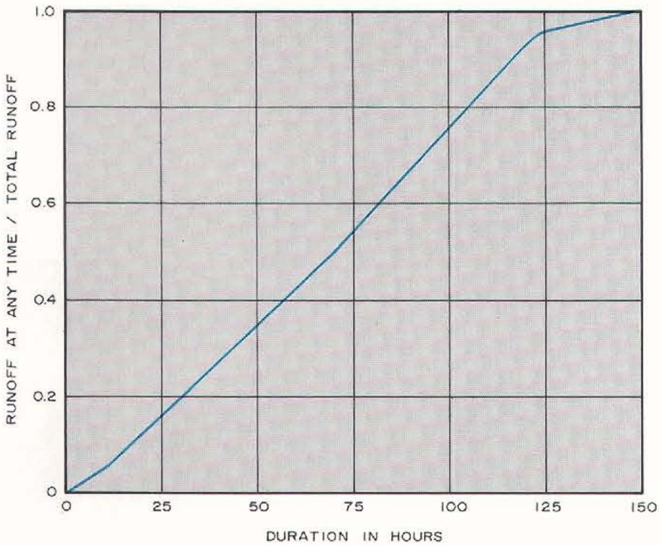
DENOTES STREAM REACHES WHERE RAINFALL MAY BE EXPECTED TO PRODUCE MAJOR FLOODS



Two basic types of floods--rainfall and snowmelt--occur within the Fox River watershed. Both were synthesized to produce 100-year and 10-year recurrence interval peak discharges for the stream system of the watershed. The map above indicates those streams for which the greatest flood flows may be expected to be caused by rainfall and those for which the greatest flood flows may be expected to be caused by snowmelt.

Source: SEWRPC.

Figure 79
RATE OF SNOWMELT RUNOFF USED IN THE SYNTHESIS OF SNOWMELT FLOODS WITHIN THE FOX RIVER WATERSHED



Source: U. S. Soil Conservation Service.

produced these floods was considered to be the flow that passed the gage during the 15-day period that followed the beginning of the flood. An estimate of the base flow during the 15-day period was deducted from the total computed volume. A frequency curve of the volumes computed is shown in Figure 80. This curve served as the basis for assigning frequency values to the snowmelt floods. That is, the 1 percent chance snowmelt flood was synthesized by routing a runoff volume that would produce 3.0 inches of runoff (1 percent chance volume) in a 15-day period. To obtain this result from the model, it was necessary to assume that 3.5 inches of runoff occurred over the entire watershed since all of the runoff for this event did not reach the gage in 15 days.

Synthesis of Floods Produced by Rainfall: Floods produced by rainfall were synthesized using the 24-hour storm duration and the storm distribution shown in Figure 47. The runoff generated by selected amounts of rainfall was determined using the SCS runoff curve number procedure. Soil moisture conditions were assumed to be at average levels prior to the rain.

Frequency was assigned to this type of flood on the basis of the rainfall used to synthesize the flood. That is, the 1 percent chance rainfall flood was synthesized by assuming 5.5 inches of rain fell in 24 hours (1 percent chance 24-hour rainfall amount). The frequency of various 24-hour rainfall amounts was obtained from studies made by the U. S. Weather Bureau.[9]

The values shown in Table 40 are point rainfall amounts. In this study rainfall events were assumed to cover the entire watershed. To adjust for the reduction in the intensity of rainfall that accompanies an increase in the areal extent of the storms producing the rainfall, the curve shown in Figure 81 was developed.[10]

Synthetic Flood Frequency Lines: The model was applied to develop discharges at various locations in the watershed for the 1 and 10 percent chance rainfall flood events and for the 1 and 10 percent chance snowmelt flood events. Flood frequency lines were then drawn for selected locations in the watershed, using the discharge values obtained from the model.[11] The frequency lines developed are shown in Appendix E. These lines are based on present land use conditions within the watershed. Lines for projected 1990 land use are also shown. All of the lines, except those that represent locations on the main stem of the Fox River below Burlington, were developed using synthesized flood discharges. On the Fox River below Burlington, flood frequency was established from analysis of the USGS streamflow records at Wilmot, as described in Chapter VII.

[9] *Rainfall Frequency Atlas of the United States, Technical Paper No. 40, U. S. Department of Commerce, Weather Bureau, 1961.*

[10] *This curve was developed partially from an analysis of summer runoff volumes recorded at gaging stations in the watershed. The curve, therefore, includes the effects of variables, such as antecedent moisture condition, that would not normally be included in an areal reduction of rainfall for structural design purposes.*

[11] *Flood frequency curves were drawn, using the two synthesized values, for both types of flood events. In some areas one type of flood was predominant. Where this situation was found to exist, the frequency line of the predominant type was used, with no modification, as the flood frequency curve for the area. In other locations an overlap occurred in the type of event that produced major floods. In these locations the frequency line of the more predominant type of flood was adjusted to better represent the annual frequency line. Adjustments were made on the basis of a study made for this report, which compared the annual flood frequency curves at USGS gaging stations with seasonal flood frequency curves developed at the same stations.*

Table 40

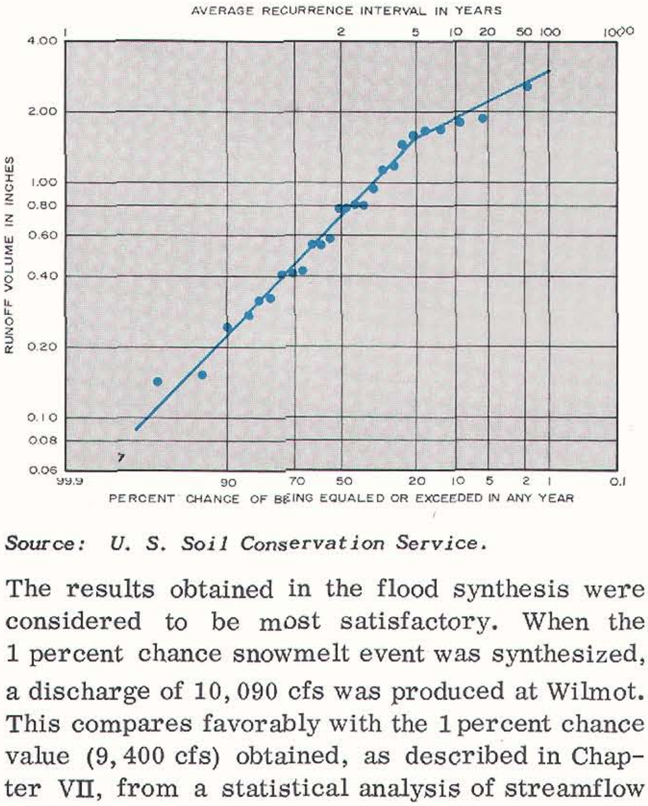
RATE OF OCCURRENCE

Percent Chance of Occurrence	24-Hour Rainfall (Inches)
1	5.50
2	5.05
4	4.55
10	3.90
20	3.45

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

Figure 80

FREQUENCY OF SNOWMELT RUNOFF VOLUMES FOX RIVER AT WILMOT



Source: U. S. Soil Conservation Service.

The results obtained in the flood synthesis were considered to be most satisfactory. When the 1 percent chance snowmelt event was synthesized, a discharge of 10,090 cfs was produced at Wilmot. This compares favorably with the 1 percent chance value (9,400 cfs) obtained, as described in Chapter VII, from a statistical analysis of streamflow records at Wilmot. Synthesis of the 1 percent chance rainfall event produced a discharge of 9,100 cfs at Wilmot. Although this value far exceeds any recorded summer discharge at Wilmot, it is not considered unreasonable in view of the previously discussed indications that severe summer floods have not occurred during the period of record at Wilmot.

Effect of Human Activities on Runoff

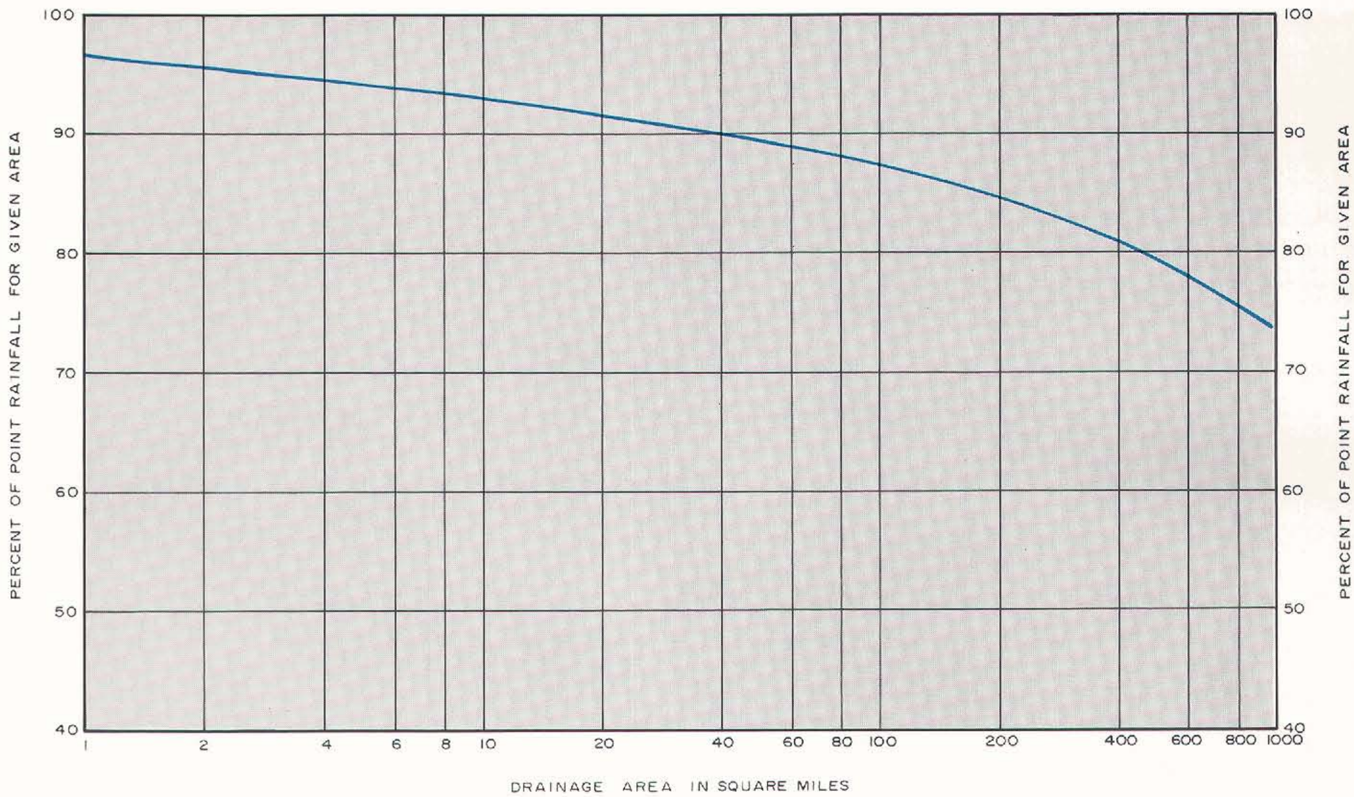
The hydrologic model was constructed and calibrated on the basis of present hydrologic conditions in the watershed. One of its principal functions, however, was to permit portrayal of the changes in river system performance under conditions of future land use and water control facility development. For this purpose components of the model were modified to reflect the land use development expected or proposed and the flood control alternatives considered.

Hydrologic Effects of Urbanization: A substantial increase in urban development in portions of the watershed is expected by 1990, the plan design target date. The analysis of the effect of urbanization on watershed hydrology was based on the adopted regional land use plan described in Volume II. The conversion of land from rural to 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.

The change in rainfall-runoff relationships accompanying urbanization was represented by changes in the runoff curve number assigned to the hydrologic subareas. 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 some agricultural uses. These two adjustments are, to some degree, compensating; but in each case, the net effect was to increase the volume of runoff from a given rainfall.

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

Figure 81
RAINFALL DEPTH-AREA RELATIONSHIP FOR THE FOX RIVER WATERSHED
24 HOUR RAINFALL



Source: U. S. Soil Conservation Service.

reduction in concentration time has the effect of shortening the time of tributary outflow and increasing peak discharge amounts.

Floods for future (1990) land use conditions were synthesized for both snowmelt and rainfall events using the same rainfall amounts and snowmelt volumes that were used to develop flood flows for present land use conditions. The effect of urbanization on snowmelt floods was found to be minimal. Minor increases were found, but these were confined to local areas. Summer flood peaks, however, were found to be substantially increased in some areas as a result of urbanization.

The effect of urbanization on summer floods was most pronounced on subarea inflow hydrographs. Peak discharges for hydrologic subareas were found to increase by as much as 70 percent; however, most local increases were in the range of 20 to 50 percent. Localized increases were found in most of the 15 subwatersheds but were most extensive in the northern and eastern portions of the watershed. Increases in the peak discharge of summer floods were also found at some locations on the main stem of the Fox River and on several major tributaries. The percentage increase varied from 12 percent at Waukesha to less than 2 percent at Wilmot.

Flood frequency lines were drawn, using the discharges established for 1990 land use conditions and are shown, together with the frequency lines developed for present land use, in Appendix E. Where only one frequency line is shown for a location, the line reflects both present and projected future land use. Discharge-frequency relationships are shown in Appendix F for selected bridge crossings in the channel system.

Effects of Structural Flood Control Facilities: Structural water control facilities considered in the watershed planning study included dikes and floodwalls through Waukesha and Burlington, a floodwater retarding structure on the Fox River just below the Vernon Marsh, a multiple-purpose structure on Sugar Creek, operation of the impoundment at Waterford to provide additional storage during periods of high flow, and alteration of the outlets of major lakes in the watershed to provide additional temporary storage.

Based on the experience gained through the operation of the hydrologic model, it was concluded that the system of earth dikes and concrete floodwalls considered through portions of Burlington and Waukesha would have a negligible effect upon flows in the balance of the Fox River system. The effects of all other works of improvement were determined by operating the hydrologic model with the assumed plan element in place.

A degree of flood control is now provided naturally by the physical features of the Vernon Marsh. One plan element considered was the enhancement of the natural flood control effect by construction of a dam on the Fox River at the outlet of the marsh. In the operation of the model, it was assumed that a dam having a fixed crest, ungated spillway would be constructed in the northeast one-quarter of Section 34, Town 5 North, Range 18 East. All storage within the reservoir was assumed to be temporary; that is, all floodwater stored would eventually be released. The effect of the dam on peak discharge amounts at selected locations and for various frequencies is shown in Table 41.

Another plan element considered was the development of a multiple-purpose reservoir on Sugar Creek (see Volume II). This structure would be constructed to provide permanent storage of water for recreational use, with additional temporary floodwater storage available during periods of high flow. In the operation of the model, it was assumed the dam having a fixed crest, ungated spillway would be constructed near the center of Section 15, Town 3 North, Range 17 East. The effect the structure would have on downstream discharges is shown in Table 42.

The model was also used to determine the degree of flood control that could be provided downstream from Waterford if the impoundment at Waterford were managed so that additional storage for floodwaters would be made available when flood events were anticipated. The amount of flood control provided by this proposal was established by assuming that the water level behind the impoundment would be drawn down to a level four feet below the spillway crest prior to the arrival of a flood. Table 43 indicates the effect this operation would have on downstream flood peaks. The management proposal for the Waterford impoundment would require that the occurrence of a flood event be predictable. Floods resulting from snowmelt generally can be anticipated, but floods generated by rainfall are usually not predictable. For this reason the effects of this proposal, as shown in Table 42 , apply only to snowmelt events.

The possibility that a degree of flood control could be provided in the watershed by altering the outflow characteristics of ten of the major lakes was also investigated. To establish what effect this condition would have on flood peaks, it was assumed that water levels on these lakes could be raised one foot by the inflow of floodwater before any discharge would occur at the lake outlet. The ten lakes considered in this proposal were Pewaukee, Eagle Springs, Beulah, Muskego, Eagle, Lauderdale, Como, Geneva, Browns, and Silver. The effects of this proposal on peak discharge amounts are shown for selected locations in Table 44.

In addition to reducing peak discharge amounts, these project measures generally provide a reduction in the duration of flooding. This decrease in the period of flooding is illustrated by the two hydrographs shown in Figure 82. This figure shows the synthetic hydrographs developed for the Fox River just upstream from Burlington. It indicates both the reduction in peak discharge and the reduction in the duration of flooding that occurred in the synthesized 100-year flood event when the Vernon Marsh structure was assumed to be in operation.

SURFACE WATER QUALITY SIMULATION

As already noted, the watershed planning process requires definitive knowledge of both the present and probable future surface water quality conditions. The existing surface water quality conditions prevailing within the Fox River watershed are described in Chapter IX of this report. Future water quality conditions can be expected to differ significantly from present conditions, either because of the adverse effect that continued urban development within the watershed will have on water quality or because of the desirable effect that implementation of sound water quality management and pollution abatement plans may have on water quality. Thus, a rational method for forecasting probable future water quality conditions, considering the location, quantity, and quality of waste discharges into the stream system under future land use conditions and the natural waste assimilation capacities of the streams, had

Table 41

THE EFFECTS OF THE VERNON MARSH DAM ON FLOODS OF VARIOUS RECURRENCE INTERVALS: 1990 CONTROLLED EXISTING TREND LAND USE

Flood Recurrence Interval	Without Reservoir					
	121 Hwy 15	139 Center Dr.	145 Waterford	172 Burlington	269 Silver Lake	273 Wilmot
100-year	2370 785.1	3300 783.8	3300 770.9	4350 759.9	9300 747.7	9400 745.6
50-year	2080 784.7	2950 783.5	2950 770.5	3900 759.5	8100 747.1	8200 745.2
25-year	1810 784.3	2500 783.0	2550 770.1	3370 758.8	6900 746.4	7000 744.7
10-year	1480 783.7	2000 782.3	2050 769.4	2850 758.1	5300 745.5	5400 744.0
5-year	1180 783.0	1610 781.7	1690 768.8	2350 757.4	4100 744.8	4200 743.5
	With Reservoir					
100-year	520 781.0	1520 781.6	2100 769.4	3585 759.1	8930 747.5	9020 745.4
50-year	480 780.9	1350 781.3	1900 769.2	3200 758.6	7800 746.9	7900 745.0
25-year	360 780.1	1170 780.9	1620 768.7	2850 758.1	6550 746.3	6700 744.5
10-year	270 779.2	920 780.5	1320 768.3	2400 757.4	5050 745.4	5170 743.9
5-year	200 778.5	760 780.1	1100 767.9	2000 756.7	3950 744.7	4050 743.4

Note: Top number indicates discharge in cfs.

Bottom number indicates water surface level in Mean Sea Level Datum.

Source: U. S. Soil Conservation Service.

to be developed. The approach used was to develop a mathematical model able to simulate the ability of the streams to assimilate waste discharge under various types and degrees of waste treatment and locations of waste discharge.

The major parameters selected for use in the model to describe water quality conditions included dissolved oxygen (DO), biochemical oxygen demand (five-day BOD), coliform count, chloride ion concentration, and temperature. These parameters best describe the overall level of water quality and permit this quality to be related to water use objectives and standards formulated as a 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 model was then calibrated to represent actual existing conditions in the Fox River system by the use of water quality data obtained from stream surveys conducted within the watershed by the Commission and the Wisconsin Department of Natural Resources.

The calibrated water quality simulation model was then used to forecast future water quality conditions within the Fox River watershed by varying

Table 42

THE EFFECTS OF THE SUGAR CREEK DAM ON FLOODS OF VARIOUS RECURRENCE INTERVALS: 1990 CONTROLLED EXISTING TREND LAND USE

Flood Recurrence Interval	Without Reservoir				With Reservoir			
	(198) Peak Discharge and Stage at Bewers Road	(200) Peak Discharge and Stage at Hargroves Road	(201) Peak Discharge and Stage at Potter Road	(206) Peak Discharge and Stage at Spring Prairie Road	(198) Peak Discharge and Stage at Bewers Road	(200) Peak Discharge and Stage at Hargroves Road	(201) Peak Discharge and Stage at Potter Road	(206) Peak Discharge and Stage at Spring Prairie Road
100-year	1775 840.2	1660 810.2	1750 790.2	4100 768.6	680 837.9	1020 809.6	1540 789.8	3620 768.2
50-year	1460 839.7	1390 810.0	1500 789.8	3430 768.0	560 837.6	770 809.4	1300 789.4	3020 767.6
25-year	1180 839.3	1130 809.7	1270 789.4	2850 767.5	460 837.1	690 809.3	1070 789.0	2480 767.0
10-year	840 838.5	840 809.4	970 788.8	2130 766.6	330 836.5	500 808.9	790 788.3	1800 766.2
5-year	620 837.8	630 809.2	760 788.2	1610 766.0	240 835.9	370 808.4	600 787.7	1340 765.5

Note: Top number indicates discharge in cfs.

Bottom number indicates water surface level in Mean Sea Level Datum.

Source: U. S. Soil Conservation Service.

the inputs to the model. Forecasts were made of the probable future level of water quality in the absence of a pollution abatement program in order to analyze the effects of alternative plans on water quality conditions in the river system. These forecasts then served as a basis for evaluating the effectiveness of various alternative water quality management plans in meeting water use objectives and standards within the watershed.

Description of the Water Quality Simulation Model

The water quality simulation model developed for the study consists of three separate sub-models, one each for determining dissolved oxygen concentration, coliform count, and chloride concentration. Each of these sub-models was developed from established mathematical relationships between each of the parameters and the physical characteristics of the river system. The model was programmed for use on an IBM-7094 computer; and the program provided for an automated data print out, which produced profiles of dissolved oxygen, coliform, and chloride levels along the stream system.

Figure 83 consists of a general flow diagram of the computations involved in the water quality simulation model. The complete Fortran IV computer program used to perform the routine and repetitive calculations in the model is on file with the Commission. The computer was programmed to carry out the computations in exactly the same manner as they would be done manually so that consistent additional computations could be made manually at any time.

Dissolved Oxygen Sub-Model: The basic relationship used in the sub-model for determining the dissolved oxygen concentration in a given stream reach was the Streeter-Phelps[12] equation, as

[12] *Streeter, H. W., and Phelps, E. B., A Study of the Pollution and Natural Purification of the Ohio River, Part III, U. S. Public Health Service Bulletin 146, 1925.*

Table 43

THE EFFECTS OF OPERATING TICHIGAN LAKE ON SNOWMELT FLOODS OF VARIOUS RECURRENCE INTERVALS: 1990 CONTROLLED EXISTING TREND LAND USE

Flood Recurrence Interval	(145) Peak Discharge and Stage in Waterford	(164) Peak Discharge and Stage in Rochester	(172) Peak Discharge and Stage Above Burlington	(246) Peak Discharge and Stage in Burlington	(265) Peak Discharge and Stage Near Silver Lake
	Without Management				
100-year	3330 770.9	4130 767.8	4350 759.9	8300 759.5	9300 749.8
50-year	2900 770.5	3620 767.5	3820 759.4	7150 758.7	7950 749.1
25-year	2500 770.0	3120 767.2	3300 758.7	6050 757.9	6600 748.2
10-year	2000 769.3	2480 766.8	2610 757.8	4600 756.8	5000 747.1
5-year	1610 768.7	2000 766.6	2100 756.9	3600 755.9	3700 746.1
	With Management				
100-year	3300 770.9	4110 767.8	4320 759.9	8250 759.4	9250 749.7
50-year	2810 770.4	3450 767.4	3600 759.1	6700 758.4	7500 748.8
25-year	2400 769.9	2820 766.9	2900 758.2	5300 757.4	5900 747.8
10-year	1870 769.1	2020 766.6	2080 756.9	3700 756.0	4000 746.4
5-year	1470 768.5	1550 766.5	1550 755.9	2650 754.9	2750 745.1

Note: The discharges and frequencies shown are for snowmelt floods only.

Source: U. S. Soil Conservation Service.

modified by T. R. Camp[13] and W. E. Dobbins.[14] This basic equation has long been a standard tool in water pollution studies. The modified equation may be written as:

$$(1)\quad D = \frac{K_1\left(L_A - \dfrac{La}{K_1+K_3}\right)\left(e^{-(K_1+K_3)t} - e^{-Rt}\right)}{R-(K_1+K_3)} + D_0e^{-Rt} + \frac{K_1}{R}\left(\frac{La}{K_1+K_3} - \frac{A}{K_1}\right)\left(1-e^{-Rt}\right)$$

in which D = dissolved oxygen deficit at time t, mg/l

[13] *Camp, Thomas R., Water and Its Impurities, Reinhold Publishing Corporation, New York, 1963.*

[14] *Dobbins, W. E., "BOD and Oxygen Relationships in Streams," Journal of the Sanitary Engineering Division, American Society of Civil Engineers, Vol. 90, No. SA3, June 1964.*

Table 44

THE EFFECTS OF PROVIDING ADDITIONAL TEMPORARY FLOODWATER STORAGE IN MAJOR LAKES ON FLOODS OF VARIOUS RECURRENCE INTERVALS: 1990 CONTROLLED EXISTING TREND LAND USE

Flood Recurrence Interval	Without Reservoir							
	(89) Peak Discharge and Stage at Waukesha	(140) Peak Discharge and Stage at Big Bend	(145) Peak Discharge and Stage at Waterford	(164) Peak Discharge and Stage at Rochester	(172) Peak Discharge and Stage at Burlington	(246) Peak Discharge and Stage at Burlington	(269) Peak Discharge and Stage at Silver Lake	(273) Peak Discharge and Stage at Wilmot
100-year	3250 802.5	3300 782.8	3330 770.9	4130 767.8	4350 759.9	8300 759.5	9300 747.7	9400 745.6
50-year	2750 801.8	2950 782.5	2950 770.5	3700 767.5	3900 759.5	7400 758.8	8100 747.1	8200 745.2
25-year	2300 801.3	2500 782.1	2550 770.1	3200 767.2	3370 758.8	6300 758.0	6900 746.4	7000 744.7
10-year	1720 800.4	2000 781.5	2050 769.4	2700 766.9	2850 758.1	4800 756.9	5300 745.5	5400 744.0
5-year	1350 799.7	1610 781.1	1690 768.8	2250 766.7	2350 757.4	3800 756.1	4100 744.8	4200 743.5

Flood Recurrence Interval	With Reservoir							
	(89) Peak Discharge and Stage at Waukesha	(140) Peak Discharge and Stage at Big Bend	(145) Peak Discharge and Stage at Waterford	(164) Peak Discharge and Stage at Rochester	(172) Peak Discharge and Stage at Burlington	(246) Peak Discharge and Stage at Burlington	(269) Peak Discharge and Stage at Silver Lake	(273) Peak Discharge and Stage at Wilmot
100-year	3200 802.4	3230 782.7	3250 770.8	4040 767.7	4275 759.8	7950 759.2	8900 747.5	8950 745.4
50-year	2700 801.8	2800 782.4	2850 770.4	3550 767.4	3800 759.4	7050 758.6	7700 746.9	7800 745.0
25-year	2230 801.1	2400 782.0	2470 769.9	3100 767.1	3300 758.7	5900 757.8	6590 746.2	6650 744.5
10-year	1670 800.3	1860 781.3	1980 769.2	2530 766.8	2710 757.9	4500 756.7	5050 745.4	5150 743.9
5-year	1290 799.5	1490 780.8	1600 768.7	2100 766.6	2220 757.1	3550 755.8	4000 744.7	4080 743.4

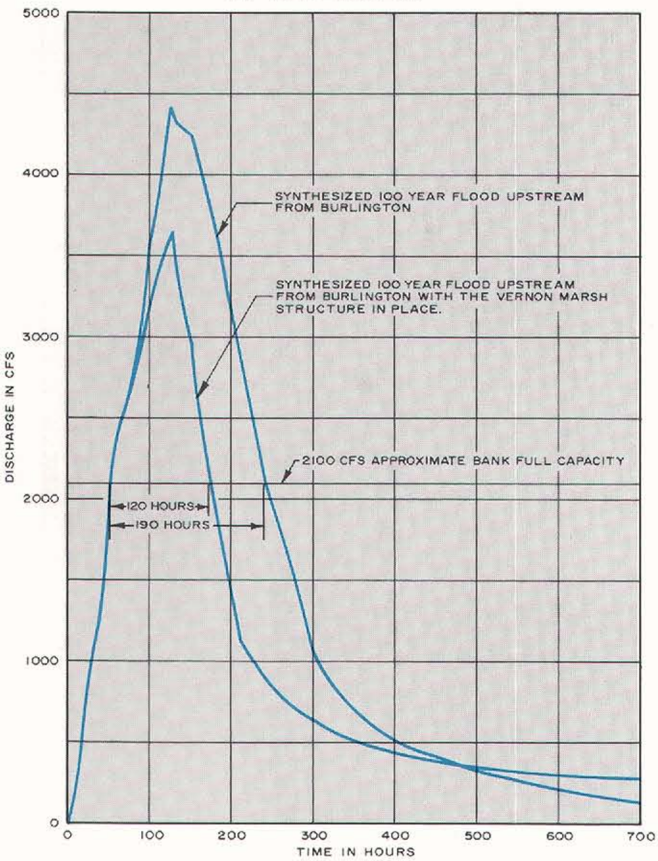
Note: Top number indicates discharge in cfs.

Bottom number indicates stage in mean Sea Level Datum.

Source: U. S. Soil Conservation Service.

Figure 82

SYNTHESIZED HYDROGRAPH FOR THE FOX RIVER AT BURLINGTON



Source: U. S. Soil Conservation Service.

D_o = dissolved oxygen deficit at the upstream end of the reach, mg/l

L_A = BOD concentration at the upstream end of the reach, mg/l

L_a = rate of addition of BOD due to runoff and/or scour, mg/l/day

A = oxygen production $(A > 0)$ or reduction $(A < 0)$ due to photosynthesis and benthal demand, mg/l/day

t = time of flow from the upstream end of the reach to the location under consideration, days

K_1 = deoxygenation rate constant, days^{-1}

K_3 = deoxygenation and absorption (of BOD) rate constant

R = reaeration rate constant, days^{-1}

e = natural logarithm base

The BOD at the end of each reach was computed using the following equation:

$$(2) \quad L = \left(L_A - \frac{La}{K_1 + K_3}\right) e^{-(K_1 + K_3)t} + \frac{La}{K_1 + K_3}$$

in which L is the BOD at the downstream end of the reach, and the other terms are as defined above.

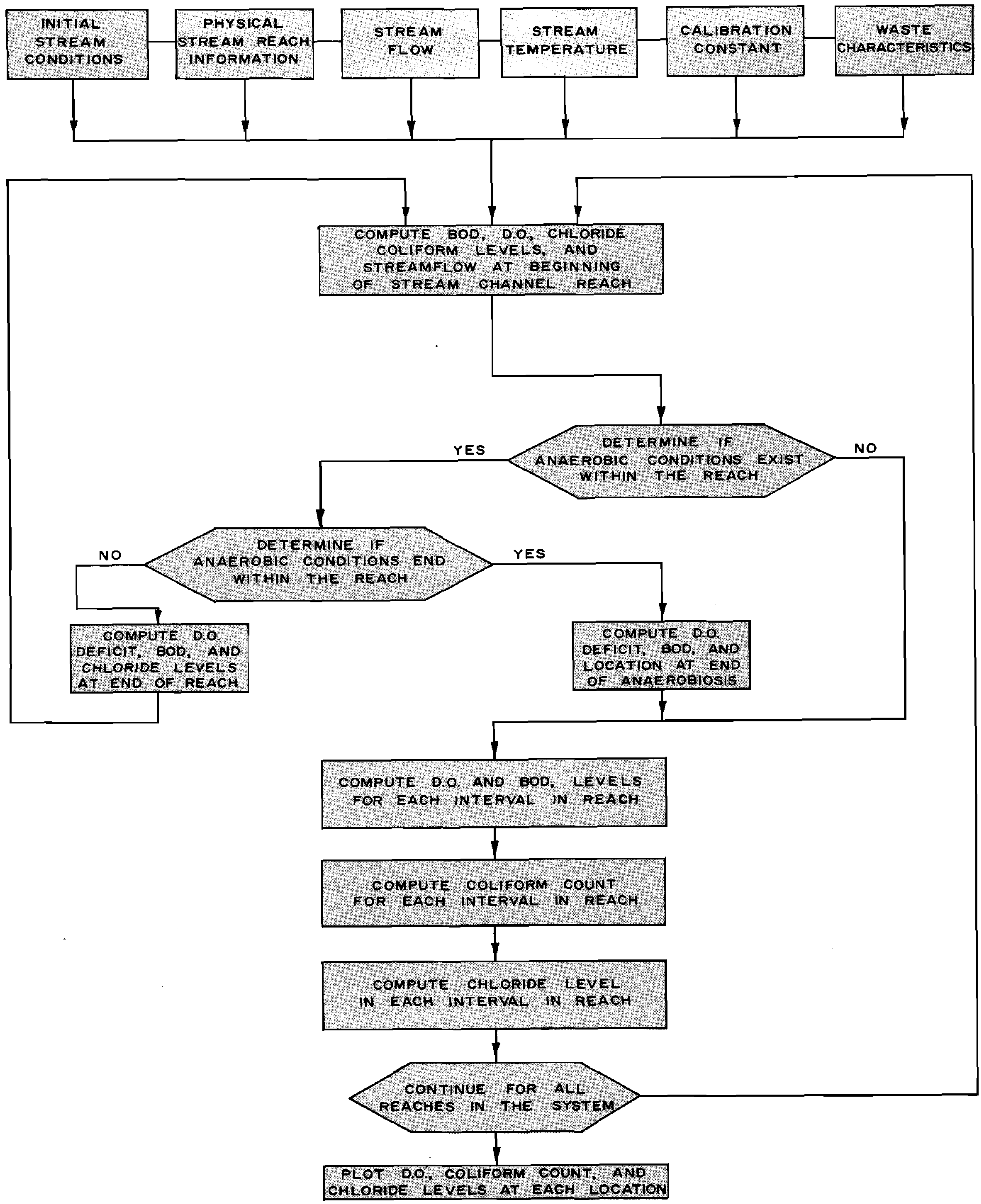
In application, the water quality simulation is begun at the upstream end of the river system. The initial conditions in terms of streamflow, dissolved oxygen, BOD, and temperature are determined, as described in a following section, and entered into the model. The initial conditions are determined in the model by adding the dissolved oxygen and BOD inputs at the beginning of the first reach to the amounts already present in the stream water. The DO and BOD levels at various locations throughout the reach are then computed in the model by application of the two equations set forth above. At the end of the first reach, the computed DO and BOD levels are added to the input DO and BOD at the start of the second reach; and, assuming complete mixing, new values are determined for the beginning of the second reach. These values then serve as the initial conditions for computing DO and BOD levels in the second reach. This procedure is followed for all the reaches in the stream system.

Because the Streeter-Phelps equation is applicable only for aerobic conditions, a separate routine was necessary where anaerobic conditions developed within a channel reach. When a stream reach becomes devoid of oxygen, the amount of BOD that can be exerted is limited by, and equal to, the amount of oxygen supplied in the reach. This holds true until the oxygen supplied exceeds the amount of BOD being exerted, at which time the dissolved oxygen concentration increases and aerobic conditions are restored. This relationship formed the basis for determining the length of the stream reaches in which anaerobic conditions exist.

Chloride Sub-Model: The sub-model for determining chloride concentration in a stream reach is relatively simple, since dilution is the only means by which the chloride concentration can be reduced. Essentially, the chloride concentration

Figure 83

FLOW DIAGRAM FOR WATER QUALITY FOR THE FOX RIVER WATERSHED



Source: Harza Engineering Company.

at the beginning of each reach is computed in the model by adding the amount of chloride input at the beginning of the reach to the amount of chloride already present in the stream water. This chloride concentration is then assumed to be representative for the entire reach, since the streamflow is assumed to be constant throughout each reach. This procedure is followed for each reach in the river system to obtain a profile of chloride concentration.

Coliform Sub-Model: Two separate mathematical relationships were used for determining the concentration of coliform bacteria in a given stream reach. Recent investigations[15] have shown that the number of coliform bacteria existing in a stream below a waste discharge increases to a maximum density of four to eight times their original concentration, with the maximum density being reached at a point located approximately one-half day's flow distance below the waste outfall. Based on this data, and assuming that complete mixing of the stream water and waste discharge occurs, the following relationship was developed for use in the model:

(3) $C = 10\ Nt + N$

in which C = concentration of coliform bacteria at a point in the stream, expressed in bacteria/100 ml

N = concentration of coliform bacteria at the waste outfall, expressed in bacteria/100 ml

t = time of flow below the waste outfall, expressed in days

This equation assumes a linear relationship between the original concentration and the maximum density, assumed to be six times the original. The equation is valid only for a time of flow less than one-half day below the waste outfall.

The second relationship utilized in the coliform routine computes the coliform density in a stream at any point further than one-half day's flow distance below a waste outfall. The equation, based on biological purification in a stream, may be written as:

(4) $C = N_o \left[1 + nk\ (t - 0.5)\right]^{-1/n}$

in which C = concentration of coliform bacteria at any point in a stream, expressed in bacteria/100 ml

N_o = maximum coliform density, as described above

n = coefficient of non-uniformity associated with the bacterial group - dimensionless

k = initial die-away constant for a specific bacterial population group days to the minus 1

t = time of flow below the waste outfall, expressed in days

The above two equations form the basis of the coliform computation routine used in the model. In order to determine the coliform density at any location in the river system, the concentration at that location due to each of the upstream waste discharges is computed and added to obtain the total coliform density at the particular location under consideration. This procedure was applied at a number of points along each stream channel reach to obtain a complete profile of coliform bacteria levels throughout the river system.

Plotting Routine: The routine for plotting output information from the computer program was not an essential part of the water quality simulation model but greatly facilitated the analysis of the data generated by the model. Basically, this routine recorded the values of dissolved oxygen, coliform count, and chloride concentration that were generated at each location and plotted these values in the form of profiles along the river. These profiles provided a visual indication of forecast water quality conditions in the river system and greatly aided comparisons of the conditions resulting from each alternative plan.

Calibration of the Model

Since general theoretical and empirical relationships were used to develop the water quality model, it was necessary to calibrate the model to the specific characteristics of the Fox River system. This involved the determination of the

[15] *Kittrell, F. W., and Furfari, S. A., ''Observation of Coliform Bacteria in Streams,'' Journal of the Water Pollution Control Federation, Vol. 35, November 1963.*

constants in the dissolved oxygen routine and the coliform routine from data obtained by the Commission and the Wisconsin Department of Natural Resources in water quality surveys of the Fox River watershed. The procedures used to compute these constants are described below.

Dissolved Oxygen Sub-Model Routine Constants: Data available from recent water quality surveys provided several profiles of dissolved oxygen, BOD, and temperature for the Fox River system during the critical summer months. Streamflow information was available from the USGS gaging stations at Waukesha and Wilmot. Flows at other locations in the system were estimated from this data and from low-flow discharge measurements made by the USGS, the SCS, and the Wisconsin Conservation Commission as a part of the watershed study. Times of travel for the various stream reaches were calculated by dividing the length of the reach by the average velocity within the reach. Data on major waste discharges were obtained from the Commission and the Wisconsin Department of Natural Resources water quality surveys. This information was utilized to develop the dissolved oxygen routine constants applicable to the Fox River system.

The value of the deoxygenation constant, K_1, was taken as 0.025 $days^{-1}$ at 20^oC. This represents the generally accepted value for normal domestic sewage. The net rate of oxygen production, A, was assumed to be zero. In effect, this means that the amount of oxygen produced by photosynthesis during the daylight hours was assumed equal to the amount consumed by the photosynthetic plants at night.

Using these values for K_1 and A, the remaining constants were determined. The river system was divided into reaches, each reach being that stretch of river extending from one water quality sampling station to the next or from a sampling station to a tributary discharge point. Starting with the reach farthest upstream, the five-day, 20^oC BOD at the upstream and downstream ends of the reach was converted to ultimate BOD by multiplying by 1.40; and these ultimate BOD's at 20^oC were adjusted to the actual stream temperature by using the appropriate relationship contained in the model. The deoxygenation constant, K_1, was similarly adjusted to stream temperature. Using these values, equation (2) was solved for the rate of addition of BOD, La, and the sedimentation and absorption rate, K_3, according to the following procedure:

a) If the BOD decreased through the reach and L was less than $L_A e^{-K_1 t}$, then $L_a = 0$ and the equation was solved for K_3;

b) If the BOD decreased through the reach but L was greater than $L_A e^{-K_1 t}$, then $K_3 = 0$ and the equation was solved for L_a;

c) If the BOD was constant or increased through the reach, then $K_3 = 0$ and the equation was solved for L_a.

Next the dissolved oxygen deficit was computed for the upstream and downstream ends of the reach by subtracting the observed DO from the saturation DO at the existing stream temperature. These values, together with the previously determined values of K_1, K_3, L_a, and A, were used to solve equation (1) for the reaeration constant, R.

This procedure resulted in the determination of the oxygen sag equation constants for each reach of the river system for a particular dissolved oxygen, BOD, and temperature profile. The calculations were repeated for each profile available from the stream sampling surveys of the Fox River system. This resulted in a set of values for each constant in each reach, which were adjusted to 20^oC and averaged to obtain the final values used in the water quality model, as shown in Table 45. These values were based on the data available for the Fox River system; and, thus, they reflect the actual purification performance in the streams only to the extent that the available data accurately describe this performance. 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. In this way, a more accurate predictive model can be evolved for the Fox River system.

Coliform Sub-Model Routine Constants: The coliform routine constants applicable to the Fox River system were determined from the same basic data used for the dissolved oxygen routine constants and from profiles of the coliform density obtained in the stream sampling surveys. The value of the nonuniformity coefficient, n, was computed according to a procedure suggested by Fair and Geyer.[16] The following relationship was used:

[16] See: *Water Supply and Waste Water Disposal*, Fair and Geyer.

Table 45

DISSOLVED OXYGEN ROUTINE CONSTANTS

Reach	Constants[a] K_1	R	K_3	L_a	A
Fox River					
Mill Road to Sussex Creek	0.25	1.3	0.0	3.0	0
Sussex Creek to Brookfield Sewage Treatment Plant	0.25	1.3	0.0	3.0	0
Brookfield Sewage Treatment Plant to CTH Y	0.25	0.3	4.5	0.0	0
CTH Y to Poplar Creek	0.25	0.3	0.0	4.0	0
Poplar Creek to Pewaukee River	0.25	0.3	0.0	4.0	0
Pewaukee River to Waukesha Sewage Treatment Plant	0.25	2.0	0.0	3.5	0
Waukesha Sewage Treatment Plant to CTH X	0.25	0.2	13.0	0.0	0
CTH X to Pebble Creek	0.25	1.0	0.0	1.5	0
Pebble Creek to Genesee Creek	0.25	1.0	0.0	1.5	0
Genesee Creek to Pebble Brook	0.25	1.0	0.0	1.5	0
Pebble Brook to Mukwonago River	0.25	1.0	0.0	1.5	0
Mukwonago River to Tichigan Lake	0.25	1.0	0.0	2.0	0
Waterford Impoundment	0.25	0.5	0.0	1.2	0
Waterford Dam to Waterford Sewage Treatment Plant	0.25	2.0	0.0	1.2	0
Waterford Sewage Treatment Plant to Rochester Dam	0.25	0.9	0.0	1.0	0
Rochester Dam to White River	0.25	0.9	0.0	1.0	0
White River to Burlington Sewage Treatment Plant	0.25	0.9	0.0	6.0	0
Burlington Sewage Treatment Plant to County Line Road	0.25	1.0	0.0	2.0	0
County Line Road to Bassett Creek	0.25	1.0	0.0	2.0	0
Bassett Creek to Wilmot Dam	0.25	1.0	0.0	2.0	0
Wilmot Dam to State Line	0.25	1.0	0.0	2.0	0
Sussex Creek					
Sussex Sewage Treatment Plant to Fox River	0.25	0.5	0.5	0.0	0
Pewaukee River					
Pewaukee Sewage Treatment Plant to Fox River	0.25	1.1	0.7	0.0	0
Mukwonago River					
Mukwonago Sewage Treatment Plant to Fox River	0.25	1.0	1.0	0.0	0
Honey Creek					
East Troy Sewage Treatment Plant to Spring Creek	0.25	0.6	0.0	1.9	0
Spring Creek to Sugar Creek	0.25	1.0	0.0	2.0	0
Sugar Creek to Echo Lake	0.25	1.0	0.0	2.0	0
White River					
Lake Geneva Sewage Treatment Plant to Como Creek	0.25	1.9	2.3	0.0	0
Como Creek to Echo Lake	0.25	1.3	0.0	2.7	0
Echo Lake to Fox River	0.25	1.0	0.0	1.3	0
Bassett Creek					
Twin Lakes Sewage Treatment Plant to Fox River	0.25	2.2	0.7	0.0	0

[a] *All values at 20° Centigrade.*

Source: Harza Engineering Company.

$$(5) \quad n = \frac{\log t_2/t_1}{1 \log p_1/p_2}$$

in which t = time of flow below the point of maximum coliform density expressed in days.

p = ratio of the coliform density at time t to the maximum density at time t = 0. p is expressed in bacteria per 100 ml.

After n had been determined for each coliform profile available for the summer months, equation (4) was solved for the die-away constant, k. These values for each profile were then averaged to determine representative values for the river system. The final values used in the water quality model were k = 7.50 and n = 0.80. Refinement of these values to indicate differences between each reach was not possible because of a lack of sufficient basic data.

Input to the Model

In order to use the water quality model, it was necessary to know the streamflow in each reach, the time of flow through each reach, the quantity and quality of wastes discharged to the streams, and the initial conditions at the beginning of the first reach in each stream. This information, together with the previously described constants, constituted the base from which water quality forecasts were made for the Fox River system.

Streamflow: Since long-term continuous streamflow records within the Fox River watershed were available at only one station, that located at Wilmot near the state line, flows at other locations had to be synthesized in a manner that related the flow at a given location to that at Wilmot. An analysis of existing water quality conditions in the Fox River watershed indicated that critical conditions with respect to the dissolved oxygen content of the streams normally occur during the summer months of July and August. These are the months in which the highest water temperatures, as well as relatively low flows, may be expected. Thus, it was necessary to develop a method to estimate the streamflow at various locations in the basin during the critical months of July and August.

Since runoff characteristics are quite variable throughout the basin, it was decided that proportioning flows solely on the basis of tributary drainage area would not be representative of actual conditions. Therefore, it was determined that a procedure should be developed that would take into account the variable runoff characteristics of the various sub-basins throughout the watershed. The method developed involves determining the ratio which may be expected between the flow per square mile at the desired location and the flow per square mile at Wilmot. This ratio indicates the relative difference in runoff characteristics between a particular sub-basin and the entire Fox River watershed. Available streamflow data were used to determine these ratios for various locations in the basin.

Streamflow information available for the Fox River and its tributaries includes the following: 28 years of record at Wilmot, 5 years of record at Waukesha, and 3 years of daily summer flow measurements only on the White River near Burlington, low-flow measurements obtained at 7 USGS low-flow partial record stations, and individual flow measurements made by the USGS and the Wisconsin Department of Natural Resources at approximately 70 locations throughout the basin. This information was utilized to determine the ratio existing between the low streamflow at the gaging station locations and the low flow at Wilmot.

All flow measurements were first adjusted to reflect natural flow conditions by subtracting any sewage treatment plant effluent contributions from the measured flows. These adjusted flows were then expressed in terms of cfs per square mile by dividing by the tributary drainage area above the point of measurement of the flow. For the daily records of the Fox River at Waukesha and of the White River near Burlington, periods of the base flow were determined by plotting the daily summer flows in the form of a hydrograph. The ratio of the base flow at each of these locations to the flow at Wilmot was determined by dividing the average base flow at each location by the average flow at Wilmot for the same time period. The procedure was then reversed, and the base flows were determined at Wilmot and ratios obtained between the average base flow at Wilmot and the average flows for the same time period at Waukesha and Burlington. This procedure was followed for each year of record and the resultant ratios obtained. Finally, the mean ratios of the flow at Waukesha to the flow at Wilmot and of the flow at Burlington to the flow at Wilmot were calculated.

The procedure for analyzing the individual low-flow measurements was similar. All flows were adjusted by subtracting any sewage treatment plant effluent contribution and converted to flows in terms of cfs per square mile. A ratio was then determined between each of these individual flows and the average flow at Wilmot for the corresponding time period. For any location at which more than one low-flow measurement was made (USGS low-flow partial record stations), the corresponding ratios were averaged to determine the mean value of the ratio of flow at that location to the flow at Wilmot.

All of these ratios were then plotted on a map of the Fox River watershed to determine similarities and differences between various areas. Representative values for various streams and sub-watersheds were chosen, based on the calculated ratios for each area and the general geologic and topographic characteristics of the area. For the determination of representative values, greatest emphasis was placed on the ratios at Waukesha and Burlington, lesser emphasis on the ratios at the low-flow partial record stations, and the least emphasis on the ratios at locations where only one flow measurement was available. Some of the representative values chosen for the ratio are shown in Table 46. The ratios in this table represent the ratio of the low flow in cfs per square mile at the location to the low flow in cfs per square mile at Wilmot.

These ratios provide a method of estimating the low flow at various locations in the Fox River watershed for a given low flow at Wilmot. The ratios are applicable only to summer base flow conditions since they were derived exclusively from data for these conditions. The ratios were used in the water quality simulation model to determine streamflow at key locations in the watershed. An example of the flow distribution in the watershed for an assumed low flow of 100 cfs at Wilmot is shown in Table 47.

The design flow that was used in the water quality management studies was the lowest seven-consecutive-day flow that may be expected to occur on the average of once in ten years in the months of July and August. This flow was determined at Wilmot by plotting the lowest seven-day flow occurring in July or August of each year versus the recurrence interval of that flow, as determined from the 28 years of record at the gaging station at Wilmot. The seven-day, one in ten-year low flow was then determined for various locations in the basin by multiplying the ratio determined for that location, as previously described, by the flow at Wilmot. Table 48 indicates these seven-day, one in ten-year low flows in the Fox River system. The flows shown in this table are natural flow; that is, do not include any flow contribution from waste discharges or artificial augmentation.

Time of Flow: The time of flow for each reach in the river system was calculated through the use of Manning's equation. This equation was solved for the mean velocity in each reach utilizing slope and cross-section data supplied by the Commission, channel friction factors supplied by the SCS, and flow information developed by Harza Engineering Company. The velocities were determined both for design low-flow and average summer flow con-

Table 46

LOW-FLOW RATIOS IN THE FOX RIVER WATERSHED

Location	Ratio of Low Flow at Location to Low Flow at USGS Stream Gaging Station at Wilmot
Fox River at Waukesha	0.67
Fox River at Waterford	0.85
Fox River at Burlington	0.87
Fox River at Wilmot	1.00
Mukwonago River Basin	1.10
White River Basin	0.69
Sugar Creek Basin	1.30
Honey Creek Basin	1.30

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

ditions, and the time of travel was obtained by dividing the length of each reach by its mean velocity. The time of flow through impoundments in the system was computed by dividing the volume of that portion of the impoundment through which flow occurs by the total flow through the impoundment.

Waste Discharges: Information on the present quantity and quality of wastes discharged to surface waters within the Fox River watershed was obtained from the Commission, the Wisconsin Department of Natural Resources, and the operators' reports for the Brookfield and Waukesha sewage treatment plants. The data consisted of average sewage flow and influent and effluent BOD concentrations. Since there was no information available on the concentration of dissolved oxygen, coliform bacteria, or chlorides in the effluent from sewage treatment plants in the Fox River watershed, approximate values for these parameters were assigned on the basis of normal values for the effluent from plants treating primarily domestic sewage. Therefore, in the case of a trickling filter plant, 10 percent of the raw coliform count would be used as the amount discharged to the stream; and in the case of an activated sludge plant, a 5 percent amount discharging to the stream would be assumed. The values obtained and subsequently used in the water quality model included the following: effluent dissolved oxygen content, 25 to 50 percent of saturation; effluent chloride concentration, 150 mg/l; raw sewage coliform count, 25,000,000 organisms per 100 ml. This information, together with sewage flows and BOD 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 in the watershed on water quality.

Initial Conditions: In the application of the water quality simulation model, it was necessary to determine the water quality conditions at the beginning of the first reach of each stream. This was accomplished by analyzing the data available from the stream sampling surveys and determining the average dissolved oxygen, BOD, and coliform concentrations at each location under consideration. Since the first stream reach was chosen so that it would be upstream from any present or future major waste discharges, future water quality conditions at that location may be expected to remain similar to the present conditions. Thus, the values determined from existing data in these initial reaches were used both in the description of present water quality conditions and in the forecast of future water quality conditions for these reaches.

Output From the Model

The output from the water quality simulation model consists of forecasts of water quality conditions in the Fox River system corresponding to various input conditions in terms of the quantity, quality, and location of waste discharges. The output includes the computer print-out of dissolved oxygen and coliform concentrations at various locations in each reach; the BOD and chloride concentrations at the beginning and end of each reach; the initial streamflow and the amount of flow added in each reach; and the dissolved oxygen, BOD, and chloride contents of the added flow.

LAKE NUTRIENT BUDGETS

The major water-quality-associated problem in the lakes of the Fox River watershed is excessive

Table 47

FLOW DISTRIBUTION FOR AN ASSUMED FLOW OF 100 CFS AT WILMOT

Location	Flow (cfs)
Fox River at Brookfield Sewage Treatment Plant	1.0
Fox River at Waukesha Sewage Treatment Plant	9.2
Fox River at Waterford Sewage Treatment Plant	38.0
Fox River above White River	43.0
Fox River at Burlington Sewage Treatment Plant	76.0
Fox River at Wilmot	100.0
Mukwonago River at Fox River	14.0
Honey Creek at Echo Lake	24.0
White River at Echo Lake	7.2

Source: *Harza Engineering Company.*

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 use. 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, 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 lakes. Since no information of this type was available for any of the lakes in the Fox 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

The nutrients most often associated with excessive fertilization of lakes and streams are nitrogen and phosphorus. They are derived principally from domestic sewage, urban and rural runoff, precipitation, ground water, and wetland drainage. Most of the data used in this study concerning these sources was obtained from a study of the nutrient sources of Lake Mendota, Madison, Wisconsin[17] and from a report on water fertilization in the State of Wisconsin.[18] 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. Conventional secondary treatment facilities generally remove less than half of the nitrogen and phosphorus contained in raw domestic sewage and consequently discharge large amounts of these nutrients

[17] *Report on the Nutrient Sources of Lake Mendota*, Nutrient Sources Subcommittee of the Technical Committee of the Lake Mendota Problems Committee, Madison, Wisconsin (1966).

[18] *Excessive Water Fertilization*, Working Group on Control Techniques and Research on Water Fertilization, Report to the Water Subcommittee, Natural Resources Committee of State Agencies, Madison, Wisconsin (1967).

Table 48

DESIGN LOW FLOW IN THE FOX RIVER SYSTEM[a]

Location	Flow (cfs)
Fox River	
at Mill Road	0.0
at Brookfield Sewage Treatment Plant outfall	0.5
at Pewaukee River	1.7
at Waukesha Sewage Treatment Plant outfall	4.7
at Mukwonago River	10.2
at White River	21.7
at Wilmot	51.0
Sussex Creek at Fox River	0.1
Mukwonago River at Fox River	7.0
Pewaukee River at Fox River	0.1
Honey Creek at East Troy	2.4
Honey Creek at Echo Lake	12.0
Sugar Creek at Honey Creek	5.3
White River at Lake Geneva Sewage Treatment Plant	0.1
White River at Fox River	15.7
Nippersink Creek at Genoa City	2.8

[a] *Seven-day, one in ten-year low flow.*

Source: Harza Engineering Company.

into the receiving waters. The annual per capita contributions of 6.5 pounds of nitrogen and 1.9 pounds of phosphorus that were used in this study represent the average contributions to surface waters from the effluent of secondary sewage treatment plants.

Sewage disposal facilities at homes and cottages around most of the major lakes in 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 using average per capita contributions of 10.0 pounds nitrogen and 3.5 pounds phosphorus in the raw sewage and assuming that 30 percent of the nitrogen and 5 percent of the phosphorus ultimately reach the lakes.[19]

The amount of nitrogen and phosphorus contained in surface 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 ten 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.

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

[19] *Ibid.*, footnotes 17 and 18.

Table 49

MAJOR NUTRIENT CONTRIBUTIONS

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 lbs./Capita/Yr.
Rural Runoff:		
Cropland and Pasture.	0.06 lbs./Acre/Yr.	0.04 lbs./Acre/Yr.
Forest Land.	0.03 lbs./Acre/Yr.	0.003 lbs./Acre/Yr.
Manured Land.	3.0 lbs./Acre/Yr.	1.0 lbs./Acre/Yr.
Urban Runoff.	8.0 lbs./Acre/Yr.	2.2 lbs./Acre/Yr.
Precipitation	8.0 lbs./Acre/Yr.	0.14 lbs./Acre/Yr.
Ground Water.	1.2 mg/l	0.01 mg/l

Source: Lake Mendota Problems Committee; Natural Resources Committee of State Agencies.

runoff from a residential-light commercial area in Cincinnati, Ohio.[20] The values for the Fox River watershed were taken as 90 percent of the Cincinnati values to reflect the lower average annual precipitation in the southeastern Wisconsin area.

Precipitation directly on the lake 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 phosphorous content of rainwater, however, have yielded extremely variable results. For purposes of this study, a value of 0.02 mg/l of phosphorus was used; and the average annual rainfall was taken as 31.6 inches throughout the watershed. This resulted in an average annual phosphorus contribution of 0.14 pounds 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 nitrogen and 0.01 mg/l 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 Fox 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.

Municipal sewage treatment plant effluent is not a source of nutrients in most of the major lakes in the watershed. Only two lakes—Tichigan Lake and the Waterford impoundment—presently receive treated effluent contained in the waters of the Fox River. Estimates of the nutrients contributed to these two lakes by treatment plant effluent were made by applying the values listed in Table 49 to the total population presently served by upstream sewage treatment facilities. This includes the facilities at Sussex, Pewaukee, Brookfield, Waukesha, and Mukwonago.

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 quarter-section totals included within the delineated tributary drainage areas located around each lake. Areas served by a municipal sanitary sewerage 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, was then estimated using the values shown in Table 49. The contribution from wetlands was not estimated since no data exist on 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 on 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 nutri-

[20] *Weibel, S. R., Anderson, R. J., and Woodward, R. L., "Urban Land Runoff as a Factor in Stream Pollution," Water Pollution Control Federation Journal, Vol. 36, No. 7 (July 1964).*

ents 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 Waukesha, Racine, Kenosha, and Walworth 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 surface area of the major lakes in the Fox River watershed were obtained from the Wisconsin Conservation Commission.

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 nitrogen and phosphorus concentrations shown in Table 49. Ground water inflow was determined by assuming a contribution of 3.5 inches per acre of contributing area as determined from a piezometric map of ground water levels in the Fox River watershed prepared by the USGS. The 3.5 inches represent the average combined ground water outflow plus well pumpage for the State of Wisconsin. In those few lakes in the watershed in which ground water movement is entirely from the lake into the ground, the nutrient contribution by ground water was taken as zero.

Utilization of the Results

The total amounts of nitrogen and phosphorus contributed to 22 of the 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 Chapter IX of this report. 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.

SUMMARY

The preparation of sound long-range comprehensive watershed development plans requires definitive information on the range of river performance that may be expected over a period of time and under differing land use conditions. This knowledge must extend to the quality, as well as to the quantity, of streamflow and requires quantitative analysis of both the hydraulics and pollution loadings to be carried by the stream system. As suitable historical records of sufficient duration were not available and as river performance could be expected to change with changing land use development within the watershed, it was necessary to use the available data to construct mathematical models which could be used to simulate the performance of the river system. This chapter has described the construction and application of the two mathematical models developed to simulate the flooding and the surface water quality performance of the Fox River system under varying land use conditions through the watershed plan design year 1990.

The flood simulation model was constructed using:

1. Rainfall-runoff relationships to estimate the amount of runoff produced by rainfall and a volume-frequency analysis of actual winter and spring flood volumes, as measured at the stream gaging station at Wilmot, to estimate the amount of runoff produced by snowmelt. These rainfall-runoff and snowmelt-runoff relationships were established for 109 subareas of the total watershed, each having reasonably uniform hydrologic characteristics.

2. Synthetic unit hydrograph procedures to estimate the time distribution of runoff for 151 sub-basins of the total watershed.

3. The convex method of routing to establish how flows move through the river system and the storage indication method of routing to determine how flows are modified as they pass through water control structures.

Stage-discharge curves were prepared for 589 cross section locations in the 260 miles of channel length studied. At all cross sections, a water surface elevation was determined for each of six selected discharges; and curves were drawn using the six established points.

The hydrologic model was calibrated to reproduce actual river performance by use of recorded flow hydrographs at existing stream gaging stations, recorded rainfall-runoff relationships, and historic high-water marks. The performance of the model was further checked against flood flows and frequency relationships derived from application of a regional flood correlation technique developed by the U. S. Geological Survey.

After satisfactory calibration was achieved, the model was used to develop flood flows and to establish flood frequency. Two types of floods, those produced by melting snow and those produced by rainfall, were synthesized. Discharges were developed, at various locations in the watershed, for the 10-year and 100-year recurrence interval rainfall flood events and for the 10-year and 100-year recurrence interval snowmelt flood events. Frequency was assigned to summer floods on the basis of the rainfall used to synthesize the event. Frequency was assigned to spring floods on the basis of the volume of flood flow. The two types of events were then combined to produce a synthesized annual frequency line for selected locations on the stream channel system. All of the discharge-frequency relationships, except those that represent locations on the Fox River between Burlington and Wilmot, were developed by application of the model. Between Burlington and Wilmot, the discharge-frequency relationship was established by statistical analysis of the USGS streamflow records at Wilmot.

The flood simulation model was used to establish floods of the 100-year, 50-year, 25-year, 10-year, and 5-year recurrence intervals under both present and planned future land use conditions within the watershed. Elements of the model were adjusted to incorporate the hydrologic changes expected to occur as a result of future urbanization within the watershed. The adjustments were based upon three assumptions, the validity of which were indicated by both analysis and experience: first, that the total volume of runoff from future snowmelt floods will not be changed significantly by urbanization since the generally frozen or saturated soil conditions attendant to such floods approximates a highly impervious surface over the watershed; second, the rate at which runoff is transported to main stream channels will be substantially increased by urbanization, since attendant pavement and storm sewer improvements will increase overland flow velocities; and third, that the volume of runoff from summer rainfalls will increase with urbanization because of the attendant increase in impervious area within the watershed. This increase will be partially compensated for, however, by the greater retention capability of soils under lawn cover as compared to such soils under some agricultural uses. Application of the hydrologic simulation model indicated that urbanization may be expected to increase spring snowmelt flood peak rates of discharge by only minor amounts, roughly from zero to 2 percent. Summer rainfall flood peak rates of discharge may be expected to increase from 20 to 50 percent for individual subareas and by approximately 2 percent at Wilmot.

The hydrologic simulation model also served as the basis for the identification and delineation of the channel, floodway, and floodplain areas of the watershed and was modified to determine the effects of proposed alternative structural flood control measures on the performance of the river system. The construction of floodwalls and levees in the Waukesha and Burlington areas of the watershed was concluded to have an insignificant effect upon peak flood flows and stages both upstream and downstream from the proposed improvements. A floodwater storage reservoir located at the Vernon Marsh in the Towns of Vernon and Mukwonago, Waukesha County, could be expected to reduce the peak discharge of the 100-year recurrence interval flood at Waterford from 3,300 to 2,100 cfs, near Burlington from 4,350 to 3,585 cfs, and at Wilmot from 9,400 to 9,020 cfs, with concomitant reductions in the peak flood stage of 1.5 feet, 0.8 foot, and 0.2 foot, respectively. A multiple-purpose reservoir located on Sugar Creek in the Town of LaFayette, Walworth County, could be expected to reduce the peak discharge of the 100-year recurrence interval flood at Spring Prairie Road in Section 31, Town 3 North, Range 19 East, from 4,100 to 3,620 cfs, with a concomitant reduction in the peak flood stage of 0.4 foot.

The effects of operation of existing major reservoirs or lakes within the watershed were also evaluated using the model. Operation of the Waterford impoundment may be expected to reduce the 25-year recurrence interval snowmelt discharge at Waterford from 2,500 to 2,400 cfs, at Rochester from 3,120 to 2,820 cfs, in Burlington from 6,050 to 5,300 cfs, and near Silver Lake from 6,600 to 5,900 cfs, with concomitant reductions in peak flood stages of 0.1 foot, 0.3 foot, 0.5 foot, and 0.4 foot, respectively. The effects of providing additional temporary floodwater storage on ten major lakes within the watershed could be expected to reduce the peak discharge of the 100-year recurrence interval flood at Waukesha from 3,250 to 3,200 cfs; at Big Bend from 3,300 to 3,250 cfs; at Rochester from 4,130 to 4,040 cfs; at Burlington from 8,300 to 7,950 cfs; at Silver Lake from 9,300 to 8,900 cfs; and at Wilmot from 9,400 to 8,950 cfs, with concomitant reductions in the peak flood stages of 0.1 foot, 0.1 foot, 0.1 foot, 0.3 foot, 0.2 foot and 0.2 foot, respectively.

The stream water quality simulation model was designed and used to simulate stream water quality conditions under both present and planned future land use conditions within the watershed. The model was based upon dissolved oxygen, chloride, and coliform concentration subroutines, incorporating accepted relationships between the levels of these parameters and streamflow and temperature. The major parameters used to describe present and future water quality conditions were dissolved oxygen content, biochemical oxygen demand, coliform count, chloride ion concentration, and water temperature. Forecasts of 1990 water quality conditions using existing trend information, and 1990 water quality management plans determined from the simulated parameters, were used to compare future water uses of the various streams within the watershed. Comparisons of stream use were made with regard to water-based recreation activities, maintenance of fish life, industrial cooling and water supply, livestock and wildlife watering, irrigation, and aesthetics as indicated in Chapter IX.

The model also provided 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 water use objectives and standards. The model inputs were modified to represent the effects of continued urbanization within the watershed and the effects of proposed water quality control facility and management alternatives. Application of the model to evaluate the effectiveness of alternative pollution abatement measures indicated that there are three distinct measures that could be used to obtain stream water quality levels suitable for the water use objectives and standards established for the Fox River watershed. These measures are: 1) the provision of higher levels of treatment for major waste discharges in the watershed, 2) the elimination of waste discharge to streams in the watershed, and 3) the provision of augmentation water to dilute waste discharges during periods of low natural streamflow. Several combinations of these measures were also evaluated in terms of their improvements in water quality.

Many of the major lakes in the Fox River watershed already show signs of deteriorating water quality as the result of receiving excessive amounts of nutrients, and the frequency and severity of this deterioration may be expected to increase with further urbanization unless controlled through sound land and water management practices. Problems resulting from excessive fertilization include luxuriant growths of aquatic life, losses in property value, and nuisance conditions that impair aesthetic enjoyment.

Estimates of the amounts of nutrients being contributed to a lake from both natural and man-induced sources were developed for each of the 22 major lakes within the watershed. These calculations were based upon information contained in reports of the Wisconsin Natural Resources Committee of State Agencies and the University of Wisconsin on excessive water fertilization in Wisconsin. The analyses indicated that the major nutrient contributions to lakes in the Fox River watershed are derived from drainage from septic tanks serving homes around the lakes and from runoff from agricultural land on which artificial fertilizer and manure have been spread while the soil is frozen. These two sources contribute approximately three-fourths of the phosphorus and one-half of the nitrogen presently entering the major lakes in the watershed.

Chapter IX

SURFACE WATER QUALITY AND POLLUTION

INTRODUCTION

The term "water quality" refers to the physical, chemical, biological, 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 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, pollution is 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 impaired the usefulness of the water.

Before the intensive settlement of the watershed, water quality in the Fox 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 Fox River watershed, particularly on the Fox River and its major tributaries above Mukwonago. Most of the lakes within the watershed are also presently experiencing problems in water quality and prolific algae and other aquatic vegetation growth. As population levels 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 of the Fox 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 Fox 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 dissolved oxygen concentration varies inversely with the water temperature, with saturation levels ranging from a high of 14.6 milligrams per liter (mg/l) at 32°F to 7.6 mg/l at 86°F. Major sources of dissolved oxygen in surface waters are the atmosphere and aquatic plant life. Large reductions 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 in 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 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 used during a given time and at a given temperature by aerobic bacteria in the process of decomposing organic wastes. The time and temperature normally used as a standard of measurement are five days and 20° Centigrade (68°F). BOD is expressed either as the concentration present in mg/l in a given amount of water or as the total amount present in pounds. In itself BOD is not a pollutant. It is, however, 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 discharged, the rate at which the BOD is exerted, and the 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 apparently harmless microorganisms, which occur in extremely large concentrations in the intestinal tracts of man and warm-blooded animals. Pathogenic (disease-producing) bacteria may also exist in the intestines; and, 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. Also, the absence of any coliform bacteria is used as an indicator of the probable absence of pathogenic bacteria. Coliform bacteria may originate from sources other than the human intestinal tract, however, 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 U. S. Public Health Service Drinking Water Standards 1962 limit the average monthly coliform concentration in drinking water to one organism per 100 ml or a membrane filter coliform count (MFCC) of one per 100 ml. In waters used for recreational purposes, coliform limits are generally established on the order of an average of 1,000 MFCC per 100 ml or less and a maximum of 2,500 MFCC per 100 ml for whole-body-contact recreation, such as swimming, and an average of 5,000 MFCC or less per 100 ml and a maximum of 20,000 MFCC per 100 ml for partial-body-contact recreation, such as boating.

Chlorides

Chlorides are present in practically all surface and ground water, as 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 the chlorides may be induced through human activities, including domestic and industrial waste discharges, agricultural drainage, and application of salts to roads for winter maintenance. When 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 chloride concentration in the Fox River watershed is on the order of 10 mg/l. Concentrations higher than this amount 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 300-400 mg/l, however, impart a salty taste to water, render it unsuitable for many industrial uses, and inhibit the growth of certain aquatic plants.

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 algae 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.

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 southeastern Wisconsin natural climatic temperature conditions usually 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 indivuals 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. Nuisance organisms, such as mosquitoes and algal slimes, may become prevalent and severely impair many uses of the water. Thus, a biological evaluation will indicate those reaches of a stream which are relatively unpolluted, those which are polluted, and the intermediate recovery zones.

[1] *Sawyer, C.N., "Fertilization of Lakes by Agricultural and Urban Drainage," Journal New England Water Works Assn., Vol. 61, 1947.*

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 Chapter 614 of the Laws of Wisconsin 1965, the Wisconsin Resource Development Board on April 26, 1967, acted to adopt water quality standards for Wisconsin waters. These standards were formulated for the following major water uses: preservation and enhancement of fish life, recreation, and industrial and cooling water. In addition, certain minimum standards for all uses were specified. The adopted state standards are set forth in Table 50, together with similar standards formulated for these same major water uses by the Commission for use within the Southeastern Wisconsin Region. The Commission standards were formulated on an advisory basis in 1964, three years prior to the adoption of the state standards. The two sets of standards are, however, very similar, as shown in Table 50. Only the officially adopted state standards will be used in the planning effort, and any succeeding references to such standards in this report will refer to the adopted state standards. The intent of the state standards, as expressed in Section 144.025(2)(b) of the Wisconsin Statutes, is:

> . . . such 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, commerical, 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.

It should be noted that the water use objectives adopted by the State of Illinois for the Fox River are identical to those adopted by the State of Wisconsin; namely: recreation, waste assimilation, industrial supply, fishing, irrigation, and all water uses except public water supply. It should also be noted that the supporting standards are the same with but two exceptions:

1. Temperature for fish life—Illinois adds not to exceed 60°F at any time during the months of December to April (see Illinois Rule 1.05).

2. Illinois specifically sets the maximum concentration of chemical constituents allowed in a stream, while Wisconsin covers this matter by not allowing quantities of substances in excess of amounts toxic to fish and other aquatic life. The Illinois limitation on hexavalent chromium is 0.05, mg/l while the Commission standard limits this to 0.50 mg/l. These exceptions are not considered significant for plan preparation.

Minimum Standards for All Uses

The adopted state minimum standards for all uses, listed in Table 50, 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

Table 50

ADOPTED WATER QUALITY STANDARDS[a] FOR WISCONSIN: 1967

Parameter	Preservation and Enhancement of Fish Life					Recreation				Industrial and Cooling Water		Minimum Standards for all Uses
	WRDB[b]		SEWRPC[c]			WRDB[b]		SEWRPC[c]				
	Fish Reproduction Primary Importance	Warm-Water Fishery	Intolerant Species	Faculative Species	Tolerant Species	Whole-Body Contact	Partial-Body Contact[d]	Whole-Body Contact	Partial-Body Contact	WRDB[b]	SEWRPC[c]	WRDB[b] SEWRPC[c]
Dissolved Oxygen (mg/l)	5.0M[e]	4.0M[f]	5.0M	4.0M[g]	3.0M[g]	h	h	3.0M	3.0M	1.0M[i]	1.0M	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)	--	--	--	--	--	1,000[j]	5,000[k]	2,400	5,000	--	5,000	
Chloride (mg/l)	500.0	500.0	500.0	500	500	--	--	--	--	--	250	
Temperature (°F)	84[l]	89[l]	80.0	85	90	--	--	90	90	89	80[m]	
Other Parameters:	n	o				h	h	--	--	--	--	
Chromium (hex.) (mg/l)	--	--	0.5	0.5	0.5	--	--	--	--	--	--	
Cyanide (mg/l)	--	--	0.025	0.025	0.025	--	--	--	--	--	--	
Turbidity (Jackson Candle Units)	--	--	250.0	250	250	--	--	50	250	--	250	
Color (Units)	--	--	--	--	--	--	--	50	--	--	50	
pH (Units)	--	--	6.0-9.0	6.0-9.0	6.0-9.0	--	--	--	5.0-9.0	6.0-9.0[p]	5.0-9.0	
Dissolved Solids (mg/l)	--	--	--	--	--	--	--	--	--	1,000[q]	750	

[a] *Limits are maximum permissible values, except minimum 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 April 26, 1967 for interstate waters of Wisconsin.*

[c] *Recommended standards presented in SEWRPC Technical Report No. 4, Water Quality and Flow of Streams in Southeastern Wisconsin, November 1966.*

[d] *Partial-body-contact recreation refers to fishing, boating, and hunting; whole-body-contact recreation refers to swimming, water skiing, and skin diving.*

[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] *Sixteen hours maximum exposure at indicated concentration.*

[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] *Arithmetic average of 1,000 MFCC/100ml or less and a maximum not exceeding 2,500 MFCC/100ml during recreation season. A sanitary survey and/or evaluation to assure protection from fecal pollution is the chief criterion in determining recreational suitability.*

[k] *Arithmetic average of 5,000 MFCC/100ml or less and no more than one of the last five samples exceeding 20,000 MFCC/100ml during recreation season.*

[l] *Also, no change from background by more than 5°F at any time not 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.*

[m] *Eighty° F is the limiting temperature for general industrial process water. The recommended standard for cooling water is 90°F.*

[n] *Streams classified by law as trout streams 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.*

[o] *Unauthorized concentrations of substances are not permitted that alone or in combination with other materials present are toxic to fish or other aquatic life.*

[p] *Except in natural waters, 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.*

[q] *Also, the monthly average value not to exceed 750 mg/l.*

Source: SEWRPC.

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. The consideration of quality standards for surface water to be used for public supply in the Fox River watershed is academic, however, since all public supplies are presently obtained from ground water; and it appears that ground water will continue to be the sole practical source for the foreseeable future. The state designated water uses for the Fox River excepts public water supply.

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 50.

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 uses 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 50, 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 50 are intended to assure that the water will 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. Since the quality of ground water in the Fox River watershed is much more constant than the quality of surface water, most industries depend on ground water as a source of supply either directly or by way of a municipal distribution system. Thus, 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.

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 standards as listed in Table 50 cannot be applied without the prior knowledge of existing water uses or designation of water use objectives. The Wisconsin Department of Natural Resources has specified that available dilution water, when used in evaluating compliance with the water use objectives and supporting standards, should be based on the lowest average streamflow for any period of seven consecutive days in the most recent ten years. The State Resource Development Board has adopted these water use objectives for the Fox River:

> The Fox River is used for recreation, waste assimilation, industrial supply, fishing, and irrigation. Water quality in the Fox River from the state line upstream to 5 miles below the Waukesha sewage treatment plant should have water quality suitable for all uses excepting public water supply. In the middle sector of the Fox River, which extends upstream to the Waukesha dam, water quality should meet the standards for industrial and cooling water supply and minimum conditions. Above the Waukesha dam, water quality should meet the standards

for partial-body-contact recreation and fish and aquatic life.[2]

Water use objectives as adopted by the State of Illinois for the Fox River are identical to Wisconsin water use objectives and are included here only for clarification of purpose and use between the two states.

STATEMENT OF POLICY BY THE ILLINOIS SANITARY WATER BOARD

In the Sanitary Water Board Act, it has been declared to be the public policy of this State to maintain reasonable standards of purity of the waters of the State consistent with their use for domestic and industrial water supplies, for the propagation of wildlife, fish and aquatic life, and for domestic, agricultural, industrial, recreational and other legitimate uses, including their use in the final distribution of the water-borne wastes of our economy. It has also been declared to be the public policy of this State to provide that no waste be discharged into any waters of the State without first being given the degree of treatment necessary to prevent the pollution of such waters.

These criteria of water quality prescribe the qualities or properties of the waters of the State of Illinois which are necessary for the designated public use or benefit, and which, if the limiting conditions given are exceeded, shall be considered indicative of a polluted condition subject to abatement.

b) The Pecatonica River, Rock River, North Branch Nippersink Creek, Fox River, and Des Plaines River are used for the carriage of municipal and industrial treated effluents, for fishing, boating, and recreation (including full body contact), and for industrial water supply. The stream quality should meet all of the criteria and requirements for all uses, except public water supply.[3]

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 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.

STREAM WATER QUALITY CHARACTERISTICS OF THE WATERSHED

As already noted, the quality of water resulting from natural environmental conditions within the Fox River watershed generally does not present any serious problems for most beneficial water uses. In the upper reach of the Fox River east of Lannon, however, drainage from the Tamarac Swamp causes a natural degradation of water quality. The waters draining from this swamp are frequently low in dissolved oxygen and contain relatively high concentrations of BOD. The flow is small, however, except after exceptionally heavy rainfalls, so that dilution water and natural stream purification improve the water quality downstream to a level acceptable for most uses. With the exception of the effects of this large swamp, the natural water quality of the Fox River and its tributaries is suitable for most normal water uses.

Natural Stream Purification

The ability of a stream to purify itself is an important process related to water quality. When organic wastes are discharged to a stream, the number of microorganisms in the stream rapidly increases in direct response to the increased food supply provided by the waste. 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 below a waste outfall until the amount of oxygen supplied by reaeration from the atmosphere and photosynthetic plants exceeds the amount utilized by the organisms in breaking down the wastes. At this point the dissolved oxygen begins to increase, eventually reaching a concentration equal to or greater than that above the waste outfall. This ability of a stream to assimilate organic waste and eventually to return to its original condition is referred to as natural stream purification. This

[2] *Wisconsin Administrative Code, Section RD-3.01, Water Quality Standards for Interstate Waters.*

[3] *Rules and Regulations SWB-11, Rock River, Fox River-Des Plaines River-Kankakee River and certain named interstate tributaries, Illinois Sanitary Water Board.*

natural process is important to water quality management since it permits the discharge of wastes to a stream without the degradation of water quality throughout the entire length of the stream, provided that the natural waste assimilation capacity of the stream is not exceeded.

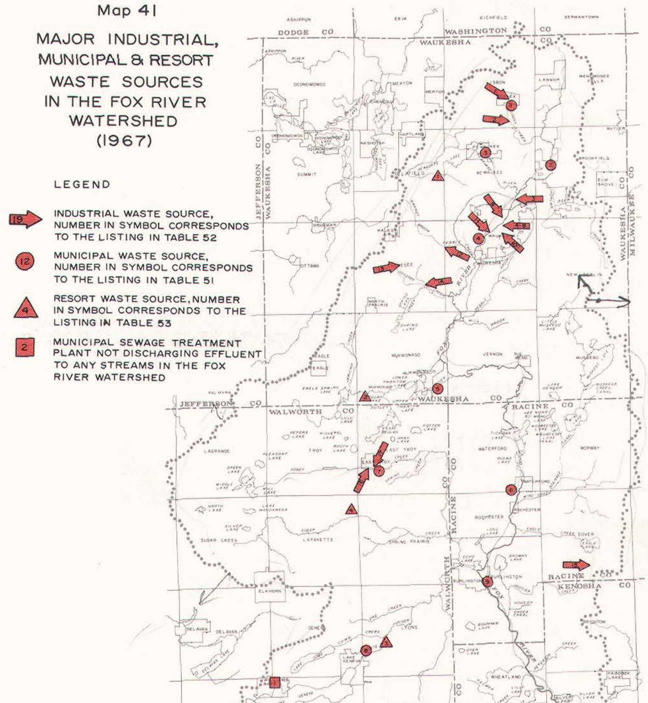
Waste Sources

As defined herein, water pollution is the direct result of human activity in the tributary watershed. 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 entirely 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 agricultural areas, storm water runoff from urban areas, overflow and drainage from septic tanks, and combined sewer overflows. Although these latter sources usually do not contribute to surface water pollution to the same extent that municipal and industrial wastes do, they may at certain times exert a significant undesirable influence on surface water quality.

Municipal Sources: Twelve major municipal waste discharges exist within the Fox River watershed. The locations of these discharges are shown on Map 41 . Information on the origin of these wastes, the type and efficiency of treatment used, the approximate daily discharge and population served, and the probable pollution load of the effluent is summarized in Table 51. All of the municipal waste treatment plants in the watershed, except the one at Waterford, presently provide secondary treatment.[4] Two additional sewage treatment plants, one at Fontana and the other at Williams Bay, both providing secondary treatment, are also located in the Fox River watershed. These two plants are not listed in Table 51, however, because their effluents are discharged to evaporation and seepage ponds that have no direct outlet to the surface water drainage system of the watershed and thus do not represent direct sources of surface water pollution.

As shown in Table 51, almost 75 percent of the total pollution load, as measured by five-day BOD, discharged to surface waters in the basin enters the Fox River system at and above the City of Waukesha. This area also contains the reaches of lowest streamflow in the Fox River. Presently, approximately 75 percent of the low flow of the Fox River below Waukesha consists of effluent

[4] *Waterford's secondary treatment facility started operation in January 1969.*



Field investigations by pollution control agencies revealed that 37 known major sources of surface water pollution existed in the Fox River watershed in 1967: 14 municipal sewage treatment plants, 19 industrial waste sources, and 4 resort waste sources.

Source: Wisconsin Department of Natural Resources.

from the waste treatment plants at Waukesha, Brookfield, Pewaukee, and Sussex. The adverse effect of the effluent from these plants on surface water quality is indicated by the low oxygen content and high coliform counts shown in Figures 84 and 85 and Table 55. The Fox River basin above Waukesha is the most rapidly urbanizing area within the watershed; and, therefore, greatly increased demands may be expected to be exerted in the future on the sewage treatment plants serving this area of the watershed. Unless higher levels of sewage treatment are provided or other appropriate water quality management measures taken, stream water quality will continue to deteriorate. Dissolved oxygen concentrations below the remaining sewage treatment plants in the basin are generally in excess of 5.0 mg/l. Coliform counts, however, are very high in these areas, indicating a potential health hazard if the streams are used for recreational purposes below the plant outfalls.

Industrial Sources: Nineteen major industrial waste discharges exist within the Fox River watershed, of which 8 are located in the vicinity of the City of Waukesha. The locations of these

Table 51
MAJOR MUNICIPAL WASTE DISCHARGES WITHIN THE FOX RIVER WATERSHED: 1966

Sources Of Wastes	Type Of Treatment	Average Daily Discharge (cfs)	Population Served	Treatment Facility Loading Five-Day BOD (Pounds Per Day)[a]	Percent Removal Of BOD By Treatment[b]	Average Five-Day BOD Discharged After Treatment (Pounds Per Day)
Village of Sussex Sewage Treatment Plant	Trickling Filter	0.30[c]	1,400[c]	238	80	48
City of Brookfield Sewage Treatment Plant	Activated Sludge	0.50[c]	2,200[c]	374	78[d]	82
Village of Pewaukee Sewage Treatment Plant	Trickling Filter	0.50[c]	2,900[c]	493	80	99
City of Waukesha Sewage Treatment Plant	Trickling Filter	11.60[d]	37,500[d]	11,800[d]	85[d]	1,770
Village of Mukwonago Sewage Treatment Plant	Trickling Filter	0.30[c]	1,900[c]	323	80	65
Village of Waterford Sewage Treatment Plant	Primary	0.30[c]	1,600[c]	272	25	204
Village of East Troy Sewage Treatment Plant	Trickling Filter	0.30[c]	1,500[c]	255	80	51
City of Lake Geneva Sewage Treatment Plant	Trickling Filter	0.80[c]	4,500[c]	765	80	153
City of Burlington Sewage Treatment Plant	Trickling Filter	1.70[c]	6,200[c]	1,050	80	210
Village of Twin Lakes Sewage Treatment Plant	Trickling Filter	0.28[d]	3,100[c]	527	80	105
Village of Genoa City Sewage Treatment Plant	Trickling Filter	0.15[e]	1,050[e]	178	80	36
Village of Silver Lake Sewage Treatment Plant	Extended Aeration	0.03	200	34	80	7

[a] *Based on 0.17 pound five-day BOD per capita per day, unless otherwise noted.*

[b] *Eighty percent for trickling filter and 25 percent for primary treatment only, unless otherwise noted.*

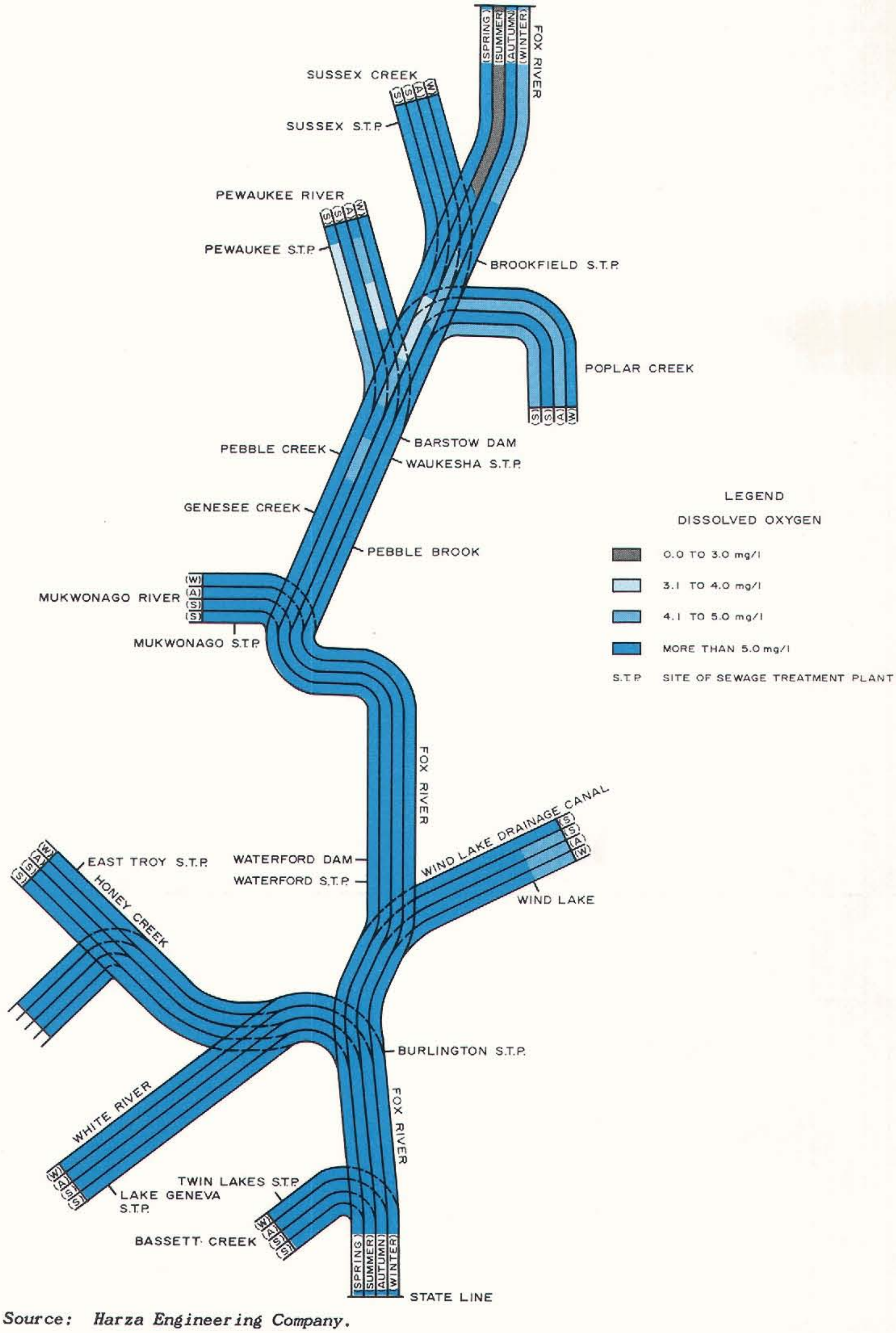
[c] *Information published in SEWRPC Technical Report No. 4, Water Quality and Flow of Streams in Southeastern Wisconsin, 1966.*

[d] *Based upon information contained in monthly sewage treatment plant operator's reports for 1966.*

[e] *Information published in SEWRPC Planning Report No. 6, The Public Utilities of Southeastern Wisconsin, 1963.*

Source: Harza Engineering Company and SEWRPC.

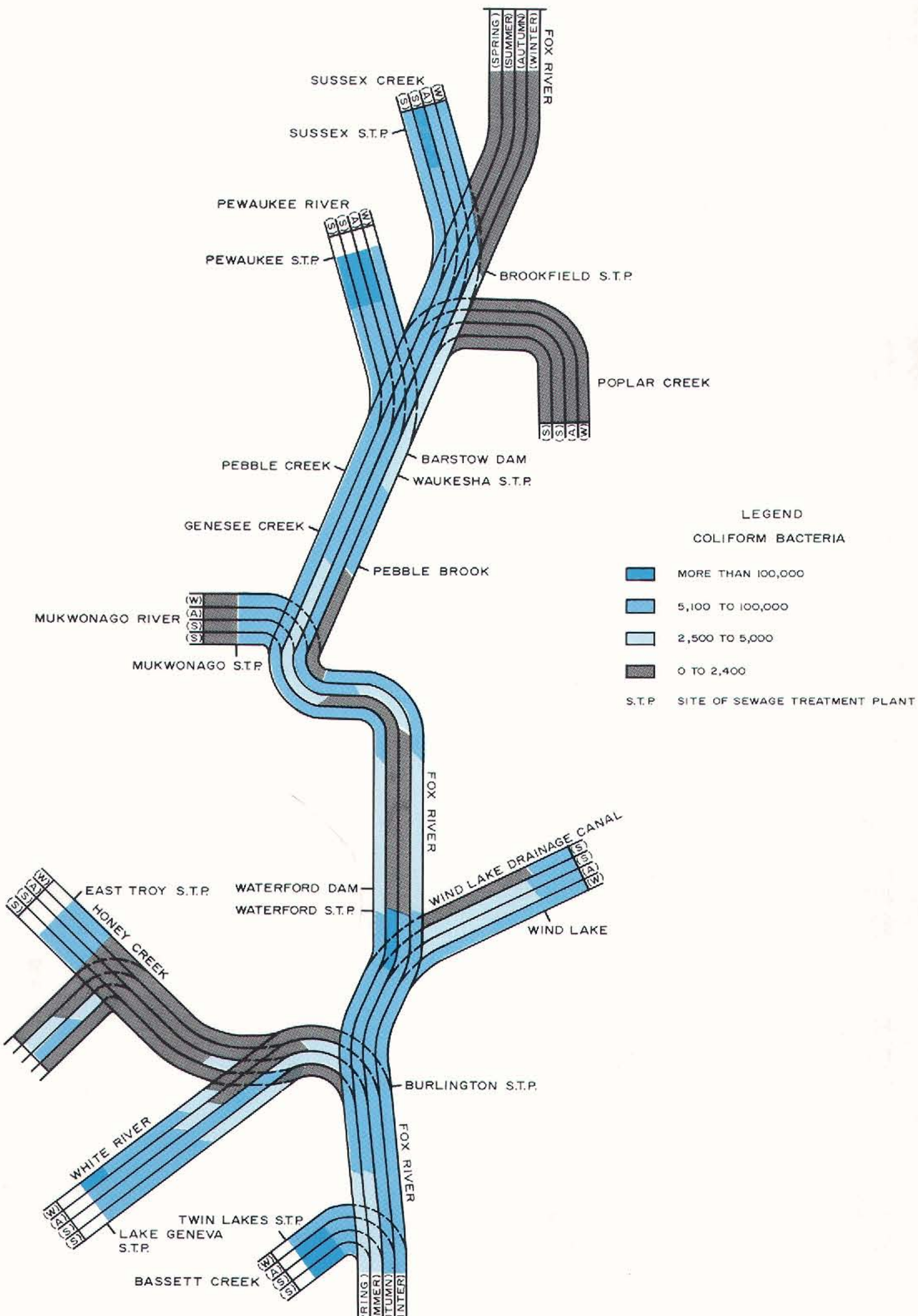
Figure 84
EXISTING SEASONAL VARIATION OF DISSOLVED OXYGEN IN THE FOX RIVER SYSTEM (1964 - 1966)



Source: Harza Engineering Company.

Figure 85

EXISTING SEASONAL VARIATION OF COLIFORM BACTERIA IN THE FOX RIVER SYSTEM (1964-1966)



Source: Harza Engineering Company.

waste sources are shown on Map 41; and information on the origin and type of these wastes, the type of treatment provided, and the receiving watercourses are listed in Table 52. Very little information is available, however, on the quantity or quality of the wastes discharged. The Wisconsin Department of Natural Resources, during the summer of 1966, sampled the quality of the stream waters above and below each industrial waste outfall. The resulting stream water quality data indicate that most industrial waste discharges in the basin have relatively little adverse effect on water quality conditions. This implies that either the quality of the effluent is good or the quantity is small in relation to the total streamflow.

There are, however, a few industrial waste discharges that do adversely affect local water quality conditions. Residents below the Mammoth Springs Canning Company on Sussex Creek have complained of occasional highly colored water and foul odors in the stream. Attempts are being made to remedy this condition through the installation of experimental aeration equipment in lagoons constructed for the treatment of wastes from plant operations. Further disposal of the effluent is provided through land irrigation. The lagooning of the wastes should also reduce the high coliform counts now present in the effluent. Samples of wastes from the Oconomowoc Electroplating Company in the City of Waukesha indicate high concentrations of cyanide, a substance extremely poisonous to humans and fish. Samples taken 0.3 mile below the outfall, however, indicated that the concentration had been reduced to safe levels. Thus, the pollution from this waste is limited to the vicinity of the outfall.

The Borden Food Company plant, located on the Fox River in the City of Waukesha, discharges boiler water at a temperature of approximately 140°F to the river. The quantity discharged, however, is relatively small and raises the tempera-

Table 52

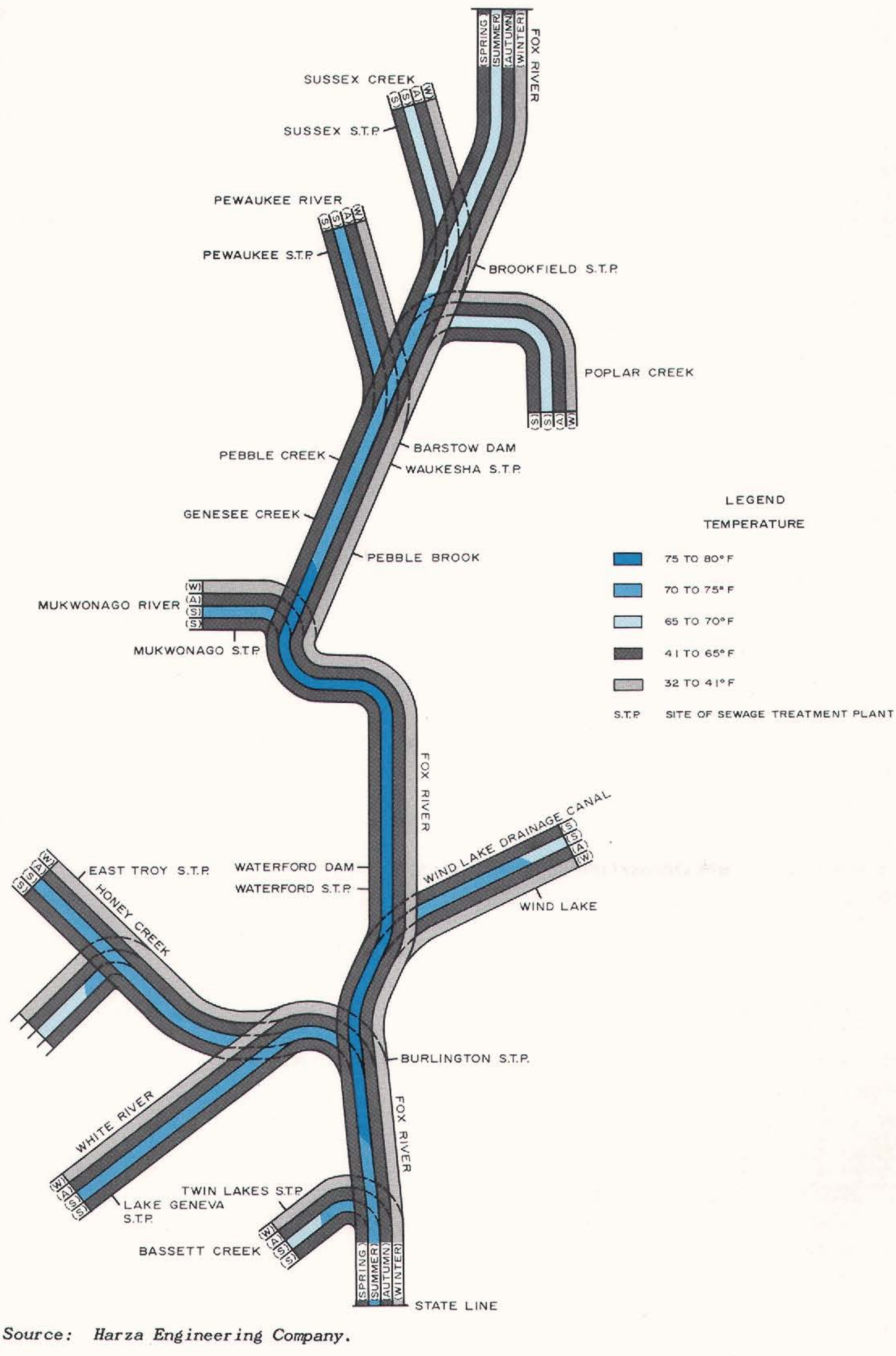
MAJOR INDUSTRIAL WASTE DISCHARGES WITHIN THE FOX RIVER WATERSHED: 1966

Source Of Waste	Type Of Waste	Type Of Treatment	Discharge
1 Mammoth Spring Canning Corporation	Canning	Lagoon	Land-Irrigation
2 Halquist Lannon Stone Company	Quarry	Settling	Sussex Creek
3 Payne and Dolan of Wisconsin, Inc.	Wash Water	Settling	Fox River
4 Oconomowoc Electroplating Company	Plating	None	Frame Park Tributary
5 Waukesha Foundry Company	Cooling	None	Frame Park Tributary
6 Butler Bin Company	Manufacturing	Settling	Frame Park Tributary
7 Alloy Products Corporation	Manufacturing	Seepage	Pits
8 International Harvester Company	Manufacturing	Settling	Frame Park Tributary
9 General Casting Corporation	Cooling	None	Fox River
10 Borden Food Company	Cooling	None	Fox River
11 Waukesha Motor Company	Cooling and Oil	Oil Separation	Fox River
12 Keystone Farms	Milk	Seepage	Lagoon
13 Brookhill Farms	Farm Drainage	None	Genesee Creek
14 Pleasant Valley Farm	Farm Drainage	None	Genesee Creek
15 Pure Milk Association	Milk	Seepage	Lagoon and Marsh
16 Baker Laboratories, Inc.	Cooling	None	Honey Creek
17 Trent Tube Company	Manufacturing	Lagoon	Honey Creek
18 Genoa City Co-op Milk Association	Milk	Secondary	Nippersink Creek
19 Pasier Products Company	Canning	Seepage	Lagoon

Source: "Report on an Investigation of the Pollution in the Fox (Illinois) River Drainage Basin Made During 1966 and 1967," Wisconsin Department of Natural Resources, Division of Resource Development, Madison, Wisconsin.

Figure 86

EXISTING SEASONAL VARIATION OF WATER TEMPERATURE IN THE FOX RIVER SYSTEM (1964 - 1966)



Source: Harza Engineering Company.

ture of the Fox River below the outfall only 1 to 2 Fahrenheit degrees during the summer months. Under low-flow fall or winter conditions, however, the discharge is sufficient to raise stream temperatures 8 to 10 Fahrenheit degrees. High coliform counts, generally in excess of 500,000 MFCC/100 ml, are present in the effluents from the Pleasant Valley Farm outfall on Genesee Creek and the Pure Milk Association lagoon outfall on a tributary to Eagle Lake. Both effluents significantly increase the coliform concentration in the streams below the outfalls.

Two samples of the effluent from a pond outfall at Trent Tube Company in East Troy indicated concentrations of 2.0 and 23.0 mg/l of iron. Stream samples taken on the same day as the second effluent measurement indicated iron concentrations of 0.7 and 9.1 mg/l above and below the outfall, respectively. This high iron content below the outfall is much greater than the maximum concentrations recommended for most uses. These high iron concentrations probably persist for only a short distance below the outfall, however, since iron in well-aerated surface waters tends to form a precipitate which settles to the bottom.

Although all the above industrial waste discharges affect stream water quality, they most seriously degrade the water quality only in the immediate vicinity of the outfall. At present, therefore, it may be concluded that industrial waste sources represent a relatively minor contribution to the water quality deterioration in the Fox River and its tributaries.

Resorts: Numerous resorts exist in the Fox River watershed, which are operated for summer and, in a few cases, for winter recreational purposes. Some of these resorts are located within urban areas of the watershed; are served by public sanitary sewerage systems; and, therefore, do not constitute independent waste discharges or sources of pollution. Most of the resorts are relatively small establishments, which dispose of liquid wastes by septic tank sewage disposal systems. These small resorts generally do not generate wastes in sufficient quantity to be of regional significance, although localized health hazards and pollution considerations may be involved should overflow or drainage from the septic tank system occur. The impact of septic tank sewage disposal systems on stream and lake quality within the watershed is treated separately in a subsequent section of this chapter.

There are, however, at least four resorts within the watershed which are of sufficient size to produce liquid waste discharges in regionally significant amounts. The location of these four resorts is shown on Map 41; and the type of sewage treatment utilized, the design discharge capacity, and the receiving watercourses are listed in Table 53. Two of these resorts, the Lake Geneva Playboy Club International and the Rainbow Springs Convention Center, are presently under construction; and, consequently, the supporting sewage treatment facilities are not as yet in operation. These two resorts, while not a present source of pollution, are listed as future waste discharges and potential future sources of pollution.

Agricultural Sources: Drainage and runoff from 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 and commercial fertilizers on frozen soils may result in large amounts of nutrients being carried to streams and lakes during the spring runoff. In excessive amounts these elements promote nuisance growths of algae and other aquatic plants in receiving streams and lakes. Such luxuriant growths often render the water unsuitable for many uses. Pesticides in runoff from agricultural, forest, and urban lands, even in minute amounts, can through accumulative effects endanger fish and wildlife and 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 certain uses.

While excessive amounts of any or all 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 that will eliminate most of these potential pollutants from the drainage and runoff. Stream quality data for the Fox River watershed indicate that agricultural drainage and runoff generally constitute a relatively minor

Table 53

MAJOR RESORT WASTE DISCHARGES WITHIN THE FOX RIVER WATERSHED: 1967

Source Of Waste	Type Of Treatment	cfs	Receiving Watercourse
Oakton Manor Lodge	Activated Sludge and Lagoon	0.056	Zion Creek (Tributary to Pewaukee Lake)
Rainbow Springs Convention Center (Under Construction)	Package-Type Activated Sludge	0.248	Tributary of Mukwonago River
Lake Geneva Playboy Club International (Under Construction)	Package-Type Activated Sludge, Post-Chlorination and Lagoon	0.128	White River
Alpine Valley Lodge	Package-Type Activated Sludge and Seepage Pit	0.062	Sugar Creek[a]

[a] *In the past sewage treatment consisted of a septic tank system, which, when over-loaded, would result in overflow to Sugar Creek. The present sewage treatment system, however, includes a seepage pit designed to percolate the effluent without surface discharge to Sugar Creek.*

Source: The Wisconsin Department of Natural Resources and SEWRPC.

source of stream pollution in the basin when compared to the pollution caused by municipal waste discharges.

Urban Runoff: Storm water runoff and combined sewer overflow in urban areas can constitute significant sources of water pollution. Recent investigations by the U. S. Public Health Service of the quality of storm water runoff from a residential area in Cincinnati indicate high concentrations of BOD, suspended solids, and nutrients, together with coliform counts varying from 3,000 to 460,000 MFCC/100 ml.[5] These findings are supported by other studies made in the United States, England, Russia, Sweden, and South Africa. The overflow from combined sewers, being a mixture of storm water runoff and raw sanitary sewage, is generally of a poorer quality than the storm water discharge through a separate storm sewer system. Although urban storm water runoff and combined sewer overflow are generally of poor quality, pollution from these sources is usually concentrated in a relatively short period of time; and its adverse effects are usually balanced by the large amounts of water available for dilution as a result of increased streamflow during storms.

[5] *Anderson, Weibel, Woodward, ''Urban Land Runoff as a Factor in Stream Pollution,'' Journal of the Water Pollution Control Federation, Vol. 36, No. 7, July 1964.*

Since the proportion of the total watershed area occupied by urban land uses is small, the contribution of urban storm runoff to total runoff in the Fox River watershed is relatively small. No combined sewerage systems are known to exist within the watershed. Therefore, it may be concluded that the effects of urban storm runoff and combined sewer overflow on stream water quality in the Fox River watershed are not at this time significant, relative to the major waste sources, particularly the municipal sewage treatment plants.

Septic Tanks: Of the 60.8 square miles of area developed for urban use in the Fox River watershed, 19.6 square miles, or about 32 percent, were served by public sanitary sewerage facilities in 1963. About 62,000 persons, or 41 percent of the total watershed population, resided within areas served by public sanitary sewerage systems. The remaining 41.16 square miles of developed urban area within the watershed and all of the rural area, containing a combined population of almost 100,000 persons, are not served by public sanitary sewerage facilities and rely mainly on individual septic tank soil absorption systems for disposal of domestic wastes. These systems will serve a home satisfactorily if they are properly located, designed, constructed, and maintained. If any of these aspects are neglected, however, liquid wastes may overflow to the ground surface. Foul odors, unsightly conditions, and health hazards will develop if these overflows are ponded on the surface or carried away in open ditches. The ponded wastes also provide excellent breeding places for mosquitoes and other insects.

Final disposal of the septic tank effluent in a suitable subsurface soil absorption system is necessary to the proper functioning of the system. Approximately 56.3 percent of the Fox River watershed is covered by soils having severe limitations for small lot residential development with soil absorption sewage disposal systems (see Map 18). Some urban development has already occurred in these areas. Some areas of the basin, particularly certain large residential subdivisions, have already experienced problems resulting from faulty soil disposal systems; and many more areas are likely to experience these problems if the soil absorption method is relied upon for sewage disposal in areas covered by soils having severe limitations for such disposal. Although faulty soil absorption systems generally do not contribute large amounts of pollutants to streams in the watershed, they do have very significant effects on local conditions in terms of nuisances and health hazards and may be a significant source of coliform contamination of many of the lakes in the watershed.

STREAM QUALITY FORECASTING METHODOLOGY

Existing water quality problems in the streams of the watershed were identified as a part of the Fox River watershed study on the basis of existing water uses and present stream water quality levels, the latter being determined from the stream sampling program carried out by the Commission. These existing water quality problems are described in the following section of this chapter. In order to identify future problems, however, it was necessary to forecast future stream water quality conditions in the absence of a water quality management plan and its implementation. This has been accomplished through application of the water quality simulation model described in Chapter VIII. All references in the following sections of this chapter to future water quality conditions refer to the conditions that may be expected to exist by the year 1990 if each of the sewage treatment plants listed in Table 54 is providing secondary treatment for the 1990 forecast sewage flows. Thus, the forecast of future water quality conditions represents the probable level of water quality which may be expected if the present policy of providing secondary treatment at each plant is continued in the future. Information relative to the probable population to be served by sewage treatment plants by the year 1990 and the locations of these plants have been obtained from SEWRPC Technical Report No. 4, Water Quality and Flow of Streams in Southeastern Wisconsin.[6]

The forecast stream quality conditions presented herein are approximations and, while believed to be realistic, are predicated upon certain assumptions. Most importantly, the forecasts are based upon the assumption that the adopted regional land use plan will be implemented and that the future land use pattern within the watershed will approximate the pattern recommended in that plan. The forecasts are based on the further assumption that essentially the present sewage treatment and disposal techniques and practices will be in use through 1990 and 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 some reason to anticipate future improvement in effluent quality, the rate at which improved 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. Finally, it should be noted that the study on which the forecasts are based was made during a period in which precipitation and streamflow were generally below normal. Assuming that normal discharges of polluting wastes occurred during this same period, the measured conditions of stream quality may be somewhat lower than might be encountered during a period of more normal precipitation and streamflow. The forecast is, therefore, believed to reflect properly stream quality conditions of most concern for planning purposes.

It is believed that by 1990 all the sewage treatment plants in the watershed will be providing secondary treatment and disinfection, even in the absence of any water quality management plan. An efficiently operated secondary treatment plant

[6] *The sewage treatment plant referred to in SEWRPC Technical Report No. 4 as serving the Muskego area was excluded from consideration since the Metropolitan Sewerage Commission of the County of Milwaukee is proposing to extend sewerage service to the Muskego area, thus eliminating the need for a treatment plant there and resulting in the export of the tributary waste flows from the watershed.*

may be expected to remove about 85 percent of the BOD of the raw sewage. Thus, for 1990 conditions the amount of BOD discharge from each sewage treatment plant was taken as 15 percent of the BOD of the raw sewage. Table 54 indicates both the existing and the 1990 plant efficiencies and BOD discharges. Forecasts of stream water quality for 1990 were made using the 1990 sewage treatment plant discharges in the water quality model. These forecasts were made for the critical conditions of low streamflow and high temperature and were utilized to identify the nature and extent of future stream water quality problems.

The state adopted water quality standards, discussed earlier in this chapter, establish the general level of water quality that should be maintained within each stream reach if the water in that reach is to be suitable for a specified use. The limiting values of various parameters set forth in these standards are based on the best available scientific knowledge of the relationships between the specified parameters and the various water uses. A degree of uncertainty exists, however, in determining the actual effects of varying concentrations of certain substances on water uses. Since the levels of many parameters may vary from hour to hour and from day to day, depending on the many factors affecting stream water quality, the values set forth in the water quality standards should not be interpreted as absolute limits but rather as indicators of the approximate concentrations at which the specified water use begins to be adversely affected by water quality.

OVERALL WATERSHED STREAM WATER QUALITY

Stream water quality conditions vary seasonally. The seasonal variation in existing and forecast stream water quality conditions in the Fox River watershed are illustrated graphically in Figures 84 through 86. This seasonal variation is primarily the result of variations in the quantity of streamflow and in the temperature of the stream water. Since most pollutants are discharged to

Table 54

EXISTING AND FUTURE MAJOR MUNICIPAL WASTE DISCHARGES WITHIN THE FOX RIVER WATERSHED: 1966 AND 1990

Source	Connected Population		Average Daily Discharge (cfs)		BOD Loading[a] (Pounds Per Day)		BOD Removal[b] Percent		BOD Discharged[a] (Pounds Per Day)	
	Existing	1990	Existing	1990	Existing	1990	Existing	1990	Existing	1990
Lannon Sewage Treatment Plant	0	18,600	0.00	5.20	0	4,650	--	85	0	700
Sussex Sewage Treatment Plant	1,400	8,800	0.30	2.50	238	2,200	80	85	48	330
Brookfield Sewage Treatment Plant	2,200	27,800	0.50	7.70	374	6,950	78	85	82	1,040
Poplar Creek Sewage Treatment Plant	0	37,000	0.00	10.30	0	9,250	--	85	0	1,390
Pewaukee Sewage Treatment Plant	2,900	6,400	0.50	1.80	493	1,600	80	85	99	240
Waukesha Sewage Treatment Plant	37,500	82,100	11.60	28.60	11,800	31,300	85	85	1,770	4,700
Mukwonago Sewage Treatment Plant	1,900	6,800	0.30	1.90	323	1,700	80	85	65	255
Waterford Sewage Treatment Plant	1,600	5,800	0.30	1.60	272	1,450	25	85	204	220
East Troy Sewage Treatment Plant	1,500	3,600	0.30	1.11	255	900	80	85	51	135
Lake Geneva Sewage Treatment Plant	4,500	11,000	0.80	4.35	765	2,750	80	85	153	410
Burlington Sewage Treatment Plant	6,200	14,200	1.70	3.90	1,050	3,550	80	85	210	530
Silver Lake Sewage Treatment Plant	200	1,000	0.03	0.20	34	250	80	85	7	40
Twin Lakes Sewage Treatment Plant	3,100	4,900	0.28	0.90	527	1,220	80	85	105	185
Genoa City Sewage Treatment Plant	1,050	1,700	0.15	0.43	178	425	80	85	36	65

[a] *Five-day, 20°C BOD.*

[b] *Eighty-five percent BOD removal assumes adequate secondary treatment facilities for all sewage treatment plants within the watershed by 1990.*

Source: Harza Engineering Company and SEWRPC.

streams at a relatively constant rate, high streamflows generally provide greater dilution and better stream water quality than do low streamflows. The dissolved oxygen content of stream water is affected by temperature since the maximum amount of free oxygen that can be retained by a body of water under saturated conditions decreases as the temperature increases. Thus, low dissolved oxygen concentrations usually may be expected to occur in the summer season during times of high temperatures and low streamflows; and the most severely polluted conditions will normally occur during the summer months. Figure 84 indicates the effect of the Brookfield and Waukesha sewage treatment plants on average summer dissolved oxygen concentrations in the Fox River and of the Pewaukee sewage treatment plant on summer dissolved oxygen concentrations in the Pewaukee River. The figure also indicates the low dissolved oxygen content in the Fox River above Sussex Creek. This is believed to be a result of drainage from the Tamarac Swamp east of Lannon.

Of greater importance, however, than the average summer dissolved oxygen concentrations are the minimum concentrations, which are critical for the preservation of fish and other desirable forms of aquatic life. Table 55 indicates the minimum dissolved oxygen concentrations that have been recorded during the summer season at various

Table 55

MINIMUM DISSOLVED OXYGEN CONCENTRATIONS IN THE FOX RIVER SYSTEM: 1960-1967

Location	Minimum Dissolved Oxygen Exclusive Of July 29, 1964		Dissolved Oxygen July 29, 1964
	(mg/l)	(Date)	(mg/l)
Fox River			
Above Sussex Creek	1.4	6-26-64	1.6
Below Brookfield Sewage Treatment Plant	0.9	9-1-65	0.0
Above Waukesha Sewage Treatment Plant	3.4[a]	8-19-64	0.0
Below Waukesha Sewage Treatment Plant (1 mile)	0.4[a]	8-19-64	0.2
Below Waukesha Sewage Treatment Plant (3.5 miles)	2.4[a]	8-19-64	0.5
Below Waukesha Sewage Treatment Plant (8.2 miles)	4.3[a]	8-19-64	1.0
Above Mukwonago River	4.5	6-30-66	0.4
Below Mukwonago River	5.8	7-18-60, 9-15-60	0.8
At Waterford Impoundment	4.6[a]	6-07-67	3.0
Above Burlington	5.0	8-16-63	11.3
Below Burlington Sewage Treatment Plant	5.6	8-16-63	6.7
At Wilmot	5.8	7-19-60	12.9
Sussex Creek Below Sussex Sewage Treatment Plant	4.4	8-15-63	5.7
Pewaukee River Below Pewaukee Sewage Treatment Plant	0.2	6-21-66	4.3
Mukwonago River Above Sewage Treatment Plant	8.3	7-18-60	9.3
Honey Creek			
Below East Troy Sewage Treatment Plant	5.0	8-18-66	5.5
Above Echo Lake	4.7	7-21-67	5.4
Sugar Creek	8.5	6-26-64	8.9
White River			
Below Lake Geneva Sewage Treatment Plant	6.6	7-20-62	5.9
Above Echo Lake	5.6	6-26-64	5.7

[a]*Indicates low point when measurements were made of the diurnal DO variation. All other values are taken from measurements made only once during the day, generally between midmorning and midafternoon.*

Source: Wisconsin Department of Natural Resources and SEWRPC.

locations in the Fox River watershed over the eight-year period from 1960 to 1967, excluding the values measured on July 29, 1964. Table 55 indicates that minimum oxygen levels under normal conditions are generally below 3.0 mg/l in the Fox River upstream from Sussex Creek to about five miles downstream from Waukesha and generally above 5.0 mg/l from Mukwonago to the state line.

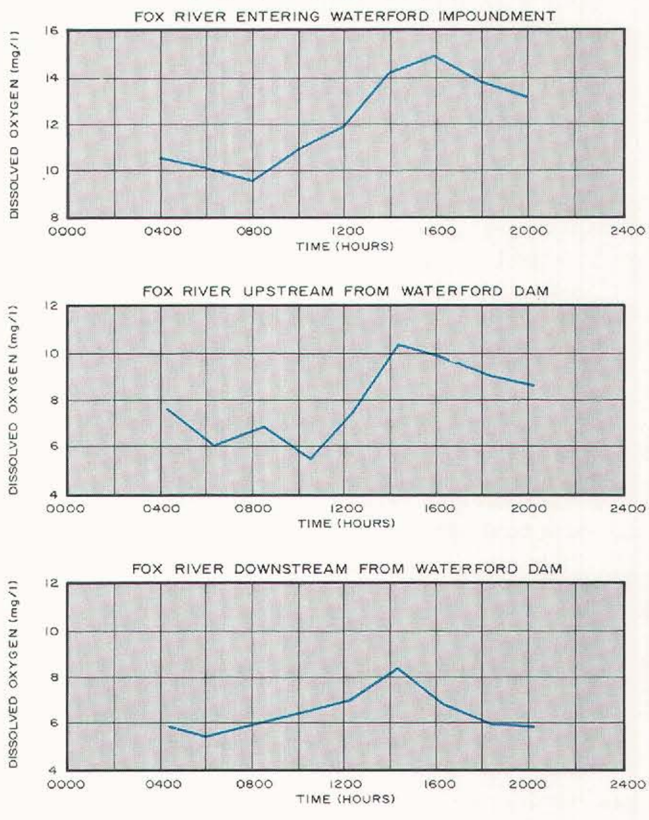
The dissolved oxygen profile measured on July 29, 1964, is shown separately in Table 55 since it indicates very unusual and adverse quality conditions in the Fox River system. On July 29, 1964, routine sampling was carried out on the Fox River system as part of the SEWRPC regional stream quality study. Dissolved oxygen levels averaged less than 1.0 mg/l over the entire length of the Fox River above the Waterford impoundment. It appears that this extremely adverse quality condition was the result of a total rainfall in excess of five inches over the two-week period preceding the sampling date. This heavy precipitation flushed large quantities of vegetal material from swampy areas in the upper reaches of the watershed, particularly the Tamarac Swamp, areas drained by Poplar Creek, and the Vernon Marsh. This heavy vegetal loading, together with heavy urban and agricultural runoff, septic tank overflow, scouring of sludge deposits from the stream bed, and temporary adverse effects on the operation of sewage treatment plants, is believed to have caused the critically low levels of dissolved oxygen in the upper half of the watershed. Since the heavy rainfall and exceptionally low dissolved oxygen levels were a very unusual occurrence, the data for July 29, 1964, have been omitted in determining the average summer DO values shown in Figure 84.

In addition to the variations in dissolved oxygen concentration resulting from changes in temperature and streamflow, there is a daily cycle in dissolved oxygen concentrations caused by algae and other aquatic plants. Figure 87 shows this diurnal cycle, as measured by the Commission on July 26, 1967, at three locations along the Fox River. Algae produce oxygen during the hours of intensive sunlight, with the result that the dissolved oxygen concentration rises during the day, reaching a peak in midafternoon. During the nighttime hours, algae consume oxygen, thereby causing a decline in dissolved oxygen levels that normally reaches a low point shortly after sunrise. The magnitude of this daily fluctuation depends upon the number of algae present and the intensity of sunlight reaching the algae. Since there are significant numbers of algae present throughout much of the Fox River, it is quite probable that this diurnal variation of dissolved oxygen is also present throughout much of the river.

With the exception of Poplar Creek, the Mukwonago River above the Mukwonago sewage treatment plant, and the Fox River above Sussex Creek, coliform counts in the Fox River and its tributaries above the Waterford impoundment, as shown in Figure 85, are generally in excess of 5,000 MFCC/100 ml, the maximum level recommended for recreational uses (see Table 50). During the summer season, however, natural purification reduces the coliform level below 5,000 MFCC/100 ml in the Fox River near Mukwonago. Figure 85 also indicates that coliform counts are less than 5,000 MFCC/100 ml through the Waterford impoundment, but effluent from the Waterford and Burlington sewage treatment plants maintains the count over 5,000 MFCC/100 ml from Waterford to the state line. Only in spring and summer is dilution and natural purification sufficient to reduce

Figure 87

DIURNAL DISSOLVED OXYGEN VARIATIONS AT SELECTED POINTS ALONG THE FOX RIVER DURING JULY 26, 1967



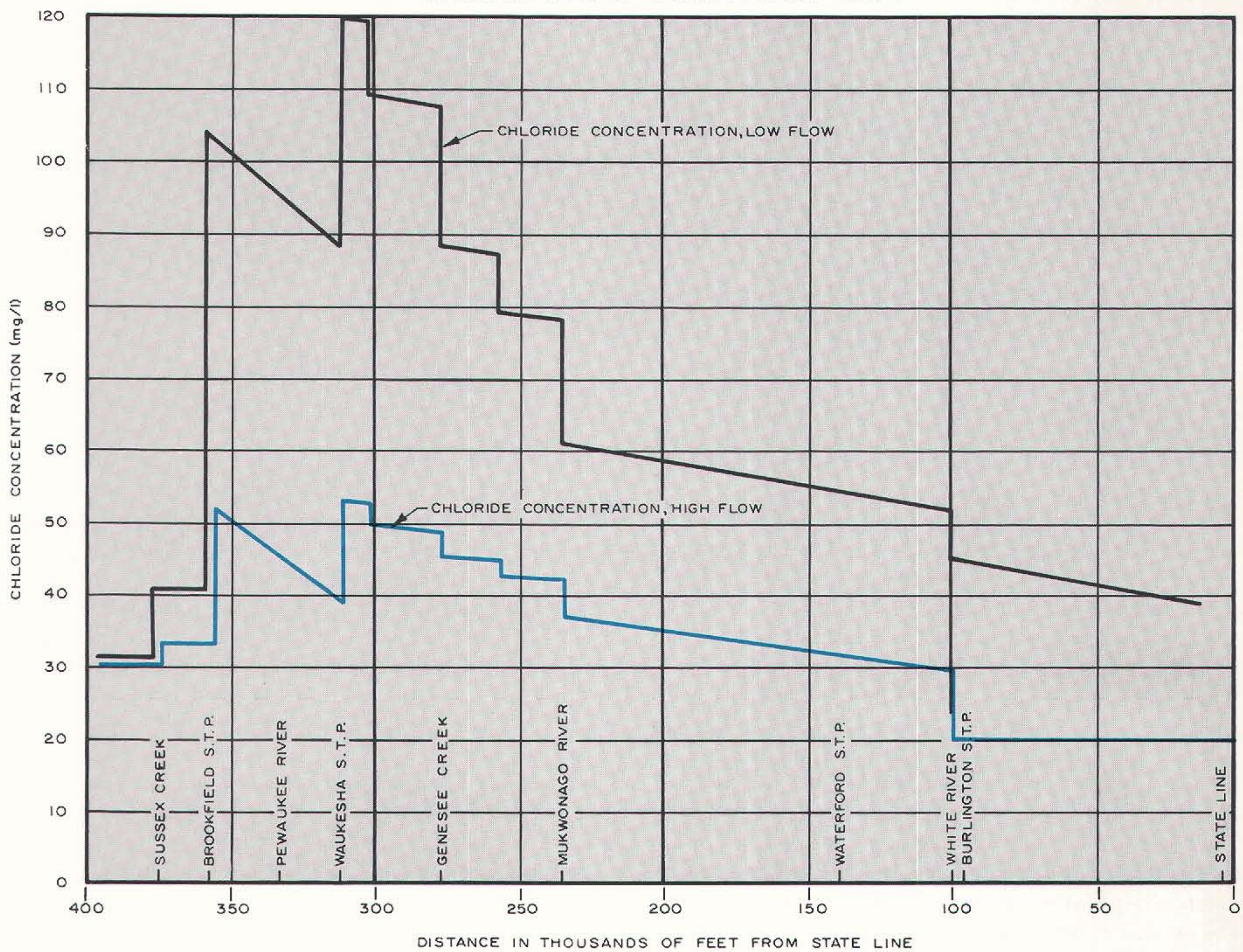
Source: SEWRPC.

the number of coliform organisms to less than 5,000 MFCC/100 ml at the state line. Figure 85 also indicates the effect of the sewage treatment plants on Honey Creek, White River, and Bassett Creek.

Temperature in the Fox River and its tributaries, as shown in Figure 86, varies from an average winter range of 32° to 42°F to an average summer range of 70° to 80°F. Maximum temperatures recorded from 1960 to 1967 range from 82° to 87°F, with the highest temperatures being recorded in the impoundment at Waterford. In general, these temperatures would not preclude any normal uses of the Fox River or its tributaries.

Figure 88 presents the average chloride ion concentrations throughout the Fox River during the periods of high streamflow in spring (bottom curve) and low streamflow in fall (top curve). The effects of treated sewage discharges from the plants at Brookfield and Waukesha on the chloride content in the river are evident from these profiles. The chloride concentrations normally experienced in the Fox River are not detrimental to any present uses of the river but do indicate the effects of human activities on water quality in the river. As already noted, natural chloride concentrations, in the absence of any human influence, would be on the order of 10 mg/l throughout the river system.

Figure 88
PROFILES OF CHLORIDE CONCENTRATIONS ALONG THE FOX RIVER UNDER HIGH AND LOW STREAM FLOW CONDITIONS-1964



Source: SEWRPC.

Biological investigations conducted by the State Department of Natural Resources during the summer of 1966 revealed polluted conditions existing below the Pewaukee, Waukesha, and Burlington sewage treatment plants and throughout the Frame Park tributary of the Fox River, as evidenced by the absence of clean-water organisms, the presence of large numbers of pollution-tolerant organisms, and the accumulation of sludge deposits below the outfalls. Recovery to a normal clean-water biotic community occurred about 20 miles below the Waukesha sewage treatment plant outfall. The absence of any intolerant organisms and the presence of large numbers of tolerant organisms were noted along the Frame Park tributary below the Waukesha Foundry, below the Alloy Products Corporation, and below the International Harvester Company. Other stream reaches that were identified as containing some pollution, as evidenced by the presence of small numbers of clean-water organisms but large numbers of pollution-tolerant organisms, included the Fox River through Waukesha, Muskego Creek downstream from a tile outfall discharging drainage from septic tanks in the City of Muskego, Eagle Lake Creek below the Pure Milk Association in Kansasville, and Honey Creek below the Trent Tube Company in East Troy. Biological investigations throughout the remainder of the streams in the Fox River watershed revealed generally balanced biotic communities with little or no effects from upstream waste discharges.

Quality Characteristics of Individual Stream Reaches

Fox River—Headwater to Waukesha Dam: Existing water uses in the reach of the Fox River from its headwaters to the Waukesha Dam include livestock and wildlife watering, maintenance of a warm-water fishery, partial-body-contact recreation, waste assimilation, and aesthetic uses. State-established water use objectives include all the existing uses plus industrial and cooling water supply.

Existing water quality in this reach, however, is suitable only for livestock and wildlife watering and waste assimilation. Minimum DO levels of less than 2.0 mg/l and average summer levels of less than 4.0 mg/l in various sections of this reach inhibit the maintenance of a warm-water fishery. Coliform concentrations well in excess of 5,000 MFCC/100 ml render the water unsuitable for any type of recreational activities. In addition, luxuriant growths of aquatic plants frequently cover the surface of the stream, particularly in the impoundment above the Barstow Street Dam in Waukesha and in other sluggish reaches of the stream. The dense green mats formed by these aquatic plants and the odor of the decaying plants often preclude aesthetic enjoyment of the stream.

Waste discharges in this reach include the sewage treatment plants at Brookfield, Sussex, and Pewaukee. These three plants served a combined population in 1963 of about 6,500 persons and discharged treated effluent at an average total rate of 1.3 cfs. Even though the sewage receives secondary treatment at these plants, there is little water available for dilution since natural streamflow is low in this reach. The waste discharges from these three sewage treatment plants are the main cause of low oxygen levels and high coliform concentrations in this reach of the Fox River, and the discharges also contribute nutrients that stimulate the growth of weeds and algae.

Future water quality conditions in this reach may be expected to be unsuitable for all uses of the stream except waste assimilation. The sewage treatment plants at Brookfield, Sussex, and Pewaukee, together with new plants proposed to serve the Lannon and Poplar Creek areas, may be expected to serve a population of almost 100,000 persons by 1990. The average volume of wastes discharged from these plants by 1990 may be expected to reach an average daily flow of 27.5 cfs, or over 20 times the volume discharged in 1963 to the stream. If continued reliance for sewage treatment at these plants is placed on secondary facilities, the total amounts of organic matter and nutrients discharged to the stream by 1990 may also be expected to reach about 20 times the amounts discharged at present. Throughout this period of rapidly increasing waste loading, however, the natural streamflow available for diluting the wastes will remain essentially the same as it is at present. These increased waste loads may be expected to lower oxygen levels to below 2.0 mg/l during low-flow summer conditions over the entire reach of the Fox River from Lannon to the upstream end of the impoundment at Waukesha. Anaerobic conditions may develop in some sections of the stream, particularly below the Brookfield and Poplar Creek sewage treatment plants. These low oxygen levels will preclude the maintenance of a warm-water fishery; and the septic conditions that may be expected to develop, with associated offensive odors, will prevent use of some reaches of the stream for anything other than waste assimilation. Approximately 90 percent of the low flow of the Fox River at Waukesha may be expected to consist of sewage treatment plant effluent by 1990. The impoundment at Waukesha will function essentially as a large oxidation pond, receiving wastes from the upstream areas. The large additions of nutrients to the river from the sewage treatment plants will stimulate weed and algae growth throughout much of the river, and it is to be expected that the impoundment at Waukesha will be alternately covered with dense mats of aquatic plants or filled with decaying weeds and algae.

If adequate disinfection of all sewage treatment plant effluent is provided in the future, coliform concentrations in this reach of the river would normally be low enough to permit some recreational activities. However, the nuisances resulting from septic conditions and heavy algae growths will preclude any use of this reach of the river for recreation.

In order to improve water quality in the Fox River from its headwaters to the Waukesha Dam to a level that is suitable for all existing and state-established future use objectives, it will be necessary to remove or dilute much of the organic waste present in the stream, to maintain oxygen levels above 5.0 mg/l, to reduce coliform concentrations to below 5,000 MFCC/100 ml, and to eliminate the occurrence of nuisance growths of algae.

Fox River—Waukesha Dam to Waterford Dam: Existing water uses in the reach of the Fox River from Waukesha to Waterford include livestock and wildlife watering, maintenance of a warm-water fishery, partial- and whole-body-contact recreation, waste assimilation, and aesthetic uses. State-established water use objectives include all of the existing uses plus irrigation and industrial and cooling water supply within this river reach except for the stream reach extending for a distance of five miles below the Waukesha sewage treatment plant.

Existing water quality conditions in this reach vary from levels unsuitable for most uses below the Waukesha sewage treatment plant to levels suitable for most uses in the impoundment at Waterford. Minimum oxygen levels of less than 1.0 mg/l and average summer levels of less than 4.0 mg/l downstream from the outfall of the sewage treatment plant at Waukesha render the stream unsuitable for the maintenance of a balanced warm-water fishery in that section. Dissolved oxygen levels increase further downstream, however, to average concentrations in excess of 5.0 mg/l and minimum concentrations greater than 4.0 mg/l. Oxygen levels are sufficient to support a warm-water fishery throughout that section of the reach below Genesee Creek.

Coliform counts in excess of 5,000 MFCC/100 ml render the stream unsuitable for any recreational activities from the Waukesha sewage treatment plant to Pebble Brook. Coliform levels from Pebble Brook to the upstream end of the Waterford impoundment are generally between 1,000 and 5,000 MFCC/100 ml during the summer months, indicating that this section of the Fox River is suitable for partial-body-contact recreation during the summer. Higher coliform concentrations during the spring, fall, and winter seasons in this section indicate unsuitable water quality for recreational activities during these seasons. Coliform concentrations in the Waterford impoundment are generally on the order of 1,000 MFCC/100 ml during the summer and fall seasons and between 2,500 and 5,000 MFCC/100 ml during the winter and spring seasons. Thus, the water quality in the impoundment is suitable for partial-body-contact recreation throughout the year but is of questionable quality for whole-body-contact recreation during summer and fall and definitely unsuitable during winter and spring.

Algae and aquatic weeds represent a major problem affecting recreational and aesthetic uses of the stream, particularly in the Waterford impoundment. Nutrients contained in the sewage treatment plan effluent stimulate the growth of aquatic plants and algae, which frequently results in a green scum on the surface of various sections of the impoundment. In addition, extensive slime and algae growths that detract from the aesthetic value of the stream are evident through the City of Waukesha and below the treatment plant outfall. Accumulations of black odorous sludge are present below the Waukesha Motor Company and below the sewage treatment plant.

The major waste discharge to this reach of the Fox River is from the Waukesha sewage treatment plant, which in 1963 served a population of about 37,500 persons and discharged treated effluent at an average rate of 11.6 cfs. A second waste source is the discharge from the Mukwonago sewage treatment plant, which in 1963 served a population of about 2,000 persons and discharged treated effluent at an average rate of 0.3 cfs.

The existing water quality problems in this reach of the Fox River that are related to low oxygen levels are caused primarily by the discharge of treated wastes from the sewage treatment plant at Waukesha. Problems related to high coliform levels are caused by discharges from the Waukesha and Mukwonago sewage treatment plants. Excessive algal growths and related problems are stimulated by nutrients contained in the effluents of the upstream sewage treatment plants and in the industrial discharges. Approximately 50 percent of the present average annual nitrogen contribution and 75 percent of the phosphorus contribution to the Waterford impoundment are from sewage treatment plant effluents discharged upstream from the impoundment.

The sewage treatment plant at Waukesha may be expected to serve a population of over 80,000 persons by 1990; and the plant at Mukwonago, of nearly 7,000 persons. The estimated effluent discharge at Waukesha may be expected to reach an average flow of 28.6 cfs by 1990, or about 2 1/2 times the present waste discharge; and organic matter and nutrient discharges may be expected to increase in about the same proportion. The discharge from the Mukwonago sewage treatment plant may be expected to increase to about 1.9 cfs by 1990, or over 6 times the present discharge, with similar increases in organic matter and nutrient discharges. By 1990 the amount of organic matter discharged to the Fox River in, and upstream from, Waukesha will be equivalent to the raw sewage of a city of over 30,000 persons. At the same time, nutrient discharges to the river will have increased to over 4 times the present discharge

Dissolved oxygen levels during low-flow summer conditions in 1990 may be expected to fall in the range of 3.0 to 5.0 mg/l, with minimum values on the order of 1.0 mg/l, from the Waukesha sewage treatment plant to the Mukwonago River, with the lowest levels generally occurring from 3 to 6 miles below the Waukesha sewage treatment plant outfall. Thus, water quality in this section of the Fox River will not be suitable for the maintenance of a warm-water fishery. Oxygen levels in that section of the river from the Mukwonago River to Waterford will generally be greater than 5.0 mg/l, and water quality will be suitable for the maintenance of a warm-water fishery.

If adequate disinfection of all sewage treatment plant discharges is provided, the 1990 coliform level should be below 1,000 MFCC/100 ml throughout the reach, indicating a water quality suitable for all types of recreational activities. It is to be expected, however, that the large quantities of nutrients being added to the river in the sewage treatment plant effluents will increase the frequency and severity of algal blooms throughout the reach, particularly in the Waterford impoundment and Tichigan Lake. The nuisances associated with these blooms and with increasing amounts of aquatic weeds may restrict recreational and aesthetic uses of this reach of the Fox River.

Water temperatures in this reach do not present any water use problems at present. Since the most heavily industrialized portion of Waukesha is located within the reach, however, there is the possibility that future industrial growth may result in the discharge of high-temperature water to the stream. If this situation should arise in the future, stream temperature could be raised to a level that would adversely affect the balance of aquatic life in the stream. The discharge of high-temperature water should be regulated to maintain a stream temperature suitable for the development of aquatic life.

State-established water use objectives for this reach require water quality levels suitable for all uses except public water supply from the Waterford Dam upstream to five miles below the Waukesha sewage treatment plant. From this point to the sewage treatment plant at Waukesha, water quality levels should meet the standards for industrial and cooling water supply and minimum conditions. Future (1990) water quality levels will generally meet the standards in that section of the reach from the Waukesha treatment plant to five miles downstream, although the probable development of heavy algal growths may violate the standard for minimum conditions. In order to maintain water quality levels suitable for all uses except public water supply in the remainder of this reach, however, it will be necessary to maintain oxygen levels above 5.0 mg/l, to reduce coliform levels to less than 1,000 MFCC/100 ml, and to reduce or eliminate the heavy algal growths.

<u>Fox River Waterford Dam to State Line:</u> Existing water uses in the reach of the Fox River from Waterford to the Wisconsin-Illinois State line include the maintenance of a warm-water fishery, partial- and whole-body-contact recreation, live-

stock and wildlife watering, waste assimilation, and aesthetic uses. State-established water use objectives for this reach of the Fox River include all of the existing uses plus irrigation and industrial and cooling water supply.

Existing water quality conditions throughout this reach are generally suitable for all of the present uses except recreation. The major waste discharges in this reach consist of treated effluent from the sewage treatment plants at Waterford, Burlington, Twin Lakes, and Silver Lake. These plants served a combined population of about 11,000 persons and discharged treated effluent at an average rate of 2.3 cfs in 1963. The waste discharges generally do not lower oxygen concentrations in the river to a level that would adversely affect any of the present uses of the river. Both average and minimum dissolved oxygen concentrations are in excess of 5.0 mg/l throughout the year, indicating the suitability of this reach for the preservation and enhancement of fish and other aquatic life. The discharge of inadequately disinfected effluent from the Waterford, Burlington, and Twin Lakes treatment plants, however, results in high coliform concentrations throughout much of this reach of the river. Coliform bacteria levels are in excess of 5,000 MFCC/100 ml from the Waterford sewage treatment plant to Wheatland during the fall and winter months. The only section of this reach that is suitable for any recreational activity is that section extending from Wheatland to the state line, where coliform levels in the range of 2,500 to 5,000 MFCC/100 ml during the spring and summer indicate a water quality suitable for partial-body-contact recreation. Discharge from the Burlington sewage treatment plant also results in extensive slime growths and accumulations of black odorous sludge along the west side of the Fox River below the plant outfall. Nutrients contained in the waste discharges presently stimulate algae growths throughout this reach of the Fox River.

By 1990 the four sewage treatment plants located within this reach may be expected to serve a combined population in excess of 25,000 persons, and the discharge of treated effluent may be expected to reach an average flow of 6.6 cfs by 1990, or almost 3 times the present discharge. If adequate secondary treatment is provided at each plant, the river will be capable of assimilating the resultant organic wastes discharged without lowering the oxygen concentration below 5.0 mg/l, the standard for the preservation of fish and other aquatic life. Secondary treatment, however, will not reduce the amount of nutrients being discharged to the river.

State-established water use objectives for this reach of the Fox River require water quality levels suitable for all uses except public water supply. Future water quality will generally meet these standards, provided that adequate disinfection of all sewage treatment plant discharges is accomplished. A potential problem may develop in this reach, however, as a result of the large amounts of nutrients added to the river by discharges from sewage treatment plants upstream from and within the reach. Estimates of the nutrient contributions to this reach of the Fox River indicate that the total amounts of nitrogen and phosphorus discharged to the river may be expected to reach 3 times the present amount by 1990, with approximately 85 percent of the phosphorus and 65 percent of the nitrogen being derived from sewage treatment plant discharges upstream from and within the reach. These nutrients may stimulate excessive growths of algae, causing nuisances that would interfere with recreational and aesthetic uses of the stream. In addition to causing problems in the Fox River in Wisconsin, the nutrients will move down the river and a portion will eventually reach the Fox Chain of Lakes in Illinois. These lakes, on the main channel of the Fox River, while intensively used for recreational purposes, are already in a highly eutrophic condition. The continued and increased inflow of nutrients to the lakes in the future will serve to further aggravate this problem.

Sussex Creek: Existing water uses of Sussex Creek include wildlife watering, waste assimilation, and aesthetic uses. State-established water use objectives include the minimum standards and partial-body-contact recreation if the flow is sufficient to support the latter use. Existing water quality conditions throughout Sussex Creek are generally of a level suitable for all present uses of the stream. Nuisance conditions have occasionally developed, however, as a result of discharges of highly colored and foul smelling wastes from the Mammoth Springs Canning Company in Sussex. Dissolved oxygen levels throughout the stream are high enough to support fish and other aquatic life; but the small size of the stream does not provide a suitable habitat for development of any fish life other than a few small species, such as minnows. Coliform levels are in excess of 5,000 MFCC/100 ml throughout the entire length of the stream and exceed 100,000 MFCC/100 ml during the fall season. These high coliform concentrations, attributable to the Sussex sewage treatment plant, do not present an immediate problem in Sussex Creek, which is not used for any recreational activities, but do contribute to pollution of the Fox River.

The Sussex sewage treatment plant served a population of approximately 1,400 persons and discharged treated effluent at an average rate of 0.3 cfs in 1963. By 1990 this plant may be expected to serve a population of 8,800 persons, and the discharge of treated effluent may be expected to reach an average rate of 2.5 cfs. The resultant waste discharge to the stream by 1990 will be about 6 times the present amount, with little or no natural streamflow available for dilution. Expansion of the canning company operations in the future would also add additional wastes to the stream.

Future water quality conditions in Sussex Creek may be expected to be such as to make the stream unsuitable for all uses other than waste assimilation. The large increases which may be expected in the amount of treated wastes discharged from the sewage treatment plant at Sussex will lower oxygen levels to such an extent that septic conditions will prevail over at least a portion of the stream. Nuisance conditions that may be expected to develop will preclude even aesthetic use of the stream. The increased waste discharge may be expected to increase streamflow, however, to the extent that use could possibly be made of the stream for the maintenance of a small warm-water fishery and for partial-body-contact recreational activities, in addition to the present uses, if water quality were improved to the level necessary to support these uses. The necessary water quality conditions would consist of dissolved oxygen levels greater than 5.0 mg/l, coliform concentrations less than 5,000 MFCC/100 ml, and the absence of any nuisances caused by excessive algae growths.

Poplar Creek: Existing water uses of Poplar Creek include partial-body-contact recreation, wildlife watering, and aesthetic uses. State-established water use objectives include all recreational uses and the maintenance of a warm-water fishery.

Low streamflow presently precludes the use of Poplar Creek for the maintenance of a significant fishery, although some small fish are present. Even though there are no known major waste discharges to the stream, dissolved oxygen levels are frequently less than 5.0 mg/l during the summer and winter months; and coliform levels are generally in the range from 500 to 2,500 MFCC/100 ml. It would appear that the major source of the coliform bacteria and depressed oxygen concentrations is seepage and overflow from the many septic tanks in the area tributary to Poplar Creek. The 1963 population of over 12,000 persons in the Poplar Creek watershed was served almost entirely by septic tank sewage disposal systems. Over 55 percent of the total area of the watershed is, however, covered by soils having severe limitations for the use of such systems.

The estimated 1990 population of the Poplar Creek watershed is about 40,000 persons. Future water quality conditions in Poplar Creek will remain unsuitable for the preservation of aquatic life as long as development relying on septic tanks for sewage disposal continues on soils that have severe limitations for such development. It is anticipated, however, that public sewerage facilities and related treatment facilities will be constructed in the future to serve the developed areas tributary to Poplar Creek. The treatment facilities would probably be located near the confluence of Poplar Creek and the Fox River. This system will eliminate much of the septic tank seepage and overflow, and as a result water quality conditions in Poplar Creek should improve to a level that is suitable for all desirable future uses of the stream.

Pewaukee River: Existing uses of the Pewaukee River include wildlife watering, waste assimilation, aesthetic uses, and partial-body-contact recreation. The major waste discharge to the stream is from the Pewaukee sewage treatment plant, which in 1963 served about 3,000 people and discharged treated effluent at an average rate of 0.5 cfs. This discharge results in severe water quality degradation in the stream. Existing water quality conditions indicate that the stream is presently unsuitable for the preservation of fish and other aquatic life and for any recreational activities. Average dissolved oxygen levels during the summer and winter months are in the range from 3.0 to 5.0 mg/l, with minimum concentrations less than 1.0 mg/l having been recorded downstream from the Pewaukee sewage treatment plant outfall. These low levels inhibit the maintenance of even a warm-water fish population in the stream. Coliform concentrations in excess of

100,000 MFCC/100 ml below the sewage treatment plant outfall and in excess of 5,000 MFCC/100 ml throughout the entire length of the stream render the Pewaukee River unsuitable for any recreational uses. State-established water use objectives, however, include partial-body-contact recreation and preservation of fish and other aquatic life, along the minimum standards. Sludge accumulations and odors below the plant outfall detract from the aesthetic value of the stream.

By 1990 the Pewaukee sewage treatment plant will serve over 6,000 people and will have a treated waste discharge of 1.8 cfs. The residual organic matter discharged will be about 2 1/2 times the present amount. This increase in waste discharged from the Pewaukee sewage treatment plant will further degrade water quality in the stream. Dissolved oxygen levels in the future under low-flow summer conditions will be on the order of 1.0 mg/l below the treatment plant outfall, and occasional septic conditions may develop. In addition, the large amounts of nutrients being discharged to the stream in the treatment plant effluent may be expected to stimulate large growths of algae and other aquatic plants. The nuisances caused by the development of septic conditions and the excessive growths of algae will render the stream unsuitable for all future uses other than waste assimilation. In order to improve water quality to a level suitable for all desirable future uses, it will be necessary to maintain dissolved oxygen levels greater than 5.0 mg/l, to reduce coliform concentrations to less than 5,000 MFCC/100 ml, and to eliminate the occurrence of nuisance blooms of algae and other aquatic plants.

Pebble Creek: Pebble Creek is presently used for a warm-water fishery, partial-body-contact recreation, wildlife watering, waste assimilation, and aesthetic uses. State-established water use objectives are recreational uses and maintenance of a warm-water fishery. Present water quality conditions are of a level that is suitable for all the existing uses except partial-body-contact recreation. Coliform levels at times in excess of 5,000 MFCC/100 ml restrict the suitability of this stream for recreational activities. The only known waste discharge in the vicinity is to a seepage pond at the Keystone Farms. Observations made during the summer of 1966 indicated there was no overflow from this pond to Pebble Creek.

Future water quality conditions may be expected to remain at a level similar to existing conditions and will be suitable for all desirable future uses of the stream, provided that the source of the present high coliform concentrations is located and adequate disinfection is provided.

Genesee Creek: Present uses of Genesee Creek include both cold- and warm-water fisheries, partial-body-contact recreation, wildlife watering, waste assimilation, and aesthetic uses. State-established water use objectives include all of the existing uses plus whole-body-contact recreation. Present water quality conditions in that section of the stream from the Saylesville Millpond downstream to the Fox River are generally suitable for all existing uses. From the millpond upstream for about four miles, however, coliform counts occasionally in excess of 5,000 MFCC/100 ml restrict the suitability of the stream for recreational activities. The sources of these relatively high coliform concentrations appear to be drainage from Pleasant Valley Farms and Brookhill Farms. Samples of the effluent from tile outfalls draining these farms indicate coliform concentrations on the order of 10,000 MFCC/100 ml in the Brookhill Farms drainage and concentrations well in excess of 100,000 MFCC/100 ml in the Pleasant Valley Farms drainage.

Future water quality conditions in Genesee Creek will be at a level that is suitable for all desirable future uses if adequate disinfection of the waste discharges to the stream is provided. It is anticipated that land use and population will remain fairly constant throughout the area tributary to Genesee Creek from the present through 1990 and that there will be no new major waste discharges to the stream that will degrade water quality.

Mukwonago River: Present uses of the Mukwonago River include both cold- and warm-water fisheries, partial- and whole-body-contact recreation, livestock and wildlife watering, waste assimilation, and aesthetic uses. State-established water use objectives include all of the existing uses plus irrigation in that section of the stream below Lower Phantom Lake. The only existing major waste discharge to the river is from the Mukwonago sewage treatment plant, which in 1963 served approximately 2,000 people and discharged treated effluent at an average rate of 0.3 cfs. This discharge does not adversely affect oxygen levels in the stream. Existing water quality of the Mukwonago River below Lower Phantom Lake is suitable for all of the present uses other than recreation. In that section of the stream down to the Mukwonago sewage treatment plant, coliform concentrations occasionally greater than 1,000 MFCC/100 ml restrict the suitability of the stream for whole-body-contact recreation. Coliform levels are less than 5,000 MFCC/100 ml through this reach, however, indicating that it is suitable for partial-body-contact recreation. Discharge of treated wastes from the Mukwonago sewage treatment plant raises coliform concentrations to a level well in excess of 5,000 MFCC/100 ml from the effluent outfall down to the Fox River, thus rendering that reach of the stream unsuitable for any recreational activities. Although there is no stream water quality data available for the Mukwonago River above Lower Phantom Lake, it is probable that water quality in that reach is of a level suitable for all uses, since there are presently no known major waste discharges to that reach of the stream. There is a potential major waste source, however, located on a small tributary to the Mukwonago River several miles upstream from Lower Phantom Lake. This is the Rainbow Springs Resort on Rainbow Springs Lake. If adequate treatment and disinfection of the wastes are provided when this resort opens, however, the waste discharge should not adversely affect water quality in the area.

By 1990 the Mukwonago sewage treatment plant will serve almost 7,000 people and will discharge 1.9 cfs of treated effluent. Natural streamflow, however, should provide sufficient dilution to prevent any adverse effects on water quality in the Mukwonago River. Future water quality conditions in the Mukwonago River should be at a level that is suitable for all of the desirable future uses of the stream. Dissolved oxygen concentrations will remain well above the minimum of 5.0 mg/l required for fish life. If adequate disinfection of all waste discharges to the stream is provided, coliform concentrations should remain below the maximum of 1,000 MFCC/100 ml permitted for whole-body-contact recreation according to the Wisconsin water quality standards.

Wind Lake Drainage Canal: The Wind Lake Drainage Canal and the Muskego Canal are presently used for a warm-water fishery, partial-body-contact recreation, livestock and wildlife watering, and aesthetic uses. State-established water use objectives include irrigation in addition to the existing uses. Present water quality in the canal from Wind Lake to the Fox River is of a level that is generally suitable for all of the existing uses. Dissolved oxygen levels are greater than 5.0 mg/l throughout the year; and coliform concentrations are less than 5,000 MFCC/100 ml during the spring, summer, and fall months. During the winter, however, coliform levels are slightly greater than 5,000 MFCC/100 ml, indicating a water of questionable suitability for partial-body-contact recreation during the winter months.

Present and future uses of the Muskego Canal, which connects Wind Lake and Muskego Lake, are the same as those for the Wind Lake Drainage Canal. Existing water quality conditions in the Muskego Canal, however, are generally not suitable for the preservation of fish and other aquatic life or for any recreational activities. Dissolved oxygen levels are frequently less than 4.0 mg/l, with minimum summer concentrations on the order of 1.0 mg/l. Coliform levels are greater than 5,000 MFCC/100 ml. It appears that the major cause of the low dissolved oxygen levels and high coliform counts is the discharge of raw or partially treated sewage from septic tanks serving residences located along the canal. Drainage from the extensive swamp areas around Muskego Lake may also be contributing to the low oxygen levels.

Future water quality conditions in the Wind Lake Drainage Canal will be similar to existing conditions. There are presently no known major waste discharges to the canal, and it is anticipated that there will not be any in the future. Thus, future water quality should generally be suitable for all of the desirable future uses of the canal. Future water quality in the Muskego Canal will remain unsuitable for the preservation of fish life and for recreational activities until the source of the present pollution is eliminated or controlled. The anticipated extension of sewer service by the Metropolitan Sewerage Commission of the County of Milwaukee to the City of Muskego will eliminate much of the seepage from septic tanks serving the area above Muskego Lake. This, together with the elimination or control of pollution sources adjacent to the Muskego Canal, should improve future water quality conditions in the canal to a level that will be suitable for all of the desirable future uses of the canal.

Honey Creek: Honey Creek is presently used for a warm-water fishery, partial-body-contact recreation, industrial and cooling water supply, livestock and wildlife watering, waste assimilation, and aesthetic uses. State-adopted water use objectives include all of the existing uses, as well as irrigation and whole-body-contact recreation.

Existing water quality in Honey Creek is suitable for all of the present uses of the stream other than recreation. The East Troy sewage treatment plant in 1963 served a population of about 1,500 people and discharged treated effluent at an average rate of 0.3 cfs. This discharge does not presently lower oxygen levels in the stream below 5.0 mg/l. Average dissolved oxygen concentrations are substantially greater than 5.0 mg/l, and minimum recorded concentrations are near 5.0 mg/l. Discharge of wastes containing high concentrations of iron from the Trent Tube Company results in an iron precipitate on the stream bottom, but this effect is generally limited to the vicinity of the outfall. Discharge of treated wastes from the East Troy sewage treatment plant, however, raises coliform levels well above the maximum of 5,000 MFCC/100 ml permitted for partial-body-contact recreation. It is probable that coliform levels in excess of 5,000 MFCC/100 ml persist for five to ten miles downstream from East Troy, thus making the stream unsuitable for any recreational activities in this reach. Water quality in the lower portion of Honey Creek, particularly from Sugar Creek to Echo Lake, is suitable for partial-body-contact recreation since coliform levels are generally in the range of 1,000 to 4,000 MFCC/100 ml in this section.

By 1990 the East Troy sewage treatment plant will serve about 3,600 people and will discharge 1.1 cfs of treated effluent. This increased discharge from the East Troy sewage treatment plant will lower average dissolved oxygen concentrations under low-flow summer conditions to a level of 4.0 mg/l from three to six miles downstream from the outfall. As a result future water quality in this section of the stream will be unsuitable for the preservation of fish and other aquatic life. Further downstream natural dilution and reaeration will increase the dissolved oxygen content of the stream to a level in excess of 5.0 mg/l, indicating that water quality will have improved to a level suitable for fish life. If adequate disinfection of the major waste discharges is provided in the future, coliform levels should be less than 5,000 MFCC/100 ml; and the stream will be suitable for partial-body-contact recreation. In general, future water quality conditions in Honey Creek will be of a level that is suitable for all of the desirable future uses, except for a five- to ten-mile length of the stream below East Troy, which will be unsuitable for the preservation of a warm-water fishery. In order to improve water quality in this reach to a level that will support fish life, it will be necessary to maintain a dissolved oxygen concentration not less than 5.0 mg/l throughout the reach.

Sugar Creek: Sugar Creek is presently used for a warm-water fishery, partial-body-contact recreation, livestock and wildlife watering, and aesthetic uses. State-established water use objectives include all of the present uses, whole-body-contact recreation, and irrigation. Existing water quality in the upper reaches of Sugar Creek is suitable for all of the present uses except during the summer months, when high coliform levels indicate unsuitable conditions for recreation. It is thought that this is a local condition, however, possibly resulting from seepage or drainage from septic tanks serving the small community of Abells Corners, which is located just upstream from where water quality samples were obtained. Although data are lacking for an evaluation of water quality conditions in the middle and lower reaches of Sugar Creek, it is believed that water quality in these reaches is suitable for all present stream uses since there are no known major waste discharges to the stream and no communities and very few residences are located near the stream in these reaches. In the past, however, there was a waste discharge to this section of the stream from the Alpine Valley Lodge. The septic tank system serving this winter resort, when overloaded, would discharge to Sugar Creek; and this apparently caused a significant deterioration of downstream water quality. The present sewage treatment system, however, includes a seepage pit designed to percolate the effluent without surface discharge to Sugar Creek.

Future water quality conditions in Sugar Creek should remain similar to present conditions since the tributary watershed will remain principally an agricultural area of low-density population. Water quality will be suitable for all of the desirable future stream uses provided that the few local pollution sources that may presently exist are eliminated or controlled.

White River: Present uses of the White River include partial-body-contact recreation, livestock and wildlife watering, a warm-water fishery, waste assimilation, and aesthetic uses. State-adopted water use objectives include all of the existing uses plus irrigation. Present water quality throughout the White River is suitable for all of the existing uses other than recreation. The major waste discharge to the White River is from the Lake Geneva sewage treatment plant, which in 1963 served a population of about 4,500 people and discharged treated effluent at an average rate of 0.8 cfs. A minor waste discharge occurs in the community of Lyons from several tile outfalls that discharge to the stream. Dissolved oxygen levels are consistently above the concentration of 5.0 mg/l necessary for the preservation of fish and other aquatic life. Coliform concentrations in excess of 5,000 MFCC/100 ml, however, render the stream unsuitable for any recreational activities throughout most of its length during the summer months and in its upper reaches during the remainder of the year. These high coliform levels occur as a result of treated waste discharges from the Lake Geneva sewage treatment plant and the discharge of septic tank effluent from numerous tile outfalls in the community of Lyons.

Future water quality conditions in the White River will generally be of a level that is not suitable for the preservation of fish and other aquatic life or for any recreational uses. By 1990 the Lake Geneva sewage treatment plant will serve approximately 11,000 people and will discharge 4.3 cfs of treated effluent. This will result in a discharge of organic matter and nutrients to the stream about 3 times greater than the present amounts. An additional future waste source will be the effluent from the Lake Geneva Playboy Club Resort, which is to be completed in the near future. The volume of this waste will be small, however; and present plans indicate that secondary treatment and disinfection will be provided. If adequate disinfection of the Lake Geneva sewage treatment plant effluent is provided, however, and if the discharge of septic tank effluent in Lyons is eliminated, future coliform levels should be lowered sufficiently to make the stream suitable for partial-body-contact recreation. Dissolved oxygen levels during low-flow summer conditions will be in the range of 3.0 to 5.0 mg/l for five to seven miles below the Lake Geneva treatment plant outfall, indicating substandard conditions for fish life. Further downstream dilution and reaeration will increase the oxygen content to levels suitable for the maintenance of fish life. In order to make the entire stream suitable for the preservation of fish and other aquatic life, it will be necessary to maintain the dissolved oxygen concentration above 5.0 mg/l throughout the entire length of the stream. The discharge of large amounts of nutrients into the treatment plant effluent will stimulate large growths of algae throughout the stream.

Bassett Creek: Present uses of Bassett Creek are limited by its small size to a warm-water fishery for small fish, wildlife watering, waste assimilation, and aesthetic uses. State-established water use objectives include all recreational uses and a warm-water fishery. Existing water quality in Bassett Creek is not suitable for the preservation of fish and other aquatic life. Discharge of treated wastes from approximately 3,000 people from the Twin Lakes sewage treatment plant lowers dissolved oxygen concentrations to a range of 2.0 to 4.0 mg/l downstream from the outfall during the summer months and raises coliform concentrations above 100,000 MFCC/100 ml during periods of low flow. These high coliform levels indicate the unsuitability of the stream for recreational activities.

Future water quality will remain unsuitable for the preservation of fish and other aquatic life. Increased discharges about 3 times the present amount by 1990, from the Twin Lakes treatment plant, will lower oxygen levels to a range of 1.0 to 3.0 mg/l during low-flow summer conditions and will add large amounts of nutrients that stimulate algae growths. In order to improve water quality in the stream to a level that is suitable for fish life, it will be necessary to maintain dissolved oxygen concentrations at or above 5.0 mg/l. If adequate disinfection of the Twin Lakes effluent is provided, coliform concentrations will be within the standards for partial-body-contact recreation. The small size of the stream, however, will limit any potential recreational activities.

Nippersink Creek: Nippersink Creek is presently used for a warm-water fishery, partial-body-contact recreation, waste assimilation, wildlife watering, and aesthetic uses. State-adopted water use objectives include all of the existing uses. Present water quality conditions in Nippersink Creek above the Wisconsin-Illinois State line are generally suitable for all existing uses of the stream, although coliform concentrations occasionally in excess of 5,000 MFCC/100 ml have been recorded. Below the Genoa City sewage treatment plant, which is located near the Illinois State line and serves approximately 1,000 people, coliform concentrations are well above 5,000

MFCC/100 ml, indicating that this section of the stream is unsuitable for any recreational activities. Average dissolved oxygen levels throughout the stream are greater than the minimum of 5.0 mg/l necessary for the preservation of fish life.

Future water quality conditions in Nippersink Creek will be at approximately the same level as present conditions. Water quality will be suitable for all of the desirable future uses of the stream above the Wisconsin-Illinois State line, but disinfection of the Genoa City sewage treatment plant effluent will be required to reduce coliform concentrations downstream from the state line to a level that is suitable for partial-body-contact recreation.

Other Streams: Within the Fox River watershed there are numerous small streams that have not been discussed in the preceding sections. Most of these streams, because of their relatively small size and limited use, are not of areawide significance. 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 uses since, with two exceptions, there are no known major waste discharges to any of these streams. The two exceptions are the Oakton Manor Resort,[7] which discharges treated effluent to a small stream tributary to Pewaukee Lake, and the Pure Milk Association at Kansasville, which discharges its wastes to a lagoon, with overflow and seepage to a marsh tributary to Eagle Lake. Future water quality conditions in the minor streams of the Fox River watershed may be expected to remain at a level suitable for all reasonable uses, provided that no new major waste discharges are established on any of these minor streams.

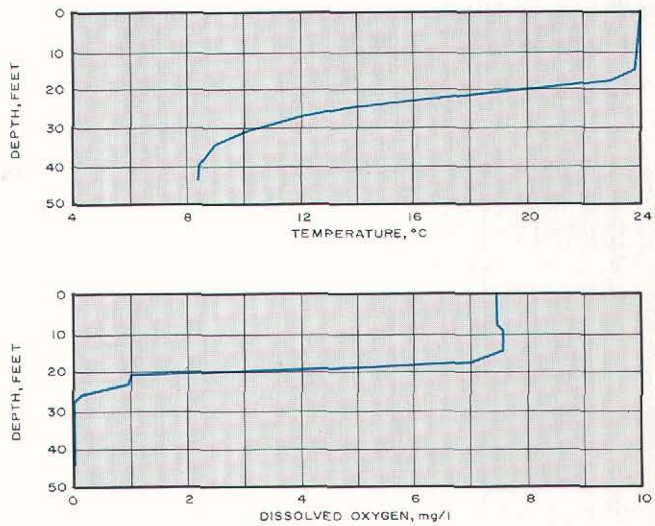
LAKE WATER QUALITY CHARACTERISTICS OF THE WATERSHED

The variation of water quality in a lake depends on the depth of the lake, as well as the season of the year. In shallow lakes the water is well mixed, and water quality is fairly uniform throughout the entire depth. In lakes deeper than 15 to 25 feet, however, two separate water zones develop during the summer months. The upper zone, or epilimnion, consists of a well-mixed layer of warm water of uniform temperature. The bottom zone, or hypolimnion, consists of the densest, coldest water in the lake. The two zones are separated by a layer of water known as the thermocline, in which there is a rapid drop in temperature with increasing depth. The thermocline acts as a thermal barrier that prevents mixing of the upper waters with the bottom water and thus maintains the thermal stratification of a lake during the summer months.

Of the 45 major lakes in the Fox River watershed, 15 have a maximum depth of less than 15 feet and, consequently, are generally not stratified. These unstratified lakes include the following: Como, Eagle, Camp, Lower Phantom, Eagle Spring, Pell, North, Long, Wandawega, Buena, Echo, Silver (Walworth County), Lilly, Peters, and Dyer Lakes. The remaining 30 lakes experience thermal stratification during the summer months. Figure 89 indicates the temperature and dissolved oxygen profiles of Browns Lake, as measured during the summer of 1966. These profiles show conditions that are typical of all of the stratified lakes in the watershed. Dissolved oxygen levels in the epilimnion of all the stratified lakes are generally in the range of 7.0 to 9.0 mg/l, and temperatures range from 70° to 85°F. In the hypolimnion, however, dissolved oxygen levels decrease to zero in all of the lakes except Geneva, and temperatures generally range from 45° to 50°F. Oxygen levels in the hypolimnion of Lake Geneva decrease to a level of 2.0 mg/l at a depth of 50 feet.

Figure 89

DISSOLVED OXYGEN AND TEMPERATURE PROFILES OF BROWNS LAKE, RACINE COUNTY, WISCONSIN: 1966



Source: Wisconsin Department of Natural Resources.

[7] *This resort was partially destroyed by fire in 1967.*

Temperature and dissolved oxygen levels in the unstratified lakes of the watershed are generally similar to the conditions 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° to 85°F. During the winter months, however, the dissolved oxygen content of the shallow lakes under an ice cover is depressed to levels critical for fish life; and frequent winter kills of fish are experienced in most of these lakes. These low oxygen levels result from the utilization of dissolved oxygen by organic matter present in the lake and from the lack of reaeration of the lake water from the atmosphere because of the presence of an ice cover. Thus, the oxygen present in the lake is depleted; and no additional oxygen is added.

Lakes in the Fox River watershed are generally classified as being moderately hard, alkaline, fertile lakes. The average chemical composition of the 45 major lakes is shown in Table 56 . 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.

The chloride and sodium ion concentrations in a lake are indicators of possible pollution. Concentrations substantially greater than the average regional levels of these ions indicate the possibility of pollution. Of the 45 major lakes in the watershed, 12 have chloride concentrations indicative of pollution; and 6 of the 12 also have sodium levels that are indicative of pollution. These lakes, and their respective chloride and sodium concentrations, are listed in Table 57. Coliform bacteria determinations made during the summer of 1967 indicated that coliform levels in all of the lakes shown in this table, except Eagle and Long Lakes, exceed 1,000 MFCC/100 ml, the maximum concentration permitted by the Wisconsin water quality standards for whole-body-contact recreational activities (see Table 50). 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, because coliforms originating in the soil are not indicative of a health hazard. A comprehensive sanitary survey of the north end of Little Muskego Lake, conducted by the Waukesha County Health Department during the summer of 1967, identified 64 homes, out of 151 homes surveyed, that had drainage to the lake or a small tributary of the lake. The drainage from about half of these 64 homes included wastes from septic tanks, which could represent a serious public health hazard. Similar drainage conditions around several other lakes in the watershed may be the cause of the polluted conditions indicated by the high chloride and sodium ion and coliform bacteria concentrations in those lakes listed in Table 57.

Concentrations of the fertilizing elements, nitrogen and phosphorus, in the major lakes of the Fox River watershed, as measured during the spring and summer of 1966 and 1967, are listed in Table 58. The first group of eight lakes listed in this table contain dissolved phosphorus concentrations in the spring that are less than 0.015 mg/l, the

Table 56

AVERAGE CHEMICAL AND PHYSICAL COMPOSITION OF MAJOR LAKES IN THE FOX RIVER WATERSHED: 1966

Composition	Average Quantity	Composition	Average Quantity
Magnesium	26.60 mg/l	Phosphorus (Dissolved)	0.05 mg/l
Calcium	26.40 mg/l	Phosphorus (Total)	0.08 mg/l
Sodium	5.60 mg/l	Nitrate Nitrogen	0.26 mg/l
Potassium	2.20 mg/l	Total Alkalinity	163.00 mg/l
Iron	0.11 mg/l	pH	8.30 units
Sulphate	48.60 mg/l	Specific Conductance	405.00 micromhos/cm
Chloride	10.90 mg/l		

Source: Wisconsin Department of Natural Resources.

approximate threshold concentration for the occurrence of algal blooms in lakes in southeastern Wisconsin. Compared to the majority of the lakes in the watershed, these eight lakes may be classified as only slightly fertile. The second group of 27 lakes listed in Table 58 are characterized in the spring by dissolved phosphorus concentrations greater than the threshold level of 0.015 mg/l but less than the average dissolved phosphorus level of 0.05 mg/l of lakes within the Region. These lakes may be classified as moderately fertile, and problems of algae and weed growth may be expected in many of these lakes. The last group of 10 lakes contain dissolved phosphorus concentrations substantially in excess of the average level of 0.05 mg/l. These lakes are highly fertile and experience frequent problems from nuisance growths of algae and aquatic weeds. Of these 10 excessively fertile lakes, seven, including Wind, Tichigan, Pewaukee, Buena, Long, Little Muskego, and Browns, also contain high levels of those ions indicative of pollution, as previously indicated in Table 57.

Table 57

LAKES OF THE FOX RIVER WATERSHED CONTAINING SODIUM AND CHLORIDE IN CONCENTRATIONS INDICATIVE OF POLLUTION

Lake	Chloride Ion (mg/l)	Sodium Ion (mg/l)
Buena	29.8	14.7
Little Muskego	27.9	10.6
Tichigan	26.4	12.9
Big Muskego (Bass Bay)	23.3	8.5
Wind	20.6	9.2
Long	19.8	--
Silver	19.0	--
Eagle	18.4	10.0
Center	18.2	--
Browns	16.5	--
Camp	16.3	--
Pewaukee	16.2	--

Source: Wisconsin Department of Natural Resources.

The relatively high phosphorus concentrations, in excess of the threshold level of 0.015 mg/l, in 37 of the 45 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, indicate that many of the lakes in the Fox River watershed are in a relatively advanced state of eutrophication.

Pesticide residues are present in varying amounts throughout surface waters in the Fox River watershed. Analyses of various species of fish taken from several lakes in the watershed indicate average concentrations of DDT of 0.88 mg/l of the whole fish population and concentrations of dieldrin of 0.05 mg/l.[8] These pesticide concentrations are substantially higher than those observed in most other areas of the state and indicate a significant level of contamination of waters in the Fox River watershed with DDT and dieldrin.

LAKE WATER QUALITY PROBLEMS

The existing water uses of the 45 major lakes within the Fox River watershed are almost exclusively related to recreational activities, the aquatic life and wildlife that support some of these activities, and aesthetic values. 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 be accessory to recreational uses. Waste assimilation use may exist as a result of accidental or illegal waste discharges into a lake, although this is a use by design in Tichigan Lake and the Waterford impoundment (Buena Lake) on the Fox River. The existing recreational water uses of the major lakes are listed in Table 59. Although partial-body-contact recreational activities are common to all 45 major lakes and whole-body-contact recreation is common to 39 lakes, this does not imply that the water quality in these 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 considered as accessory to the basic recreational uses and permissible only if compatible with the basic recreational uses. Acceptable future uses of all the 45 major lakes within the watershed will include full-body-contact recreation, preservation of wildlife, and use for aesthetic enjoyment. Flood retention and low streamflow augmentation may be permissible uses of some of the lakes. Uses that are generally con-

[8] *Information obtained from the Wisconsin Department of Natural Resources, Division of Conservation, Research Report No. 23, "DDT and Dieldrin Residues Found in Wisconsin Fishes from the Survey of 1966."*

Table 58

NITROGEN AND PHOSPHORUS CONCENTRATIONS IN THE MAJOR LAKES OF THE FOX RIVER WATERSHED: 1966 - 1967

Lake	Spring			Summer					
				Epilimnion			Hypolimnion		
	Phosphorus		Nitrate	Phosphorus		Nitrate	Phosphorus		Nitrate
	Total	Dissolved	Nitrogen	Total	Dissolved	Nitrogen	Total	Dissolved	Nitrogen
Geneva	0.03	0.01	0.28	0.03	0.01	--	0.04	0.01	--
Cross	0.04	0.01	--	0.03	0.02	0.16	0.02	0.02	--
Powers	0.05	0.01	0.17	0.04	0.03	0.05	0.11	0.02	--
Marie	0.01	0.01	--	0.04	0.03	0.04	0.03	0.01	--
Silver (Kenosha County)	0.05	0.01	0.31	0.06	0.02	0.06	0.06	0.01	--
Kee Nong Go Mong	--	0.01	0.25	0.06	0.02	0.17	--	0.02	--
Lilly	0.07	0.01	0.12	0.06	0.01	0.07	--	[a]	--
Denoon	0.04	0.01	--	0.07	0.03	0.10	0.06	0.03	--
Booth	--	0.02	0.05	0.01	0.01	0.08	0.02	0.02	--
Eagle Spring	0.23	0.02	0.56	0.03	0.02	0.06	--	[a]	--
Pell	0.04	0.02	0.14	0.03	0.03	--	--	[a]	--
Elizabeth	0.02	0.02	0.07	0.04	0.03	0.09	0.02	0.02	--
Lower Phantom	0.04	0.02	0.59	0.04	0.03	0.05	--	- [a]	--
Center	0.04	0.02	--	0.06	0.04	0.12	0.02	0.02	--
Como	0.07	0.02	1.01	0.08	0.01	--	--	[a]	--
Benedict	0.14	0.02	0.30	0.10	0.02	--	0.06	0.03	--
Waubeesee	--	0.02	0.19	0.13	0.03	0.08	0.04	0.03	--
Voltz	0.23	0.02	--	0.17	0.14	0.08	0.22	0.17	--
Lulu	--	0.03	0.14	0.01	0.01	--	0.01	--	--
Beulah	--	0.03	0.03	0.03	0.01	0.05	0.03	0.02	--
Spring	0.13	0.03	2.04	0.03	0.01	0.13	--	[a]	--
Silver	--	--	--	--	0.03	--	--	[a]	--
Camp	0.08	0.03	--	0.04	0.04	0.11	--	[a]	--
Green	--	0.03	0.02	0.04	0.04	--	0.08	0.05	--
Army	--	0.03	0.11	0.05	0.03	0.13	--	[a]	--
Eagle	--	0.03	0.06	0.06	0.03	--	--	[a]	--
Middle	--	0.03	0.16	--	--	--	0.06	0.06	--
Upper Phantom	0.06	0.03	0.64	0.06	0.03	0.08	0.02	0.02	--
North	--	0.03	0.04	0.07	0.05	--	--	[a]	--
Wandawega	--	0.03	0.03	--	0.07	--	--	[a]	--
Big Muskego	--	--	--	0.04	0.04	--	0.03	0.03	--
Mill	--	0.04	0.02	0.09	0.08	--	--	--	--
Echo	--	0.04	0.63	--	--	--	--	[a]	--
Dyer	--	--	--	--	0.04	--	--	[a]	--
Pleasant	--	0.05	0.04	0.03	0.03	--	0.09	0.06	--
Wind	--	0.07	0.27	0.10	0.02	0.13	0.03	0.03	--
Tichigan	--	0.07	0.20	--	0.05	--	0.11	0.04	--
Bohners	--	0.09	0.24	0.02	0.01	--	0.02	0.02	--
Pewaukee	0.19	0.13	0.86	0.22	0.22	0.86	0.13	0.13	--
Peters	0.14	0.13	--	0.55	0.55	--	--	[a]	--
Buena	--	0.19	0.38	0.64	0.64	0.11	--	[a]	--
Long	--	0.20	0.36	0.09	0.01	0.39	--	[a]	--
Little Muskego	--	--	--	0.20	0.11	0.08	0.09	0.09	--
Browns	--	0.25	0.05	0.27	0.27	--	0.25	0.22	--
Potters	--	--	--	0.30	0.28	0.09	0.17	--	--

[a] *Lake is not generally stratified.*

Note: All values in this table are expressed in mg/l of nitrogen or phosphorus.

Source: Wisconsin Department of Natural Resources.

sidered undesirable include industrial and cooling water use, livestock watering, irrigation, and waste assimilation.

The major water-associated problems of the lakes in the Fox River watershed are generally related to health hazards and overfertilization. Sanitary problems are indicated by the high coliform concentrations in many of the lakes. The high coliform levels suggest a water quality unsuitable for whole-body-contact recreation and, in a few lakes, unsuitable for all forms of recreation. 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 a sanitary hazard is not available. A study of Little Muskego Lake indicated that septic tank drainage directly to the lake is a major source of high coliform levels and repre-

Table 59

EXISTING RECREATIONAL WATER USES OF MAJOR LAKES OF THE FOX RIVER WATERSHED: 1966

Name Of Lake	Preservation And Enhancement Of Aquatic Life and Wildlife			Recreation Partial-Body Contact				Recreation Whole-Body Contact			Aesthetic Uses
	Marsh Fur Bearers	Waterfowl Rearing	Spawning Areas	Fishing	Waterfowl Hunting	Rowing And Canoeing	Speed Boating	Swimming	Water Skiing	Skin Diving	
Army				X	X[a]	X	X	X	X		X
Benedict	X		X[b]	X		X	X	X	X	X	X
Beulah	X	X	X	X	X	X	X	X	X	X	X
Big Muskego		X	X	X	X	X	X	X[c]	X		X
Bohners	X	X	X	X	X	X	X	X	X	X	X
Booth				X		X		X			X
Browns	X		X	X		X	X	X	X	X	X
Buena	X	X	X	X	X	X	X	X	X		X
Camp	X	X	X	X	X	X	X	X	X		X
Center	X	X	X	X	X	X	X	X	X	X	X
Como	X	X	X	X	X	X		X[d]			X
Cross	X	X	X	X	X	X	X	X	X	X	X
Denoon	X[e]		X	X	X	X	X	X	X	X	X
Dyer	X	X	X	X	X	X		X			X
Eagle	X	X	X	X	X	X	X	X	X		X
Eagle Spring	X	X	X	X	X	X	X	X[d]	X		X
Echo	X	X	X	X	X	X					X
Elizabeth	X	X	X	X	X	X	X	X	X	X	X
Geneva				X	X	X	X	X	X	X	X
Green	X	X		X	X	X	X	X	X	X	X
Kee Nong Go Mong	X	X	X	X	X	X	X	X	X		X
Lilly	X			X		X	X	X	X		X
Little Muskego				X	X	X	X	X	X		X
Long	X	X	X	X	X	X					X
Lower Phantom	X	X	X	X	X	X	X		f		X
Lulu	X	X	X	X	X	X	X	X		X	X
Marie	X			X		X	X	X	X	X[g]	X
Middle	X	X	X	X	X	X	X	X	X	X	X
Mill	X	X	X	X	X	X	X	X	X	X	X
North	X	X			X	X					X
Pell	X	X		X	X	X		X			X
Peters	X	X			X	X		X			X
Pewaukee	X	X	X	X	X	X	X	X	X		X
Pleasant	X	X	X[h]	X	X	X	i	X	i	X	X
Potters	X	X	X	X	X	X	X	X	X		X
Powers	X	X	X	X		X	X	X	X	X	X
Silver (Kenosha)	X	X	X	X	X	X	X	X	X	X	X
Silver (Walworth)	X	X			X	X					X
Spring	X	X	X	X	X	X	X		X		X
Tichigan	X	X	X	X	X	X	X	X	X	X	X
Upper Phantom	Xj	Xj	Xj	X	X[a]	X	X	X	X	X	X
Wandawega	X	X	X	X	X	X	X	X			X
Waubeesee	X	X	X	X	X	X		X	X	X	X
Wind	X	X	X	X	X	X	X	X	X	X	X

[a]*Limited marsh to sustain waterfowl hunting.*

[b]*Spawning marshes adjoin Tombeau Lake.*

[c]*The only existing swimming opportunity is on Bass Bay.*

[d]*Poor quality.*

[e]*Limited existing supply.*

[f]*Heavy aquatic growth precludes this use.*

[g]*Only a minor use.*

[h]*Marginal quality.*

[i]*An existing five mph speed limit for boats precludes the use.*

[j]*Primarily located on Lower Phantom Lake.*

Source: Wisconsin Department of Natural Resources.

sents a serious sanitary hazard to people using the lake. Since the conditions of development around Little Muskego Lake are similar to conditions around many of the lakes in the watershed, it would appear that sanitary hazards may exist at several of the lakes. Increased 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 in the lakes of the Fox 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 that water. Over extended periods of time, 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 the body of water for most of the desirable uses, such as recreation. This aging of a lake is a natural process in all surface waters and generally requires hundreds to 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 a limiting concentration. Generally, the elements thought to limit the fertility of a lake are the nitrogen and phosphorus compounds. The rate at 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 divided into natural and artificial (cultural) sources. Nutrients derived from rainfall; ground water; and runoff from marshes, forests, and other areas are indicative of natural eutrophication. Nutrients derived from man's activities in the watershed, including such sources as agricultural runoff, waste water effluents, urban runoff, and septic tank drainage, 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 man's activities can render a lake eutrophic in a few years.

Most of the lakes in the Fox 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 the eutrophication was basically a natural phenomenon in the past, nutrient inflow resulting from man's activities in the watershed has increased the rate of eutrophication in recent years. Estimates of the nutrients presently contributing to some of the lakes in the watershed from both natural and artificial sources are shown in Table 60. These figures indicate that over three-fourths of the phosphorus and slightly less than one-half of the nitrogen presently entering the lakes are derived from man's activities in the watershed. The major artificial sources 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 of 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 given rise to increased populations of rough fish, such as carp and suckers. A more detailed description of the specific problems occurring in each of the major lakes in the Fox River watershed is presented in the individual lake study reports prepared as a part of this study, but published separately.[9]

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 lake water quality problems will be intensified and new problems will develop in lakes presently suitable for recreational uses. It is to 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,

[9] *Individual lake plans for the 45 major lakes within the watershed may be obtained on a limited basis from the Southeastern Wisconsin Regional Planning Commission and the Wisconsin Department of Natural Resources.*

Table 60

ESTIMATES OF NUTRIENTS CONTRIBUTED TO LAKES IN THE FOX RIVER WATERSHED

Lake	Nutrient	Source: Municipal Waste Water (Percent)	Source: Septic Tanks (Percent)	Source: Rural Runoff (Percent)	Source: Manured Land (Percent)	Source: Urban Runoff (Percent)	Source: Precipitation (Percent)	Source: Groundwater (Percent)	Total: Percent	Total: Pounds Per Year
Beulah	Nitrogen	0	10	1	14	0	31	44	100	19,000
	Phosphorus	0	10	12	66	0	7	5	100	1,400
Bohner	Nitrogen	0	54	2	12	0	24	8	100	4,700
	Phosphorus	0	39	15	41	0	5	0	100	400
Browns	Nitrogen	0	46	1	4	0	42	7	100	7,200
	Phosphorus	0	60	5	22	0	13	0	100	400
Buena	Nitrogen	49	14	1	7	4	4	21	100	930,000
	Phosphorus	73	5	4	12	5	0	1	100	180,000
Camp And Center	Nitrogen	0	28	1	10	0	37	24	100	13,000
	Phosphorus	0	26	14	48	0	9	3	100	900
Como	Nitrogen	0	20	1	12	0	42	25	100	19,000
	Phosphorus	0	18	10	59	0	10	3	100	1,400
Eagle	Nitrogen	0	21	2	14	0	51	12	100	8,200
	Phosphorus	0	17	18	54	0	10	1	100	700
Echo	Nitrogen	9	15	2	20	1	15	38	100	410,000
	Phosphorus	22	8	11	52	3	2	2	100	52,000
Elizabeth And Marie	Nitrogen	0	7	1	7	5	38	42	100	19,000
	Phosphorus	0	8	11	40	23	12	6	100	1,100
Geneva	Nitrogen	0	8	1	11	7	52	21	100	80,000
	Phosphorus	0	7	6	47	26	12	2	100	6,000
Big Muskego[a]	Nitrogen	0	4	1	8	0	46	41	100	38,000
	Phosphorus	0	5	13	57	0	18	7	100	1,800
Little Muskego	Nitrogen	0	51	2	7	0	14	26	100	28,000
	Phosphorus	0	47	12	34	0	4	3	100	2,000
Pell	Nitrogen	0	65	1	7	0	15	12	100	6,000
	Phosphorus	0	58	4	32	0	4	2	100	500
Pewaukee	Nitrogen	0	18	1	9	3	33	36	100	57,000
	Phosphorus	0	18	14	43	11	9	5	100	3,800
Phantom[b]	Nitrogen	0	4	1	5	5	9	76	100	47,000
	Phosphorus	0	4	11	39	28	4	14	100	2,200
Powers, Tombeau, And Benedict	Nitrogen	0	21	2	13	0	40	24	100	10,000
	Phosphorus	0	17	17	54	0	9	3	100	800
Silver	Nitrogen	0	19	2	16	0	57	6	100	6,400
	Phosphorus	0	14	17	59	0	10	0	100	600
Wind[c]	Nitrogen	0	32	1	9	0	40	18	100	16,000
	Phosphorus	0	29	14	45	0	10	2	100	1,100

[a] *Does not include nutrients contained in outflow from Little Muskego Lake.*

[b] *Does not include nutrients contained in outflow from Beulah and Eagle Spring Lakes.*

[c] *Does not include nutrients contained in outflow from Big Muskego Lake.*

Source: Harza Engineering Company.

in the face of a rising demand for recreation, constitute a serious problem within the watershed.

SUMMARY

This chapter has described surface water quality conditions in the Fox 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 for the streams within the watershed; and the existing and potential surface water pollution problems in the watershed. Significant findings are summarized in the following paragraphs.

Dissolved oxygen, coliform bacteria count, and temperature were selected as the most significant parameters for evaluation of stream water quality in the Fox River watershed. Dissolved oxygen levels are normally lowest and temperature highest during the summer months. Low dissolved oxygen levels are prevalent in many areas of the Fox River above Mukwonago, Pewaukee River, and Poplar Creek. The Fox River and its tributaries below Mukwonago generally contain high concentrations of dissolved oxygen. Coliform counts are very high in the Fox River above Mukwonago and from Waterford to the state line and below all the sewage treatment plants located on tributaries to the Fox River. In general, pollution is very evident in most areas of the upper Fox River watershed and is likely to increase as urbanization increases. Some water quality degradation is also taking place below sewage treatment plants located on the tributaries, and this also is likely to increase as urbanization increases in these areas.

Municipal sewage treatment plant discharges are by far the most significant cause of water pollution in the Fox River and its tributaries. They particularly affect water quality in the upper Fox River watershed, where natural streamflow is lowest and the concentration of population highest. Industrial waste discharges, agricultural and urban runoff, and inadequate septic tank systems contribute to local stream pollution conditions; but their overall effect on regional water quality conditions is presently overshadowed by the pollution caused by municipal waste discharges.

The discharge of treated wastes from sewage treatment plants in the watershed has resulted in depressed dissolved oxygen levels and high coliform concentrations below some of the effluent outfalls and has stimulated the growth of algae and other aquatic plants in many areas. Table 61 summarizes the present and future suitability of water quality for various uses of the major streams in the watershed. Pollution has currently rendered four of the 13 major streams shown in this table unsuitable for the preservation and enhancement of aquatic life and nine unsuitable for any recreational activities either in some sections of the stream or throughout the entire stream.

Forecasts of 1990 water quality conditions made using the simulation model developed for this purpose indicate that pollution will cause water quality in six of the 13 streams within the watershed to be unsuitable for the maintenance of fish life unless an effective water quality management plan is adopted and implemented. Streams that could be expected to be unsuitable to this use included the Fox River from Lannon to Mukwonago, Sussex Creek, Pewaukee River, Honey Creek, White River, and Bassett Creek. The forecasts further indicate that 11 of the 13 streams would be unsuitable for any water-based recreational use unless adequate disinfection of waste discharges is provided. The two exceptions are Poplar Creek and Nippersink Creek. These forecasts were made under the assumption that by 1990 all of the sewage treatment plants will be providing secondary treatment and adequate disinfection of the effluent. In addition to the problems resulting from low oxygen levels and high coliform concentrations, the discharge of large amounts of nutrients in the sewage treatment plant effluents will stimulate the growth of algae and other aquatic plants in many of the streams; and this may limit the use of those streams for recreation and aesthetics.

Water quality standards applicable to surface waters in Wisconsin have been adopted by the Wisconsin Resource Development Board. These standards specify the minimum water quality that must be maintained for various uses of the water. They are of particular importance in developing alternative water quality management plans for the Fox River watershed.

The lakes of the Fox River watershed are generally in an advanced state of eutrophication, as exhibited by high phosphorus content, dissolved

Table 61

EXISTING AND FUTURE SUITABILITY OF WATER QUALITY FOR MAJOR WATER USES IN STREAMS ON THE FOX RIVER WATERSHED: 1966 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
Fox River																
Headwaters To Waukesha	U	U	NA	NA	U	U	NA	NA	S	NA	S	U	NA	NA	U	U
Waukesha To Mukwonago	U	U	NA	NA	U	S[a]	NA	S	S	S	S	S	NA	S	S	S[a]
Mukwonago To Waterford	S	S	U	S	S	S[a]	NA	S	S	S	S	S	NA	S	S	S[a]
Waterford To State Line	S	S	U	S	U	S	NA	S	S	S	S	S	NA	S	S	S
Sussex Creek	S	U	NA	NA	NA	U	NA	NA	NA	NA	S	U	NA	NA	S	U
Poplar Creek	U	S	NA	NA	S	S	NA	NA	NA	NA	S	S	NA	NA	S	S
Pewaukee River	U	U	NA	NA	U	U	NA	NA	NA	NA	S	U	NA	NA	S	U
Pebble Creek	S	S	NA	NA	U	S	NA	NA	NA	NA	S	S	NA	NA	S	S
Genesee Creek	S	S	NA	NA	U	S	NA	NA	NA	NA	S	S	NA	NA	S	S
Mukwonago River	S	S	U	S	U	S	NA	NA	S	S	S	S	NA	S	S	S
Wind Lake Drainage Canal	S	S	NA	NA	S	S	NA	NA	S	S	S	S	NA	S	S	S
Honey Creek	S	U	NA	NA	U	S	S	S	S	S	S	S	NA	S	S	S
Sugar Creek	S	S	NA	NA	U	S	NA	NA	S	S	S	S	NA	S	S	S
White River	S	U	NA	NA	U	S	NA	NA	S	S	S	S	NA	S	S	S
Bassett Creek	U	U	NA	NA	U	S[a]	NA	NA	NA	NA	S	S	NA	NA	S	S[a]
Nippersink Creek	S	S	NA	NA	S	S	NA	NA	NA	NA	S	S	NA	NA	S	S

[a] *Excessive algae blooms may restrict this use.*

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.

Source: Harza Engineering Company.

oxygen depletion, and large growths of algae and aquatic weeds. Coliform levels and concentrations of ions indicative of pollution are high in many of the lakes and may indicate a sanitary hazard resulting from domestic sewage discharges from homes around some of the lakes. High pesticide levels in the watershed indicate a significant level of contamination in the surface waters.

Existing and future water uses of the major lakes in the Fox River watershed are almost 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 Muskego Lake has been shown, and other lakes are suspected of being public health hazards 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; and depleted oxygen levels have destroyed a large portion of the sports fishery. The causes of this overfertilization are plant nutrients being supplied to the lakes from natural sources and, more importantly, from man's activities in the watershed. Future problems in the lakes will be similar to the existing problems, but they will be more intense and widespread. Unless appropriate action is taken, the number of lakes suitable for various types of recreational activities will continue to decrease in the future.

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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. Three major aquifers exist in the Fox River watershed, as indicated in Chapter IV. 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 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 aquifer." These aquifers are normally supplied with water from zones known as recharge areas. The shallow aquifers in the Fox River watershed are usually recharged by water being supplied from a surface source (stream, lake, or direct rainfall) through porous soil or rock in their immediate areas, while the deep aquifer is usually recharged by water entering the ground from the Kettle Moraine region and flowing through the porous rock to the deeper reaches of the earth's crust.

Pollution of the shallow ground water aquifer has occurred locally within the watershed through the introduction of waste discharges into creviced dolomite or limestone bedrock, where these formations outcrop or are located near the land surface. The deep aquifer, however, has not been contaminated by any sources yet known.

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 through or over 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.

Characteristics of Ground Water

The ground water of the Fox River watershed is chemically classified as hard, containing relatively high concentrations of calcium, magnesium, and sulfate. Other important constituents in the ground water include iron, manganese, sodium, bicarbonate, chloride, fluoride, and nitrate. Important physical characteristics of ground water include taste, odor, color, hardness, alkalinity, and hydrogen ion concentration (pH).

The chemical and physical characteristics of the ground water are summarized in Table 62, which lists the results of the analysis of water samples from 65 representative public and private water-supply wells drawing water from both the shallow and deep aquifers of the watershed. The locations of the sampled wells are shown on Map 42 and are representative of hundreds of such sampled wells throughout the watershed. As such, these wells provide a good indication of the quality of the water which the majority of the watershed population is consuming. These chemical analyses indicate the variability in ground water quality within the watershed, as well as the overall quality of the ground water.

The natural chemical and physical characteristics of the ground water supplies are extremely important to domestic, municipal, and industrial water users. Because knowledge of the significance of these water quality factors is basic to any study of ground water resources, the major chemical constituents and physical characteristics of these resources and the significance thereof are discussed below.

Calcium and Magnesium: Calcium and magnesium are contained in both the shallow and deep aquifer ground water supplies within the watershed, being

Table 62

CHEMICAL ANALYSES OF GROUND WATER FROM PUBLIC AND PRIVATE WATER-SUPPLY WELLS IN THE FOX RIVER WATERSHED[a]

Sample No.	Owner of Well	Well Depth (Feet)	Aquifer[b]	Date of Collection	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Nitrite (NO_2)	Total Solids	Hardness as $CaCO_3$	Alkalinity as $CaCO_3$	pH (Field)
1	C/Brookfield (Camelot Forest)	250	Nd	8- 9-66	0.36	<0.04	98	39.6	6.5	372	85	37.0	0.25	< 2.0	<0.01	512	410	305	7.3
2	C/Brookfield (Camelot Forest)	250	Nd	8- 9-66	5.00	<0.04	99	41.0	10.0	375	85	47.0	0.25	< 2.0	<0.01	566	418	307	7.4
3	C/Brookfield (Cardinal Crest)	1,025	Ss	8- 9-66	0.69	0.06	93	25.8	20.0	249	160	11.0	0.50	2.0	<0.01	504	340	204	7.5
4	C/Brookfield (Carriage Hills)	354	Nd	8-29-66	0.96	<0.05	71	35.6	6.1	359	40	5.0	0.45	< 2.0	< 0.65	348	326	294	7.3
5	C/Brookfield (Dominic Heights)	359	Nd	8- 9-66	0.45	<0.04	54	24.5	4.0	266	55	2.3	0.70	< 2.0	<0.01	304	237	218	7.4
6	C/Brookfield (Greenfield Heights)	400	Nd	8- 9-66	0.64	<0.04	75	44.3	4.5	392	45	8.5	0.40	< 2.0	< 0.01	414	372	321	7.4
7	C/Brookfield (Greenfield Heights)	401	Nd	8- 9-66	2.30	0.06	80	35.6	3.7	390	30	1.8	0.35	< 2.0	0.02	366	348	320	7.4
8	C/Brookfield (Imperial Estates)	1,740	Ss	8- 9-66	0.43	<0.04	80	20.4	16.0	211	130	12.0	0.50	< 2.0	<0.01	410	285	173	7.6
9	C/Brookfield (Imperial Estates)	350	Nd	8- 9-66	0.23	<0.04	78	27.4	11.0	278	100	6.0	0.50	< 2.0	< 0.01	384	309	228	7.6
10	C/Brookfield (Mission Heights)	360	Nd	8-30-66	1.10	<0.05	74	44.4	11.6	343	88	12.5	0.80	< 2.0	0.01	462	370	281	7.4
11	C/Burlington	995	Ss	8-31-66	0.24	<0.05	59	28.0	8.6	268	50	4.5	0.55	< 2.0	0.36	302	264	220	7.4
12	C/Burlington	1,440	Ss	8-31-66	0.44	<0.05	62	27.6	7.6	276	52	4.5	0.55	< 2.0	0.01	314	270	226	7.4
13	C/Burlington	1,492	Ss	8- 9-66	0.12	<0.04	63	24.4	4.8	283	36	3.4	0.55	< 2.0	<0.01	296	259	232	7.3
14	C/Burlington	1,475	Ss	8- 9-66	0.15	<0.04	62	24.5	6.3	295	28	2.7	0.65	< 2.0	<0.01	284	257	242	7.3
15	Country Club Estates (V/Fontana)	150	SG	7-27-66	<0.04	<0.04	80	36.2	3.8	338	44	14.0	0.15	18.1	<0.01	412	351	277	7.2
16	V/Eagle	880	Ss	8-10-66	<0.04	<0.04	60	28.6	3.4	333	6	1.3	0.45	<2.0	0.17	284	269	273	7.3
17	Eagle Lake Manor	115	SG	8-31-66	0.32	<0.05	37	34.4	35.0	331	33	3.0	0.95	< 2.0	< 0.01	298	236	271	7.7
18	Eagle Lake Manor	180	SG	8-31-66	0.30	<0.05	45	42.6	23.0	381	28	2.0	0.75	< 2.0	0.01	340	290	312	7.5

Table 62 (continued)

CHEMICAL ANALYSES OF GROUND WATER FROM PUBLIC AND PRIVATE WATER SUPPLY WELLS IN THE FOX RIVER WATERSHED[a]

Sample No.	Owner of Well	Well Depth (Feet)	Aquifer[b]	Date of Collection	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Nitrite (NO_2)	Total Solids	Hardness as $CaCO_3$	Alkalinity as $CaCO_3$	pH (Field)
19	V/East Troy	690	SG-Ss	8-10-66	1.03	< 0.04	81	46.0	10.0	398	52	1.6	0.50	< 2.0	< 0.01	512	394	326	7.4
20	V/East Troy	210	SG	8-10-66	1.40	0.04	80	40.3	4.4	394	48	8.0	0.40	< 2.0	< 0.01	452	368	323	7.4
21	V/East Troy	100	SG	8-10-66	0.17	< 0.04	80	34.1	4.6	362	39	7.5	0.40	9.2	< 0.01	428	342	297	7.4
22	C/Elkhorn	1,500	Ss	8- 9-66	0.38	< 0.04	62	32.2	12.0	395	3	< 1.0	0.30	< 2.0	< 0.01	304	289	324	7.3
23	C/Elkhorn	1,654	Ss	8- 9-66	0.23	< 0.04	56	31.4	21.0	421	2	< 1.0	0.45	< 2.0	< 0.01	326	271	345	7.3
24	C/Elkhorn	1,648	Ss	8- 9-66	0.66	0.04	59	31.6	19.0	410	2	< 1.0	0.40	< 2.0	0.02	338	279	336	7.3
25	C/Elkhorn	--	--	8- 9-66	< 0.04	< 0.04	16	29.3	13.0	238	6	3.3	--	< 2.0	0.01	158	162	195	8.4
26	V/Fontana	138	SG	7-27-66	< 0.04	< 0.04	82	41.6	2.5	371	51	3.5	0.15	9.2	< 0.01	384	365	304	7.4
27	V/Fontana	130	SG	7-27-66	< 0.04	< 0.04	77	34.8	3.6	330	36	8.5	0.05	11.0	< 0.01	344	320	270	7.6
28	V/Genoa City	1,080	SG-Ss	7-25-66	1.09	< 0.04	74	36.4	7.6	373	28	3.2	0.35	< 2.0	0.01	338	337	306	7.6
29	V/Hartland	81	SG	7- 6-66	< 0.04	< 0.04	77	34.4	5.2	325	41	10.0	0.20	9.2	0.02	404	336	266	7.4
30	Highlands Water Co-op (V/Pewaukee)	1,248	Ss	8-10-66	0.47	< 0.04	54	25.9	7.5	285	44	1.4	0.45	< 2.0	0.05	262	243	234	7.6
31	C/Lake Geneva	800	Ss	8- 8-66	0.83	< 0.04	65	34.4	9.6	394	5	1.6	0.30	< 2.0	< 0.01	314	306	323	7.3
32	C/Lake Geneva	205	SG	8- 8-66	1.70	< 0.04	76	36.0	7.2	416	13	3.9	0.30	< 2.0	< 0.01	372	340	341	7.4
33	C/Lake Geneva	95	SG	8- 8-66	0.42	< 0.04	63	35.6	16.0	336	27	27.0	0.30	4.0	0.04	410	306	275	7.4
34	C/Lake Geneva[c]	--	--	8- 8-66	< 0.04	< 0.04	67	33.7	15.0	343	24	22.0	--	4.4	0.40	394	308	282	7.7
35	Lake Knolls Subdivision (Powers Lake Area)	135	SG	7-28-66	< 0.04	< 0.04	91	41.6	4.9	407	45	9.5	0.10	12.4	0.01	450	401	334	7.2
36	V/Menomonee Falls	1,394	Ss	7-28-66	0.10	< 0.04	117	30.1	8.6	305	155	7.5	0.35	< 2.0	0.02	536	418	250	7.4
37	Monterey Park City of New Berlin	405	Nd	8-10-66	0.74	< 0.04	67	54.4	9.1	481	42	1.8	0.80	< 2.0	0.02	454	394	394	7.6
38	V/Mukwonago	--	--	7- 7-66	0.17	< 0.04	74	39.2	9.2	361	42	14.0	0.50	< 2.0	0.02	416	348	296	7.4
39	V/Mukwonago	1,541	Ss	7- 7-66	0.21	< 0.04	58	23.0	6.9	257	32	2.1	0.50	< 2.0	0.01	300	241	211	7.4
40	C/New Berlin (Forest View Heights)	1,500	Ss	8-18-66	0.54	< 0.04	96	38.0	18.0	295	143	14.0	0.50	2.0	< 0.01	484	398	242	7.6

Table 62 (continued)

CHEMICAL ANALYSES OF GROUND WATER FROM PUBLIC AND PRIVATE WATER SUPPLY WELLS IN THE FOX RIVER WATERSHED[a]

Sample No.	Owner of Well	Well Depth (Feet)	Aquifer[b]	Date of Collection	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Nitrite (NO_2)	Total Solids	Hardness as $CaCO_3$	Alkalinity as $CaCO_3$	pH (Field)
41	C/New Berlin (Industrial Park)	1,800	Ss	8-18-66	0.59	<0.04	119	24.6	17.0	305	165	14.0	1.00	< 2.0	< 0.01	542	400	250	7.2
42	North Cape	300	Nd	8- 1-66	0.09	< 0.04	16	11.3	59.0	162	65	3.2	1.30	< 2.0	0.02	246	87	133	8.0
43	Oakwood Knolls (Antioch, Ill.)	--	--	7-26-66	0.57	<0.04	46	31.7	42.0	338	65	3.9	0.90	< 2.0	<0.01	362	247	277	7.6
44	V/Pewaukee	1,345	Ss	7- 6-66	0.15	0.04	63	28.3	9.8	305	29	2.2	1.25	< 2.0	0.03	334	275	250	7.5
45	V/Pewaukee	1,250	Ss	7- 6-66	0.31	0.04	70	29.0	15.0	301	62	6.5	0.45	< 2.0	0.01	396	296	247	7.5
46	Sussex Estates	1,295	Ss	8-16-66	0.35	0.04	82	25.0	14.0	299	90	9.5	0.50	2.0	<0.01	392	309	245	7.4
47	Troy Center Sanitary District	626	Ss	8-11-66	1.20	<0.04	72	30.7	1.8	351	23	2.0	0.20	< 2.0	<0.01	340	308	288	7.4
48	V/Walworth	87	SG	7-27-66	<0.04	<0.04	77	36.1	2.9	338	51	8.0	0.15	17.3	0.02	416	343	277	7.3
49	V/Waterford	1,520	Ss	8- 9-66	0.27	<0.04	68	18.5	5.6	268	44	3.3	0.75	< 2.0	<0.01	294	247	220	7.4
50	Waterford Woods	184	Nd	8-30-66	0.36	<0.05	66	33.1	4.6	334	41	2.0	0.30	<2.0	0.03	338	308	274	7.5
51	C/Waukesha	1,907	Ss	7- 7-66	0.38	<0.04	91	28.0	10.6	278	114	12.0	0.55	<2.0	0.02	480	344	228	7.5
52	C/Waukesha	1,835	Ss	7- 7-66	0.25	< 0.04	70	25.9	8.2	267	66	4.4	0.55	<2.0	0.01	358	283	215	7.5
53	C/Waukesha	1,995	Ss	7- 7-66	0.42	0.08	87	30.3	6.9	321	73	4.6	0.50	<2.0	0.01	418	344	263	7.3
54	C/Waukesha	1,995	Ss	7- 7-66	0.41	0.04	113	26.6	6.9	293	147	4.6	0.60	2.0	0.01	528	393	240	7.5
55	C/Waukesha	2,120	Ss	7- 7-66	0.53	0.04	181	20.0	10.0	256	310	6.3	0.95	2.0	0.01	776	536	210	7.2
56	C/Waukesha	2,075	Ss	7- 7-66	0.45	0.04	79	26.0	5.8	320	53	2.1	0.50	2.0	0.01	372	306	262	7.5
57	C/Waukesha	2,141	Ss	7- 7-66	0.40	<0.04	81	22.4	5.9	282	64	2.2	0.50	<2.0	<0.01	364	296	231	7.5
58	Westbrooke Sanitary District (C/Brookfield)	314	Ss	8-16-66	0.22	<0.04	73	37.0	4.7	368	43	6.0	0.90	<2.0	0.03	354	338	302	7.5
59	Westbrooke Sanitary District	350	Ss	8-16-66	0.42	<0.04	78	36.0	3.3	342	58	9.0	0.50	<2.0	0.06	374	344	280	7.7
60	Westchester Water Co-op (C/Brookfield)	--	Nd	8-10-66	1.02	< 0.04	73	45.5	6.5	423	38	1.4	0.50	3.1	0.02	428	372	347	7.4

Table 62 (continued)

CHEMICAL ANALYSES OF GROUND WATER FROM PUBLIC AND PRIVATE WATER SUPPLY WELLS IN THE FOX RIVER WATERSHED[a]

Sample No.	Owner of Well	Well Depth (Feet)	Aquifer[b]	Date of Collection	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Nitrite (NO_2)	Total Solids	Hardness as $CaCO_3$	Alkalinity as $CaCO_3$	pH (Field)
61	Westchester Water Co-op	--	Nd	8-10-66	0.08	< 0.04	73	36.4	4.4	382	30	2.6	0.35	< 2.0	< 0.01	368	334	313	7.4
62	Westfield Water Co-op (C/Brookfield)	--	Nd	8-15-66	0.48	< 0.04	75	45.2	4.6	406	50	5.0	0.75	< 2.0	< 0.01	408	376	333	7.4
63	V/Williams Bay	257	SG	8- 8-66	3.10	< 0.04	67	38.8	20.0	471	3	<7.0	0.40	< 2.0	0.03	720	329	386	7.4
64	V/Williams Bay	290	SG	8- 8-66	1.65	< 0.04	65	34.0	20.0	466	3	<1.0	0.40	< 2.0	< 0.01	372	304	382	7.3
65	V/Williams Bay[d]	--	--	8- 8-66	0.06	< 0.04	3	19.3	20.0	168	7	<1.0	--	3.50	3.10	140	88	138	9.6

[a]*Analyses given in Mg/1 except pH, which is in units.*

[b]*SG denotes sand and gravel, Nd denotes Niagara dolomite, and Ss denotes sandstone.*

[c]*Treated water.*

[d]*Treated water from Sample No. 64.*

Note: *Underlined values exceed the U. S. Public Health Service recommendations for drinking water quality.*

Source: *U. S. Geological Survey.*

dissolved from limestone, dolomite, and other rock and soil. As shown in Table 62 , calcium concentrations in the ground water range from 16 mg/l to 181 mg/l and average about 75 mg/l. Magnesium concentrations range from 11.3 mg/l to 54.4 mg/l and average about 33 mg/l. High calcium and magnesium concentrations in the ground water are the major causes of hardness and scale-forming properties. However, ground water containing small concentrations of dissolved calcium and magnesium 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 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

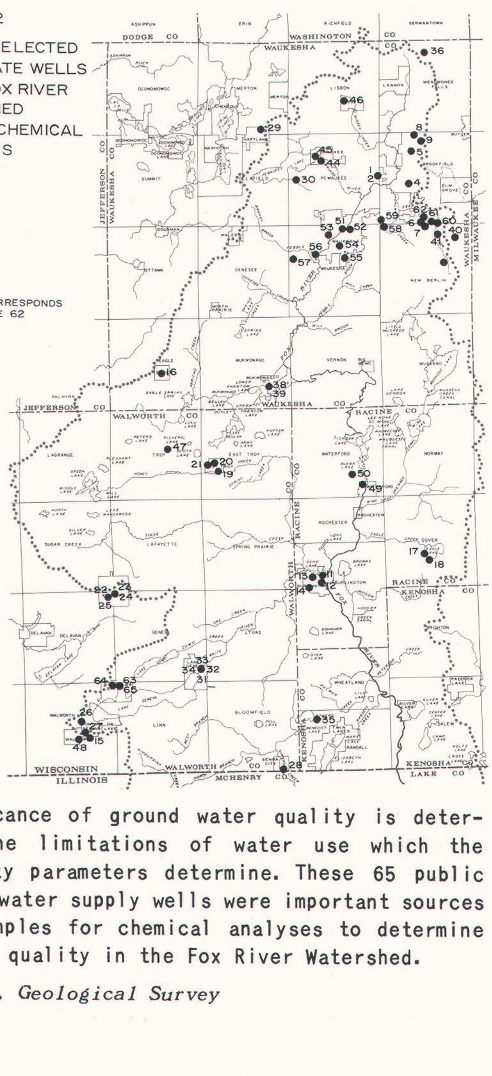
Map 42

INDEX MAP OF SELECTED PUBLIC AND PRIVATE WELLS WITHIN THE FOX RIVER WATERSHED SUBJECTED TO CHEMICAL ANALYSIS (1966)

LEGEND

● WELL SITE

NOTE: NUMBER OF SITE CORRESPONDS TO LISTING IN TABLE 62



The significance of ground water quality is determined by the limitations of water use which the water quality parameters determine. These 65 public and private water supply wells were important sources of water samples for chemical analyses to determine ground water quality in the Fox River Watershed.

Source: U.S. Geological Survey

1.8 mg/l to 59 mg/l and average about 11 mg/l, as shown in Table 62.

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 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 carbonated rocks (limestone and dolomite). The ground water supplies in the Fox River watershed are relatively high in bicarbonate, with concentrations ranging from 162 mg/l to 481 mg/l and averaging about 338 mg/l. Carbonate salts, however, are generally insoluble; and, based upon alkalinity and pH measurements, carbonate is seldom present in ground water in the area.

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, 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. In the Fox River watershed, the concentration of sulfate ranges from 2 mg/l to 310 mg/l and averages about 59 mg/l, as shown in Table 62. Only one water sample shown in this table, Sample No. 55, indicated a concentration greater than 250 mg/l, which is the recommended limiting sulfate concentration established by the U. S. Public Health Service Drinking Water Standards 1962.

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 Table 62, concentrations range from less than 1 mg/l to 47 mg/l; and over 80 percent of the water samples had chloride concentrations of less than 10 mg/l.

The small quantities of chloride contained in the ground water of the Fox River watershed have little effect on the use of water. All the ground water samples tested (see Table 62) contained chloride concentrations that were substantially less than the U. S. Public Health Service Drinking Water Standards 1962 recommended limiting concentration of 250 mg/l.

Fluoride: Fluoride compounds are not naturally abundant except in localized deposits and occur in relatively small quantities within the watershed. The fluoride content of ground water within the watershed ranges from 0.05 mg/l to 1.3 mg/l in public and private water supplies and averages about 0.5 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 on 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 by the U. S. Public Health Service Drinking Water Standards 1962 varies with the annual average maximum daily air temperature and ranges downward from 1.5 mg/l to 0.8 mg/l for an average maximum daily temperature range of 53.8 through 58.3°F. The optimum fluoride concentration for this temperature range is 1.1 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. Analyses of ground water in the Fox 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 replenished with surface water.

The U. S. Public Health Service Drinking Water Standards 1962 recommends 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 5 mg/l, nitrate has no adverse effect on most water uses. Within the watershed concentrations of nitrate range from 2.0 mg/l to 18.1 mg/l, as shown in Table 62.

Nitrite is produced by bacteria from soil ammonia. Like nitrate, the nitrite content of ground water in the Fox 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) range from 0.01 mg/l to 3.1 mg/l, as shown in Table 62.

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.

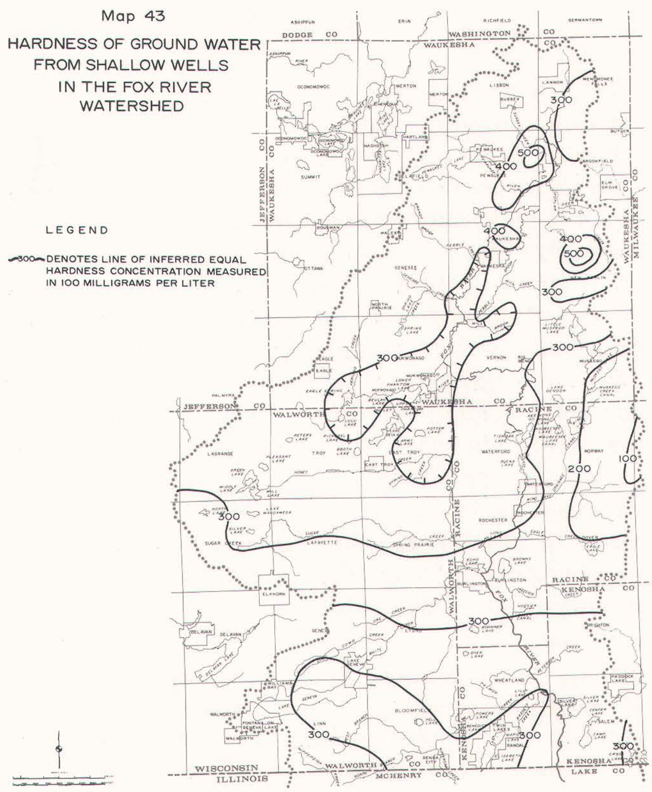
Iron: Because iron is one of the more abundant metallic elements of the earth's crust, iron is dissolved from nearly all rock and soil. Objectionable amounts of iron occur in most wells and range to more than 10 mg/l in parts of the watershed. The occurrence of iron appears to be unpredictable, and high iron concentrations are found throughout the watershed. An important criterion, however, appears to be that wells yielding objectionable concentrations of iron often are in swamp or marsh areas or in areas where ground water movement is extremely slow. Wells in the sandstone aquifer generally yield water lower in iron content than do shallower wells in the same portions of the watershed.

Many uses of water are adversely affected by high iron content. Concentrations higher than about 0.3 mg/l stain laundry, porcelain, and enamel ware; and iron in water supplies is objectionable for food processing, beverages, dyeing, bleaching, ice manufacturing, and brewing. Large 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. The U. S. Public Health Advisory Committee on Drinking Water Standards recommends that iron concentrations in water supplies not exceed 0.3 mg/l. Table 62 shows at least 39 wells exist within the watershed which produce water containing iron concentrations in excess of this amount.

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 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 246 mg/l to 776 mg/l and averaging about 400 mg/l. As indicated in Table 62 , nine wells produced water with concentrations higher than the U. S. Public Health Service Drinking Water Standards 1962 recommended limiting concentration of 500 mg/l. High dissolved solids concentrations are common to both shallow and deep wells within the watershed. As a result of high dissolved solids concentrations, two water utilities within the watershed, one serving the City of Elkhorn and one at the Village of Williams Bay, treat their raw water to remove excessive mineralization.

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 Fox River watershed. Map 43 indicates the geographical distribution of hardness within the shallow aquifer of the watershed. The hardness in some wells in eastern Waukesha County is greater than 500 mg/l. Water from public and private water utilities averages about 320 mg/l. The water utilities serving the City of Elkhorn and Village of Williams Bay treat their raw water to remove part of the hardness. Table 63 is useful in the evaluation of ground water hardness and, in a general way, as to its suitability for public and domestic water supplies.



The Ground Water in the shallow aquifer underlying the Fox River Watershed is generally hard reaching in excess of 500 mgll of equivalent calcium carbonate hardness in the upper areas of the watershed.

Source: U.S. Geological Survey

Table 63

U. S. GEOLOGICAL SURVEY WATER HARDNESS RATINGS

Hardness Range As $CaCO_3$ (In Mg/l)	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	Generally unsuitable for public or domestic use without softening.
More than 180[a]	Very Hard Water	Requires softening for almost all uses other than irrigation.

[a]*The values for very hard water in this table vary from those given in SEWRPC Technical Report No. 4, Water Quality and Flow of Streams in Southeastern Wisconsin, page 64.*

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 Fox River watershed is relatively high, ranging from 133 mg/l to 394 mg/l and averaging about 273 mg/l, as shown on Table 62. This level of alkalinity is, however, acceptable for most water uses.

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 Fox River watershed, raw water supplies used by public and private water utilities are generally slightly basic in character. Of the samples shown in Table 62 , about 90 percent of the pH values lie within the range 7.2 to 7.6; and the average pH value is about 7.4. Water treatment, as provided by the water utilities serving the City of Elkhorn and the Village of Williams Bay, to remove objectionable mineral constituents may greatly increase the pH, as indicated by the analyses of Sample Nos. 25 and 65 in Table 62.

Ground Water Suitability for Selected Uses

The foregoing description of the major dissolved constituents and physical properties of the ground water of the Fox River watershed sets forth, in a general way, the factors which may limit the use of water for domestic, municipal, industrial, and agricultural purposes. Requirements of water quality differ widely between specified water uses, and the water quality requirements of some industries are far more rigid than the requirements for public supplies. The chemical character of water for public supplies is commonly judged through the use of the recommendations for drinking water standards of the U. S. Public Health Service.[1] These recommendations, together with commonly prescribed water quality standards for selected

[1] *Drinking Water Standards, U. S. Public Health Service Publication No. 956, 1962.*

industrial and agricultural uses, have been compiled by the Commission and are presented in Table 64.

The quality of the ground water supplies of the watershed is, in general, superior to the stream water quality because large fluctuations of stream discharge result in concentration or dilution of dissolved mineral constituents. Municipal and industrial waste discharges and urban and rural runoff result in stream contamination.

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 90. 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 in 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.

Most ground water contains little or no dissolved oxygen; and where it enters a stream in large quantities, the overall dissolved oxygen content is reduced. This factor may be important under base flow stream conditions because high dissolved oxygen content is needed to oxidize organic pollutants, which may be present in the stream, and to maintain a balanced aquatic population. In most streams of the Fox River watershed, however, the discharge rate of ground water into the stream system is sufficiently low that only minor reduction of dissolved oxygen levels is apparent.

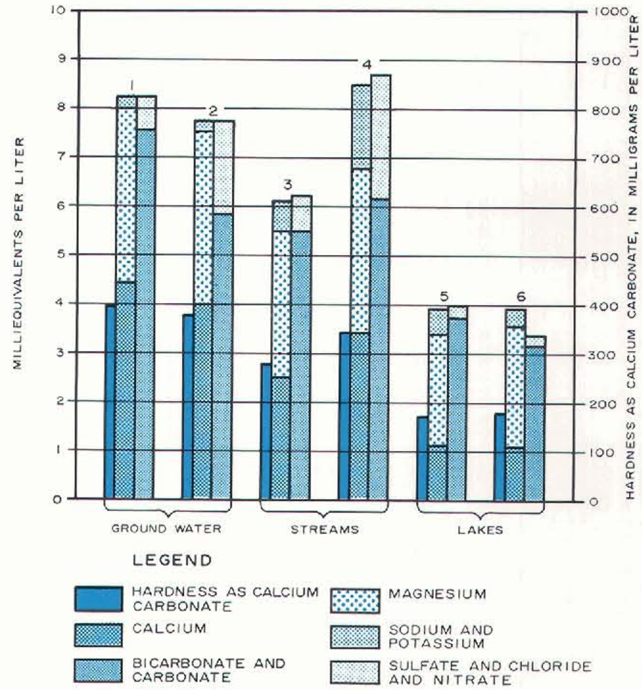
PRESENT AND POTENTIAL POLLUTION OF GROUND WATER

Source and Movement

Many potential sources of ground water pollution exist in the Fox 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

Figure 90

MINERALIZATION OF GROUND WATERS, STREAM WATER AT BASE FLOW, AND LAKE WATER IN THE FOX RIVER WATERSHED



SOURCE

1. FROM 152-FT. WELL IN DOLOMITE. SEC. 27, T. 5N., R. 19E., TOWN OF VERNON, WAUKESHA COUNTY
2. FROM 75-FT. WELL IN SAND AND GRAVEL. SEC. 18, T. 2 N. R. 19 E., TOWN OF BURLINGTON, RACINE COUNTY
3. MUKWONAGO RIVER AT MUKWONAGO. BASE FLOW ON OCTOBER 7, 1964
4. FOX RIVER AT WILMOT. BASE FLOW ON OCTOBER 7, 1964
5. LITTLE MUSKEGO LAKE, WAUKESHA CO., ON SEPTEMBER 13, 1966, DEPTH 30 FT.
6. SILVER LAKE, KENOSHA CO., ON AUGUST 23, 1966, DEPTH 30 FT.

Source: U. S. Geological Survey.

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.

[2] *Since December 31, 1965, the sale of non-biodegradable (hard) detergents containing alkyl benzene sulfonate has been prohibited in Wisconsin (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 are of the ''soft'' type.*

Table 64

WATER QUALITY STANDARDS[a] FOR MAJOR WATER USES RECOMMENDED BY THE SEWRPC

Parameter[b]	Municipal (Public) Water Supply		Industrial Water Supply														
	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	Cooling
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	---	---	---
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	---	---	---
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
Specific Conductance	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
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/l) 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.*

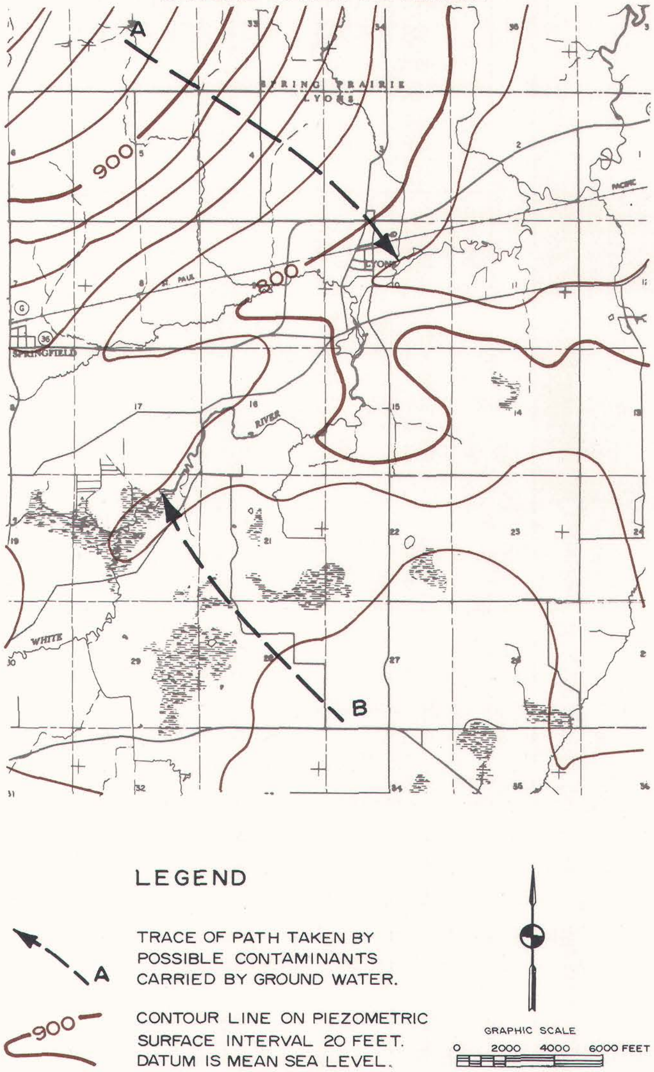
Source: SEWRPC.

Pollutants may enter aquifers by continuous seepage through highly pervious material or by intermittent seepage during periods of ground water recharge. (In the Fox River basin, natural recharge to shallow aquifers usually occurs about 20 times a 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, depth to the water table, and the character of the material. Once the contaminant enters the aquifer, it becomes part of the local ground water movement; and its velocity and direction of travel can be determined by ground water hydraulics.

Movement of ground water is most commonly shown by means of piezometric maps, which indicate horizontal components of flow. Map 44 shows a portion of the piezometric map of the shallow dolomite aquifer in the Fox River watershed. Generally, water in an aquifer moves at right angles to the piezometric contours. Thus, a contaminant starting at point "A," for example, will follow a curved path southeastward to empty into the White River at Lyons. It could enter a pumping well anywhere along the way. A contaminant starting at point "B" will follow a path northwestward to the White River. 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 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, detrimental bacteria or virus may not remain in the water flow long enough to die before ingestion.

Map 44

PIEZOMETRIC MAP OF THE SHALLOW DOLOMITE AQUIFER IN A PART OF THE FOX RIVER WATERSHED SHOWING GENERAL DIRECTION OF GROUND WATER MOVEMENT



Generally, water in an aquifer will move along paths at right angles to the piezometric 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 may create a public health hazard.

Source: U. S. Geological Survey.

Problem Areas

The pollution of ground water is a present and potential problem in many local areas of the Fox River watershed. Increased chance of pollution exists in those 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 limestone or dolomite bedrock that extends to or near the land surface.

6. The aquifer is thin and is underlain by impervious clay.

Perhaps the most serious ground water pollution problem in the Fox River watershed occurs in areas where the creviced limestone and dolomite bedrock is at or near the land surface (Map 45). Where drinking water supplies are obtained from such aquifers, a severe threat to public health may exist. Private on-site soil absorption waste disposal systems constitute the major potential source of ground water pollution under these conditions. Where the unconsolidated ground cover over the creviced bedrock is less than five feet thick, as occurs in portions of the watershed, these systems may actually be placed in immediate contact with the bedrock, since the absorption field of a septic tank system is commonly placed four to five feet below the ground surface in order to assure continuous operation in the winter without being affected by frost. Under such conditions disease-causing bacteria and other pollutants may travel rapidly into the local ground water supply. Once the pollutants reach the underground water table, they may move along with the flow of ground water and pollute wells and other drinking water sources in the path of movement.

Sanitary surveys of private water supplies have been conducted at five places in Waukesha County where pollutants are believed to be entering water supplies through creviced bedrock. A survey conducted by the Waukesha County Health Department indicated that 13 percent of 107 wells tested near and in the Village of Lannon were unsafe as a drinking water supply. A survey conducted by the Waukesha County Health Department indicated that 29 percent of 287 wells tested in and near the Village of Sussex were similarly unsafe. Further surveys by the Waukesha County Health Department indicate that from 27 percent to 69 percent of the private wells tested serving residential subdivisions in the unincorporated areas of the upper watershed were unsafe as a drinking water supply (see Table 65). Based on the results of these tests, local health authorities recommended that the users: 1) consider the construction of a centralized public water supply system to meet future needs, or 2) consider the reconstruction or the replacement of all contaminated individual private wells. The latter would offer less dependable protection of the public health than a public utility well and distribution system. Public utility systems have not been provided to date in these areas, and only a few residents have reconstructed or replaced their wells. Water pollution problems and the associated health problems may, therefore, be expected to increase in these areas.

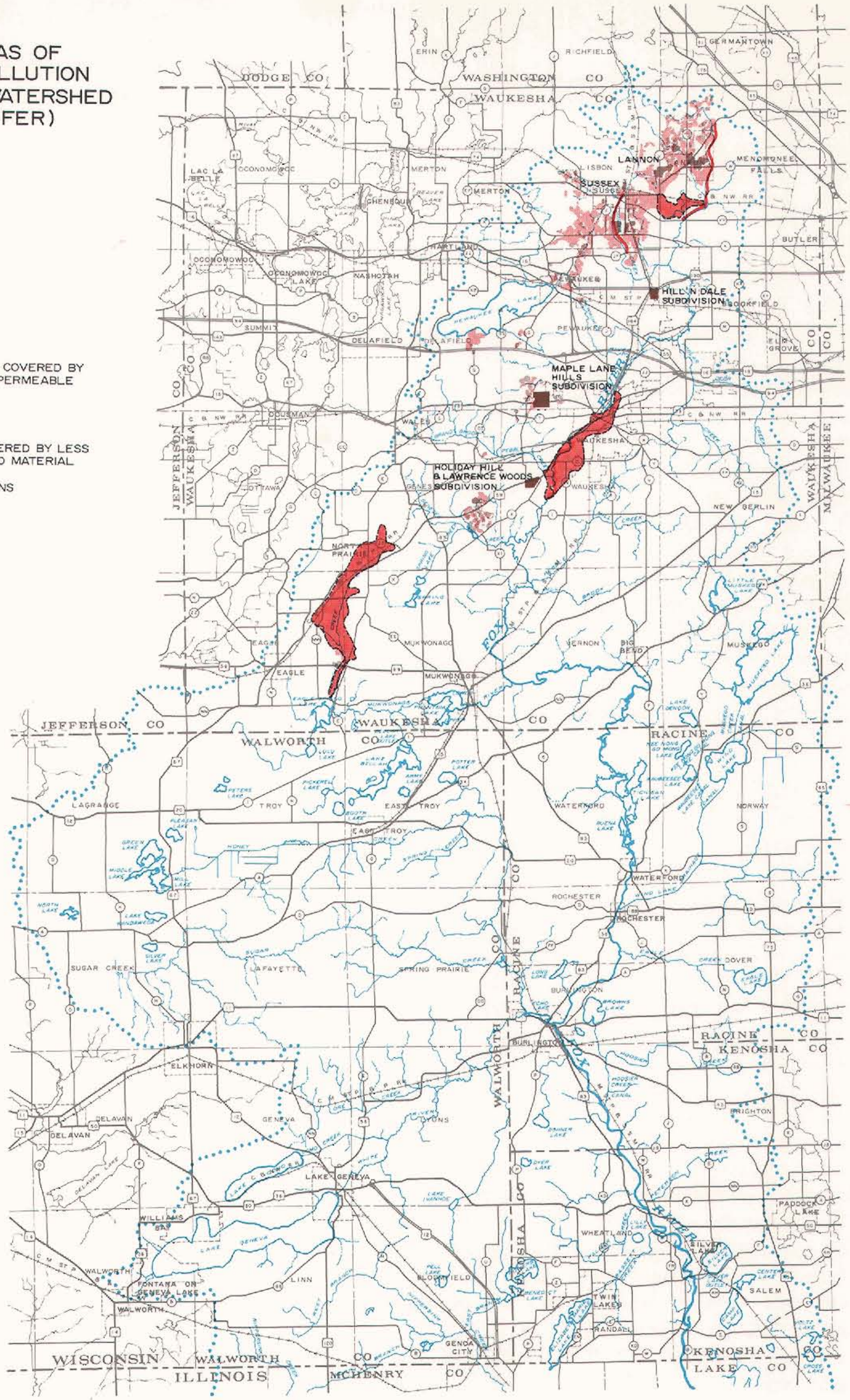
Similar conditions occur in northeastern Walworth County on the north side of Potter Lake and in the vicinity of Burlington, where creviced bedrock is exposed in quarries or lies just beneath the land surface. Ground water in these areas has not been studied through sanitary surveys; and, therefore, it has not been determined if the ground water is polluted.

Map 45 shows the three areas of the Waukesha County portion of the Fox River watershed covered by outwash sand and gravel soils and having a water table within 20 feet of the land surface. Ground water in these areas is 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 beneath Waukesha must be disinfected before use. Many of the famous springs at Waukesha had to be abandoned because the ground water in these deposits became polluted.

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 91). 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 or gaining because of impervious material in its bed.

Map 45

POTENTIAL AREAS OF GROUND WATER POLLUTION IN THE FOX RIVER WATERSHED (SHALLOW AQUIFER)



LEGEND

- AREAS IN WHICH WATERTABLE IS COVERED BY LESS THAN 20 FEET OF HIGHLY PERMEABLE SAND AND GRAVEL
- INFLUENT STREAM
- AREAS IN WHICH BEDROCK IS COVERED BY LESS THAN 5 FEET OF UNCONSOLIDATED MATERIAL
- SUBDIVISION OR VILLAGE LOCATIONS
- LIMESTONE QUARRY
- BEDROCK OUTCROP

The map above shows those areas of the Fox 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 are all located in the upper watershed; only a few areas too small to be mapped at this scale are located elsewhere in the watershed.

Source: U. S. Geological Survey.

Table 65

SUMMARY OF PRINCIPAL SANITARY SURVEYS OF PRIVATE WATER SUPPLIES IN THE FOX RIVER WATERSHED IN WAUKESHA COUNTY

Location of Survey	Date of Survey	Number of Wells Sampled	Percentage of Unsafe Wells[a]	Hydrogeologic Description	Inferred Source of Pollution
Village of Lannon	February-March 1962	107	13	Creviced bedrock lies at or near the surface. Many quarries. Ground water lies relatively close to the surface and flows from northwest to southeast.	Discharge from septic tank sewage disposal systems and privies. Runoff from refuse dumps. Urban storm water runoff.
Village of Sussex	October-December 1965	287	29	Creviced bedrock lies at or near the surface on the west, south, and east sides of the village. Glacial deposits range to over 100 feet thick. Ground water lies relatively close to the surface and flows from northwest to southeast.	Leakage to the ground water of public sanitary sewerage system. Runoff from refuse dumps. Urban storm water runoff.
Hill 'n Dale Subdivision. . .	April-May 1963	60	52	Creviced bedrock lies 5 to 15 feet below the land surface. Ground water lies relatively close to the surface and flows from northwest to southeast at a very low gradient.	Discharge from septic tank sewage disposal systems.
Holiday Hill and Lawrence Woods Subdivisions . .	1965 1966	16	69	Creviced bedrock lies 150 to 250 feet below land surface. Ground water lies 30 to 140 feet below the surface and flows from northwest to southeast.	Source of pollution is unknown. Affected wells terminate in sand and gravel and creviced bedrock aquifer over a relatively large area.
Maple Lane Hills Subdivision . . .	1965 1966	37	27	Creviced bedrock lies 5 to 65 feet below the land surface. Ground water lies 30 to 60 feet below surface and flows generally from northeast to southwest. Some wells receive water from creviced dolomite rock in the Maquoketa shale and have water levels over 100 feet below land surface.	Discharge from septic tank sewage disposal systems.

[a]*Well location and construction requirements are important to the safe production of water. For specific information concerning the location and construction of the wells sampled see the Wisconsin Department of Natural Resources.*

Source: Data from U. S. Geological Survey, Wisconsin Department of Natural Resources, and Waukesha County Health Department.

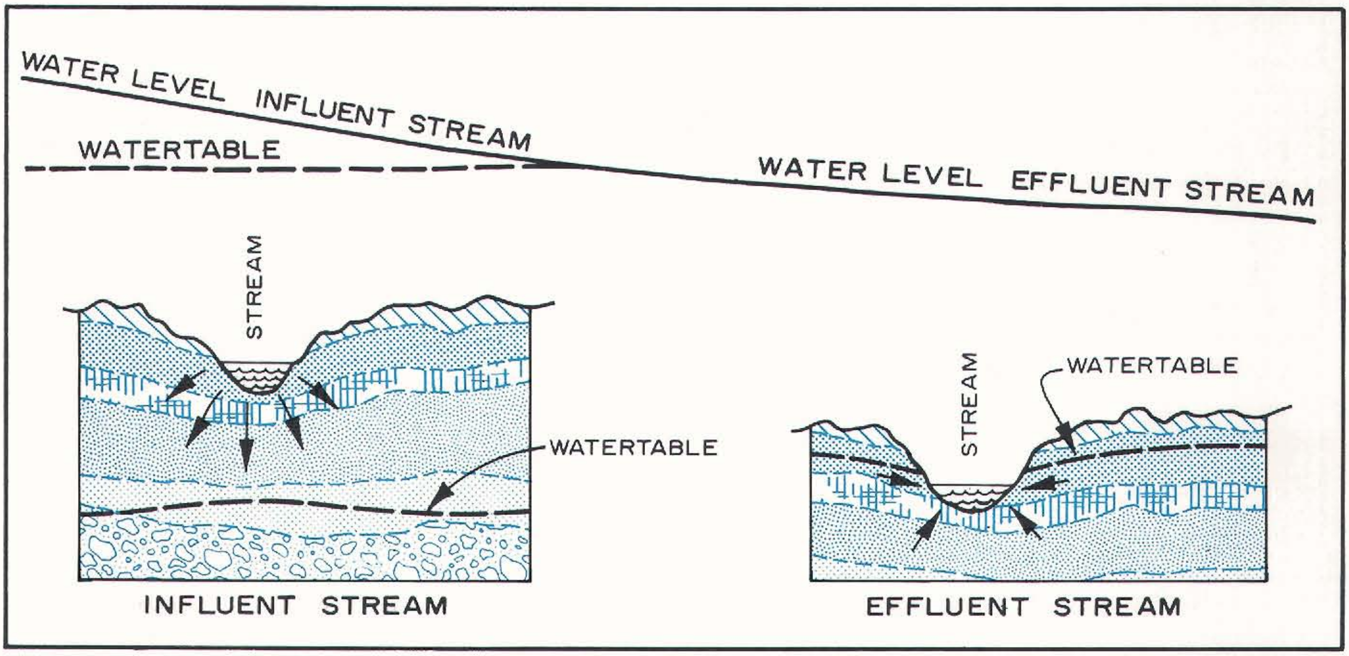
Three reaches of perennial streams in the Fox River are influent, as shown on Map 45. Influent streams may pollute adjacent ground water supplies if the influent water is polluted. The general direction of ground water movement from these streams can be determined by analyses of the piezometric surface (see Map 29). Heavily pumped wells located near streams may induce polluted surface water to move into the ground water supply, and eventually, into the wells.

Influent and effluent conditions may also occur in lakes. The surface and ground water relationships, for example, at Browns Lake (see Chapter V) suggest that pollutants are moving from the lake into the shallow ground water aquifer and may be affecting the chemical, physical, and bacteriological quality of the ground water.

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

Figure 91
DIAGRAM SHOWING INFLUENT AND EFFLUENT STREAMS



Source: U. S. Geological Survey.

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 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. Areas of particular concern in this regard include a nine square mile area in and around the Villages of Sussex and Lannon, an intermittent two square mile area in and around the City of Waukesha, and a three square mile area near the Village of North Prairie, all in the Waukesha County portion of the watershed, together with a few small areas throughout the rest of the watershed (see Map 45).

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 aquifers is generally classified as hard and contains high concentrations of calcium, magnesium, and sulfate. Other important chemical constituents of the ground water supply include iron, manganese, sodium, bicarbonate, chloride, fluoride, and nitrate. Physically, the ground water from both aquifers is generally clear, cool, tasteless, and odorless. Through institution of good pollution prevention and abatement programs, the use of this extremely important natural resource can be assured for future generations.

Chapter XI

WATER USE AND SUPPLY

INTRODUCTION

Ground water is presently the principal source of domestic, municipal, agricultural, and industrial water supply within the Fox River watershed. Moreover, engineering and economic considerations, as well as legal constraints, would appear to preclude supplementation of this supply with significant quantities of Lake Michigan water or other imported surface water in the foreseeable future.[1] It is extremely important, therefore, that an understanding of the major existing and potential problems of ground water use and supply be developed as a basis for the preparation of a comprehensive plan for the physical development of the Fox River watershed.

Although the major water use and supply problems within the Fox River watershed are associated with urban development, the rural portions of the watershed have special water management problems associated with agricultural land use. Poor or improper drainage of surface floodwaters is a generally widespread and persistent problem in the rural, as it is in the urban, portions of the watershed. Other rural water management problems are specifically related to special agricultural practices, such as irrigation. Any comprehensive watershed plan must consider these water 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 land use within the watershed.

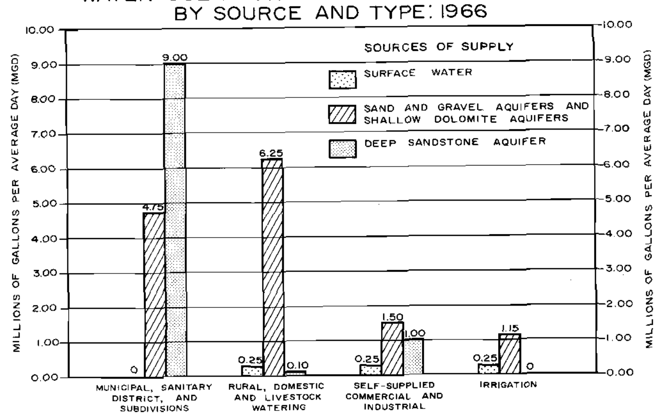
For convenience as well as clarity, a discussion of only the quantitative aspects of water use and supply and of related rural water management problems within the watershed is presented in this chapter. A discussion of qualitative aspects of the water supply and potential problems relating to the impairment of this water supply, that is, to ground water pollution, was presented in Chapter X of this report.

GROUND WATER USE

Approximately 9 billion gallons of water were used in the Fox River watershed during calendar year 1966 for all domestic, municipal, industrial, and agricultural purposes. This is equivalent to an average rate of use of 24.7 million gallons per day (mgd). Of this total, an estimated 97 percent was supplied by ground water sources—wells and springs—while the remaining 3 percent was supplied by surface water sources—lakes, streams, and impoundments. About 83 percent of the water withdrawn in the basin during 1966, averaging about 20.5 mgd, was used for municipal and domestic purposes. The remaining 17 percent, averaging about 4.2 mgd, was used by self-supplied industries and commercial establishments and for irrigation. Water withdrawal by source and type of use within the watershed is shown graphically in Figure 92. The total quantity of water used in the basin averages about 150 gallons per capita per day, based upon the estimated 1966 withdrawal rate of 24.7 mgd and an estimated 1966 resident watershed population of about 162,000 people.

Significantly, most of the water used in the basin is ultimately discharged as waste water into streams and watercourses and thereby becomes a portion of the streamflow (see Table 54). In reference to Table 54, 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

Figure 92
WATER USE IN THE FOX RIVER WATERSHED BY SOURCE AND TYPE: 1966



Source: U. S. Geological Survey.

[1] *See Chapter XVI, ''Water Law,'' and Chapter XVII, ''Alternative Plans.''*

sewer system. For example, water used for lawn sprinkling does not normally find its way into the sanitary sewer system. However, any such losses are usually more than offset by ground and storm water infiltrations. The inventory of surface water withdrawals cited in this report, therefore, includes an undetermined quantity of reused ground water. Although this amount is negligible in terms of the total annual streamflow, it does constitute a significant proportion of low flows in the headwater areas of the watershed.

Municipal Water Use

The greatest use of ground water in the Fox River watershed is by the public water supply utilities which serve the major urban centers. In 1966 public water supply systems[2] served a total combined area of about 20.71 square miles, or 2.2 percent of the total area of the watershed, and a total connected population of about 73,000 people, or 45 percent of the total population of the watershed. In 1966 the City of Waukesha municipal water utility served a population of 36,400 people living in a 6.88 square mile area and was by far the largest public water supply system within the basin in terms of population and area served and in quantity of ground water delivered for domestic, commercial, and industrial purposes. As shown in Table 66, this water utility distributed 2.38 billion gallons of water in 1966, or 63 percent of the total municipal pumpage in the watershed.

The water utilities serving the City of Elkhorn and the Villages of Hartland, Menomonee Falls, and Walworth provide water to communities which lie only partly within the watershed and, therefore, also provide water to areas lying outside the watershed (see Map 11). The City of Elkhorn municipal water utility serves a total area of approximately 1.6 square miles, with approximately equal portions of the total service area lying inside and outside the Fox River basin. The total population served, consisting of 3,800 persons, used 338.7 million gallons of water in 1966.

The Village of Hartland municipal water utility in 1966 served a population of 2,100 persons living in a 1.7 square mile area and delivered 84.0 million gallons of water. The Village of Menomonee Falls system served a population of 16,200 persons living in a 3 1/2 square mile area and delivered 589.5 million gallons of water in 1966. The Village of Walworth system served a population of 1,600 people living in a 1 square mile area and delivered 89.8 million gallons of water in 1966. These three municipalities serve areas lying mostly outside the Fox River watershed, with an estimated total connected population of only 1,900 persons living inside the watershed for all three systems.

Public water supply systems operated by sanitary districts and private water supply systems serving isolated residential subdivisions served a combined area of 2.07 square miles and a total population of about 5,000 people in the watershed in 1966, or less than 1 percent of the watershed area and about 3 percent of the watershed population. These quasi-public and private water supply systems are listed in Table 67, and their geographic location is shown on Map 11. The amount of water pumped for the sanitary districts and subdivisions is not known as few accurate records of water use are kept by these small utilities. An estimate of the pumpage was made, however, by applying an average per capita water use figure of 60 gallons per day to the population served, which resulted in an estimated total of about 300,000 gallons pumped each day or a total of about 110 million gallons pumped during 1966. As was true of the municipal water utilities within the watershed, all water used by the sanitary districts and private subdivision water supply systems was pumped from ground water sources.

Self-Supplied Commercial and Industrial Use

A relatively small quantity of water is used by self-supplied commercial and industrial establishments within the watershed. The total 1966 pumpage by such establishments probably did not exceed 1 billion gallons. The largest self-supplied industrial pumpage occurs in the City of Waukesha where two industries pumped a total of about 225 million gallons in 1966, the largest of which pumped 210 million gallons. The Waukesha County Institution, northwest of the City of Waukesha, is also a relatively large self-supplied water user and pumped approximately 100,000 gallons per day, or 36.5 million gallons annually, in 1966. A second large center of self-supplied industrial pumpage is within the Village of East Troy, where approximately 75 million gallons were used in 1966.

[2] *In Wisconsin the term ''public water supply system'' is defined as a water utility serving a municipality or a group of ten or more premises of mixed ownership.*

Table 66

PRESENT AND ESTIMATED FUTURE MUNICIPAL WATER USE IN THE FOX RIVER WATERSHED:[a] 1966 AND 1990

Municipality	Present Consumption (1966)									Forecast Consumption (1990)		
	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[b]	Average Per Capita Water Use[c] (Gallons Per Day)	Estimated Average Consumption (Million Gallons Per Day)	Estimated Population To Be Served[d]	Estimated Average Per Capita Water Use[c] (Gallons Per Day)
Brookfield	1.68	82,938,900	82,938,900	--	--	227,200	--[e]	2,600	90	5.00	27,800	180
Burlington	2.11	377,674,000	130,314,000	84,150,000	94,398,000	1,034,700	2,084,000	6,800	150	2.30	14,200	160
Eagle	0.25	11,994,100	10,562,500	729,000	--	32,900	59,900	700	50	0.16	1,600	100
East Troy	0.52	84,361,990	25,737,965	13,916,250	20,832,400	231,100	475,500	1,700	140	0.72	3,600	200
Elkhorn	0.79	169,371,000	63,422,550	42,526,649	33,646,950	464,000	750,000	3,800	120	2.25	10,000	220
Fontana	1.12	71,227,000	33,527,000	37,700,000	--	195,100	--[e]	1,500	130	0.33	3,400	100
Genoa City	0.26	24,111,000	12,563,000	4,322,000	2,994,000	66,100	183,900	1,100	60	0.28	1,700	160
Lake Geneva[f]	1.88	294,565,000	92,824,000	148,934,000	10,920,000	807,000	1,590,000	5,500	150	2.86	11,000	260
Mukwonago	0.73	76,533,000	36,892,000	13,539,000	141,000	209,700	--[e]	2,400	90	0.85	6,800	120
Pewaukee	0.77	134,590,000	45,824,000	32,113,000	35,057,000	368,700	610,000	2,700	140	1.15	6,400	180
Waterford	0.63	72,939,900	33,309,517	13,370,115	--	199,800	347,300	1,700	120	0.87	5,800	150
Waukesha	6.88	2,381,123,000	662,154,900	271,424,900	1,143,426,700	6,523,600	11,003,000	36,400	180	19.70	82,100	240
Williams Bay[f]	1.02	102,524,000	64,872,000	19,887,000	--	280,900	765,000	1,500	190	0.88	3,500	250
Watershed Total And Average	18.64	3,883,952,890	1,294,941,432	682,611,914	1,341,416,050	10,640,800	--	68,400	160	37.34	182,400	200

[a] *Does not include pumpage of the Villages of Hartland, Menomonee Falls, or Walworth.*

[b] *Present population served was estimated from the reported total customers of the municipal water utility.*

[c] *Average per capita water use was calculated by dividing average consumption per day by the estimated population served.*

[d] *Forecast 1990 population estimates correspond to projected connected population for sanitary sewer service area. See SEWRPC Technical Report No. 4, Water Quality and Flow of Streams in Southeastern Wisconsin, November 1966.*

[e] *Not recorded.*

[f] *Indicates plants with wide seasonal variations in resident population.*

Source: U. S. Geological Survey and SEWRPC.

Table 67

ESTIMATED POPULATION SERVED BY SANITARY DISTRICTS AND SUBDIVISIONS IN THE FOX RIVER WATERSHED HAVING A COOPERATIVE WATER SUPPLY: 1966

Name Of Water Supplier	Location	Estimated Population Served
Sanitary Districts		
North Cape	Racine County	350
Troy Center No. 1	Walworth County	130
Westbrooke	Waukesha County	680
Westchester	Waukesha County	200
Subtotal Sanitary Districts		*1,360*
Subdivisions[a]		
Edgewater Park	Kenosha County	130
Twin Lakes Park	Kenosha County	300
Lake Knolls	Kenosha County	300
Oakwood Knolls (Served By Antioch, Illinois)	Kenosha County	50
Wywood	Kenosha County	60
Eagle Lake Manor	Racine County	350
Waterford Woods Association	Racine County	50
Camp Sybil	Walworth County	180
Country Club Estates	Walworth County	400
Gardens Association	Walworth County	80
Nippersink	Walworth County	80
Oak Shores	Walworth County	70
Shore Haven Association	Walworth County	100
Carriage Hills	Waukesha County	100
Highlands	Waukesha County	90
Monterey Park	Waukesha County	240
Sussex Estates	Waukesha County	940
Westfield	Waukesha County	100
Subtotal Subdivisions		*3,620*
Total Sanitary Districts And Subdivisions		4,980

[a] *Knollwood and Sunset Hills Subdivisions located in the Town of Linn, Walworth County, supply water to summer residents only and, therefore, were not included in the estimate.*

Source: U. S. Geological Survey.

The major use of water by industry and commerce is for cooling, boiler feed, sanitation, and drinking purposes. Nearly all of the larger commercial and industrial self-supplied water users obtain the supply from the sandstone aquifer, due to the high reliability and dependable quality of this supply. The high cost of drilling and operating deep wells is probably the major reason for the relatively small pumpage by industrial users. Industries 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 (see Tables 62 and 66). For these reasons, future commercial and industrial water use in the Fox River watershed is expected to continue its heavy reliance on municipal water systems.

Self-Supplied Domestic and Agricultural Use

In 1966 private wells provided water to approximately 87,000 persons, or about 55 percent of the total population of the watershed, residing in the 921 square miles of the watershed not served by public water supply systems (see Map 11). In addition, most of the water used for rural domestic purposes is obtained from private ground water sources. The installation of modern plumbing facilities and appliances in rural homes, coupled with the increasing water requirements of agriculture, have resulted in significant increases in private rural well water use in recent years. In 1966 private wells provided about 5.2 million gallons per day to suburban and rural homes in the watershed, or about 1.9 billion gallons annually. Nearly all of this water was withdrawn from the shallow dolomite and sand and gravel aquifers. In 1966 approximately 500 million gallons of water was used within the watershed for livestock watering purposes; and of this quantity about 75 percent was withdrawn from the shallow dolomite and sand and gravel aquifers, while farm ponds, streams, and lakes contributed the remaining 25 percent.

Irrigation

Irrigation, although still a relatively minor use of water in the watershed, is becoming increasingly important. The production of sod, vegetables, and fruit and the maintenance of golf courses are the leading purposes for irrigation; and, although the irrigation of agricultural crops is not extensively practiced within the Fox River watershed, the number of acres under irrigation has shown a rapid increase in recent years. Agricultural irrigation in southeastern Wisconsin is applied during the 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 high 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 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 Fox River watershed indicates that approximately 240,000 acres, or about 45 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 necessary quantity of water used in irrigation must come from either surface water or ground water supplies. In other areas of the United States, effluent from sewage treatment plants and industrial waste water have been used for irrigation; but these sources are not presently being used for agricultural purposes within the Fox River watershed.[3] 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

[3] *Some spray irrigation is used seasonally within the watershed for waste disposal by food processing industries.*

waste dilution needs. Natural lakes are an excellent 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, surface or subsurface methods of application are not presently being used in the watershed. An estimated 6,600 acres, or about 1 percent of the total area of the watershed, however, are presently under sprinkler system irrigation.[4] 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 six times the present acreage.[5]

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 3.8 inches (see Chapter V, "Hydrology"). The flat, relatively level areas of the watershed located southeast of Wind Lake in Racine County, the headwater area of Honey Creek above the Village of East Troy in Walworth County, and the headwater area of the Fox River above IH 94 in Waukesha County are the most intensively irrigated portions of the watershed. Irrigation water was supplied from several sources within the watershed in 1966, including about 400 million gallons pumped from shallow wells, about 3 million gallons directly diverted from ditches and streams, and about 100 million gallons pumped from pits dug near stream channels. No lake is known to be used to supply water for irrigation.

Drainage

Agricultural land drainage in a 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 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 removel 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

[4] *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.*

[5] *This value was established by extrapolating the information on land irrigated in southeastern Wisconsin as published in the U.S. Census of Agriculture for the years 1954, 1959, and 1964.*

recognized categories which may exist separately or in various combinations:

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 Fox River watershed to provide landowners and operators with a legal means to accomplish satisfactory drainage. Fourteen such drainage districts, covering 92.2 square miles of area, have been organized; but only 3, covering 57 square miles in area, remain active under the present state law (Chapter 88 of the 1965 Wisconsin Statutes). In addition to the legally constituted drainage districts, other groups of farm owners and operators have accomplished drainage improvements through group enterprise ventures; and at least 55 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 131,400 acres, or 22 percent of the watershed, are covered by wet soils 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 30,090 acres in the watershed. Table 68 lists the extent of wet soils 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 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 now intensively cropped and, therefore, reduces soil erosion, sedimentation, and stream deterioration. 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 of Ground Water Use

The reconstruction of historic water use and trends is a prerequisite to the preparation of forecasts of future ground water needs within the

Table 68

FOX RIVER WATERSHED WET SOILS: 1967

County	Watershed Area (Acres)	Wet Soil Area (Acres)	Installed Drainage Improvements (Acres)
Kenosha	61,999	12,400	5,980
Milwaukee	163	40	--
Racine	105,400	21,100	20,550
Walworth	217,896	34,900	1,390
Washington	324	70	--
Waukesha	216,881	62,900	2,170
Total	602,663	131,410	30,090

Source: U. S. Soil Conservation Service.

watershed. Adequate records have not been kept of all uses; and, therefore, only estimates of past water use can be derived from the available data. Available municipal water utility records have been expanded to include the total watershed area and population. Reliable records of municipal water pumpage are available only from 1940 to the present, although the establishment of some of these utilities dates back to 1900 and before. Therefore, only pumpages from the year 1940 to the present have been tabulated (see Table 69) and utilized in preparing the forecast.

Municipal water pumpage, as shown in Table 69 , has increased steadily within the watershed from 2.75 mgd in 1940 to 10.64 mgd in 1966, a 287 percent increase in 26 years. Projecting these same historic trends to total ground water pumpage in the watershed, it is estimated that a total of approximately 6.1 mgd of ground water was pumped in 1940, as compared to the present total rate of 23.8 mgd. When pumpage is compared to the estimated population served, an average per capita use is determined. As shown in Table 69 , the average municipal per capita water use in the Fox River watershed has doubled since 1940 to 1966, from an average of 80 gallons per person per day to 160 gallons per person per day. These figures illustrate that the combination of increased population, increased industrial and agricultural productivity, and a rising standard of living have had a significant impact on ground water use within the watershed.

FORECAST OF FUTURE WATER USE

By the plan design year of 1990, the population of the Fox River watershed is expected to more than double to an estimated 359,000 people (see Chapter VI). Total water use may be expected to more than double and may reach as much as 65 million gallons per day by 1990. The estimated 1990 water use by category of use is summarized in Table 70 , which indicates that almost 71 percent of the total water use will be for municipal, sanitary district, and subdivision supply, while the self-supplied industry and the domestic and agricultural uses will account for the remaining 29 percent of water use. Of this 29 percent, about half of the use will be for self-supplied industry and domestic uses, with the remainder being used for agricultural purposes, primarily irrigation. The municipal use of water by 1990 will be by far the most important use of water in the basin and will average over 44 million gallons per day. The historic and forecast trends in water use by municipality are shown graphically on Map 46, and a tabular summary is given in Table 69 and 71. (See Appendix J for computation of forecast trends of individual municipal pumpages.)

WATER SUPPLY PROBLEMS

A water supply adequate to meet foreseeable municipal, industrial, domestic, and agricultural needs exists within the Fox River watershed, even within the rapidly urbanizing headwater portion of the basin where large increases in water use are expected to accompany the rapidly increasing pop-

Table 69

SUMMARY OF HISTORIC AND PRESENT MUNICIPAL WATER PUMPAGE IN THE FOX RIVER WATERSHED: 1940-1966

Municipality	1940			1950			1960			1966			
	Water Pumped (mgd)	Estimated Population Served	Average Per Capita Use (Gallons Per Day)	Water Pumped (mgd)	Estimated Population Served	Average Per Capita Use (Gallons Per Day)	Water Pumped (mgd)	Estimated Population Served	Average Per Capita Use (Gallons Per Day)	Water Pumped (mgd)	Estimated Population Served	Average Per Capita Use (Gallons Per Day)	Pumpage Percent Increase (1940-1966)
C/Brookfield	--[a]	--	--	--[a]	--	--	--[a]	--	--	0.23	2,600	90	--
C/Burlington	0.44	4,414	100	0.51	4,780	110	0.70	5,856	120	1.03	6,800	150	134
V/Eagle	--[a]	--	--	--[a]	--	--	0.03	620	50	0.03	700	50	0[b]
V/East Troy	0.06	925	60	0.10	1,052	100	0.16	1,455	120	0.23	1,700	140	283
C/Elkhorn	0.18	2,382	70	0.34	2,935	110	0.33	3,586	90	0.46	3,800	120	156
V/Fontana	--[a]	--	--	0.03	726	40	0.09	890	100	0.20	1,500	130	567[c]
V/Genoa City	0.02	715	30	0.04	866	50	0.06	1,005	60	0.07	1,100	60	250
C/Lake Geneva	0.29	3,238	90	0.36	4,300	80	0.55	4,929	110	0.81	5,500	150	179
V/Mukwonago	0.07	855	80	0.13	1,207	110	0.14	1,877	70	0.21	2,400	90	200
V/Pewaukee	0.06	1,352	40	0.21	1,792	120	0.24	2,484	100	0.37	2,700	140	517
V/Waterford	0.07	786	90	0.10	1,100	90	0.12	1,500	80	0.20	1,700	120	186
C/Waukesha	1.45	19,242	75	2.68	21,233	130	4.00	30,004	130	6.52	36,400	180	350
V/Williams Bay	0.11	717	150	0.19	1,118	170	0.24	1,347	180	0.28	1,500	190	173
Total	2.75	34,626	80	4.69	41,109	110	6.68	55,355	120	10.64	67,900	160	287

[a] *No municipal water utility in operation.*

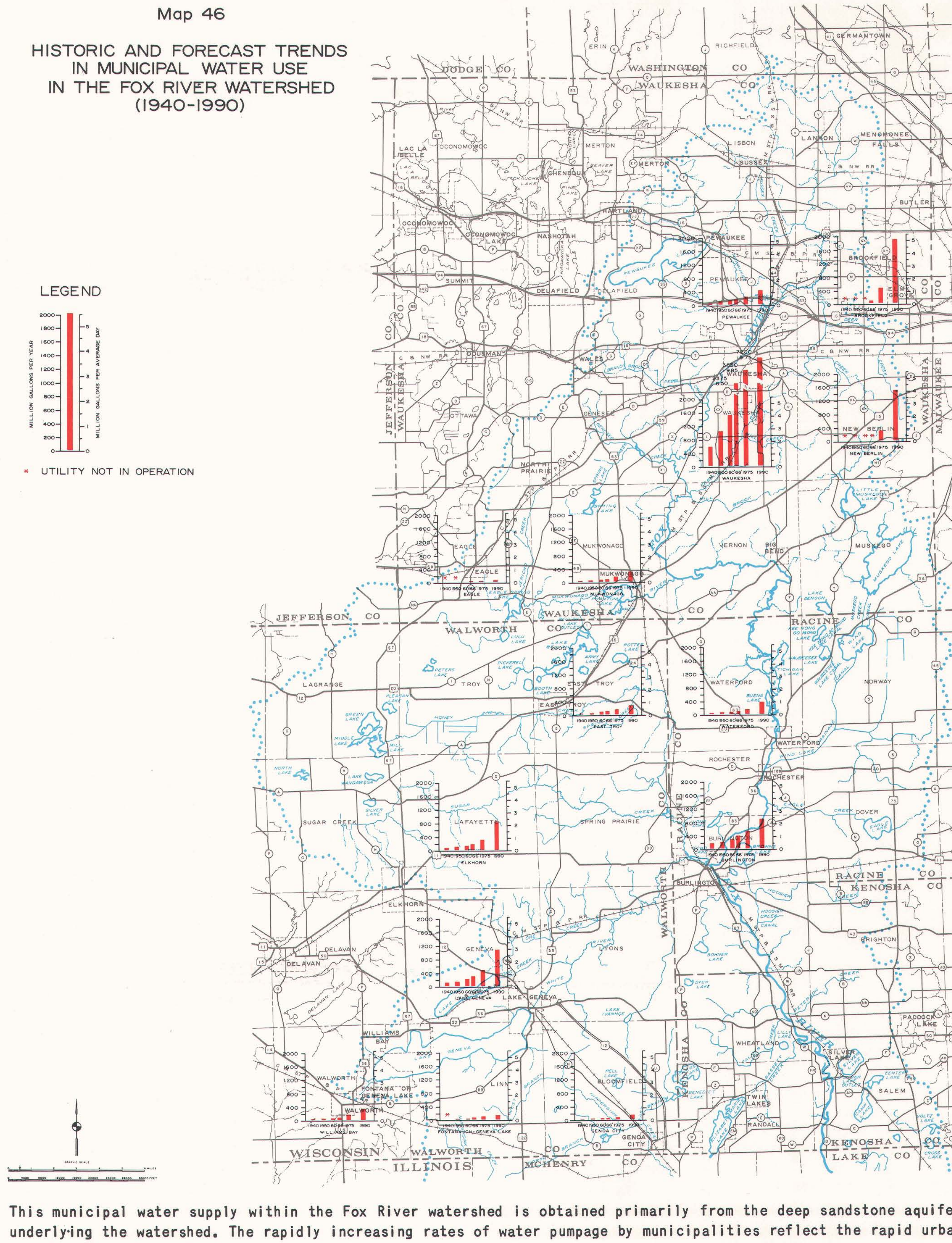
[b] *Increase 1960-1966.*

[c] *Increase 1950-1966.*

Source: U. S. Geological Survey and SEWRPC.

Map 46

HISTORIC AND FORECAST TRENDS IN MUNICIPAL WATER USE IN THE FOX RIVER WATERSHED (1940-1990)



This municipal water supply within the Fox River watershed is obtained primarily from the deep sandstone aquifer underlying the watershed. The rapidly increasing rates of water pumpage by municipalities reflect the rapid urban growth taking place within the watershed.

Source: U. S. Geological Survey and SEWRPC.

Table 70

ESTIMATED WITHDRAWAL OF WATER IN THE FOX RIVER WATERSHED BY TYPE OF USE: 1990

Type Of Use	Water Use (mgd)	Percentage Of Total Use
Municipal, Sanitary District, And Subdivision	46	70.8
Self-Supplied Commerce And Industry	4	6.2
Domestic	6	9.2
Agriculture		
Livestock	1	1.5
Irrigation	8[a]	12.3
Total Water Use	65	100.0

[a] *This estimate of future water use for irrigation is conservative, being based upon an extrapolation of historic trends. Changes in agricultural practices within the watershed could increase future water use for irrigation to over 30 mgd, and such changes may be necessary if agriculture, as an economic activity within the watershed, is to maintain its competitive position nationally. Many factors, however, affect the feasibility of irrigation; and any upward revision forecast of water use for irrigation must await the completion of more detailed economic studies now being made by the U. S. Department of Agriculture as a part of a federal Type IV river basin study of eastern Wisconsin.*

Source: U. S. Geological Survey.

ulation levels. Problems of inadequate ground water supply within the watershed are rare. Small-to-moderate well yields to meet domestic and agricultural needs can be obtained almost everywhere from shallow aquifers; and large yields of excellent quality water, sufficient for municipal and industrial needs, are available throughout the watershed within the deep sandstone aquifer. It should not be inferred from this, however, that no water supply problems of a quantitative nature exist or are anticipated within the basin. Rather, it must be emphasized that a sound ground water resource management program must be formulated to ensure that the excellent potential of the available ground water supply will be fully realized.

Probably the most significant water supply problems of the basin are related to the rapidly declining water levels, particularly within the sandstone aquifer, that have accompanied the heavy ground water pumpage both within the basin and within the Milwaukee and Chicago metropolitan areas. Recharge to the shallow aquifers is generally sufficient to permit large withdrawals without excessive lowering of water levels. It is only within portions of the Cities of Brookfield and New Berlin and the Village of Menomonee Falls that the shallow aquifer water level declines are significant, averaging about one foot per year. (see Map 30). These declines are the result of the poor recharge characteristics of the thick deposits of relatively impermeable glacial till in these areas.

Effects of Regional Development

Ground water in the sandstone aquifer beneath the Fox River watershed is affected by pumpage throughout all of southeastern Wisconsin and by deep-well pumpage in the Chicago region. The changes in artesian pressure produced by pumpage are pronounced and widespread. Since the first well was drilled into this aquifer approxi-

Table 71

SUMMARY OF FORECAST

MUNICIPAL PUMPAGE OF THE FOX RIVER WATERSHED[a]

Municipality	Million Gallons Per Day	
	1990	1966-1990 Increase
Brookfield	5.0	4.8
Burlington	2.3	1.3
Eagle	0.2	0.2
East Troy	0.7	0.5
Elkhorn	2.3	1.8
Fontana On Geneva Lake	0.3	0.1
Genoa City	0.3	0.2
Lake Geneva	2.9	2.1
Menomonee Falls	2.5	2.4
Mukwonago	0.9	0.7
New Berlin[b]	4.0	4.0
Pewaukee	1.2	0.8
Waterford	0.9	0.7
Waukesha	19.7	13.2
Williams Bay	0.9	0.6
Total	44.1	33.4

[a] *By 1990 municipal water utilities may be established at the Villages of Big Bend, North Prairie, Silver Lake, Sussex, and Twin Lakes and the Town of Norway.*

[b] *New Berlin water utility began operation in 1967.*

Source: U. S. Geological Survey.

mately 100 years ago, water levels have declined nearly 700 feet at Chicago, more than 300 feet at Milwaukee, and more than 200 feet in parts of the Fox River watershed. These water level changes, due to pumpage at distant places, are called regional effects. The shallow aquifers in the Fox River watershed, however, show no such regional effects of ground water pumpage.

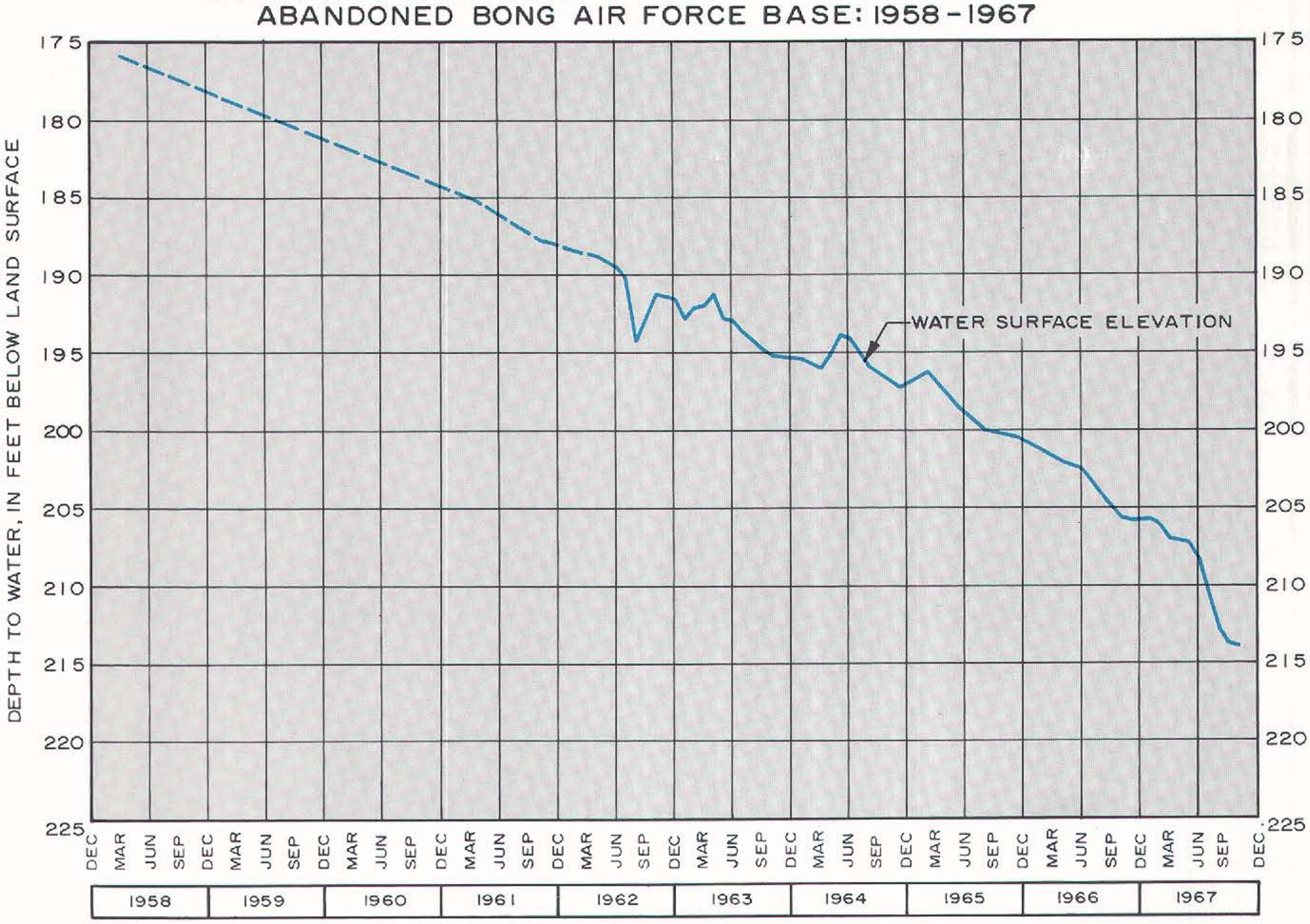
Present regional pumpage is causing the water level in the sandstone aquifer underlying the Fox River watershed to decline at the rate of about three to four feet per year in Racine and Kenosha Counties, one to four feet per year in Waukesha County, and one to three feet per year in Walworth County. Regional water level declines are illustrated by the hydrograph of water level of one presently unused deep well at the Bong Air Base site in Kenosha County, where declines have averaged about 3.5 feet per year, as shown in Figure 93. These rates of ground water decline are expected to increase as ground water withdrawals increase in the future in response to growing demand.

Effects of Local Development

The increases in ground water pumpage forecast for the Fox River watershed will significantly affect artesian water levels in the sandstone aquifer. In order to quantify these effects, the theoretical relationships between pumpage and drawdown for varying distances and times have been established and are graphically shown in Figures 94 and 95 for sandstone aquifer wells in eastern Waukesha County, where the heaviest ground water pumpage of the basin is forecast. Figure 94 indicates the amount of drawdown in feet, or water level declines, at distances of 1,000 feet to 20,000 feet from a well pumping at a continuous rate of 1 mgd (695 gpm) for 30 days, for

Figure 93

HYDROGRAPH OF WELL TAPPING DEEP AQUIFER AT THE ABANDONED BONG AIR FORCE BASE: 1958-1967



Source: U. S. Geological Survey.

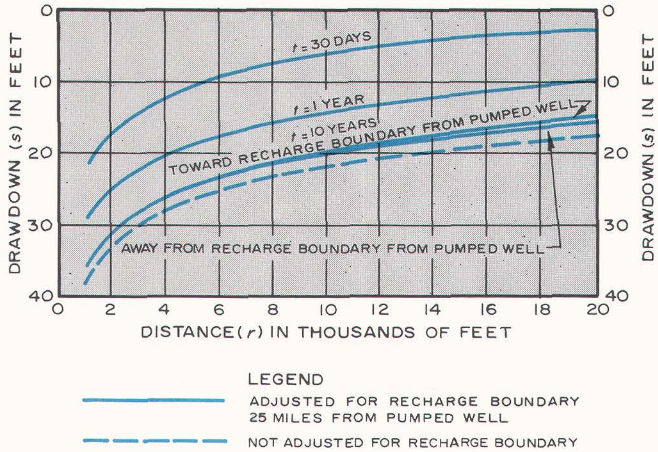
1 year, and for 10 years. The solid line curves shown on the figure have been adjusted for the effect of the ground water recharge boundary in western Waukesha County; whereas, the dashed line indicates the theoretical water level declines which would occur without this adjustment. Figure 95 indicates the amount of drawdown in feet at any time from 50 to 4,000 days at 0.5 mile, 1 mile, and 5 miles from well pumping at a continuous rate of 1 mgd. As in Figure 94, the solid line curves have been adjusted for the effect of the ground water recharge boundary; whereas, the dashed line is not adjusted. In both figures the upper limb of each solid line curve indicates the theoretical drawdown at points on a line drawn westerly through the pumped well; and the lower solid limb indicates the drawdown along a line drawn easterly through the pumped well. The curves are based upon the nonequilibrium equation of Theis, in which the drawdown of water levels (s) is assumed to be directly proportional to the quantity of water withdrawn (Q) as described by Foley, Walton, and Drescher.[6]

[6] *W. S. Drescher, F. C. Foley, and W. C. Walton, Geological Survey Water Supply Paper 1229; Ground Water Conditions in the Milwaukee-Waukesha Area, Wisconsin; U.S. Geological Survey, 1953.*

Figure 94

DISTANCE-DRAWNDOWN CURVES FOR ESTIMATING WELL INTERFERENCE IN THE SANDSTONE AQUIFER IN EASTERN WAUKESHA COUNTY

Q=1 mgd, T=23,800 gpd per ft, S=0.00039

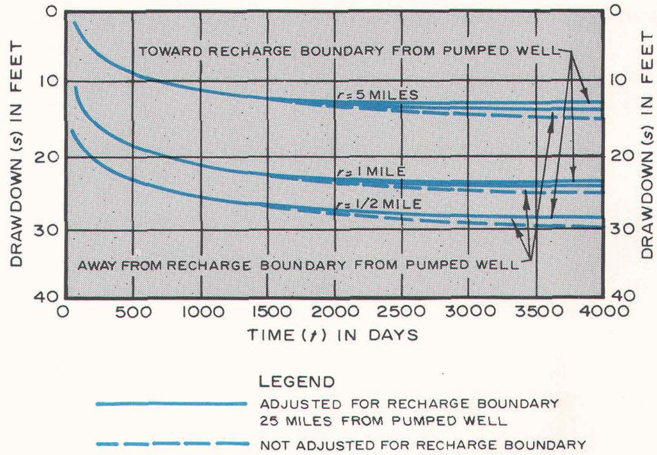


Source: U. S. Geological Survey.

Figure 95

TIME-DRAWNDOWN CURVES FOR ESTIMATING WELL INTERFERENCE IN THE SANDSTONE AQUIFER IN EASTERN WAUKESHA COUNTY

Q=1 mgd, T=23,800 gpd per ft, S=0.00039



Source: U. S. Geological Survey.

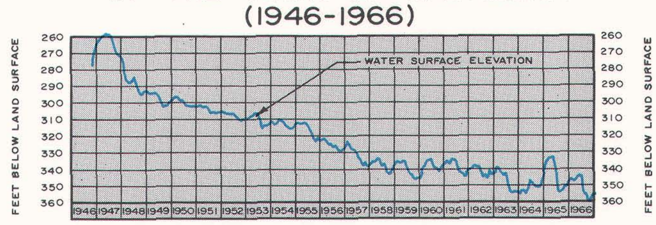
The use of the above curves for application to conditions of wells within the Fox River watershed is demonstrated in the following example:

> A new well located in the City of Brookfield, and pumped at the rate of 1 mgd continuously for a period of 1 year, could be expected to lower the water levels in another well located 2 miles away about 14 feet. If the well was located 1 mile away, the water level could be expected to be lowered about 18 feet. The same well could be expected to cause decline in the water level of only 11 feet in a well 5 miles away, even if pumped continuously for a period of 3 years. Greater or lesser pumpage rates would have directly proportional effects.

The combination of local and regional pumping is causing water levels to decline up to eight feet per year in some wells in the City of Waukesha. The location of new wells in the rural areas south and west of the City, however, tends to reduce the local effects of heavy pumpage. The hydrograph of an observation well in the City of Waukesha, as shown in Figure 96 , indicates a reduced rate of water level decline starting in 1957, with the inferred cause being the shifting of the city pumpage center southwest in the general direction of the recharge area.

Figure 96

HYDROGRAPH OF WELL TAPPING DEEP AQUIFER IN THE TOWN OF WAUKESHA (1946-1966)



WAUKESHA CO., Well-14 *Wk-6/19/2-14*

New Tribes Mission. NW¼ Section 2, T.6N., R.19E. Drilled unused artesian well in sandstone of Cambrian age and St. Peter Sandstone of Middle Ordovician age, diameter 8 inches reported depth 1,300 ft., elevation of land surface 875 ft. above msl. Top of casing at ground level. Affected primarily by pumping of nearby municipal wells. Recording gage. Lowest monthly elevation plotted.

Source: U. S. Geological Survey.

The piezometric map prepared for the planning study indicates that large cones of depression have not developed in the shallow dolomite aquifers (see Map 30). Locally depressed water levels in some private wells, however, may cause water shortages in the summer because the wells are too close together; and heavy pumpage then causes water levels to temporarily decline. Such water shortages are more likely to occur in areas where natural ground water storage is low. Figure 97 shows that ground water storage, indicated by water levels in wells, was relatively low in 1950-51, 1958-59, and 1963-65.

Of major concern in the watershed, especially to owners and operators of wells in the sandstone aquifer, are the water level declines 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 electricity to operate the pumping equipment is the largest direct operating expense, and many operators feel that increased electric 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, indicates the level of additional operator cost which is involved in pumping from a relatively high-capacity well. 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 one 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;

Q = discharge rate, in gpm;

H = head decline, in feet;

C_e = cost of electricity per KWH, in dollar, assumed to be \$0.015; and

E = wire to water efficiency, assumed to be 0.6.

Substituting:

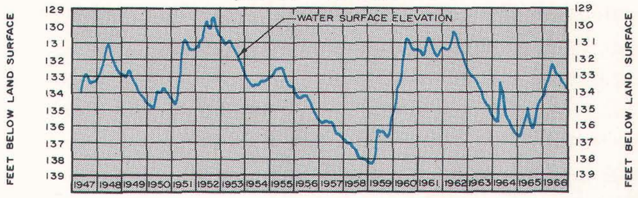
$$C_a = \frac{1.65(695)(5)(0.015)}{0.6}$$

or \$143 per year increase in direct operating expense of the well.

The character of ground water problems of the basin can best be exemplified through a discussion of the problems and management potential of the ground water supply of the largest water user of the Fox River watershed—the City of Waukesha. The demand for more water for home and industry, the relatively small area of the city, the rapidly declining water levels due to well interference, and the effects of regional pumpage have made it necessary for the City of Waukesha Water Utility to seek additional water supplies outside

Figure 97

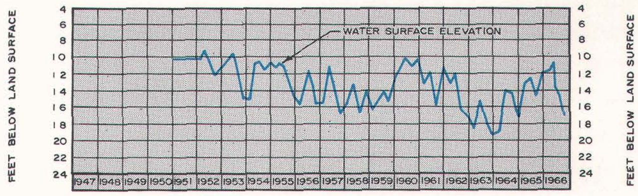
HYDROGRAPH OF WELL TAPPING SHALLOW AQUIFER IN THE TOWN OF VERNON (1947-1966)



WAUKESHA CO., Well-31 Wk-5/19/2-31

William M. Foss. NW¼ Section 2, T.5N., R.19E. Drilled unused artesian well in the Niagara dolomite aquifer, diameter 6 inches, depth 508 ft., cased to 434, elevation of land surface 962 ft. above msl. top of casing, 1.00 ft. above land surface. Recording gage. Lowest monthly elevation plotted.

HYDROGRAPH OF WELL TAPPING SHALLOW AQUIFER IN THE VILLAGE OF LANNON (1947-1966)



WAUKESHA CO., Well-50 Wk-8/20/19-50

Richard H. Nelson. NE¼ Section 19, T.8N., R.20E. Drilled domestic artesian well in Niagara dolomite aquifer, diameter 6 inches reported depth 86 ft., elevation of land surface 878 ft. above msl. top of casing, 2.50 ft. above land surface. Measured monthly. All plotted.

Source: U. S. Geological Survey.

the city limits since the early 1950's. Moreover, industrial growth in the city raised the per capita water use to 180 gallons per day by 1966, or 20 gpd higher than the average per capita water use within the basin; and by 1990 the City of Waukesha per capita water use is expected to increase to about 240 gpd, placing an even greater load on the ground water resources.

The Waukesha Water Utility is presently operating under good ground water management practices by developing its well field west of the city toward the recharge area of the sandstone aquifer and by spacing the wells at least one mile apart to reduce interference effects. This practice is expected to continue in the future, and the sandstone aquifer is expected to remain the primary source of water for the City of Waukesha through the year 1990. It is anticipated that new wells will be drilled west of the city, as in the past; and if the projected increase in water use of 13.2 mgd between 1966 and 1990 is to be obtained from the sandstone aquifer, 10 to 12 deep wells will have to be added to the present system. In such an event, the well field would probably extend to the western boundary of the watershed, which is also close to the eastern boundary of the recharge area.

A potential water supply for Waukesha also exists in the shallow sand and gravel deposits along the east side of the Fox River south of the city. Water supplies, possibly equal to more than half of the expected future increase, may be available by induced infiltration of the Fox River. It may be possible to develop shallow wells in this area with individual well capacities up to two mgd and, therefore, suitable for municipal use. Before this water supply could be quantified, however, tests would need to be conducted to determine the hydraulic characteristics of the shallow aquifer and whether pollutants could be naturally filtered from the water induced from the Fox River. Finished water would have to be chlorinated to protect against any remaining biological pollution that reached the distribution system. While the cost of treating water from this source may be higher than treating water from the sandstone aquifer, the overall production costs could be lower because of reduced capital and operating costs. Comparative estimates of actual production costs would have to be determined on the basis of preliminary engineering studies of the alternative supply systems. At least 95 percent of the water induced from the Fox River would be returned to it as waste water.

The deep sandstone aquifer is recharged primarily through the Platteville-Galena unit, which, as indicated in Chapter V, occurs near the surface in western Walworth and Waukesha Counties but primarily beyond the limits of the Fox River watershed. The recharge occurring beyond the limits of the watershed is estimated at 12 mgd. A minor amount of recharge, estimated at one or two mgd, leaks into the deep aquifer through the approximate 824 square miles of Maquoketa shale underlying the watershed. As indicated in Chapter V, minor amounts of recharge also occur through wells extending through the shallow aquifer into the deep aquifer.

SUMMARY

Rapid urbanization is occurring within the Fox 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 Fox River watershed study indicate that ground water is presently the principal source of domestic, municipal, agricultural, and industrial water supply within the Fox River watershed. Water use within the basin in 1966 totaled 24.5 mgd, 97 percent being obtained from ground water sources. A total population of about 162,000 persons was supplied and the total quantity of water used in the basin averaged 150 gallons per capita per day. This average fluctuated within the basin, depending upon the social and economic characteristics of the individual communities, from a high of 180 gallons per capita per average day in the highly industrialized City of Waukesha to 60 gallons per capita per day in a typical rural-urban fringe area subdivision.

Water users were subdivided for analytical purposes into three major groups: 1) municipal and privately owned public water utilities, 2) self-supplied commercial and industrial users, and 3) self-supplied domestic and agricultural users. The average daily use by these groups was, respectively: 1) 13.75 mgd, or 56 percent of the total use; 2) 2.75 mgd, or 11 percent of the total use; and 3) 8.00 mgd, or 33 percent of the total use. About 35 percent of the total municipal and private utility supply was obtained from the shallow aquifer and about 65 percent from the deep aquifer. These two 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, including a plan of evenly spaced wells, is effected throughout the watershed.

Approximately 36 percent of the self-supplied commercial and industrial use was obtained from the deep aquifer; and 55 percent was pumped from the shallow aquifers of the watershed. To date, self-supplied commercial and industrial users have no known problems anywhere within the watershed with respect to current or future supply. The water resources management program within the basin, however, must include these major users.

The self-supplied domestic and agricultural water supplies are different from the other two major users with most of the supply, 93 percent, being derived from the shallow aquifers and 1.3 percent obtained from the deep aquifer. The major water management problems of the rural portions of the Fox River watershed are more related to agricultural practices, such as irrigation or drainage, than to domestic and livestock watering needs. A comprehensive watershed plan must consider these problems since river performance, land use patterns, and water use are all affected by these problems and the alternative solutions to these problems. Agricultural irrigation is presently not extensively practiced within the watershed; and only 6,600 acres, or 1 percent of the total area of the watershed, is 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 six times the present amount. Detailed soils maps of the watershed indicate that approximately 240,000 acres are covered by soils having characteristics that make them potentially irrigable. If in the future additional acreage is brought into irrigation systems, demands 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 3.8 inches per year average recharge rate of the shallow aquifer and, if not carefully managed, could result in local water supply conflicts and problems.

Soils maps indicate that approximately 131,400 acres in the watershed are covered by soils with impaired drainage. Fourteen agricultural drainage districts, two of which remain active, have been organized, and 55 group enterprise projects established, in order to implement agricultural drainage practices. To date, drainage improvements have been carried out on about 30,090 acres within the watershed.

Total water use may be expected to more than double within the watershed by 1990, reaching an approximate total pumping rate of 65 million gallons per day, or 23 billion gallons per year. Municipal use, dependent almost entirely upon the deep ground water aquifer for its supply, may be expected to comprise over 70 percent of this total water use. The deep aquifer is a very complicated water supply, extending far beyond the surface boundaries of the watershed. Water levels in this aquifer have and will continue to show a decline within the Fox River watershed especially in the areas of concentrated pumping rates. This decline, however, is insignificant with respect to the magnitude of the total amount of water which has been stored within the aquifer for thousands of years. Although the total available supply cannot be quantified on the basis of the information presently available, this water supply is believed to be adequate for both municipal and industrial pumpage within the watershed, not only to the plan design year of 1990 but for many years beyond that design year. As the level of the deep aquifer declines, the cost of pumping from the deep aquifer may be expected to increase. Such an increase in pumpage cost should not, however, become a determining factor in the selection of alternative water supplies through the year 1990.

A ground water resource management program will also 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 effects of well interference.

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Chapter XII

NATURAL RESOURCE AND RECREATION—RELATED RESOURCE PROBLEMS

INTRODUCTION

The Fox River watershed constitutes an important natural resource area within the rapidly urbanizing Southeastern Wisconsin Region. The watershed is particularly rich in resource base elements important to recreational pursuits such as lakes, streams, wetlands, woodlands, fish, game, and other wildlife. Rapid population growth and urbanization within the Region and the watershed are increasing the importance of these elements of the natural resource base as recreational assets, while at the same time impairing their quality and reducing their quantity. Problems relating to these resources and their recreational uses within the watershed are of two distinct but often interrelated kinds: 1) 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, and 2) those relating to the continuing deterioration of the resources induced or aggravated by human activity within the watershed.

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 lakes of the watershed presented within this chapter, individual lake reports have been prepared for the 45 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 of 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. A typical lake report is reproduced in Appendix D of this report.

LAKES AND STREAMS

Description of the Recreational 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 which may have been made or may have taken place.

Thermal Stratification

Many of the deeper lakes within 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. By spring the entire body of water contained in a lake within the Region will, typically, have achieved a uniform, low temperature at or near the temperature of maximum water density (4°C or 39°F). Heating in the spring will warm the surface water; and wind acting on the lake surface will produce turbulence which transports the heated water downward, creating a vertically circulating layer of warm surface water, known as the epilimnion.

The depth to which the warm layer of circulating water will extend 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, which produces a resistance to mixing. Immediately below the warm epilimnion lies a region of rapid decrease in temperature, known as the thermocline, which varies in thickness and range of temperatures. Below the

[1] *Individual lake reports may be obtained on request from the Southeastern Wisconsin Regional Planning Commission or the Wisconsin Department of Natural Resources.*

thermocline lies a deep, cold, undisturbed region of water, known as the hypolimnion. In fall surface cooling causes the epilimnion to deepen by convective mixing. 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 spring temperatures under the ice layer may rise above $4^{o}C$ without disturbing the stable density gradient below. Once the ice has left, 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 through photosynthesis determine the dissolved oxygen content of the warm 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. In summer many lakes within the Southeastern Wisconsin Region lose oxygen in the hypolimnion as a result of consumption in the process of the decay of organic matter. As light does not normally penetrate deeply into the water body, oxygen produced during photosynthesis does not offset this loss; and this deficit increases as the season progresses. Because 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 unusually 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 lake within the Fox 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 72.

Table 72

SUMMARY DATA FOR MAJOR LAKES IN THE FOX RIVER WATERSHED

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 Maximum	(Feet) Mean[a]	Thermocline (Depth In Top Feet)	Area (Square Miles) Shore Length
Geneva	Walworth	5,262	320,984	1	5	77	71	135	61	27	0.407
Pewaukee	Waukesha	2,493	36,863	8	20	23	23	45	15	26	0.284
Big Muskego	Waukesha	2,260	6,564	--g	--g	--g	--g	23	3	7	0.199
Como	Walworth	946	4,033	--g	--g	--g	--g	9	4	--h	0.177
Wind	Racine	936	8,995	32	26	15	11	47	10	20	0.157
Tichigan	Racine	891	6,746	13	18	31	30	63	15	19	0.104
Beulah	Walworth	837	14,489	12	16	34	35	58	17	17	0.096
Elizabeth	Kenosha	638	6,900	15	26	21	8	32	11	26	0.166
Eagle	Racine	520	3,669	21	33	--	--	15	7	--h	0.186
Little Muskego	Waukesha	506	7,170	27	19	26	30	65	14	7	0.112
Silver	Kenosha	464	4,820	21	26	17	17	44	10	18	0.186
Camp	Kenosha	461	2,328	60	50	--	--	19	5	--h	0.149
Powers	Kenosha	459	7,337	17	18	42	19	33	16	27	0.135
Lower Phantom	Waukesha	433	1,555	--g	--g	--g	--g	12	4	--h	0.120
Browns	Racine	396	3,135	12	36	2	2	44	8	19	0.112
Eagle Spring	Waukesha	311	1,127	--g	--g	--g	--g	8	4	--h	0.103
Green	Walworth	311	7,656	11	12	55	23	57	25	20	0.110
Marie	Kenosha	310	2,798	18	30	12	7	33	9	20	0.138
Mill	Walworth	271	2,234	28	32	8	4	42	8	15	0.083
Middle	Walworth	259	2,701	34	25	17	7	42	10	18	0.076
North	Walworth	244	732	95	98	--	--	11	3	--h	0.079
Buena	Racine	241	366	--g	--g	--g	--g	8	2	--h	C.041
Denoon	Waukesha	162	2,940	20	15	40	15	55	18	10	0.094
Potters	Walworth	162	1,304	19	60	5	1	26	8	8	0.115
Pleasant	Walworth	155	1,910	17	22	25	7	29	12	13	0.086
Waubeesee	Racine	129	2,450	16	22	37	43	73	19	15	0.066
Center	Kenosha	129	1,140	18	30	20	3	28	8	14	0.031
Bohner	Racine	124	1,196	27	27	20	3	30	10	13	0.106
Long	Racine	124	312	59	89	--	--	5	3	--h	0.078
Wandawega	Walworth	119	480	32	62	--	--	8	4	--h	0.083
Booth	Walworth	113	1,376	18	24	18	5	24	12	11	0.099
Spring	Waukesha	107	588	43	46	4	<1	22	5	15	0.071
Upper Phantom	Waukesha	106	1,154	8	27	12	4	29	11	15	0.085
Cross	Kenosha	87	1,029	19	22	33	18	35	12	13	0.062
Kee Nong Go Mong	Racine	87	770	20	31	5	1	25	9	13	0.055
Lilly	Kenosha	87	416	15	57	--	--	6	5	--h	0.101
Pell	Walworth	86	314	55	62	--	--	13	4	--h	0.038
Silver	Walworth	85	211	100	100	--	--	3	2	--h	0.083
Lulu	Walworth	84	2,009	10	12	63	35	40	24	9	0.055
Benedict	Kenosha	78	1,207	13	34	40	39	37	15	23	0.072
Army	Walworth	78	625	18	35	--	--	17	8	15	0.081
Echo	Racine	71	130	--g	--g	--g	--g	11	2	--h	0.045
Peters	Walworth	64	215	43	72	--	--	8	3	--h	0.066
Dyer	Kenosha	56	275	20	54	--	--	13	5	--h	0.076
Voltz	Kenosha	52	363	26	38	6	2	24	7	12	0.035

Table 72 (continued)

SUMMARY DATA FOR MAJOR LAKES IN THE FOX RIVER WATERSHED

Lake Name	Percent Of Total Volume With > 2 mg/l DO	Nuisance[b] Hazard Based On Cl		Fertility Based On Spring PO_4[c]	Fertility Based On Alkalinity	Fertility Rating[d] Plant Tissue PO_4/Cl	Use Problems[e]								Recreational Rating[f]
							Winterkill	Pollution	Stunted Panfish	Carp	Weeds	Algae	Fluctuating Water Level	High Fishing Pressure	
Geneva	62	Low	0.7	Low	Moderate	Moderate									70
Pewaukee	89	Medium	1.7	High	Excessive	Excessive		X			X	X		X	57
Big Muskego	79	High	2.7	High	Moderate	--i	X			X	X		X		40
Como	100	Medium	1.1	Low	Very Fertile	--i	X	X			X				44
Wind	87	High	2.2	High	Moderate	Excessive				X				X	61
Tichigan	65	High	2.8	High	Very Fertile	--i		X		X	X	X		X	54
Beulah	84	Low	0.4	Medium	Very Fertile	Moderate					X				57
Elizabeth	98	Low	0.8	Medium	Moderate	Excessive								X	70
Eagle	100	High	2.1	Medium	Moderate	--i	X	X		X	X	X	X	X	53
Little Muskego	77	High	2.9	Medium	Moderate	Excessive		X			X	X		X	37
Silver	84	High	2.1	Low	Moderate	Excessive								X	66
Camp	99	Medium	1.5	Medium	Moderate	Excessive	X				X	X		X	47
Powers	98	Low	0.6	Low	Moderate	Moderate-Limiting								X	70
Lower Phantom	100	Low	0.7	Medium	Moderate	Moderate					X	X		X	52
Browns	99	Medium	1.8	High	Moderate	--i					X				52
Eagle Spring	100	Low	0.7	Low	Moderate	Moderate					X				54
Green	89	Low	0.4	Medium	Moderate	--i								X	60
Marie	97	Medium	1.0	Low	Moderate	Excessive								X	60
Mill	99	Low	0.9	Medium	Moderate	--i					X			X	60
Middle	92	Low	0.4	Medium	Moderate	--i								X	60
North	100	Low	0.3	Medium	Fairly Fertile	--i	X				X		X	X	36
Buena	100	High	3.7	High	Very Fertile	Excessive		X		X	X			X	47
Denoon	63	Medium	1.4	Low	Moderate	Moderate-Limiting			X		X			X	63
Potters	87	Medium	1.1	Moderate	Moderate	Excessive		X	X		X	X		X	42
Pleasant	93	Low	0.6	Low-Limiting	Moderate	--i								X	61
Waubeesee	84	Medium	1.4	Medium	Moderate	Excessive								X	65
Center	81	Medium	1.9	Medium	Very Fertile	Excessive					X			X	56
Bohner	89	Low	0.8	Medium	Moderate	--i								X	63
Long	100	High	2.5	High	Very Fertile	Excessive	X		X		X		X	X	49
Wandawega	100	Low	0.1	Medium	Fairly Fertile	--i	X				X		X	X	41
Booth	96	Low	0.5	Low-Limiting	Moderate	Moderate-Limiting								X	59
Spring	95	Low	0.3	Medium	Moderate	Moderate					X			Y	62
Upper Phantom	96	Low	0.7	Medium	Moderate	--i					X			X	52
Cross	88	Medium	1.1	Low	Moderate	Moderate-Limiting							X	X	61
Kee Nong Go Mong	87	Medium	1.4	Low	Moderate	Excessive								X	49
Lilly	100	Low	0.5	Low	Fairly Fertile	Moderate	X				X		X	X	59
Pell	100	Medium	1.1	Medium	Moderate	Excessive	X		X				X	X	41
Silver	100	Low	0.4	Low	Moderate	--i	X				X		X	X	36
Lulu	62	Low	0.3	Medium	Very Fertile	--i								X	61
Benedict	98	Low	0.8	Medium	Very Fertile	--i								X	59
Army	99	Medium	1.0	Medium	Moderate	Moderate								X	61
Echo	100	Medium	1.2	Medium	Very Fertile	--i		X	X	X				X	38
Peters	100	Low	0.4	High	Moderate	--i	X						X	X	38
Dyer	100		--i	High	Very Fertile	--i	X							X	53
Voltz	90	Medium	1.1	High	Moderate	Excessive					X		X	X	--

[a] *Volume/Area equals mean depth.*

[b] *Pollution hazard rating:*
High = more than 2 $\overline{X}$;
Medium = mean to less than 2 $\overline{X}$;
Low = less than $\overline{X}$; mean ($\overline{X}$) = 10 mg/l.

[c] *Spring phosphate fertility rating:*
Low = <0.06 mg/l;
Medium = 0.06 - 0.15 mg/l;
High = >0.15 mg/l.

[d] *Plant tissue rating: see Table 12-2.*

[e] *An X indicates problem areas.*

[f] *Recreational rating: Highest possible score is 72; see individual lake plans for rating summaries.*

[g] *Not measured.*

[h] *No thermocline measured because lake was too shallow.*

[i] *No analysis made.*

Source: Wisconsin Department of Natural Resources.

Following the fall mixing period, when the entire water column becomes well oxygenated, the lake surface freezes and chemical and biological oxygen demands again determine the dissolved oxygen concentrations. In winter thick ice and snow cover prevent photosynthesis, and oxygen replenishment is negligible even near the surface.

Of the 45 major lakes within the Fox River watershed, 26 stratify thermally every year. The midsummer thermal characteristics of 12 of these 26 lakes are illustrated in Figure 98, with summary information for all 45 major lakes shown in Table 72. The larger lakes have deeper thermoclines due to the influence of fetch; and several lakes, such as Cross and Powers Lakes in Kenosha County, have thermoclines which extend to the bottom. In some lakes, such as Middle Lake in Walworth County, the epilimnion, fading into the thermocline, is not a distinct layer. The classic temperature profile is near that exhibited by such lakes as Silver Lake in Kenosha County and Browns Lake in Racine County. The mean midsummer surface temperature of the 26 major lakes in the watershed exhibiting thermal stratification was found to be 25.7°C (78.3°F); and the mean bottom temperature, 12.0°C (53.6°F). The maximum rate of temperature decrease in the thermoclines was found to be about 1.2°C decrease per foot increase in depth. The average depth from the surface to the top of the thermocline was found to be 16.5 feet, with a range from 7 to 30 feet.

Oxygen Content

Since oxygen concentrations in midsummer determine the depths to which fish are found, oxygen profiles were prepared for the 26 major lakes within the watershed which exhibited thermal stratification and, therefore, deep-water oxygen deficits. Twelve of these profiles are also illustrated in Figure 98. The larger lakes with deeper thermoclines have greater concentrations of dissolved oxygen through the thermoclines. In some cases, such as Little Muskego Lake in Waukesha County, an oxygen deficit exists nearly to the surface. The average oxygen concentration one foot below the surface for the 26 lakes was found to be 8.3 mg/l, with a range from 6.7 to 11.4 mg/l. The average bottom oxygen concentration encountered was less than 0.1 mg/l with 24 of the 26 lakes having no measurable oxygen content near the bottom. Dissolved oxygen contents were found to decrease to less than 2 mg/l on the average at 20 feet of depth, with a range from 8 feet for Potters Lake in Walworth County to 50 feet for Geneva Lake in Walworth County.

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 more plant growth. Photosynthesis decreases alkalinity by producing calcium carbonate, which tends to precipitate out of solution, while decomposition increases alkalinity by bringing carbonates 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 plant materials produced and settled from above, may be expected to have higher alkalinities. Lakes are generally classified as fertile if their waters contain 40 mg/l or more of total alkalinity (see Table 73). By this definition all lakes of the Fox River watershed are fertile and productive. The mean total alkalinity of the 45 major lakes within the Fox River watershed during the spring mixing period was found to be 183 mg/l, with a range of from 52 mg/l to 291 mg/l (see Table 74). In late summer under stratified conditions, the upper layers were found to average 175 mg/l total alkalinity.

Table 73

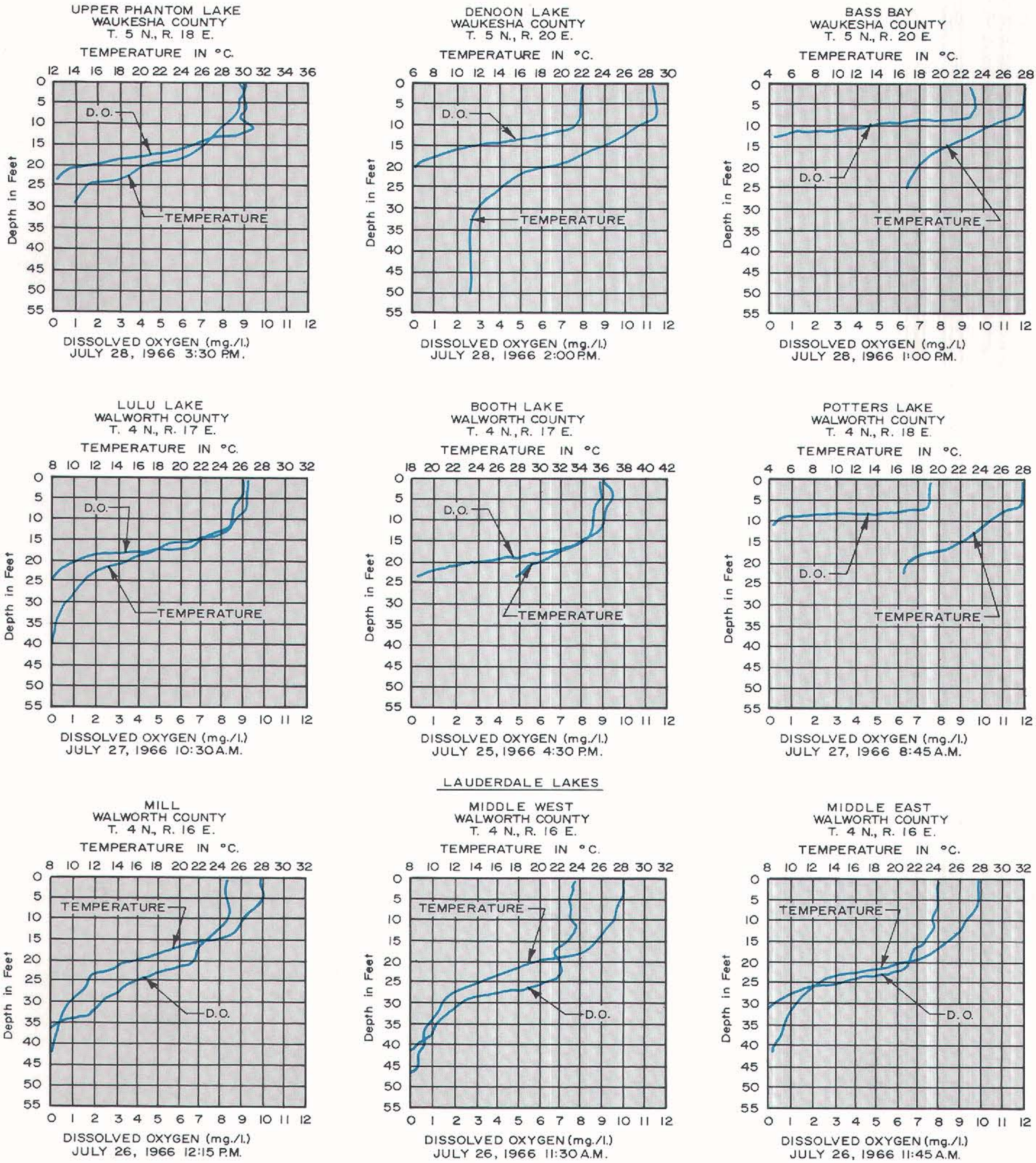
GENERAL LAKE WATER FERTILITY RATING BASED ON TOTAL ALKALINITY MEASURED

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.

Figure 98

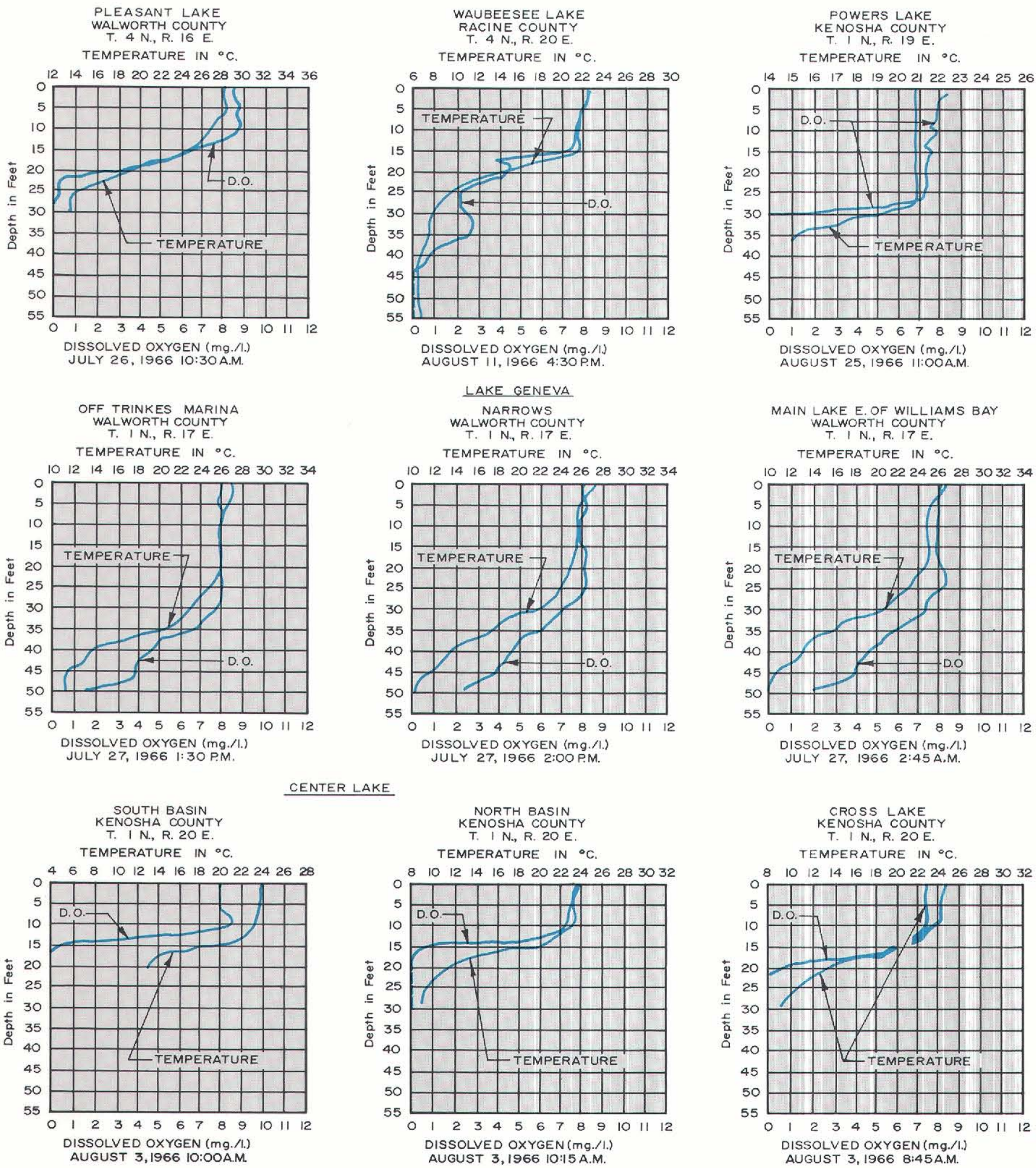
MIDSUMMER THERMAL CHARACTERISTICS AND DISSOLVED OXYGEN PROFILES FOR SELECTED LAKES IN THE FOX RIVER WATERSHED



Source: Wisconsin Department of Natural Resources.

Figure 98 (continued)

MIDSUMMER THERMAL CHARACTERISTICS AND DISSOLVED OXYGEN PROFILES FOR SELECTED LAKES IN THE FOX RIVER WATERSHED



Source: Wisconsin Department of Natural Resources.

Table 74

DETAILED WATER ANALYSES OF MAJOR LAKES IN THE FOX RIVER WATERSHED: 1960-1966

Lake Name	Acreage	Date Of Sample	Specific Conductance (micromhos/cm At 25C°)	pH (Units)	Total Alkalinity (mg/l As $CaCO_3$)	Nitrate As Nitrogen (mg/l)	Total Phosphates (mg/l)	Dissolved Phosphates (mg/l)	Chlorides (mg/l)
Geneva	5,262	5/13/60	394	7.9	168	0.06	0.09	0.02	5.7
		3/21/66	394	8.2	176	0.27	0.10	0.04	6.7
		3/21/66	387	8.3	181	0.29	--	0.04	6.3
		3/21/66	386	8.3	177	0.30	0.09	0.04	6.0
		3/21/66	406	8.3	181	0.27	0.07	0.04	6.3
		3/21/66	391	8.2	181	0.29	0.08	0.04	6.2
		3/21/66	387	8.3	178	0.28	0.26	0.06	6.1
		8/22/66	373	8.2	168	--	0.11	0.02	7.6
		8/22/66	367	8.3	168	--	0.08	0.02	6.9
		8/22/66	365	8.3	172	--	0.08	0.03	7.1
		8/22/66	368	8.3	172	--	0.13	0.02	6.9
		8/22/66	368	8.2	173	--	0.07	0.01	6.9
		8/22/66	373	8.3	173	--	0.09	0.03	7.4
		8/22/66	369	8.3	172	--	0.08	0.02	6.9
		8/22/66	380	8.2	170	--	0.09	0.04	7.1
		8/22/66	381	8.1	177	--	0.17	0.07	6.9
		8/22/66	371	8.2	172	--	0.15	0.03	7.1
		8/22/66	384	7.8	168	--	0.13	0.04	11.5
		8/22/66	385	8.2	172	--	0.05	0.03	6.7
		8/22/66	361	8.3	167	--	0.37	0.03	7.1
Pewaukee	2,493	4/11/63	379	8.5	195	--	--	0.09	12.7
		7/08/63	414	8.5	179	0.13	--	0.78	11.4
		7/08/63	408	8.5	178	--	--	0.98	11.9
		3/28/66	493	7.9	196	0.79	0.62	0.36	15.7
		3/28/66	481	8.0	195	0.74	0.54	0.45	15.7
		3/28/66	493	8.0	188	1.06	--	--	14.7
		3/28/66	457	8.4	187	0.90	0.61	0.08	14.9
		9/13/66	457	8.4	195	--	0.39	0.39	17.4
		9/13/66	464	8.0	198	--	0.39	0.39	17.4
Big Muskego	2,260	9/13/66	498	8.5	158	--	0.08	0.08	21.3
		9/13/66	448	9.0	121	--	0.17	0.17	27.4
		9/13/66	519	7.7	169	--	0.08	0.08	21.3
Como	946	5/13/60	417	8.2	180	0.05	0.04	0.01	4.8
		3/22/66	406	7.8	192	0.91	0.24	0.04	8.0
		3/22/66	425	7.9	198	1.05	0.22	0.05	8.4
		3/22/66	430	7.8	206	1.07	0.15	0.13	8.7
		8/22/66	331	9.0	157	--	0.22	0.01	10.3
		8/22/66	327	8.8	151	--	0.22	0.09	10.3
		8/22/66	346	8.8	157	--	0.21	0.01	10.3
		8/22/66	406	8.3	186	--	0.30	0.04	10.8
		8/22/66	434	8.0	200	--	0.12	0.07	10.8

Table 74 (continued)

DETAILED WATER ANALYSES OF MAJOR LAKES IN THE FOX RIVER WATERSHED: 1960-1966

Lake Name	Acreage	Date Of Sample	Specific Conductance (micromhos/cm At 25C°)	pH (Units)	Total Alkalinity (mg/l As $CaCO_3$)	Nitrate As Nitrogen (mg/l)	Total Phosphates (mg/l)	Dissolved Phosphates (mg/l)	Chlorides (mg/l)
Wind	936	4/14/66	488	8.4	172	0.28	--	0.40	19.5
		4/14/66	511	8.4	173	0.26	--	0.03	19.8
		4/14/66	469	8.4	173	0.25	--	0.10	20.0
		8/24/66	498	8.4	138	--	0.05	0.02	21.6
		8/24/66	512	7.8	151	--	0.08	0.08	21.3
Tichigan	891	4/14/66	514	8.2	207	0.15	--	0.18	24.3
		4/14/66	513	8.4	208	0.26	--	0.27	23.8
		8/24/66	460	9.0	146	--	--	0.15	27.7
		8/24/66	466	9.0	148	--	0.33	0.04	27.9
		9/16/66	496	8.4	162	--	0.32	0.22	28.4
Beulah	837	5/13/60	457	7.8	215	0.05	0.10	0.05	2.8
		4/06/66	440	8.2	219	0.03	--	0.09	2.8
		4/06/66	379	8.3	182	0.03	--	0.12	2.5
		4/06/66	347	8.3	173	0.01	--	0.12	3.3
		9/12/66	410	8.1	200	--	0.11	--	4.0
		9/12/66	410	8.0	203	--	0.10	0.07	4.2
Elizabeth	638	4/15/60	433	8.0	190	0.50	0.12	0.02	6.2
		4/15/60	433	8.0	180	0.50	0.10	0.02	6.0
		3/31/66	393	--	180	0.10	0.08	0.08	8.5
		3/31/66	397	--	178	0.05	0.04	0.02	8.3
		3/31/66	401	--	178	0.05	--	0.09	8.5
		8/24/66	391	8.4	168	--	0.05	0.05	9.3
		8/24/66	391	8.4	168	--	0.06	0.06	9.3
Eagle	520	4/15/60	478	8.0	147	1.70	0.46	0.28	11.2
		4/15/60	478	8.0	151	2.00	0.43	0.23	11.6
		4/14/66	432	8.0	154	0.04	--	0.10	17.3
		4/14/66	423	8.2	156	0.08	--	0.07	17.0
		8/23/66	453	8.8	140	--	0.17	0.10	20.8
Little Muskego	506	4/11/63	413	8.0	191	--	--	0.06	18.2
		9/13/66	471	8.5	162	--	0.42	0.32	28.6
		9/13/66	501	7.8	186	--	0.29	0.28	27.2
Silver (Kenosha County)	464	4/15/60	485	8.0	168	1.90	0.22	0.02	10.8
		4/15/60	485	7.9	175	0.40	0.38	0.03	10.5
		4/01/66	489	--	163	0.01	0.19	0.04	17.2
		4/01/66	494	--	165	0.31	0.12	0.03	17.0
		4/01/66	509	--	168	0.37	0.21	0.04	18.1
		8/23/66	476	8.4	157	--	0.14	0.03	20.8
		8/23/66	486	8.2	159	--	0.19	0.03	20.8

Table 74 (continued)

DETAILED WATER ANALYSES OF MAJOR LAKES IN THE FOX RIVER WATERSHED: 1960-1966

Lake Name	Acreage	Date Of Sample	Specific Conductance (micromhos/cm At. 25C°)	pH (Units)	Total Alkalinity (mg/l As $CaCO_3$)	Nitrate As Nitrogen (mg/l)	Total Phosphates (mg/l)	Dissolved Phosphates (mg/l)	Chlorides (mg/l)
Camp	461	4/20/66	395	8.2	188	--	0.24	0.13	15.5
		4/20/66	411	8.1	189	--	0.28	0.05	15.0
		8/24/66	466	8.1	153	--	0.05	0.05	18.4
Powers	459	3/31/66	373	--	176	0.16	0.18	0.04	6.1
		3/31/66	484	--	171	0.18	0.13	0.04	6.0
		3/31/66	484	--	212	1.11	0.37	0.04	6.8
Lower Phantom	433	3/28/66	420	8.2	194	0.59	0.13	0.07	5.2
		3/28/66	431	8.1	194	0.83	0.51	0.51	5.1
		9/13/66	346	8.7	174	--	0.05	0.07	6.6
Browns	396	4/15/60	433	8.1	184	0.50	0.53	0.29	8.4
		4/15/63	433	8.1	186	1.75	0.57	0.24	9.2
		4/14/66	369	8.5	172	0.05	--	0.78	14.0
		8/23/66	401	8.7	159	--	0.82	0.82	17.2
		8/23/66	401	8.6	160	--	0.86	0.83	17.2
		9/16/66	421	8.4	164	--	0.78	0.68	17.5
Eagle Spring	311	3/28/66	388	8.3	184	0.56	0.71	0.06	3.5
		3/28/66	478	8.1	215	1.79	0.16	0.03	6.6
		9/13/66	293	9.0	157	--	0.09	0.05	5.1
Green	311	4/06/66	351	8.4	174	0.02	--	0.08	3.0
		9/12/66	312	8.5	159	--	0.13	0.13	3.9
Marie	310	4/20/66	343	7.9	191	--	0.04	0.04	9.3
		8/24/66	406	8.5	170	--	0.08	0.04	10.8
		8/24/66	407	8.5	171	--	0.07	0.04	10.8
Mill	271	4/06/66	379	8.1	184	0.01	--	0.18	4.5
		4/26/66	351	8.5	186	--	0.10	0.08	3.5
		9/12/66	330	8.5	160	--	0.28	0.24	4.7
Middle	259	4/06/66	417	8.3	195	0.16	--	0.10	3.5
		9/12/66	348	8.3	171	--	0.07	0.33	4.2
		9/12/66	417	7.4	197	--	0.18	0.17	4.2
North	244	4/06/66	144	7.8	53	0.04	--	0.08	2.5
		9/12/66	203	7.4	100	--	0.21	0.15	3.4
Buena	241	4/14/66	597	8.6	258	0.38	--	0.58	22.8
		8/24/66	640	8.5	245	--	1.95	1.95	36.8
Denoon	162	4/26/66	435	8.6	168	--	0.12	0.04	12.3
		8/24/66	418	8.4	137	--	0.10	0.06	14.0
		8/24/66	463	7.6	163	--	0.19	0.09	14.0
Potters	162	5/13/60	318	7.8	148	0.20	0.44	0.06	5.3
		9/12/66	299	8.0	135	--	0.99	0.87	10.5
		9/12/66	302	7.3	138	--	0.51	--	10.5

Table 74 (continued)

DETAILED WATER ANALYSES OF MAJOR LAKES IN THE FOX RIVER WATERSHED: 1960-1966

Lake Name	Acreage	Date Of Sample	Specific Conductance (micromhos/cm At 25C°)	pH (Units)	Total Alkalinity (mg/l As $CaCO_3$)	Nitrate As Nitrogen (mg/l)	Total Phosphates (mg/l)	Dissolved Phosphates (mg/l)	Chlorides (mg/l)
Pleasant	155	5/13/60	336	7.9	152	0.05	0.15	0.04	3.8
		4/19/65	118	7.3	52	0.07	0.05	0.02	2.6
		4/19/65	197	8.0	98	0.06	0.02	0.02	3.4
		4/19/65	348	8.1	170	0.08	0.25	0.02	5.4
		4/06/66	348	8.4	163	0.04	--	0.15	4.3
		4/06/66	351	8.2	163	0.05	--	0.16	5.0
		9/12/66	315	8.4	152	--	0.09	0.08	5.6
		9/12/66	325	8.3	156	--	0.28	0.17	5.6
Waubeesee	129	4/14/66	427	8.1	160	0.19	--	0.07	12.8
		4/26/66	465	8.2	163	--	0.06	0.08	11.3
		8/24/66	453	8.3	136	--	0.04	0.04	13.5
		8/24/66	477	8.0	147	--	0.12	0.08	13.0
Center	129	4/20/66	467	8.7	222	--	0.11	0.06	17.5
		4/20/66	468	8.5	224	--	0.48	0.07	18.5
		8/24/66	538	8.2	180	--	0.05	0.05	18.4
		8/24/66	522	8.3	167	--	0.15	0.05	18.6
Bohner	124	4/14/66	390	8.6	193	0.24	--	0.28	6.3
		4/26/66	445	8.5	195	--	0.06	0.05	6.5
		8/23/66	402	8.4	171	--	0.05	0.03	7.8
		8/23/66	419	8.1	185	--	0.07	0.07	7.7
		8/23/66	436	8.0	192	--	0.09	0.07	8.3
Long	124	4/14/66	565	8.3	238	0.68	--	0.04	13.8
		4/14/66	661	8.5	274	0.05	--	0.17	25.3
		8/23/66	593	8.0	211	--	0.03	0.03	20.3
Wandewega	119	4/06/66	148	8.4	67	0.03	--	0.08	1.3
Booth	113	5/13/60	326	8.4	145	0.32	0.04	0.01	3.5
		4/06/66	308	8.2	145	0.05	--	0.06	2.8
		9/12/66	320	7.9	149	--	0.05	0.05	4.9
		9/12/66	320	8.2	147	--	0.05	0.02	4.9
Spring	107	3/28/66	461	8.3	176	2.04	0.41	0.10	3.3
Upper Phantom	106	3/28/66	404	8.3	195	0.64	0.17	0.08	6.1
		3/28/66	416	8.2	195	0.49	0.12	0.01	6.3
		9/13/66	351	8.6	172	--	0.25	0.10	6.9
		9/13/66	357	8.5	173	--	0.06	0.06	7.0
Cross	87	4/20/66	367	8.1	160	--	0.12	0.03	10.0
		8/23/66	402	8.7	126	--	0.05	0.02	10.5
		8/23/66	417	8.4	134	--	0.06	0.05	10.5

Table 74 (continued)

DETAILED WATER ANALYSES OF MAJOR LAKES IN THE FOX RIVER WATERSHED: 1960-1966

Lake Name	Acreage	Date Of Sample	Specific Conductance (micromhos/cm At 25C°)	pH (Units)	Total Alkalinity (mg/l As $CaCO_3$)	Nitrate As Nitrogen (mg/l)	Total Phosphates (mg/l)	Dissolved Phosphates (mg/l)	Chlorides (mg/l)
Kee Nong Go Mong	87	4/14/66	511	8.0	177	0.25	--	0.04	13.0
		8/24/66	499	8.4	134	--	0.08	0.05	13.5
		8/24/66	496	8.3	135	--	--	0.06	13.5
Lilly	87	4/01/66	285	--	139	0.13	0.16	0.03	4.5
		4/01/66	276	--	139	0.11	0.26	0.04	4.6
		8/24/66	207	9.0	91	--	0.20	0.04	5.4
Pell	86	3/31/66	348	--	168	0.09	0.10	0.10	11.0
		3/31/66	353	--	164	0.18	0.17	0.05	11.0
		8/24/66	327	8.3	146	--	0.10	0.10	12.5
Silver (Walworth County)	85	5/13/60	371	8.0	180	0.20	0.34	0.06	2.7
Lulu	84	4/06/66	436	8.3	224	0.14	--	0.09	2.0
		9/13/66	370	8.3	201	--	0.04	0.04	2.5
		9/13/66	408	7.9	219	--	0.02	--	2.9
Benedict	78	3/31/66	426	--	200	0.26	0.44	0.04	7.6
		3/31/66	423	--	200	0.35	--	0.08	7.6
Army	78	4/06/66	424	8.3	180	0.11	--	0.08	7.3
		9/12/66	383	8.5	168	--	0.16	0.14	10.3
Echo	71	4/14/66	535	8.4	260	0.63	--	0.13	9.8
		8/23/66	566	8.0	250	--	0.28	0.28	11.5
Peters	64	4/26/66	259	8.6	126	--	0.42	0.39	2.5
		9/12/66	366	8.3	191	--	1.68	1.68	4.4
Dyer	56	(no information available at this time)							
Voltz	52	4/26/66	332	8.8	142	--	0.72	0.07	8.5
		4/26/66	332	8.8	142	--	0.72	0.07	8.5
		4/26/66	329	8.5	141	--	0.15	0.09	7.8
		8/23/66	382	8.1	168	--	0.58	0.52	10.8
		8/23/66	378	7.6	169	--	0.68	0.53	10.7

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. Although more tolerant species can survive at high pH values, such values are generally considered hazardous to fish life. The mean pH value of the 45 major lakes within the Fox River watershed during the spring mixing period was found to be 8.2, with a range from 7.3 to 8.7. In late summer upper waters were found to average 8.4 and ranged from 7.6 to 9.8, while deep waters averaged 8.0 and ranged from 7.4 to 9.0 (see Table 74). Extreme values were encountered in Bass Bay of Big Muskego Lake in Waukesha County, Lilly Lake in Kenosha County, Tichigan Lake in Racine County, and Como Lake in Walworth County 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 animal urine associated with heavy lake use by water fowl, from sewage and industrial wastes, and from surface runoff. Little variation was found in the vertical distribution of chlorides. The mean chloride content of the 45 major lakes within the Fox River watershed was found to be 10.0 mg/l, with a range from 1.3 mg/l to 71.8 mg/l (see Table 74). Those lakes with chloride concentrations higher than twice the mean are considered to reflect potential local problems. These include Silver Lake in Kenosha County; Eagle, Buena, Long, Tichigan, and Wind Lakes in Racine County; and Bass Bay of Big Muskego Lake and Little Muskego Lake in Waukesha County.

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, chlorine, boron, cobalt, and silicon. Others, termed macronutrients, must be present in larger amounts and include phosphorus, nitrogen, carbon, hydrogen, oxygen, potassium, magnesium, calcium, and sulphur.

Phosphorus compounds are important in energy transformation, especially photosynthesis. Algae are dependent upon phosphorus for growth; and, therefore, the production of the 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 0.5 mg/l, nuisance algal blooms can be anticipated. In lakes that 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 45 major lakes within the watershed were found to be 0.23 and 0.11 mg/l, respectively (see Table 74). The range of these average levels for both total and dissolved phosphate varied from 0 to 1.95 mg/l. During the summer the average total phosphate and dissolved phosphate levels in the surface layers were found to be the same, 0.23 and 0.11 mg/l, respectively. Deeper samples taken in midsummer indicated total phosphate contents averaging 0.21 mg/l; and dissolved phosphate, 0.12 mg/l. Of the 11 major lakes within the watershed exhibiting limiting concentrations of available phosphate in spring, only two—Pleasant and Booth Lakes in Walworth County—appear to have truly limiting phosphate levels. All other lakes studied had considerable growth of rooted aquatic vegetation or early spring algal blooms at the time of sampling.

Aquatic Plants

All of the lakes within the Fox River watershed have moderate-to-abundant growths of aquatic plant vegetation extending from the shorelines to depths as great as 30 feet. Generally, lakes with combinations of extensive shallow water areas, clear water, and muck bottoms produce more vegetation per acre than lakes with limited shallow water areas, either turbid or dark-colored water, and sand or gravel bottoms. A continuum of vegetative growths were found to exist, ranging from Geneva Lake in Walworth County with relatively little plant life to lakes, such as Lower Phantom Lake in Waukesha County, which was found to have an abundance of plants over its entire basin (see Table 75). Some of the lakes surveyed had unusually rank aquatic growth or excessive algal blooms, indicating pollution through unnatural enrichment. Such enrichment can be caused by drainage from fertilized agricultural lands, storm water runoff from urban areas, septic tank effluent seepage, and domestic and industrial liquid waste disposal. Lakes exhibiting a rank abundance of plant growth were Camp and Lilly Lakes in Kenosha County; Tichigan Lake in Racine County; Pell and Wandawega Lakes in Walworth County; and Eagle Spring, Little Muskego, and Lower Phantom Lakes in Waukesha County.

The depth to which aquatic vegetation is encountered varies directly with the relative transparency of the lake water. When samples from 27 moderately deep lakes were compared, the ratio of secchi transparency depth readings to maximum depth of plant growth was found to be 0.55 to 1. Thus, in general, plants were found to grow to a depth of 1.82 times the transparency depth measured.

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 72 for the 39 major natural lakes within the Fox River watershed. In this respect, the distinction between natural lakes and impoundments should be noted, the latter being defined as those bodies of water which owe more than one-half of their surface area to the existence of an impounding structure. Of the 45 major lakes within the Fox River watershed, six are considered to be impoundments: Big Muskego, Como, Lower Phantom, Eagle Spring, Buena, and Echo. These impoundments are characterized as having irregular shorelines, elongated basins, predominately silt bottoms, and extensive areas of shallow waters in the upper portion of the impoundment.

The area of open water per unit of shoreline varies in response to the irregularity of the shoreline and is expressed by the 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. This factor can never be less than 1.0. Figure 99 indicates the relationship of lake area to shoreline length for the 39 major natural lakes within 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. The shorelines of lakes ranging in size from 100 up to 500 acres in area, because of the direction of the prevailing winds within the Region, commonly have sand or gravel wave-washed shorelines along the 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 of the lakes within the watershed, as presented in Table 72, indicates that in general the major lakes of the watershed are shallow enough that nearly all of their total water volume is sufficiently oxygenated to support fish life in summer. Seventeen of the major lakes have no water areas greater than 20 feet in depth, however, and may be expected occasionally to lack sufficient oxygen for over winter survival of fish life. Growth of emergent rooted aquatic vegetation is generally limited to areas covered by water less than three feet deep. Such shallow waters constitute approximately 16 percent of the major lake acreage and approximately 11 percent of the major lake volume.

Fish Life

Every major lake within the Fox River watershed was found to support a fishery comprised of northern pike, largemouth bass, bluegills, and bullheads (see Figure 100 and Map 47). Over half of the lakes studied contained populations of rough fish, principally carp, and in six lakes—Big Muskego in Waukesha County and Wind, Tichigan, Eagle, Buena and Echo Lakes in Racine County—rough fish occurred in such abundance as to be

Table 75

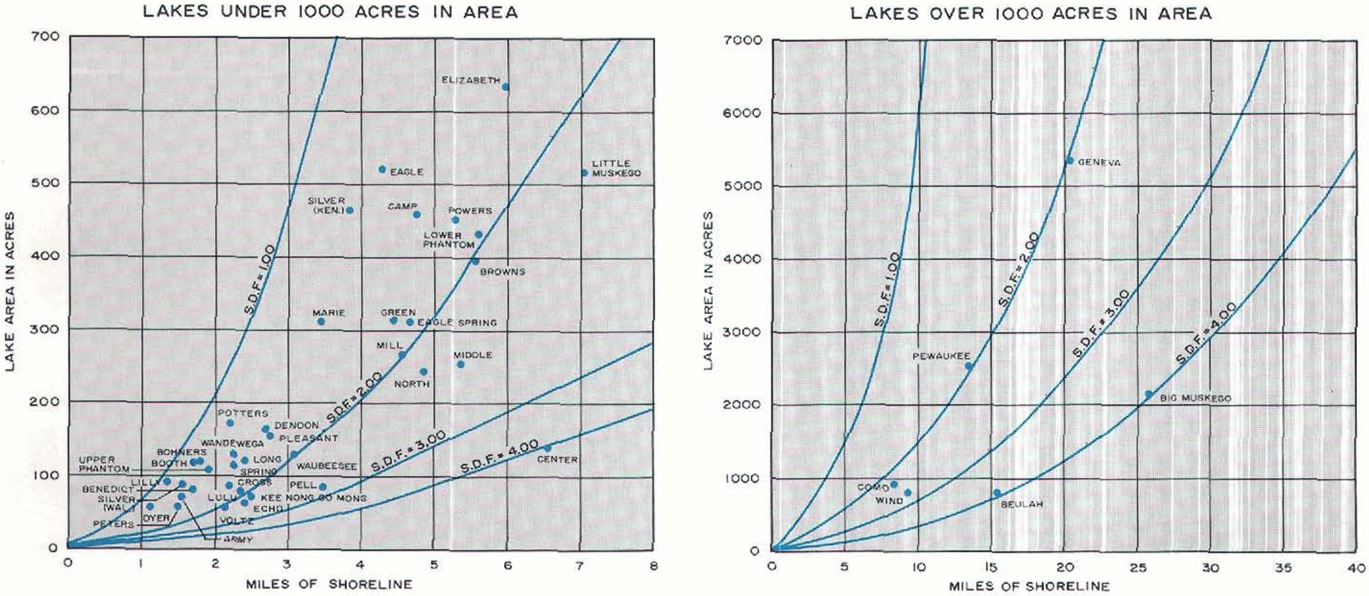
RELATIVE ABUNDANCE AND PRESENCE OF AOUATIC PLANT TYPES IN ALL LAKES OF THE FOX RIVER WATERSHED IN THE SOUTHEASTERN WISCONSIN REGION: 1966

Aquatic Plant Type: Scientific Name	Aquatic Plant Type: Common Name	Type Of Aquatic Vegetation	Percent Of Total Aquatic Vegetation	Percent Occurrence In All Lakes
Chara		Submergent	18.73	93.1
Potamogeton	Pondweed	Submergent -Floating	16.76	100.0
P. pectinatus	Sago Pondweed	Submergent	3.62	97.7
P. natans	Floating-Leaf Pondweed	Floating	2.63	70.4
P. amplifolius	Largeleaf Pondweed	Submergent -Floating	2.54	38.6
P. praelongus	Whitestem Pondweed	Submergent	2.27	43.1
P. spp. (Narrow Leaf)	Narrowleaf Pondweed	Submergent	1.51	75.0
P. zosteriformis	Flatstem Pondweed	Submergent	1.51	45.4
P. crispus	Curlyleaf Pondweed	Submergent	1.49	52.2
P. spp. (Broad Leaf)	Broad Leaf Pondweed	Submergent -Floating	0.75	34.0
P. illinoensis	Illinois Pondweed	Submergent -Floating	0.94	22.7
P. gramineus	Variable Pondweed	Submergent -Floating	0.59	38.6
P. robbinsii	Flatleaf Pondweed	Submergent	0.37	20.4
P. nodosus	American Pondweed	Submergent -Floating	0.26	25.0
P. oakesianus		Submergent	0.26	4.5
P. richardsonii	Richardson Pondweed	Submergent	0.23	6.8
P. lucens		Submergent	0.08	4.5
P. vaseyi	Vasey's Pondweed	Submergent -Floating	0.03	2.2
Myriophyllus	Water Milfoil	Submergent	8.51	88.6
Typha	Cattail spp.	Emergent	7.16	84.0
Najas	Spiny Niad-Bushy Pondweed	Submergent	6.76	61.3
Nuphar	Yellow Water Lily	Floating	6.23	81.8
Nymphaea	White Water Lily	Floating	5.85	88.6
Scirpus validus	Bulrush	Emergent	5.78	86.3
Ceratophyllum	Coontail	Submergent	4.28	61.3
Cyperaceae (Excluding Scirpus validus)	Sedges	Emergent	3.75	72.7
Vallisneria	Eel Grass	Submergent	2.84	59.0
Decodon	Swamp Loosestrife	Emergent	2.56	45.4
Nitella	Nitella	Submergent	2.50	29.7
Ruppia	Widgeon Grass	Emergent	2.28	9.0
Lemna	Duckweed	Floating	1.85	22.7
Anacharis	Elodea	Submergent	0.72	50.0
Utricularia	Bladderwort	Submergent -Floating	0.72	45.4
Pontederia	Pickerel Weed	Emergent	0.72	20.4
Sagittaria	Arrowhead	Emergent	0.53	36.3
Sparganium	Bur-Reed	Emergent	0.36	31.8
Brasenia	Water Shield	Floating	0.33	6.8
Wolffia	Watermeal	Floating	0.31	4.5
Ranunculus	Buttercup	Emergent	0.30	22.7
Zizania	Wild Rice	Emergent	0.14	11.3
Rumex	Dock	Emergent	0.13	18.1
Polygonum	Smartweed	Emergent -Floating	0.08	13.6
Phragmites	Reed Grass	Emergent	0.05	6.8

Source: Wisconsin Department of Natural Resources.

Figure 99

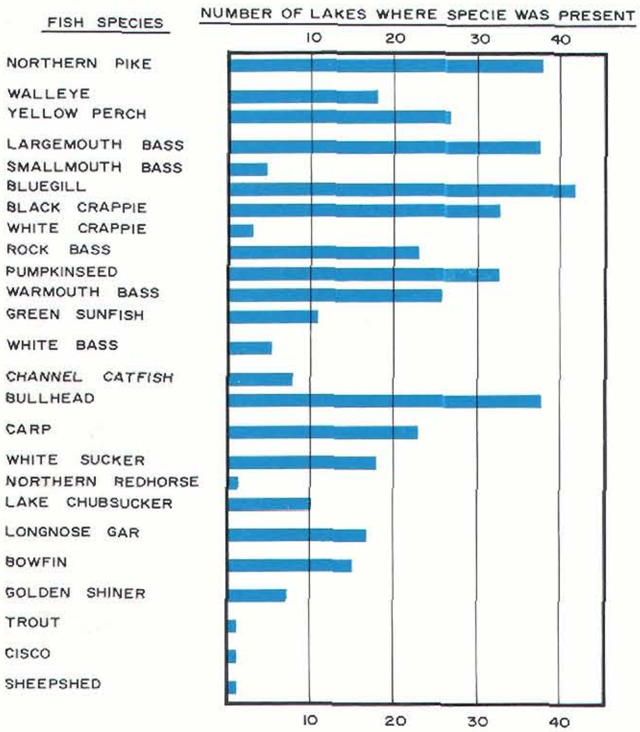
SHORE DEVELOPMENT FACTOR FOR LAKES IN THE FOX RIVER WATERSHED



Source: Wisconsin Department of Natural Resources.

Figure 100

OCCURRENCE OF VARIOUS SPECIES OF FISH IN THE 45 MAJOR LAKES OF THE FOX RIVER WATERSHED: 1967



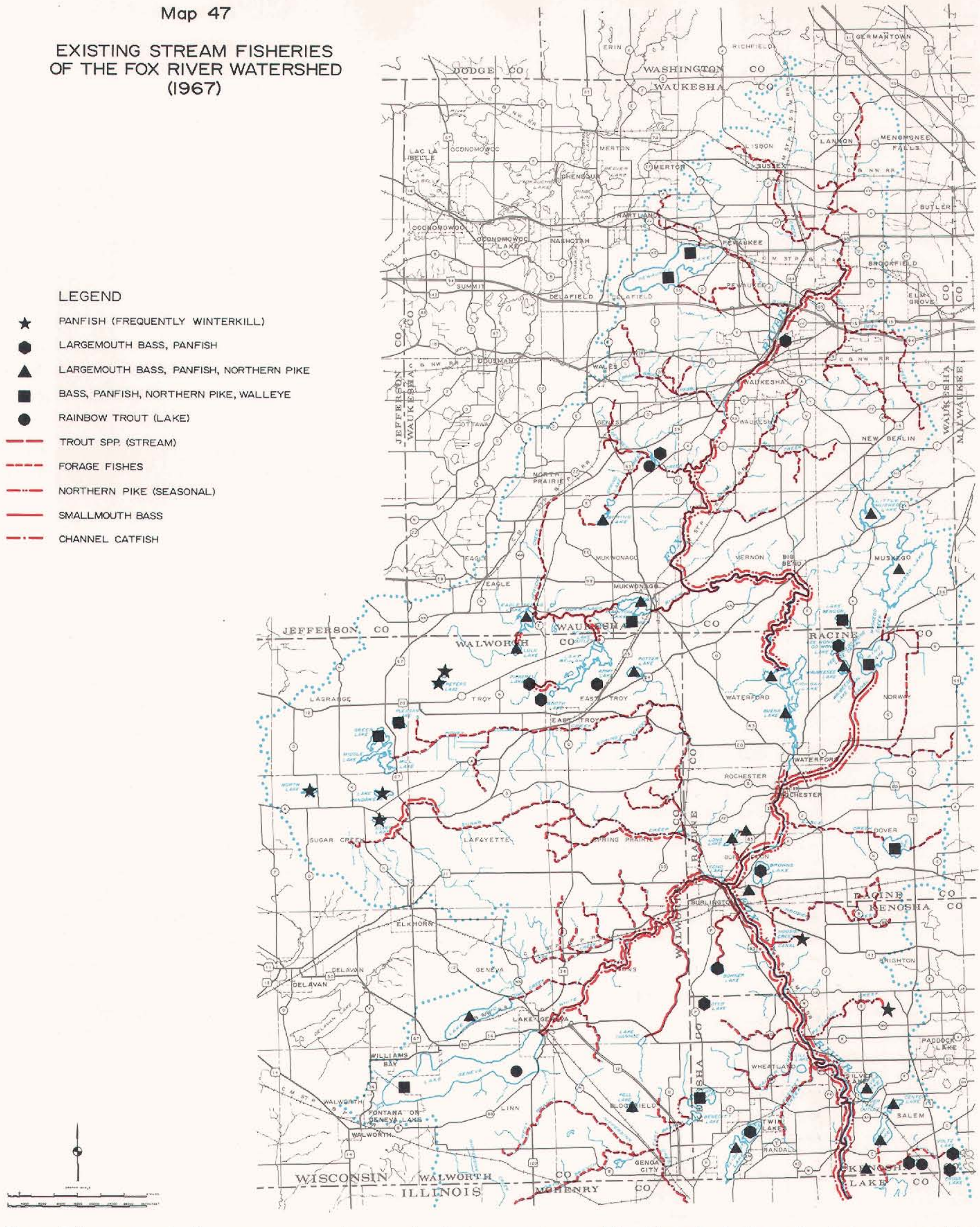
Source: Wisconsin Department of Natural Resources.

considered detrimental to the other more desirable forms of fishlife. The various fishery problems encountered within the lakes of the watershed are summarized in Table 72. 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.

Stream fisheries of any consequence exist on only seven streams within the watershed, including the main stem of the Fox River, Mukwonago River, Genesee Creek, White River, Palmer Creek, Sugar Creek, and Honey Creek. Trout are found in three streams—Sugar Creek, Palmer Creek, and Genesee Creek—but the population is believed to persist only because of annual stocking. The warm-water fishery most common to the smaller streams within the watershed was found to be comprised of largemouth bass, northern pike, rock bass, and black crappies, with each stream having small populations of the species mentioned. The White River, Sugar Creek, Honey Creek, and Mukwonago River are secondary warm-water fishery streams. The principal warm-water fishery stream is the main stem of the Fox River below Waterford. Here walleyes, northern pike, smallmouth bass, channel catfish, black and white crappies, white bass, yellow perch, bluegills, and bullheads contribute to the fishery. Most of the

Map 47

EXISTING STREAM FISHERIES
OF THE FOX RIVER WATERSHED
(1967)



The maintenance and, in some cases, enhancement of stream 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. Some stream reaches are already devoid of fish life during most of the year due to the low oxygen levels existing in the streams. Nutrients and oxygen-demanding organic materials are the major pollutional causes of fish management problems in the watershed.

Source: Wisconsin Department of Natural Resources.

streams within the watershed have detrimental fish populations, with carp, white suckers, and northern red horse either abundant or dominating in pools. The presence of carp in some streams, including Honey Creek and Sugar Creek, limits the distribution of other more desirable species. Other determinants of distribution include the presence of dams, poor water quality, and intermittent or insufficient streamflow.

Problems Related to Lakes and Streams

Inadequate Water Depth: A major recreational inadequacy existing in many of the lakes within the Fox River watershed is the lack of sufficient depth. An examination of Table 72 would indicate that the small lakes are not always the shallowest and that several of the larger lakes have more than 20 percent of their total area covered by waters 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 are vegetal aging and sedimentation.

The fertile lakes of the watershed produce great quantities of organic matter, and rich organic deposits accumulate rapidly on the bottom. On leeward shores and in protected bays, emergent and eventually terrestrial vegetation develops readily; and marsh may progressively replace 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 72). Shallow water permits rooted aquatic vegetation to grow in profusion, which interferes with its use for boating and swimming. Such vegetation is a major problem on 24 of the 45 major lakes within the Fox River watershed. Shallow lakes are subject to winterkill and the loss of fish due to inadequate oxygen supply. This is a major problem on 12 of the 45 major lakes within the Fox 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. A minimum desirable depth for boating approximates five feet. Thirteen of the 45 major lakes within the watershed were found to have a mean depth of less than five feet; and, 13 additional lakes were found to have a mean depth of less than 10 feet. Finally, light penetration in shallow lakes affects a much greater proportion of the water than in deeper lakes resulting in excessive growth of algae and weeds and concomitant impairment of recreational use. Fifteen of the 45 lakes studied are in this shallow category.

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, defined as lakes having a surface area of less than 50 acres, are generally considered unsuited to the use of motor-powered boats. Thirty-one such small lakes exist within the watershed; and these were, because of their size and limited recreational value, excluded from intensive study. Of the 45 major lakes within the watershed, 23 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 19 lakes within the Fox 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 the largest lakes, those of more than 1,000 acres surface area, can all recreational activities be permitted with a minimum of limitations. Only two such lakes exist within the watershed, Geneva Lake in Walworth County and Pewaukee Lake in Waukesha County, Big Muskego Lake in Waukesha County being excluded because of its shallow depth. 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 and streams. These classification standards are set forth in Appendix K of this report.

Under some conditions the fisheries of the lakes may be subject to excessive use when angling reaches the 50-man-hour per acre per year level. Under a good management program, however, the fisheries of some lakes can tolerate 100 to 200 man hours of fishing per acre per year. Of the 45 major lakes within the watershed, 38 now receive more than 50 man hours per acre per year of fishing use, as indicated in Table 72; and 10 of these 38 have a surface area of less than 100 acres. Unless sound conservation measures are instituted, the fisheries of these lakes may be expected to deteriorate rapidly.

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 cold-water 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 Fox River watershed, and low summer flows are also a problem of most major tributaries.

Lake Level Instability: Lake level instability is not a major recreational problem within the Fox River watershed except during extreme weather conditions. Lake level fluctuations within the watershed seldom exceed one foot per year. Increases in lake levels normally occur in the spring and are the result of snowmelt, rainfall, and heavy surface runoff. Decreases in lake levels normally occur in the summer and are the result of evaporation, transpiration, discharge to outlet streams, and discharge to the ground water reservoir. Only extreme weather conditions, such as prolonged droughts, will produce fluctuations sufficient to impair recreational use activities.

Of the 45 major lakes within the Fox River watershed, only 14 were found to have levels which fluctuated more than one foot per year and could thus be considered unstable (see Table 72). The causes of the instability in these lakes were found to be varied, ranging from uncontrolled outlets to fluctuations in ground water levels.

Only three of the 45 major lakes within the Fox River watershed—Long Lake in Racine County, Lulu Lake in Walworth County, and Spring Lake in Waukesha County—were found to have uncontrolled outlets and can, therefore, be expected to have relatively large fluctuations in water levels. An additional nine lakes—Browns, Eagle, Kee Nong Go Mong, and Waubeesee Lakes in Racine County; Camp, Center, Powers, and Silver Lakes in Kenosha County; and Army Lake in Walworth County—have outlet channels which discharge only seasonally during periods of high-water level. Twenty-four lakes were found both to receive water only from, and to discharge water only to, the ground water reservoir and can, therefore, be expected to have relatively small fluctuations in water levels. Two lakes—Cross Lake in Kenosha County and Eagle Lake in Racine County—were found to discharge to the ground water reservoir without receiving water from it and can, therefore, be expected to also have unstable water levels.

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 revealed the existence of eight sewered lake communities within the watershed where such water loss may presently occur: the Villages of Silver Lake and Twin Lakes in Kenosha County, the Village of Waterford and the City of Burlington in Racine County, the City of Lake Geneva in Walworth County, and the Villages of Mukwonago and Pewaukee and the City of Muskego in Waukesha County.

The effects of large lake level fluctuations on recreational activities are pronounced and readily noticeable. At extreme low-water levels, navigation may be impeded, especially at boat launching ramps and across normally shallow bars. Shallow fish spawning and nursery areas may be lost. Crowding of fish populations may increase predation. New bottom areas may be exposed to sunlight, producing denser growths of rooted aquatic vegetation. Areas entirely exposed during periods of low water may acquire a profusion of terrestrial vegetation. Winterkill is more likely to occur in lakes which enter the winter season with low-lake levels, since oxygen demand must be satisfied by a much smaller volume of water. A decline in lake level of one foot may be expected to constitute a loss of about 5 percent of the total water volume of a typical major lake within the watershed and a greater proportionate loss of total oxygen content. Extremely high-water levels may also cause recreational use problems, as well as other resource-related problems. Boat ramps and septic tank sewage disposal systems may be flooded out, the latter, when made inoperable, may discharge raw or partially treated sanitary sewage directly to lakes.

The Wisconsin Public Service Commission, after public hearing, establishes a normal water level for all lakes having a controlled outlet. This level must normally be maintained at the outlet control structure by the owner of the structure (see Table 76). This regulatory action is intended to provide a safeguard against extremely high-water levels but does not assure operation to minimize total fluctuations in water levels or periods of extreme low water.

Eutrophication: A term of recent popularity, eutrophication, requires definition as regards its use in discussions relative to the recreational use of lakes. The term "eutrophic," as originally defined, identified lakes exhibiting an extreme reduction in oxygen concentration with depth. The more recent and popular definition of the term identifies lakes that are well supplied with nutrients and, therefore, rich in the production of organic material. Eutrophication is a natural process of maturation of lakes, leading ultimately to their extinction through deposition of both inorganic and organic materials. The rate at which eutrophication occurs presently 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 "summer kill," major fish mortality resulting from the excessive consumption of oxygen, decomposing algae, and other vegetation on calm, often 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.

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 tissues versus the mean chloride content of the water. The average ionic composition of lake waters within the Fox River watershed is set forth in Table 77, which is based upon analysis of 600 water samples collected from lakes within the watershed. Individual lakes are evaluated with respect to water quality and fertility in several ways in Table 72. Of the 45 major lakes within the Fox River watershed, 10 were found to be high in spring phosphates, 10 very fertile as measured by total alkalinity, and 15 excessively fertile as measured by plant tissue content.

Animal Pests Affecting Recreational Water Use: Midges (Chironomidae), or blind mosquitoes, are a common insect pest 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 spring and early summer, with massive occurrences common in late afternoon or early evening. Midges create nuisances by entering the eyes and noses of people, discoloring painted surfaces, reducing visibility, and accumulating on lighting fixtures.

Although mosquitoes (Culicidae) are another common insect pest around lakes, streams, and wetlands with floating-leaved vegetation, they are generally bred in areas temporarily covered by shallow, standing water. Open water surfaces are required for emergence, however, and hence the presence of extremely dense vegetation does not imply severe mosquito problems.

Leeches (Hirudinea) abound in still, shallow waters of the watershed where a suitable substrata of plant, 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 many 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 control of insect pests is facilitated by the use of various pesticides. Because these pesticides may constitute a form of environmental pollution and a danger to desirable forms of animal life, they must be used only with great care and extreme caution.

Table 76

MILL DAMS AND LAKE LEVEL CONTROL STRUCTURES IN THE FOX RIVER WATERSHED

Dam Name	Location		Description				Date of Original Construction	Purpose of Original Structure	Present Use	Present Owner (In 1963)
	Lake or Stream	Town, Range, and Section	General	Type Control	Dam Height	Spillway Elevation[a]				
Barstow Street Dam	Saratoga Lake (Fox River)	6-19-03	Masonry and Concrete	Radial Gate	4.2	810.30	1836	Saw and Grist Mill	Lake Level	City of Waukesha
Beulah Dam	Beulah Lake	4-18-04	Earth and Concrete	No Control	7.8	808.00	1840's	Flour Mill	Lake Level	Wm. D. Platz
Blott Dam	Linnie Lac	6-20-32	Clay and Gravel	Stop Log Gate	8.3	814.30	1837	Saw Mill	Lake Level	Mrs. John Blott
Bohner Lake Dam	Bohner Lake	2-19-17	2 Concrete Dams	Gate on Second Dam	8.0	801.10	-	Lake Level and Fish Control	Lake Level	Conservation Department
Browns Lake Dam	Browns Lake	3-19-34	Stone and Concrete	No Control	1.6	768.30	-	Lake Level	Lake Level	Racine County
Burlington Dam	Echo Lake	3-19-32	Stone and Concrete	Radial Gates	4.0	761.60	1835	Saw, Wool, Flour	Lake Level	City of Burlington
Camp Lake Dam	Camp Lake	1-20-32	Concrete and Stone	No Control	1.7	740.60	1933	Lake Level	Lake Level	Camp Lake Water Level Association
Cedar Grove Dam	Honey Creek Millpond	4-16-36	C.M.P. and Dam Comb.	Wood 2" x 4"	5.6	873.00	1850's	Saw Mill	Lake Level	Samual Block
Center Lake Dam	Center Lake	1-19-21	Concrete	No Control	1.0	741.08	-	Lake Level	Lake Level	Conservation and Sportsmans Club, Inc.
Como Lake Dam	Como Lake	2-17-26	Rock and Concrete	Adjustable Boards	0.7	849.00	-	Lake Level	Lake Level	Town of Geneva
Cross Lake Dam	Cross Lake	1-20-35	Earth and C.M.P.	No Control	-	-	1939	Lake Level	Lake Level	B. J. Corbin and George Wiley
Lake Denoon Dam	Lake Denoon	4-20-05	Boulders and Concrete	No Control	0.7	780.32	1904	Lake Level	Lake Level	Riparians
Dyer Lake Dam	Dyer Lake	2-19-30	Concrete	No Control	2.6	827.60	1960's	Lake Level	Lake Level	Kenosha County Boy Scouts
Eagle Lake Dam	Eagle Lake	3-20-21	Boulders and Concrete	No Control	5.2	796.30	1958	Lake Level	Lake Level	Eagle Lake Property Association
East Troy Dam	East Troy Millpond	4-18-29	Concrete	Removable Board	11.0	831.20	1840	Saw and Flour Mill	Store Cooling Water	Trent Tube Company
Elizabeth Lake Dam	Elizabeth Lake	46-18-03 (Illinois)	Concrete	No Adjustment	0.0	-	-	Lake Level	Lake Level	Game Farms, Inc.
Eagle Spring Dam	Eagle Spring Lake	5-17-36	Earth, Gravel, Concrete	Adjustable Boards	7.3	817.10	1836	Saw and Grist Mill	Lake Level	L. Wambold
Genesee Millpond Dam	Genesee Millpond	6-18-27	Earth, Gravel, Concrete	Removable 2"x6" Boards	3.4	835.10	1847	Grist and Feed Mill	Lake Level	L. E. Lawrence
Geneva Dam	Lake Geneva	2-17-36	Concrete	Adjustable Boards	9.0	864.30	1836	Saw Mill	Lake Level	Lake Geneva Water Power and Level Association
Hilburn Dam	Honey Creek	4-18-22	Concrete	Adjustable Boards	8.0	811.40	1840	Flour Mill	Lake Level	H. B. Austin
Honey Lake Dam	Sugar Creek	3-18-03	Concrete	Six Adjustable Boards	6.0	770.00	1926	Grist and Feed Mill	Lake Level	Honey Lake Property Association
Kee Nong Go Mong Dam	Lake Kee Nong Go Mong	4-20-07	Concrete	Adjustable Boards	1.5	776.50	1945	Lake Level	Lake Level	A. Tubiszewski

[a]*Elevation referred to Mean Sea Level Datum, 1929 Adjustment.*

Table 76 (continued)

MILL DAMS AND LAKE LEVEL CONTROL STRUCTURES IN THE FOX RIVER WATERSHED

Lyons Millpond Dam	Lyons Millpond	2-18-10	Concrete	Adjustable Boards	5.2	796.20	1845	Saw Mill	Lake Level	E. J. Hemingway
Marie Lake Dam	Marie Lake	1-19-28	Concrete	No Control	0.5	793.90	1932	Lake Level	Lake Level	Twin Lakes Park Association
Mill Lake Dam	Lauderdale Lakes	4-16-36	Concrete and Steel Weir	No Control	10.5	884.40	1840's	Saw Mill	Lake Level	Lauderdale Lakes Improvement Association
Morey Dam	White River	6-18-27	Concrete	Adjustable Boards	3.4	835.10	-	Ice Pond	Lake Level	Dr. Hurbert F. Sydow
Mukwonago Dam	Lower Phantom Lake	5-18-35	Concrete	Adjustable Boards	7.3	788.30	1848	Saw Mill	Lake Level	Mukwonago Lakes Improvement Association
Big Muskego Dam	Big Muskego Lake	5-20-33	Stone and Concrete	Adjustable Boards	3.7	771.50	1896	Lake Level	Lake Level	Ceasars' Tavern
Little Muskego Dam	Little Muskego Lake	5-20-09	Concrete	Adjustable Boards	8.0	792.00	1836	First Saw Mill in Waukesha	Lake Level	J. Prestin and Mrs. W. J. Boszhart
Pell Lake Dam	Pell Lake	1-18-15	Earth and C.M.P.	No Adjustment	1.4	859.40	1925	Lake Level	Lake Level	Pell Lake Property Owners Association
Pewaukee Lake Dam	Pewaukee Lake	7-19-09	Gravel and Concrete	Steel Gate	4.0	852.00	1842	Flour Mill	Lake Level	Village of Pewaukee
Rock Lake Dam	Rock Lake	1-20-34	Concrete and C.M.P.	4.0' Stop Log	5.6	751.00	1929	Lake Level	Lake Level	Anne Tichener (1947)
Rochester Dam	Fox River	3-19-11	Rock and Concrete	2.15' Radial Gates	5.0	765.20	1843	Grist and Feed Mill	Lake Level	Village of Rochester
Saylesville Dam	Saylesville Millpond	6-18-25	Stone and Concrete	No Control	3.4	796.40	1856	Saw Mill	Lake Level	Mrs. Schmidt
Silver Lake Dam	Silver Lake	1-20-17	Timber and Concrete	Removable 4" x 8" Board	1.5	747.50	1930	Lake Level	Lake Level	William Maruca
Tombeau Dam	Tombeau Lake	1-18-24	Concrete	No Control	2.0	824.90	1939	Lake Level	Lake Level	E. G. Shiner (1935)
Voltz Dam	Voltz Lake	1-20-36	Concrete Box Culvert	No Adjustment	3.2	-	1925	Lake Level	Lake Level	Castelle
Waterford Dam	Fox River	4-19-35	Stone and Concrete	No Control	4.2	773.40	1838	Saw and Flour Mill	Lake Level	Village of Waterford
Waubeesee Dam	Lake Waubeesee	4-20-07	Concrete	No Control	4.0	777.60	1929	Lake Level	Lake Level	Lake Waubeesee Consv. and Advisory Assoc.
Willow Spring Dam	Willow Spring Lake	5-18-03	Earth	No Control	13.0	913.51	1967	Lake Level	Lake Level	Willow Springs Subdivision
Wilmot Dam	Fox River	1-20-30	Stone and Concrete	Three Lift Gates	3.5	739.50	1840	Saw Mill	River Level	Kenosha County
Wind Lake Dam	Wind Lake	4-20-16	Stone and Concrete	2" x 10" Board	3.6	768.40	1905	Lake Level	Lake Level	M. J. Johnson and Roy Brandt

Source: Wisconsin Department of Natural Resources and SEWRPC.

Table 77

AVERAGE IONIC COMPOSITION OF ALL LAKE WATERS IN THE FOX RIVER WATERSHED IN THE SOUTHEASTERN WISCONSIN REGION: 1966

Parameter	Average For The Watershed[a]
Specific Conductance	415.00 (Mmhos)
pH	8.20 (Units)
Total Alkalinity	
(mg/l $CaCO_3$)	183.00[b]
Calcium	29.80
Magnesium	28.60
Sodium	5.10
Potassium	2.10
Iron	0.11[b]
Organic Nitrogen	--
Ammonia Nitrogen	0.39
Nitrate Nitrogen	0.44[b]
Total Phosphate	0.23
Dissolved Phosphate	0.11
Chloride	10.00
Sulphate	43.70

[a] *Expressed in mg/l unless otherwise specified.*

[b] *Based on spring measurements only.*

Source: Wisconsin Department of Natural Resources.

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 Fox 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 Fox River watershed—Geneva Lake in Walworth County and Powers Lake in Kenosha County. These are the clearest lakes within the watershed and, therefore, the most desirable for swimming.

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. Although opinions concerning the desirability of rooted aquatic plant growths will differ with different intended recreational uses—with fishermen, for example, considering weed beds desirable and swimmers considering them objectionable—excessive algae growths are objectionable to most recreational uses.

The excessive growth of rooted aquatic vegetation was found to be a problem in 17 of the 45 major lakes within the watershed. In addition, excessive algae growths were found to exist on four lakes. Some form of weed cutting and harvesting was reported to have been conducted on 13 of these 17 lakes during 1967, while 24 lakes received applications of herbicides in an attempt to control rooted aquatic plants or algae. Thus, about half of the major lakes in the watershed have aquatic plant problems sufficiently serious to warrant expenditures for control measures.

A listing of the relative abundance and presence of aquatic plants found in the Fox River watershed is presented in Table 75. The most abundant species in those lakes that have excessive vegetation growths, as shown in the table, are stonewort, pondweed, and water milfoil. Though efforts have been made to control aquatic vegetation, quite frequently less desirable species replace those which are 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, and these blooms are marked by characteristic shifts in distribution and composition of the algal community. The "blue-green" (Anabaena, Aphanizomenon, Microcystis) algae tend to dominate over the green 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 lakes within the watershed—Big Muskego Lake in Waukesha County and Wind, Tichigan, Eagle, Buena, and Echo Lakes in Racine County—is associated with excessive fertility.

Fish Management Problems: The most serious fish management 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 occurring on four major lakes: Big Muskego and Little Muskego Lakes in Waukesha County and Echo and Buena Lakes in Racine County. Channel improvement and the creation of open waterways through wetland areas bordering lakes have created additional areas of shallow water and increased plant productivity of certain lakes. Considerable areas of northern pike spawning habitat have been lost through the ditching and draining of wetlands contiguous to lake shorelines. About 62 percent of the original area of such wetlands have been ditched and drained to the extent that, without water level control in the spring, they are useless for spawning. 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 existing within the watershed is the abundance of rough fishes. 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. All lakes draining directly into the Fox 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 panfishes are harvested extensively, crowding has led to stunting or slow growth rates in at least five of the 45 major lakes within the watershed. Although a practical method of control 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 present a major fishery problem on some of the shallower lakes, with northern pike mortalities due to disease having occurred at least twice in the watershed on Como and Potters Lakes. Fish mortalities resulting from oxygen depletion occur in both summer and winter, although winterkill is considered to be, in most instances, a natural phenomenon abetted by human activity within the watershed. The frequency of fishery type is summarized for the major lakes of the Fox River watershed in Figure 100; and fishery locations for all streams within the watershed are shown on Map 47.

WETLANDS

Description of the Recreational Resource

Wetlands are a prominent feature of the landscape and an important element of the natural environment. Wetlands not only comprise an integral part of the hydrologic system of a watershed and therefore significantly influence stream flows, but also have topographical, biological, and agricultural values and relationships. Wetlands are also important recreation-related resources, having not only recreational value as hunting preserves and wildlife habitat areas but also scientific values as natural laboratories and aesthetic value as highly visible parts of the natural landscape. Although the identification of wetlands involves the consideration of a number of physical and vegetative conditions, the term "wetland" was defined for the purposes of this study as: any 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 basic types: pothole, fresh meadow, shallow marsh, deep marsh, shrub swamp, timber swamp, and bog. The definitions for these seven types are set forth in Appendix L of this report.

All of the wetlands within the watershed, as identified by application of the above referenced definition, and having a surface area of 50 acres or more were mapped and studied as complexes of the aforelisted seven basic types. Utilizing topographic maps, current Commission aerial photography, detailed operational soils maps, and piezometric maps, 203 wetland units, totaling 83.1 square miles in surface area, were identified and delineated within the watershed (see Map 21). Although some of the wetland units mapped and studied constituted monotypes, typically the units consisted of a mixture of all or several types which could be grouped into one of four composite type categories: meadow, marsh, shrub swamp, and timber swamp. A determination of the composite type of each of the 203 wetland units was carried out by a point sampling method with the results indicated in Table 78.

The composition of the marsh composite type of the wetlands was estimated to be: 22 percent, shallow marsh; 8 percent, deep marsh; and 1 percent or less each of pothole and bog marsh. The marsh composite type includes the "wettest" types with some exposed surface water and totals 31 percent of the total wetland area identified, delineated, and mapped. The remaining categories, constituting the "drier" types, comprise 69 percent of the total wetland area identified, delineated, and mapped. A summary listing of the acreage, major plant and animal species, quality rating of, and recommended management practices for each of the composite wetland types is set forth in Table M-1 of Appendix M to this report.

As is true of lakes, two general morphological conditions produce wetlands. The first is a basin or seepage situation; 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 Fox River watershed, a basin situation was found to exist for about 60 percent of the 203 identified wetland units; and approximately 28 percent was the product of a drainage situation often lying in the floodplain of a stream or watercourse. The remaining 12 percent was found along lakeshores and could represent either situation. Of all of the units mapped, 62 percent were found to have been artificially ditched for drainage.

Table 78

WETLAND AREAS IN THE FOX RIVER WATERSHED BY COMPOSITE TYPE

Composite Type	Wetland Type	Percent of Total Wetland Area Mapped
Meadow	Fresh Meadow	41.3
Marsh	Pothole, Bog, Shallow Marsh, Deep Marsh	31.0
Shrub Swamp	Shrub Swamp	14.8
Timber Swamp	Timber Swamp	12.9
Total		100.0

Source: Wisconsin Department of Natural Resources.

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 of muck and peat soils over a very high water table. Therefore, any fluctuation in the water level has its immediate and readily apparent effect on the entire wetland surface.

The drainage type of wetlands conforms to the configuration of the valley floor in which it lies and hence is 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.

A comparison of wetland surface elevations with piezometric surface elevations indicated that 15 of the wetland units mapped, as indicated on Map 21, were in a perched condition; and one was in a depressed condition under artesian pressure. The perched units occur on clay and silt soils covering the eastern portion of the watershed, which are sufficiently impermeable to form a seal.

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 profusion of these soils near lime-bearing waters. This is contrary to the usual condition of peat soils being highly acidic. The peat and mucks within the wetlands were found to vary in depth from five feet to over 20 feet. 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 climate 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 condensation, as indicated by fog formation, is also present; and the latent heat released may ameliorate, in part, lower temperatures. The net evaporation-transpiration rate for wetlands with emergent vegetation is generally believed to be little different from that for open water.

Loss of Wetlands: An estimate of the loss of wetlands within the Fox River watershed due to the activities of man within the basin was made as a part of the study. The estimate was based upon a comparison of analyses of historic vegetative maps and of the areas covered by selected wetland soil types—peats, mucks, and poorly and very poorly drained mineral soils—as mapped in the regional soil surveys, with the area covered by the existing wetlands as mapped in the wetland inventory. The analyses indicated that approximately 217 square miles, or 23 percent of the area of the Fox River watershed, was originally covered by wetlands (see Map 48) and that only 83.1 square miles, or 38 percent, of this original wetland area remains. Thus, over one-half of the original wetlands existing within the Fox River watershed have been destroyed. Although this areal change does not reflect the deterioration of the remaining wetland quality, it is evident that such deterioration 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 and communities, undesirable natural water quality, conversion to agricultural use, conversion to urban use, wildlife, and loss of environmental amenities. Each of these problems is discussed briefly in the following sections.

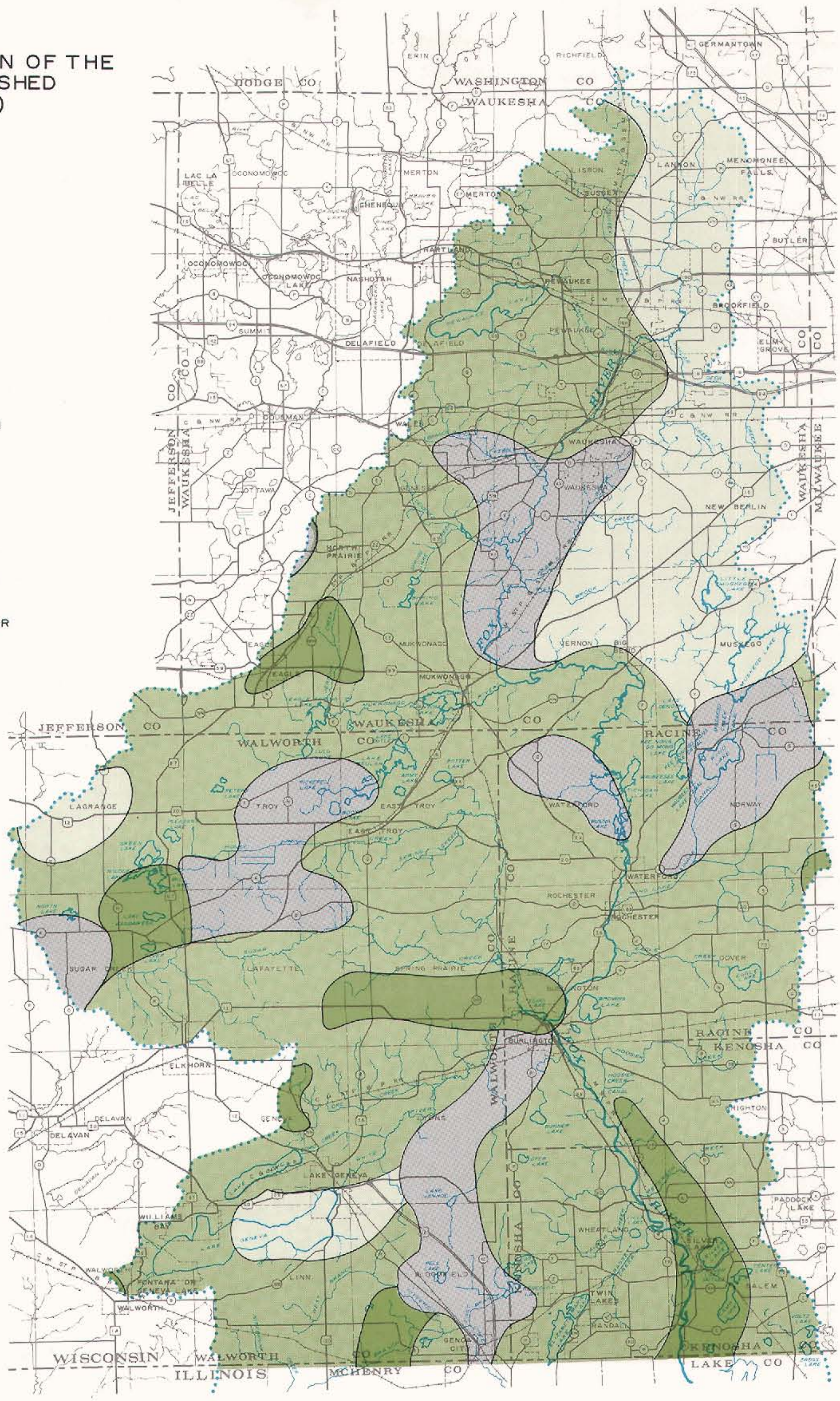
Recycling of Nutrients and Water Quality: Wetlands adjacent to lakes and streams have great value as fish and wildlife habitat. The effect of wetlands on water quality, however, is not well understood. Wetlands are sometimes considered to act as filters of waters flowing through them, trapping nutrients 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 surface

Map 48

HISTORICAL VEGETATION OF THE FOX RIVER WATERSHED (EARLY 1800'S)

LEGEND

- PRAIRIE: BLUESTEM, COMPOSITES
- OAK SAVANNA: BUR OAK, WHITE OAK, BLUESTEM
- SOUTHERN OAK FOREST: WHITE, BLACK AND RED OAK
- SOUTHERN MESIC FOREST: SUGAR MAPLE, BASSWOOD, ELM
- LOWLAND HARDWOOD: WILLOWS, SOFT MAPLE, ASH
- SEDGE MEADOWS: SEDGES, BLUEJOINT, CORD GRASS
- CONIFER SWAMP: BLACK SPRUCE, TAMARACK, CEDAR



Approximately one-half of the Fox River watershed was covered by woodlands when the first European settlers entered the watershed in the early 1830's, and about one-quarter was covered by wetlands. Today only about 20 percent of this woodland area and 38 percent of this wetland area remain, and the destruction of the remaining woodlands and wetlands continues.

Source: Wisconsin Department of Natural Resources.

water fertility. In addition, drainage from marshes and bogs sometimes contributes water low in dissolved oxygen and high in iron, color, and organic material and thereby creates what may be termed "natural pollution" in the receiving body of water.

These undesirable effects upon surface water quality conditions within a watershed, when naturally induced, probably do not offset the high recreation and aesthetic values of wetlands. If wetlands, however, are drained or waste filled to the extent that natural cycles of growth and decomposition are disturbed, the contribution of undesirable nutrients and other materials to receiving waters 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 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 having a muck surface. The type of decomposition is important in wetland chemistry because, under anaerobic conditions, methane (marsh gas), sulphides, and ammonia are the normal end products of decomposition, while, under aerobic conditions, the end products are carbon dioxide, water, sulfates, and nitrates. Usually anaerobic conditions prevail in wetlands, and the end products are quite odoriferous. Actually, these odors are only noticeable when the decomposing materials are exposed, as through drought or drainage, or disturbed as in sampling.

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 bound 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.

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 process. Thus, basin-type wetlands can be expected to retain nutrients. 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.

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 is achieved only over 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 inducted into the area. The threat of such changes may be ameliorated or may be aggravated by human activities. If seasonal flooding is either prolonged or unduly restricted, changes in the characteristics of the wetlands may result. Flooding and excessive water depths, if prolonged, will kill cattail stands; in contrast, restriction of flooding and water depths will inhibit such often undesirable species as the millets, smartweeds, and duck potato.

Fluctuation of the water level will provide an opportunity for 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 may avail themselves of the temporary open 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 sulphide, 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 are less of a contributor to the mosquito problem than they are commonly believed to be. There are many species of mosquitoes, only some of which bite man; and mosquitoes may be produced in large numbers in other than wetland areas. 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 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 Fox 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 facilitated by ditch and canal 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, the more extensively farmed wetland areas undergo further changes. Muck soils become friable and powdery when dry and, due to their organic composition, are also very light in weight. Such soils are thus susceptible to severe 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 if 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 may transfer the pesticides into other areas, creating serious problems of environmental pollution.

Undesirable Plant Communities: The 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 where the grazing becomes severe. On drained peatlands redtop grass gives way to bluegrass as compaction or further drainage causes more drying of the site. In the absence of occasional mowing or burning, shrub carr will invade the pastured meadow as it does ungrazed meadows. Resisting stinging nettle may become a problem on drained and burned peat lands.

Conversion to Urban Uses: The expansion of urban development within the Fox River watershed has been 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 runoff containing nutrients from lawn fertilizers and septic tank seepage. In such instances, the remaining wetland may degenerate into a cesspool condition. Use for sanitary landfill or other forms of solid waste disposal such as dumping obliterates the wetlands.

The proximity of urban development to a 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 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 verified 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 urban development. The suppression of predators, such as hawks and owls, may permit rapid growth of field mice populations, and may permit rabbit and squirrel populations to become 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 ruggedness exists in the topography, the wetlands form a base level for the landscape. Drainage and filling of wetlands for agricultural, for solid waste disposal, or for 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 a balance of nature. When a community is fully stocked, it is buffered by more pathways of energy flow and opportunity for internal adjustments. Such complexity helps prevent outbreaks or irruptions of pests or nuisances. Diversity is the original biological control that must increasingly be turned 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.

In any consideration of the potential loss of wetlands and the values associated therewith, it is important to note that, of the total of 53,200 acres of wetlands remaining within the watershed in 1967, approximately 5,000 acres, or 9.0 percent, were in state ownership; approximately 100 acres, or 0.2 percent, were in county ownership; and approximately 200 acres, or 0.4 percent, were in municipal ownership. The remaining approximately 47,900 acres, or approximately 90.4 percent, were in private ownership.

WOODLANDS

Description of the Recreation Resource

Woodlands are a resource with immense and varied value to a civilized society. When the first European settlers came to the Fox River watershed, they encountered abundant woodlands of oak, maple, ash, linden, cherry, walnut, elm, and other hardwood species. 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 311,000 acres, or 51 percent of the total area of the watershed, was covered by woodlands (see Map 48). These woodlands were not only beautiful but also constituted a great economic asset, as their products were most useful to the development of the watershed and the Region. Extensive timber cutting over the years greatly 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, however, prevented the settlers from clearing all of the land. Most of the areas left in woodland cover were better suited to growing trees than agricultural crops then, just as they are today.

Woodland inventories made as a part of the Fox River watershed study, utilizing Commission 1967 aerial photographs, indicate that woodlands presently cover 67,270 acres, or approximately 11 percent of the total area of the Fox River watershed (see Map 49). Thus, only 22 percent of the original woodland cover of the watershed remains. The remaining woodlands constitute an invaluable natural resource. They assist in maintaining the unique natural relationships between plant and animal communities, reduce storm water runoff, contribute to the atmospheric oxygen and water supply, and provide a resource base for the forest product industries. Woodlands also make a valuable contribution to the natural beauty of the countryside and enhance land values. Most of the remaining woodland cover within the watershed is located on moraines, stream bottom lands, and wetland areas.

It is estimated that the amount of woodland acreage being destroyed within the watershed for construction of roads, buildings, and other purposes is about equal to that being planted to trees. Approximately 350 acres of woodlands are being destroyed annually, and about 350,000 trees are being planted annually within the Fox River watershed on approximately 350 acres of land. Because of the type, quality, and age of the remaining woodland stands within the watershed, however, this balance cannot be expected to be maintained unless a woodland management and an active reforestation program is instituted. Five major woodland types are established within the Fox River watershed: 1) oak, 2) central hardwoods, 3) lowland hardwoods, 4) upland conifers, and 5) wetland conifer—hardwoods. The acreage of each type within the watershed was estimated by foresters of the Department of Natural Resources utilizing 1967 Commission aerial photographs, U. S. Geological Survey Maps, and their personal knowledge of the woodland areas of the Fox

Map 49

EXISTING WOODLANDS
OF THE FOX RIVER WATERSHED
(1967)

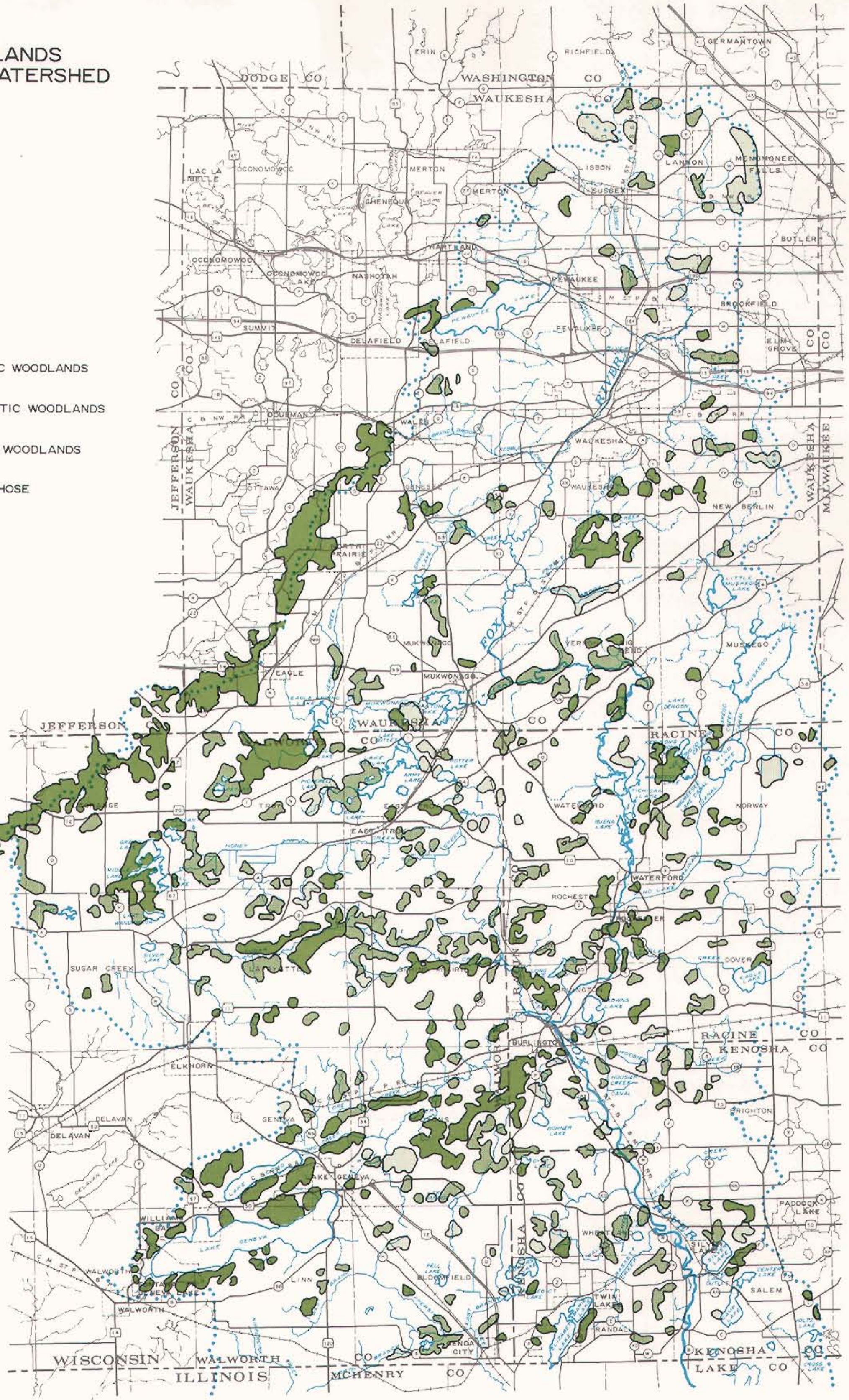
LEGEND

DENOTES HIGH-VALUE AESTHETIC WOODLANDS

DENOTES MEDIUM-VALUE AESTHETIC WOODLANDS

DENOTES LOW-VALUE AESTHETIC WOODLANDS

NOTE: WOODLAND AREAS SHOWN ARE THOSE 20 ACRES OR LARGER



Approximately 11 percent of the total area of the watershed is in woodland cover. These remaining woodlands, however, constitute an invaluable natural resource. They assist in maintaining the unique natural relationships between plant and animal communities, reduce storm water runoff, contribute to the atmospheric oxygen and water supply, and provide a resource base for the forest product industries. Woodlands also make a valuable contribution to the natural beauty of the countryside and enhance land values.

Source: Wisconsin Department of Natural Resources.

River watershed, supplemented by field checks on approximately 5 percent of the total woodland acreage within the watershed.

Oak Type: The oak type is most common within the watershed, comprising 23,060 acres, or 34 percent of the total woodland cover. It occurs primarily on the glacial moraines, gravelly, well-drained soils having comparatively low fertility. Species include bur, white, red, and black oak and hickory. Because of a lack of proper management, oak type woodlands have deteriorated rapidly over recent years. An inherent characteristic of this woodland type is a low reproduction potential. Heavy grazing by livestock has been the chief contributing cause to the generally poor condition of this woodland type within the watershed. Most of the oak woodlands are understocked and deficient in reproduction and sapling size trees. They have a park-like appearance; and because of this condition, as well as their location, possess not only a significant aesthetic value but a high value for urban type residential development. Oak woodlands are usually established on ridges and on the upper slopes of well-drained land, where the trees can be seen from a distance.

Virtually no management of the oak type woodlands is being presently accomplished by private landowners. Without management the stands of trees are nearing maturity, and there is little or no reproduction taking place to sustain the stands. As a consequence of this neglect, this type of woodland may be expected to decrease rapidly in size and to disappear slowly from the watershed.

Central Hardwoods Type: The central hardwoods type is the second most abundant type of woodland within the watershed, comprising 17,590 acres, or 26 percent of the total woodland cover. It occurs on rolling ground moraines with fertile well-drained sandy loam and silt soils. Species include red and white oak, white ash, silver and sugar maple, linden, black walnut, and American elm. Lack of management and grazing by livestock have made this type deficient in reproduction and in stands of younger trees. This woodland type has a good reproduction potential if livestock are excluded, but it must be properly managed to be fully productive and have a sustained yield. This woodland type can provide good timber for the commercial market, as well as provide wildlife habitat and contribute to the natural beauty of the watershed.

Lowland Hardwoods Type: The lowland hardwoods type comprises 14,820 acres, or 22 percent of the total woodland cover within the watershed. It is established primarily on the alluvial soils in the bottom lands of the Fox River watershed. Such sites have good moisture and fertility and deep soils, conditions conducive to the production of quality timber if management is applied. Species include silver maple, black and white ash, black walnut, and American 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.

Upland Conifer Type: The upland conifer type comprises 7,910 acres, or 12 percent of the total woodland cover within the watershed. It consists of plantations mostly of white and red pine and spruce. Plantations are even aged in blocks, having been planted by machine on open land. Many of the older plantations are badly in need of management, particularly in a form of thinning to optimum density and pruning the crop trees. This woodland type provides greenery to the countryside during the winter season, as well as during the summer.

Wetland Conifer-Hardwoods Type: The wetland conifer-hardwoods type comprises approximately 3,890 acres, or 6 percent, of the total woodland cover within the watershed. It is established on the poorly drained peat soils of the watershed. Tamarack is the only deciduous conifer native to Wisconsin and the only tree species growing naturally within southeastern Wisconsin today that has survived from the original post-glacial forest. This species is extremely susceptible to even minor changes in the water table level and is the only important conifer in this woodland type. Various hardwood species occur in the wetland conifer-hardwoods type, but the trees are seldom of an adequate size of quality for commercial use. This woodland type is important as wetland cover and serves as a retreat and shelter for wildlife, as well as contributing to the natural beauty of the countryside. Drainage of wetlands has had a serious detrimental effect on this woodland type.

The woodlands of the Fox River watershed serve a dual role, providing a scenic and recreational asset on the one hand and a crop to be harvested on the other. In a rapidly urbanizing region such as southeastern Wisconsin, the scenic and recreational values of the remaining woodlands are far more important than the commerical value. Forty-five percent of the remaining woodlands of the Fox River watershed have a high aesthetic value; 43 percent a medium aesthetic value; and 12 percent a low aesthetic value. Table 79 indicates the acreage of high, medium, and low aesthetic value woodland within each of the counties within the watershed, and Map 49 indicates the spatial distribution of these woodlands. The aesthetic value ratings of the woodland areas are based on such factors as visibility, location, accessibility, and quality of cover and drainage, as well as on specie, density, and quality of the stand. A further explanation of the criteria used in the aesthetic classification of the woodlands follows:

1. Location—this criteria included consideration of visibility of the stand from roads and nearness to population centers, lakes and streams, and whether located within the primary or secondary environmental corridors.

2. Accessibility—this criteria included consideration of the terrain, isolation, such as islands of woodlands within larger wetlands, and proximity to roads.

3. Quality of Cover—this criteria included consideration of the age of the stand, the amount and quality of the cover, and the species and the overall condition of the woodland.

4. Drainage—this criteria included consideration of the location on upland with good drainage or on wetland with poor drainage.

Woodlands managed for scenic, recreational, and resource conservation purposes can and should also produce commercial timber. Woodlands in the Fox River watershed generally are poorly to moderately stocked with respect to commercial timber. The few managed stands exhibit more young growth and high quality timber while the unmanaged stands usually consist primarily of low quality timber and culls. Such woodlands need careful management over a period of years to return them to a highly productive condition, as well as retaining their aesthetic values.

Problems Related to Woodlands

Insects and Disease: Adequate protection is an essential part of the management of woodlands valued for aesthetic, recreation, timber, wildlife habitat, or homesite purposes. Only when woodlands are protected from the various destructive agents can their long-range development and use be assured. Insect and disease enemies of woodlands are numerous and constantly working to destroy the stands, and prompt action is required in dealing with these destructive agents in order to prevent not only monetary losses but also the loss of other woodland values.

Healthy, vigorous, rapidly-growing trees in a well-managed woodland are less likely to be damaged by insects or disease than in an unmanaged woodland. But even these trees are not immune to attack by pests. Trees subjected to livestock grazing, fire, too little or too much moisture, and

Table 79

VALUE RATINGS OF WOODLANDS

BY COUNTY WITHIN THE FOX RIVER WATERSHED: 1967

County	Aesthetic Woodlands (Value Rating)						Total Acres
	High Value		Medium Value		Low Value		
	Acres	Percent	Acres	Percent	Acres	Percent	
Jefferson	630	100	--	--	--	--	630
Kenosha	1,910	27	4,060	58	1,050	15	7,020
Racine	5,080	51	3,720	37	1,240	12	10,040
Walworth	12,170	44	12,900	47	2,390	9	27,460
Waukesha	10,630	48	8,190	37	3,300	15	22,120
Total	30,420	45	28,870	43	7,980	12	67,270

Source: Wisconsin Department of Natural Resources and SEWRPC.

overcrowding are most vulnerable to attack by insects and disease. They 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 Fox River watershed consist primarily of mixed tree species, which suffer severe losses less frequently than do woodlands of a single species.

The most serious disease of trees in the Fox 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. Disease symptoms vary; but usually the top leaves on one or more branches wilt, droop, turn yellow, and 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 within the watershed; but for the most part, the disease is being 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 Fox 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.

Heart rots, cankers, and root rots are other common diseases that damage trees. Bark beetles, borers, and leaf defoliators 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, also are present.

Prevention is the ideal form of woodland protection. Periodic checks by owners of managed woodlands often enables the detection of outbreaks of either insects or diseases in their early stages, and this permits proper remedial action before a minor problem becomes serious and, in extreme cases, catastrophic.

<u>Urban Encroachment</u>: Woodlands, perhaps more than other rural lands are affected by the rapid conversion of land from rural to urban use taking place within the watershed; and wooded areas, especially those on ridges and slopes, are undergoing an accelerated destruction. Urban sprawl in the form of isolated residential development is also 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 67,270 acres of woodlands existing within the watershed, 6,131 acres, or 9.1 percent, are in state ownership; 274 acres, or 0.4 percent, in county ownership; and 775 acres, or 1.2 percent, in local municipal ownership. The remaining 60,900 acres, or 89.3 percent, are in private ownership.

Unfortunately, altogether too few woodland owners, when considering the development of their lands for urban use, are interested in preserving the woodlands and associated scenic values by use of 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 assures 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 lawn areas. 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, thinnings, 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 and enhance its land values. Such provision will not only benefit the overall environment of the watershed and Region but also add value to the individual homesites and increase the monetary return to the developer.

Degradation of Woodlands From Livestock Grazing: Woodlands in the Fox River watershed have been subjected to heavy damage from livestock grazing. The widespread practice of allowing livestock to graze in woodlands can be attributed to several factors: many woodlands in the watershed are composed almost entirely of hardwood species, which 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 60 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 of woodlands is most injurious to reproduction and, in the long run, may become as damaging to wildlife. Livestock trampling and browsing kill the tree seedlings. Heavy trampling by cattle also packs the forest soil, thus reducing its water-holding capacity. Grazed woodlands become understocked, and existing trees grow slowly and become poorer in quality. There will be few seedlings or saplings to replace old trees.

Fire: Uncontrolled fire has been responsible for substantial losses of woodland in the Fox River watershed since the days of early settlement of the watershed by Europeans. Some woodlands over the years have burned several times, destroying new plants, 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 slowly increasing in the last few years as more and more people use the woodlands. Fortunately, as hardwood stands increase in stocking, 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 drifting smoke from these fires may interfere with visibility on highways, creating a safety hazard. The disagreeable smell from burning peat is also annoying, a form of air pollution, and in extreme cases may cause illness.

Fire protection efforts have been intensified in recent years. Protection, however, does not keep fires from starting. Woodland fires 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 or more 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, may destroy buildings. Less than 1 percent of all fires are known to start from lightning; thus, approximately 99 percent are man-made. Virtually all fires are caused through carelessness and, therefore, can be prevented. Smokers unintentionally set many fires. Uncontrolled debris and brush burning cause many fires. Campers, hunters, and fishermen cause many destructive fires. Other fires are caused occasionally by arsonists. Fire protection in the watershed is directed by the Wisconsin Department of Natural Resources, cooperating with local agencies and individuals.

Game Management: The wildlife resource within woodlands of the Fox River watershed is substantial, although limited in variety. Management of woodlands is needed to develop and maintain a 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 also are required to sustain wildlife. 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.

Other Basic Woodland Resource Values: It is most important that the total values of well managed woodlands to an area, such as the Fox River watershed, be fully understood. Woodlands provide 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 well managed woodland are equally as important to the adjacent areas as they are to the woodland area itself. Soil organisms, pollinating insects, natural predators of undesirable species, and a host of other species produced in the woodlands are all required to maintain a natural balance in the surrounding areas. Finally, it is also essential to recognize that the woodlands which exist within the Southeastern Wisconsin Region and the Fox River watershed cannot be reproduced in other parts of the state, the climate, soil type, geological history, and other characteristics being unique to the area.

WILDLIFE

Mammals

A complete list of the mammals found in the Fox 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.

White-Tailed Deer: Greatest concentrations of deer occur in the western slopes of the watershed in Waukesha and Walworth Counties, where there are more and larger wetland and woodland areas. These populations are contiguous with the herds living on the eastern slopes of the Rock River watershed and the Kettle Moraine area generally. Deer habitat is estimated to comprise about 1 percent of the total area of the watershed, or about 6,500 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 15 percent of the total area of the watershed.

Estimated deer harvests in watershed portions of the four counties comprising the majority of the watershed over the past five years are given in Table 80. These estimates were arrived at by adjusting known deer harvest registrations by county by the proportion of the total county deer population believed to inhabit the watershed. These proportions for Racine, Kenosha, Walworth, and Waukesha counties, respectively, are 0.80, 0.80, 0.70, and 0.45. For the entire four-county area, this proportion, further weighted by the five-year harvest record, is estimated to be 0.58.

The average annual harvest over the past five years has been about 200 deer per year, including a limited harvest taken with bow and arrow. There is considerable additional attrition of the herd through collision with automobiles, especially in Waukesha County. This additional loss is estimated to be about 115 animals yer year, based upon reported auto kills by county prorated for the watershed. Unreported collision losses are known to occur, as well as losses from occasional poaching, killing by dogs, and other accidents. These are estimated to approximate 40 to 50 deer per year, bringing the total estimated cropping of deer within the watershed to 350 to 400 deer per year.

Whether the size of the deer herd has reached 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 limited to 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.

Table 80

DEER HARVESTS[a] IN THE FOX RIVER WATERSHED BY COUNTY: 1963-1967

Year	Number Of Deer Harvested				Watershed Total
	Kenosha County	Racine County	Walworth County	Waukesha County	
1963	3	15	75	58	151
1964	12	23	105	97	237
1965	9	25	57	73	164
1966	14	20	104	83	221
1967	24	17	102	89	232
Five-Year Average	12	20	89	80	201

[a] *Includes Bow and Arrow.*

Source: Wisconsin Department of Natural Resources.

Fur Bearers: The fur bearers of the Fox 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 are greatly abundant in the watershed, with the exception of the beaver and otter. Population estimates indicate the number of muskrats within the watershed in the fall at about 50,000; 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 total approximately 2,500.

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, deep marshes, shallow marshes, small ponds, rivers, small creeks, and drainage ditches may provide a homesite for muskrats. In marshes the familiar muskrat house possesses sight value and contributes a certain amount of interest to the landscape. These houses are much 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 Fox River water areas in the fall of 1966 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 freeze-out from low water and thick ice, muskrats will quickly repopulate these areas when favorable conditions return. While some muskrats are always taken by trapping each year, 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, although some 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. With its apparently great intelligence and physical characteristics, it is highly adaptable to changes in land use.

Both the red and gray fox occur commonly in the watershed area. The red fox is more characteristic of mixed habitat and farm land, while the gray occurs in hilly wooded areas. Many people place a high aesthetic sight value on the fox, while others conceive of it as a challenging game animal; and 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 but are the major carrier of rabies in Wisconsin. The opossum is largely harmless. Both seek habitat in woodland areas bordering farm lands and venture onto the wetlands in search of food. Both the 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 the several species of mice and shrews. These occur in a variety of habitat types, and most are relatively innocuous and highly interesting.

Birds

A complete list of the birds found in the Fox River watershed is included in Appendix O 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 programs largely based upon the pheasant. With average fall population within the Fox River watershed estimated at 40,000 birds, or about 40 per square mile, the range of densities between areas of township size may vary from a very few to well over 100 or more per square mile. Generally the eastern portions of the watershed contain higher average pheasant population densities than the western portions, although good population densities are found in the Mukwonago River and Sugar and Honey Creek subwatersheds. Of the total non-cropland game range within the watershed the acreage estimated to be used by pheasant according to quality category is shown in Table 81.

Table 81

PHEASANT RATING AND RANGE ACREAGE WITHIN THE FOX RIVER WATERSHED: 1966

Rating	Range Acreage	Percent Of Watershed
Good	26,800	4.4
Fair	23,100	3.8
Poor	15,400	2.6
Total	65,300	10.8

Source: Wisconsin Department of Natural Resources.

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 found 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, tamarack swamps, and shrub 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 will suffice. 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 constitute a death trap when hens, drawn in by early vegetative growth, are caught by high-speed harvest machinery before hatching has been accomplished. 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.

Waterfowl: Waterfowl are of universal appeal both when on the water and in the air. The Fox River watershed is a major pathway in the Mississippi Flyway. It is estimated that approximately 5 percent of the waterfowl take in the state occurs in the watershed. Provision of the opportunity to hunt waterfowl is one of the major activities in the field of game management. Many club, as well as state, efforts are directed to this end; and it is the present major source of public support for high quality wetland preservation. Average density observed for the watershed in 1967 was 6.7 breeding ducks per square mile as compared to a statewide average of 5.0 per square mile. The observed makeup of the breeding population was as follows: mallard, 57 percent; blue-winged teal, 28 percent; and other, 15 percent.

A much greater variety of species is encountered during spring or fall migration. Virtually all of the species using the Mississippi Flyway have been observed 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 occurring early in the fall season would be the blue-winged and green-winged teal, the mallard, wood-duck, ringneck, and the baldpate. Later arrivals in numbers would be the scaup and ringnecks. Lesser and irregular numbers of others occur. These include pintails, black ducks, shovellers, redheads, and canvasbacks. Among the geese the Canada goose and its subspecies regularly occur in 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 occur in spring migration, especially on Little Muskego Lake and Vernon Marsh. Appendix O indicates those species which may reasonably be expected to be found as breeders or migrants.

Waterfowl favor the smaller and shallower bodies of water in the watershed, including potholes and marshes, as habitat. Among the larger good habitat areas are the Vernon Marsh and Big Muskego Lake. Lake Geneva is heavily used by migrating waterfowl. Marshy shorelines of other lakes, as well as of streams and drainage ditches, also provide good habitat. Of the total non-cropland game range, the acreage estimated to be used by waterfowl according to quality category is shown in Table 82.

Table 82

WATERFOWL RATINGS AND ESTIMATED ACREAGE WITHIN THE FOX RIVER WATERSHED: 1966

Rating	Estimated Acreage	Percent Of Watershed
Good	25,000	4.2
Fair	12,800	2.1
Poor	1,700	0.3
Total	39,500	6.6

Source: Wisconsin Department of Natural Resources.

Waterfowl foods, other than 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, pondweed, various smartweeds, 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 farm lands. 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.

Ruffed Grouse and Bobwhite Quail: These birds are extirpated or possibly of irregular rare occurrence in the watershed. However, the range potential exists for these birds within the watershed. The quail makes use of the more brushy irregular lands in farming areas, while the ruffed grouse uses the larger wooded hills and timber swamps. The major limiting factor for these two birds appears to be the discontinuity with other suitable occupied range, for larger populations of these birds are located 75 to 100 miles away from the watershed.

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 grebes nest in or use 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. No major rookeries exist in the watershed, however.

The jacksnipe and woodcock commonly occur in migration, 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. Unusual birds include the Forster's tern, which nests in Big Muskego Lake. An extremely favorable study area for most of these species is the Vernon Marsh Wildlife Area, but many of the other wetland units within the watershed 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 (rare).

There are no known bird species present that are unique to the watershed. Pest species may be considered to include the imported English sparrow, starling, and common pigeon. The native redwinged blackbird is very abundant and may damage sweet corn stands. There is some poultry loss to hawks and owls.

Other Wildlife

Much of the biological activity in the environment depends on the myriads of lesser invertebrate organisms. Many of these fulfill essential roles, in absence of which the natural world could not function. These organisms range from viruses through the amoeba, zooplankton, free-living nematodes, annelids, and molluscs, the numerous beneficial and harmful insects. 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 by thoughtless activities of man within the watershed. In southeastern Wisconsin, as in any highly urbanized area, much of the natural environment has already been destroyed and the remaining severely disturbed. Every possible action must, therefore, be taken to protect the remaining wetlands; natural shorelines 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.

Of the approximately 119,500 acres of remaining wildlife habitat areas within the watershed, 30,243 acres is rated as high value, 38,373 acres as medium value and 50,923 acres as low value (see Table 83 and Map 50). The preservation of the remaining wetlands and woodlands along with affective management of existing unused lands and water areas will simultaneously preserve most of the remaining wildlife habitat areas which totals less than 20 percent of the total area of the watershed.

Table 83

WILDLIFE HABITAT AREA
IN THE FOX RIVER WATERSHED BY VALUE RATING BY COUNTY: 1967

County	Value Of Habitat Area In Acres			Total
	High	Medium	Low	
Waukesha	10,430	17,120	18,242	45,792
Walworth	10,483	13,107	19,338	42,928
Kenosha	2,878	3,214	5,823	11,915
Racine	6,452	4,932	7,520	18,904
Watershed Total	30,243	38,373	50,923	119,539

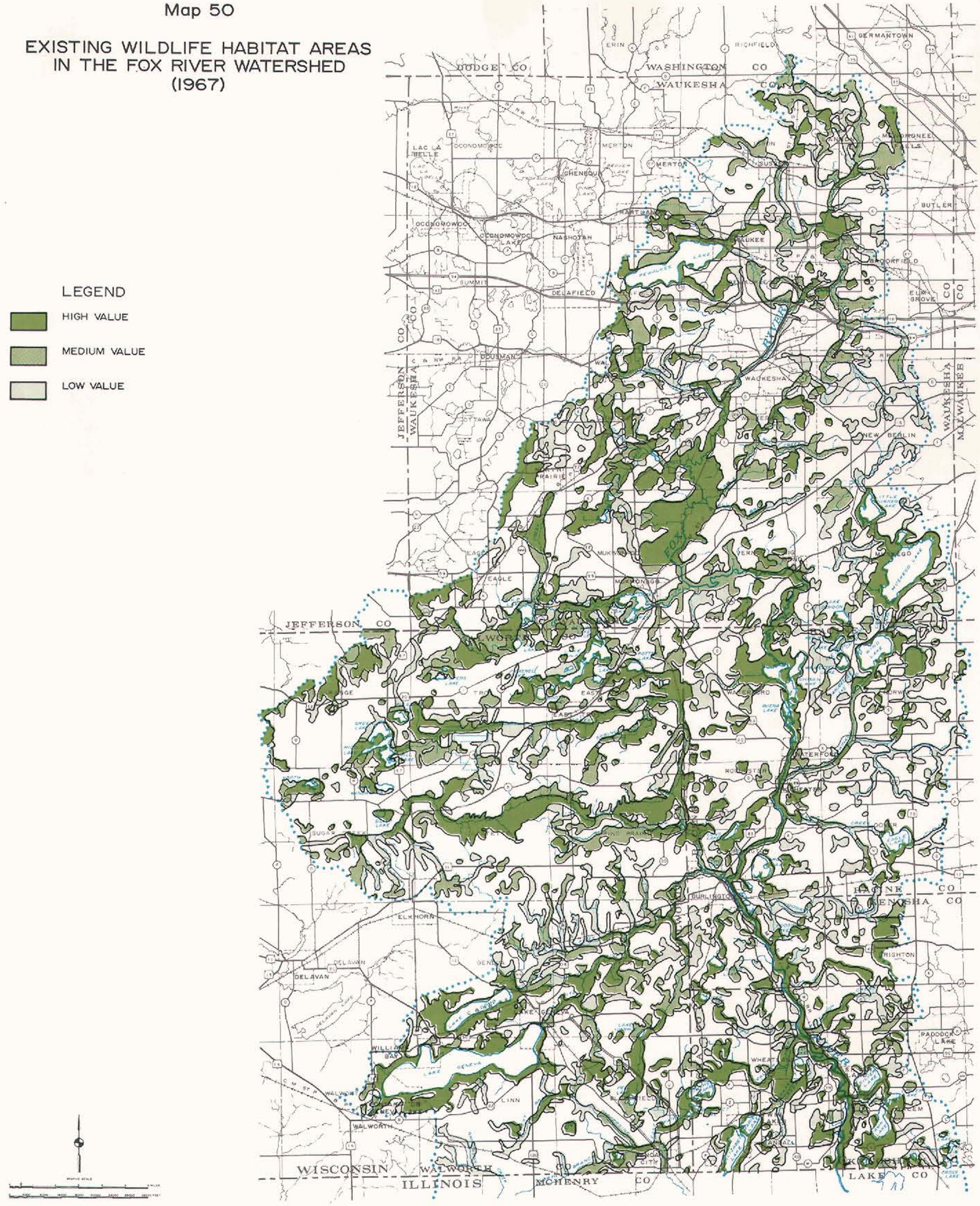
Source: Wisconsin Department of Natural Resources.

Map 50

EXISTING WILDLIFE HABITAT AREAS IN THE FOX RIVER WATERSHED (1967)

LEGEND

- HIGH VALUE
- MEDIUM VALUE
- LOW VALUE



Of the approximately 120,000 acres of wildlife habitat area remaining in the Fox River watershed, about one-quarter is rated as high value; and about one-third, as medium value. In the absence of a sound watershed plan and its implementation, further urban development in the watershed may be expected to destroy this important recreational asset.

Source: Wisconsin Department of Natural Resources.

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. Comprising an integral system with a total area of 198 square miles, or 21 percent of the total watershed area, the primary environmental corridor pattern within the watershed can be broken down into 46 distinct corridors, as shown on Map 51 and listed in Table 84. 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.

As noted in Chapter IV, the primary environmental corridors contain almost all of the remaining high-value elements of the natural resource base within the watershed. More specifically, the 198 square miles of primary environmental corridor within the Fox River watershed contain 163.9 lineal miles of lake shoreline, or 66.1 percent of the total lineal miles of shoreline on the 45 major lakes within the watershed. The environmental corridors also contain 276.7 lineal miles, or 92 percent of the 300 total lineal miles of perennial stream channel length within the watershed. Moreover, 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 approximately 36,638 acres, or 69 percent of all of the remaining wetlands within the watershed. The corridors also contain 26,851 acres, or approximately 40 percent of the remaining 67,270 acres of woodland cover within the watershed, including 25 percent of the oak type, 39 percent of the central hardwoods type, 41 percent of the lowland hardwoods type, 73 percent of the upland conifer type, and 100 percent of the wetland conifer-hardwoods type. The corridors contain 15,858 acres, or 52 percent of the high-value aesthetic woodlands; 8,063 acres, or 28 percent of the medium-value aesthetic woodlands; and 2,956 acres, or 37 percent of the low-value woodlands, remaining within the watershed. The environmental corridors also contain 66,550 acres, or 56 percent of the wildlife habitat areas within the watershed.

The existing land use within the primary corridors of the watershed is indicated in Table 84. It should be noted that approximately 66,550 acres, or 52 percent of the total corridor area is in woodland, wetland, or other open land use; 18 percent is in surface water, while an additional 30 percent is in agricultural use. The continued 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 also 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 Fox River watershed constitutes an important natural resource area and a valuable recreational asset within the rapidly urbanizing Southeastern Wisconsin Region. This chapter has described in some detail the physical characteristics of the major elements of the recreational-related resources of the watershed and the major problems relating to the conservation of these resources, those which are related to the natural characteristics of the resources themselves, as well as those which are induced or aggravated by human activity within the watershed. The resources involved include the lakes and streams, the wetlands and woodlands, and the wildlife habitat areas of the watershed.

There are 76 lakes within the Fox River watershed, of which 45 have a surface area of 50 acres or more. The 76 lakes have a combined surface area of 34.9 square miles, or 4 percent of the total watershed area. The 45 major lakes have a total surface area of 34 square miles, or 98 percent of the total lake surface area within the watershed, and a total shoreline length of 228 miles, or 89 percent of the total lake shoreline within the watershed. These lakes, together with the 300 miles of perennial streams within the

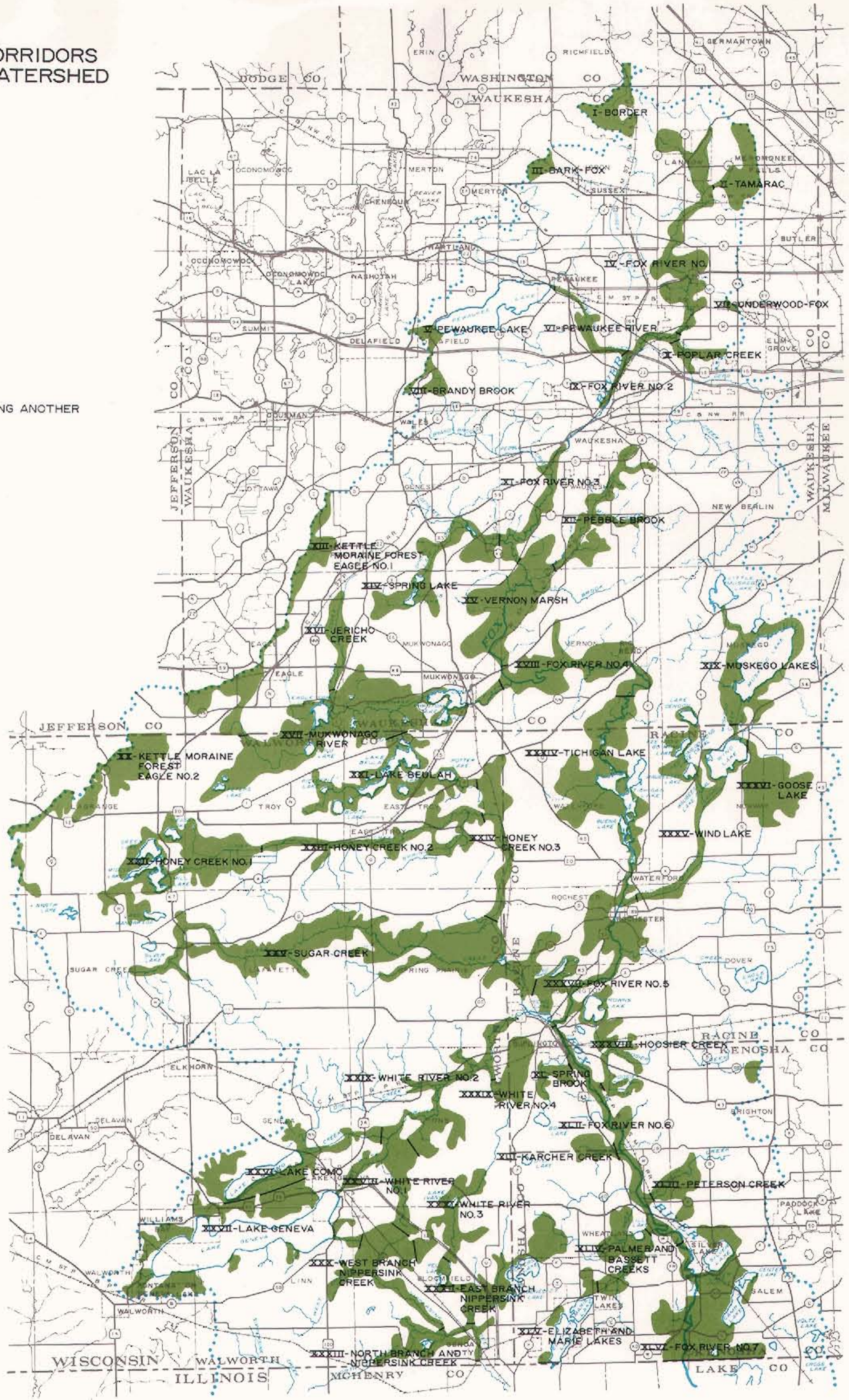
Map 51

ENVIRONMENTAL CORRIDORS OF THE FOX RIVER WATERSHED (1967)

LEGEND

ENVIRONMENTAL CORRIDOR

ENVIRONMENTAL CORRIDOR JOINING ANOTHER



Stream valleys and ridge lines within the watershed form linear patterns of concentrated high-value natural resources. Together these environmental corridors comprise only about 20 percent of the total area of the watershed but contain 66 percent of the total lineal miles of major lake shoreline, 92 percent of the total lineal miles of perrenial stream shoreline, 69 percent of the remaining wetlands, 40 percent of the remaining woodlands, and 56 percent of the wildlife habitat area. Preservation of these corridors in open uses is, therefore, essential to the maintenance of a good environment within the watershed and to the preservation of its unique natural heritage and beauty.

Source: Wisconsin Department of Natural Resources and SEWRPC.

Table 84

EXISTING LAND USE WITHIN THE ENVIRONMENTAL CORRIDORS OF THE FOX RIVER WATERSHED: 1963

			Corridor Land Use														Corridor Resource Use					
			Net Corridor Total		Agriculture And Related		Water		Wetland		Woodland		Unused Land		Wildlife Habitat		Recreational Use			
																	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	Acres	Percent Of Corridor	Acres	Percent Of Corridor	Acres	Percent Of Corridor	Acres	Percent Of Corridor
1	Border	T8N-R19E T9N-R19E	1,440	100.0	692	48.1	2	0.1	481	33.4	233	16.2	32	2.2	746	51.8	18	1.3	195	13.5
2	Tamarack	T8N-R20E	1,356	100.0	79	5.8	2	0.1	1,188	87.6	42	3.2	45	3.3	1,275	94.1	--	--	1,200	88.5
3	Bark - Fox	T8N-R19E	335	100.0	86	25.7	1	0.3	151	45.0	86	25.7	11	3.3	248	74.2	--	--	--	--
4	Fox River No. 1	T7N-R20E T8N-R20E	2,806	100.0	742	26.4	66	2.4	1,391	49.5	479	17.1	128	4.6	1,998	71.2	557	19.9	610	21.7
5	Pewaukee Lake	T7N-R18E T7N-R19E	2,601	100.0	24	0.9	2,376	91.3	85	3.3	69	2.7	47	1.8	201	7.8	441	17.0	700	26.9
6	Pewaukee River	T7N-R19E	468	100.0	202	43.2	10	2.1	196	41.9	46	9.8	14	3.0	256	54.7	--	--	--	--
7	Underwood - Fox	T7N-R20E	16	100.0	--	--	--	--	16	100.0	--	--	--	--	16	100.0	--	--	--	--
8	Brandy Brook	T7N-R18E	1,130	100.0	613	54.3	3	0.31	378	33.4	135	11.9	1	0.1	514	45.5	--	--	225	19.9
9	Fox River No. 2	T6N-R19E T7N-R19E	293	100.0	44	15.0	75	25.6	92	31.4	44	15.0	38	13.0	174	59.4	37	12.6	--	--
10	Poplar Creek	T7N-R20E	417	100.0	37	8.9	1	0.2	107	25.7	267	64.0	5	1.2	379	90.9	--	--	160	38.4
11	Fox River No. 3	T6N-R19E	796	100.0	143	18.0	90	11.3	420	52.7	143	18.0	--	--	563	70.7	115	14.4	200	25.1
12	Pebble Brook	T5N-R19E T6N-R19E	1,468	100.0	341	23.2	--	--	931	63.5	193	13.1	3	0.2	1,127	76.8	436	29.7	1,380	94.0
13a	Kettle Moraine Forest-Eagle No. 1 (Waukesha County)	T5N-R17E T6N-R17E	3,270	100.0	966	29.5	15	0.5	257	7.9	1,952	59.7	80	2.4	2,289	70.0	2,575	78.7	--	--
14	Spring Lake	T5N-R18E T6N-R18E	2,612	100.0	1,185	45.4	165	6.3	711	27.2	527	20.2	24	0.9	1,262	48.8	2	0.1	890	34.1
15	Vernon Marsh	T5N-R18E T5N-R19E	4,721	100.0	1,300	27.5	81	1.7	2,918	61.9	422	8.9	--	--	3,340	70.8	3,023	64.0	40	0.8
16	Jericho Creek	T5N-R17E T5N-R18E	1,062	100.0	403	37.9	--	--	213	20.1	446	42.0	--	--	659	62.1	60	5.6	--	--
17	Mukwonago River	T4N-R17E T5N-R18E	8,618	100.0	2,375	27.6	1,052	12.2	2,300	26.7	2,628	30.5	763	3.0	5,191	60.3	3,113	36.1	972	11.3

Table 84 (continued)

EXISTING LAND USE WITHIN THE ENVIRONMENTAL CORRIDORS OF THE FOX RIVER WATERSHED: 1963

			Corridor Land Use												Corridor Resource Use					
			Net Corridor Total		Agriculture And Related		Water		Wetland		Woodland		Unused Land		Wildlife Habitat		Recreational Use			
																	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	Acres	Percent Of Corridor	Acres	Percent Of Corridor	Acres	Percent Of Corridor	Acres	Percent Of Corridor
18	Fox River No. 4	T5N-R18E T5N-R19E	3,625	100.0	1,026	28.3	203	5.6	1,363	37.7	937	25.8	96	2.6	2,396	66.1	25	0.7	1,080	29.8
19	Muskego Lake	T5N-R20E	5,128	100.0	737	14.4	2,627	51.1	1,536	30.0	208	4.1	20	0.4	1,764	34.5	150	2.9	185	3.6
20	Kettle Moraine Forest-Eagle No. 2	T4N-R15E T4N-R16E	3,600	100.0	919	25.5	40	1.1	77	2.1	2,546	70.8	18	0.5	2,641	73.4	1,020	28.4	--	--
21	Lake Beulah	T4N-R17E T4N-R18E	3,259	100.0	416	12.8	1,142	35.0	979	30.0	628	19.3	94	2.9	1,701	52.2	874	26.8	475	14.6
22	Honey Creek No. 1	T4N-R16E T4N-R17E	5,887	100.0	2,386	40.4	1,129	19.2	998	17.0	1,314	22.4	60	1.2	2,372	40.3	651	11.1	380	6.5
23	Honey Creek No. 2	T4N-R17E T4N-R18E	3,500	100.0	1,865	53.2	75	2.1	847	24.2	434	12.3	279	7.9	1,560	44.6	--	--	460	13.1
24	Honey Creek No. 3	T4N-R18E T4N-R19E	1,683	100.0	701	41.7	44	2.6	703	41.8	234	13.9	1	--	938	55.7	178	10.6	140	8.3
25a	Sugar Creek West	T3N-R16E T3N-R17E	4,683	100.0	1,735	37.1	32	0.7	1,004	21.4	1,789	38.2	123	2.6	2,916	62.2	650	13.9	2,945	62.9
25b	Sugar Creek East	T3N-R18E T3N-R19E	4,796	100.0	2,240	46.7	171	3.6	1,435	29.9	905	18.9	45	0.9	2,385	49.7	132	2.8	320	6.7
26	Lake Como	T2N-R17E T2N-R18E	3,767	100.0	766	20.3	913	24.2	388	10.3	1,508	40.1	192	5.1	2,088	55.5	639	17.0	1,960	52.0
27	Lake Geneva	T1N-R16E T1N-R17E	7,654	100.0	732	9.6	5,239	68.4	171	2.2	1,321	17.3	191	2.5	1,683	22.0	761	9.9	230	3.0
28	White River No. 1	T1N-R18E T2N-R18E	2,557	100.0	1,224	48.0	36	1.4	838	32.7	391	15.3	68	2.6	1,297	50.8	81	3.2	80	3.1
29	White River No. 2	T2N-R18E T3N-R18E	2,689	100.0	992	36.9	111	4.1	1,072	39.9	484	18.0	30	1.1	1,586	59.0	80	3.0	340	12.6
30	West Branch Nippersink Creek	T1N-R17E T1N-R18E	2,770	100.0	827	29.9	23	0.8	1,350	48.7	404	14.6	166	6.0	1,920	69.3	160	5.8	150	5.4
31	White River No. 3	T1N-R18E T2N-R18E	1,651	100.0	230	13.9	47	2.8	1,037	62.9	309	18.7	28	1.7	1,374	83.2	12	0.7	240	14.5
32	East Branch Nippersink Creek	T1N-R18E T1N-R19E	3,135	100.0	823	26.2	657	21.0	1,327	42.3	200	6.4	128	4.1	1,655	52.9	177	5.7	40	1.3

Table 84 (continued)

EXISTING LAND USE WITHIN THE ENVIRONMENTAL CORRIDORS OF THE FOX RIVER WATERSHED: 1963

Corridor Number	Corridor Name	Location	Corridor Land Use												Corridor Resource Use					
			Net Corridor Total		Agriculture And Related		Water		Wetland		Woodland		Unused Land		Wildlife Habitat		Recreational Use			
																	Existing		Potential	
			Acres	Percent Of Corridor	Acres	Percent Of Corridor	Acres	Percent Of Corridor	Acres	Percent Of Corridor	Acres	Percent Of Corridor	Acres	Percent Of Corridor	Acres	Percent Of Corridor	Acres	Percent Of Corridor	Acres	Percent Of Corridor
33	North Branch and Nippersink Creek	T1N-R18E	1,833	100.0	679	37.1	52	2.8	373	20.3	684	37.3	45	2.5	1,102	60.1	117	6.4	1,580	86.2
34	Tichigan Lake	T4N-R19E T5N-R19E	5,328	100.0	1,361	25.5	1,165	21.9	2,037	38.2	722	13.6	43	0.8	2,802	52.6	1,907	35.8	662	12.4
35	Wind Lake	T3N-R20E T4N-R20E	3,182	100.0	530	16.6	1,273	40.0	989	31.1	365	11.5	25	0.8	1,379	43.4	50	1.6	140	4.4
36	Goose Lake	T4N-R20E	2,735	100.0	1,940	71.0	2	0.1	671	24.5	122	4.4	--	--	793	29.0	--	--	--	--
37	Fox River No. 5	T3N-R19E T4N-R19E	4,435	100.0	1,555	35.0	776	17.5	824	18.6	1,162	26.2	118	2.7	2,104	47.5	811	18.3	2,512	56.7
38	Hoosier Creek	T2N-R19E T3N-R19E	1,267	100.0	637	50.3	12	0.9	375	29.6	214	16.9	29	2.3	618	48.8	2	0.2	80	6.3
39	White River No. 4	T2N-R18E T2N-R19E	1,179	100.0	235	19.9	13	1.1	178	15.1	686	58.2	67	5.7	931	79.0	2	0.2	800	67.9
40	Spring Brook	T2N-R19E	520	100.0	306	58.8	--	--	83	16.0	131	25.2	--	--	214	41.2	--	--	290	55.8
41	Karcher Marsh	T2N-R19E	916	100.0	435	47.5	1	0.1	295	32.2	185	20.2	--	--	480	52.4	200	21.8	110	12.0
42	Fox River No. 6	T1N-R19E T2N-R19E	1,564	100.0	546	34.9	251	16.1	444	28.4	274	17.5	49	3.1	767	49.0	85	5.4	485	31.0
43	Peterson Creek	T1N-R20E T2N-R20E	1,108	100.0	463	41.8	4	0.4	612	55.2	28	2.5	1	0.1	641	57.8	--	--	40	3.6
44	Palmer and Bassett Creeks	T1N-R19E	1,566	100.0	462	29.5	73	4.7	808	51.6	187	11.9	36	2.3	1,031	65.8	1,134	72.4	170	10.9
45	Elizabeth and Marie Lakes	T1N-R19E	1,216	100.0	33	2.7	942	77.5	190	15.6	35	2.9	16	1.3	241	19.8	32	2.6	160	13.2
46	Fox River No. 7	T1N-R19E T1N-R20E	6,053	100.0	1,707	28.2	1,413	23.4	1,799	29.7	732	12.1	402	6.6	2,933	48.5	737	12.2	580	9.60
Total			126,695	100.0	37,740	29.8	22,405	17.7	36,638	28.9	26,851	21.2	3,061	2.4	66,550	52.5	21,044	16.6	23,206	18.3

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 floodwater retention reservoirs, thereby attenuating peak flood discharges from the watershed; and provide one of the most pleasing aesthetic elements of the landscape, enhancing adjacent property values. Major recreational inadequacies of the lakes within the watershed include insufficient depth and 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 last problem which involves 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. Seventeen of the 45 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. A characteristic problem is "summer kill," the major fish mortality resulting from the excessive consumption of oxygen, decomposing algae and other vegetation on calm, often dark summer days. The most pressing need in this respect is to reduce or eliminate nutrient contribution to the lakes from domestic sewage and 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 the deposition of sedimentary materials 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 concomitant stream and lake sedimentation is one of the more serious, immediate fish management 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 forms of aquatic plant and animal life.

There are 203 wetland units having a surface area of 50 acres or more within the watershed. These wetlands have a combined surface area of 83.1 square miles, or about 8.6 percent of the total area of the watershed. Approximately 216.7 square miles, or 23 percent of the total area of the watershed, was originally covered by wetlands, so that well over one-half of the original wetlands existing within the watershed have been destroyed since settlement of the basin by Europeans. 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 attenuating peak flood discharges within the watershed; and contribute to the aesthetic character and overall quality of the environment within the watershed. Problems associated with wetlands, include, in addition to destruction through conversion to agricultural and urban land uses, unstable water levels, odors, undesirable insect populations, disturbance of wildlife by human activities, and occasional natural pollution of downstream watercourses through release of stored nutrients during unusual weather conditions.

Woodlands are another important natural resource of the watershed. Originally, approximately 486 square miles, or 51 percent of the total area of the watershed, was covered by woodlands. This has been reduced to 105.1 square miles, or about 11 percent of the total area of the watershed, so that over 78 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 agricultural and urban land use development, is estimated to be about equal to that being planted to trees, 350 acres per year. Because of the type, quality, and age of the remaining woodland stands within the watershed, however, this balance cannot be expected to be maintained as urbanization proceeds 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 also 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 wildlife grazing, and fire.

Approximately 187 square miles, or 20 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, muskrat, skunk, fox, 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 198 square miles, or 21 percent of the total watershed area. These corridors, however, encompass 66 percent of the lake shorelines of the 45 major lakes within the watershed, 92 percent of the total lineal miles of perrenial stream channel length within the watershed, 69 percent of all remaining wetlands, and 40 percent of all the remaining woodlands, as well as 56 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 good environment for life within the watershed, to the preservation of its wildlife, its unique cultural and natural heritage, and its natural beauty. These environmental corridors are a heritage which cannot be replaced and which must serve the watershed for all time to come. The value of these corridors will increase with time and increasing urbanization, and, properly protected and wisely used, can provide the resource base for all future life within the watershed.

Chapter XIII

OUTDOOR RECREATION DEMAND

INTRODUCTION

Rapid population increase and urbanization, combined with rising income levels, increasing leisure time and changing attitudes toward utilization of that leisure time, 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 seven million urban residents, many of whom seek outdoor recreational opportunities in southeastern Wisconsin. The Fox River watershed, with its many streams and lakes, varied topography, woodlands, wetlands, and wildlife habitat areas, comprises a prime recreational resource; and its close proximity to the Chicago urbanized area, as well as to the Milwaukee, Racine, and Kenosha urbanized areas, serves to increase its potential recreational value. If this recreational potential is to be fully developed to meet the growing demands, careful attention must be given in the comprehensive watershed planning effort both to a quantification of the existing and potential demand for outdoor recreation and to the means available to meet this demand. This chapter, which is primarily concerned with the determination of gross recreational land needs within the Fox River watershed to the year 1990, also summarizes the supply of existing outdoor recreational facilities, both public and nonpublic, and participant demand for the major outdoor recreational activities, both existing and forecast, within the watershed.

EXISTING OUTDOOR RECREATIONAL FACILITY 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 Retional Planning Commission (SEWRPC), revealed that there were 358 such public and nonpublic sites within the Fox River watershed, encompassing a total of 36,312 acres, or approximately 6 percent of the total watershed area. These 358 sites encompass 303 acres of water surface area, or about 1.1 percent of the total of 28,000 acres of water surface area within the watershed (see Chapter IV, Table 16 and Map 23). These sites within the watershed represent about 32 percent of the total of such public and nonpublic sites within the Region and about 37 percent of the total area of 97,527 acres of such sites within the Region. Publicly controlled lands owned or leased by a governmental body or agency account for 26,097 acres, or 71.9 percent of the total acreage of recreation and related open-space sites within the watershed; and nonpublic ownership accounts for the remaining 10,215 acres, or 28.1 percent (see Table 85). These watershed sites, in turn, represent 34 percent of the total regional acreage in public ownership and 47 percent of the total regional acreage in private ownership, respectively. Public land ownership by county within the watershed is summarized in Table 86.

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 actual active use. A more detailed analysis of site activities indicates that only 14,239 acres, or approximately 55 percent, of the publicly controlled recreational lands within the watershed are available for the 16 major water- and land-based outdoor recreational activities listed in Table 85. Lands acquired and protected for their natural biotic values but open to public hunting total 13,475 acres or comprise over 94 percent of these recreation lands. Only 764 acres, or approximately 6 percent of the total publicly controlled recreation lands available for all 16 major outdoor recreational activities, are available for the remaining 15 activities.

Undeveloped outdoor recreation lands total 11,504 acres, or approximately 44 percent, of the total public ownership, and may be subdivided as shown in Table 87 into two categories:

1. Developable lands, or those lands which have been acquired for development for specific outdoor recreational activities.

Table 85

ACREAGE OF OUTDOOR RECREATION LANDS IN THE FOX 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	25	27	54	34	32	43	109	163
Boating	3	4	18	25	15	17	60	92	117
Fishing	2	--	9	11	14	12	23	49	60
Canoeing[b]	--	--	--	--	--	--	--	--	--
Water Skiing[b]	--	--	--	--	--	--	--	--	--
Subtotal	*7*	*29*	*54*	*90*	*63*	*61*	*126*	*250*	*340*
Land-Based									
Site Activities									
Camping	30	82	3	115	180	2,349	310	2,839	2,954
Picnicking	101	217	77	395	16	96	71	183	578
Golfing	--	152	--	152	568	158	1,616	2,342	2,494
Hunting	13,475	--	--	13,475	455	--	3	458	13,933
Skiing	--	--	--	--	10	--	233	243	243
Road Activities									
Sightseeing[b]	--	--	--	--	--	--	--	--	--
Pleasure Driving[b]	--	--	--	--	--	--	--	--	--
Bicycling	--	--	--	--	--	--	--	--	--
Trail Activities									
Hiking	--	--	--	--	--	--	--	--	--
Nature Walking	--	100	2	102	179	762	--	941	1,043
Horseback Riding	--	--	--	--	--	--	--	--	--
Subtotal	*13,606*	*557*	*82*	*14,239*	*1,408*	*3,365*	*2,233*	*7,006*	*21,245*
Other Minor Land - Or Water-Based Activities	--	84	180	264	49	286	68	403	667
Total Developed Recreation Lands	13,613	664	316	14,593	1,520	3,712	2,427	7,659	22,252
Total Undeveloped Recreation Lands (Unused Land And Open Space Land)[c]	10,005	776	723	11,504	116	906	1,534	2,556	14,060
Total Recreation Lands	23,618	1,440	1,039	26,097	1,636	4,168	3,961	10,215	36,312

[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] *Undeveloped lands are further classified in Table 87.*

Source: *Wisconsin Department of Natural Resources and SEWRPC.*

Table 86

OUTDOOR RECREATION LANDS IN THE FOX RIVER WATERSHED BY COUNTY AND TYPE OF OWNERSHIP: 1967

County	Public Acres				Nonpublic Acres				Total County Acreage
	Local	County	State	Total	Private (Restricted)	Organizational	Commercial	Total	
Kenosha	23	167	7,591	7,781	125	424	601	1,150	8,931
Racine	91	123	3,911	4,125	29	238	355	622	4,747
Walworth	112	--	8,387	8,499	1,107	3,693	1,103	5,903	14,402
Washington	--	--	95	95	--	--	--	--	95
Waukesha	813	1,150	3,634	5,597	375	263	1,902	2,540	8,137
Total	1,039	1,440	23,618	26,097	1,636	4,618	3,961	10,215	36,312

Source: SEWRPC.

Table 87

EXISTING UNDEVELOPED OUTDOOR RECREATION LANDS IN THE FOX RIVER WATERSHED BY TYPE OF OWNERSHIP: 1967

Ownership	Developable Lands		Backup Lands[a]		Total Lands (Acres)
	Acres	Percent Of Total Land	Acres	Percent Of Total Land	
Public					
Local	434	60.0	289	40.0	723
County	537	69.2	239	30.8	776
State	4,538[b]	45.4	5,467	54.6	10,005
Subtotal	*5,509*	*47.9*	*5,995*	*52.1*	*11,504*
Nonpublic					
Private (Restricted)	15	12.9	101	87.1	116
Organizational	697	76.9	209	23.1	906
Commercial	574	37.4	960	62.6	1,534
Subtotal	*1,286*	*50.3*	*1,270*	*49.7*	*2,556*
Total	6,795	48.3	7,265	51.7	14,060

[a] *Backup 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.*

[b] *Includes remaining government owned area of former Richard I. Bong U. S. Air Force Base Site, Kenosha County, Wisconsin.*

Source: Wisconsin Department of Natural Resources and SEWRPC.

These lands total 6,795 acres, or 48 percent, of the total undeveloped outdoor recreational lands in the watershed.

2. Backup lands, or those lands which have been acquired for the purpose of providing open space or undeveloped land adjacent to specific intensive outdoor recreational activity land and which, while essential to protection and enhancement of the intensively used sites, are not intended to be further developed. These lands total 7,265 acres, or 52 percent, of the total undeveloped outdoor recreation land in the watershed. As shown in Table 88, certain of these backup lands can be readily assigned to the support of lands developed for specific major intensive outdoor recreational activities.

Nonpublic outdoor recreation lands total 10,215 acres, or 1.7 percent of the watershed area; and of this total 7,659 acres, or approximately 75 percent, has been developed for active outdoor recreation use; and 2,556 acres, or approximately 25 percent, remain in backup and unused but developable area.

In addition to ownership, the existing outdoor recreation base of the watershed has also been inventoried by types of recreational facilities provided. The facilities have been divided into two major categories, water-based and land-based recreational facilities, and the 16 major outdoor recreational activities included within each major category are shown in Table 85. These 16 major outdoor recreational activities are consistent with the Wisconsin Department of Natural Resources outdoor recreation analysis categories. Other minor land- and water-based activities have also been inventoried and include playfields, trapshoot areas, and skating areas. Total acreage devoted to these activities is also shown in Table 85.

Water-Based Facilities

Public Water-Based Facilities: Water-based recreational facilities include those which provide access to a water body. Swimming beaches, boat launching areas, and fishing water-access areas are examples of these types of facilities (see Chapter IV, Map 23). Public water-based recreational facilities within the watershed are limited to beach and boat water-access developments and are usually combined with a large multi-use land-based outdoor recreational facility. Lands devoted to such public use account for only 26 percent of the total water-based outdoor recreational area in the watershed; and presently

Table 88

STATUS OF BACKUP LANDS FOR MAJOR RECREATIONAL ACTIVITIES IN THE FOX RIVER WATERSHED BY TYPE OF OWNERSHIP: 1967

(IN ACRES)

Ownership	Assignable Backup Lands				Unassignable Backup Lands	Total Backup Lands
	Swimming	Picnicking	Camping	Total		
Public						
Local	36	29	--	65	224	289
County	34	136	59	229	10	239
State	8	66	66	140	5,327	5,467
Subtotal	*78*	*231*	*125*	*434*	*5,561*	*5,995*
Nonpublic						
Private (Restricted)	22	--	--	22	79	101
Organizational	18	19	52	89	120	209
Commercial	29	23	60	112	848	960
Subtotal	*69*	*42*	*112*	*223*	*1,047*	*1,270*
Total	147	273	237	657	6,608	7,265

Source: Wisconsin Department of Natural Resources and SEWRPC.

there is a total of only 54 acres of public swimming beaches, having a combined shoreline frontage of 8,500 feet, and 36 acres of public boat access, having a combined shoreline frontage of 1,450 feet, available in the watershed. Of the total public water-based land, 92 percent is owned and operated by local units of government. It should be noted that state owned lands developed for water-based activities account for less than 8 percent of the total public acreage of such sites.

Nonpublic Water-Based Facilities: Private water-based recreational facilities within the watershed include provisions for swimming, sailing, canoeing, water skiing, and power boating. These are of both a private restricted or organizational type controlled by private groups permitting access only to members and of a commercial type permitting access to the general public for a fee. Commercial water-based recreational facilities generally center on boat rental, bait sale, and fishing access points surrounding lakes. These facilities provide the non-boat-owning public an opportunity to enjoy water activities by providing equipment on a rental basis, as well as access to a water body. Presently (1967) there are 109 acres of nonpublicly owned swimming beaches, having a combined shoreline frontage of 26,200 feet, and 141 acres of nonpublicly owned boat access areas, having a combined shoreline frontage of 7,100 feet, available within the watershed. Some of the larger multi-use commercial recreation establishments also provide swimming pools in addition to other recreational facilities.

Land-Based Facilities

Public Land-Based Facilities: Land-based recreational facilities include all those facilities for recreational pursuits performed wholly on land. Public land-based recreational facilities within the watershed are presently provided by three levels of government: local, county, and state. The local units of government presently provide most of the day use active recreation areas in the form of neighborhood and community parks and playgrounds (see Table 85). Emphasis on the design and improvement of such facilities is placed on intensive use activities, such as ball fields and swimming pools, with the facilities usually being operated and maintained by local park and recreation departments.

County owned recreational lands within the watershed generally consist of larger multi-use facilities serving county and regional recreational needs, as well as meeting some local needs. County facilities provide picnic areas, playfields, golfing, hiking, and camping areas (see Table 85). Waukesha County currently has the largest and most completely developed county recreational facilities within the watershed, totaling 1,150 acres, or about 80 percent, of the total county owned recreational facility lands within the watershed (see Table 86).

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. The state forest and wildlife habitat areas, although not developed nor intended for intensive use, do, however, provide opportunities for sightseeing, pleasure driving, hiking, and hunting and are essential to the protection of certain important elements of the natural resource base. The only major intensively developed state outdoor recreational facility within the watershed is Big Foot Beach State Park, located on the east shore of Geneva Lake. Camping and picnic areas, as well as beach facilities, are included at this park. Additional intensively developed state facilities include special activity areas, such as wayside parks and public water access and boat launching areas (see Table 85).

Nonpublic Land-Based Facilities: Approximately 6 percent of the total land-based recreational area within the watershed is accounted for under the private-restricted lands category. These facilities are devoted primarily to three types of activities: private golf courses, private group campgrounds, and private hunting grounds. Other specialized land activities offered include picnic grounds, playfields, trapshoots, and nature hiking areas (see Table 85). Although some of these private-restricted facilities are of a multi-use nature, access is restricted by membership regulations; and, therefore, these recreational facilities are available to only a limited number of people. Generally heavily used on weekends only, these areas serve a valuable limited-use open-space function throughout the warm weather months, although some private-restricted establishments also provide for year-round recreational activities. Walworth County ranks first in both the acreage and in the number of sites devoted to private-restricted recreational use (see Table 86).

Organizational group lands presently account for approximately 13 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 the Girl Scouts, Boy Scouts, YMCA, YWCA, churches, boys clubs, and service clubs. Typical of the facilities provided are group camping areas, picnic areas, trapshooting, hiking trails, and some golf facilities (see Table 85). Some of these facilities stress nature study and the preservation of open space. Walworth County ranks first in both the acreage and the number of sites devoted to private organizational use within the watershed (see Table 86).

Many commercial recreational facilities are located throughout the watershed, and these lands account for approximately 11 percent of the total land-based recreation 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 camping, horseback riding, golfing, and skiing. In recent years, however, the trend of commercial recreation development in the watershed has been to large multi-use, year-round facilities, such as Alpine Valley recreation area and the Playboy resort, both in Walworth County. Golf and skiing facilities constitute the largest amount of commercial recreational land in the watershed. Waukesha County currently ranks first in both the acreage and the number of sites devoted to commerical recreational use within the watershed (see Table 86).

Not included in the recreational inventories and analyses made for the Fox River watershed study are the indoor recreational facilities within the watershed. These include facilities in public and private school buildings open for use to the general public; facilities under the jurisdiction of local park and recreation agencies; and facilities operated by private groups and available only to the group membership, as well as facilities operated by private individuals or groups commercially for profit. Indoor facilities do represent a significant resource in meeting the varied recreational demands generated within the area. The Fox River watershed planning program was designed to deal only with those elements of recreation having a direct impact on the natural resources of the watershed. Indoor recreational activities do not have a significant direct impact on the natural resource base and it was for this reason that the supply of indoor recreational facilities was not accounted for in the Fox River watershed study. Forecast participant demand for indoor recreational facilities has also, consequently, been omitted from the recreation demand forecast presented in this report. A detailed accounting and analysis of the supply of indoor recreational facilities and of the demand for such facilities is more properly an element of a recreation planning program.

FACTORS AFFECTING THE EXISTING AND FUTURE DEMAND FOR OUTDOOR RECREATIONAL FACILITIES

The greatest use of outdoor recreational facilities within the Fox 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 time for the majority of persons having school age children affected by the school-term residence requirements. The Fox River watershed generally experiences its greatest recreational use pressures and largest number of users during the last two weeks in July and the first week in August.[1]

As already noted, the Fox River watershed is located within southeastern Wisconsin, one of the most rapidly urbanizing regions of the United States. It is located, moreover, immediately adjacent to the northeastern Illinois metropolitan region. 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 89 and Map 52). These forecast population levels constitute increases of approximately 1 million people, or 60 percent, and approximately 3 million people, or 45 percent, respectively, over the 1963 population levels of these two regions. Increased demand for outdoor recreation is certain to be generated by the rapid increases in population expected to occur within these two urbanizing regions.

Urbanization within the watershed itself is already exerting a direct and rapidly increasing pressure on the recreational resources of the watershed.

[1] *State Department of Resource Development, Private Seasonal Housing, p. 35, Madison, Wisconsin, 1966.*

Table 89

EXISTING AND FORECAST POPULATION IN THE FOX RIVER WATERSHED[a] AND ADJACENT URBAN AREAS: 1963 AND 1990

Area	Population		Percent Increase
	1963	1990	
Fox River Watershed	159,500[b]	359,000[c]	125
Southeastern Wisconsin Region[d]	1,674,000[b]	2,678,000[c]	60
Northeastern Illinois[e]	6,557,800[f]	9,537,200[g]	45

[a] *Includes only that area of the Fox River watershed which lies within the State of Wisconsin.*

[b] *SEWRPC 1963 O & D Studies.*

[c] *SEWRPC Planning Report No. 7, Volume 2, Forecasts and Alternative Plans--1990.*

[d] *Includes population in the Fox River watershed.*

[e] *Includes all of Cook, DuPage, Kane, Lake, McHenry and Will Counties in Northeastern Illinois.*

[f] *Interpolated by SEWRPC from 1960 and 1965 population data compiled by the Northeastern Illinois Planning Commission (NIPC) and reported in NIPC Planning Paper No. 10.*

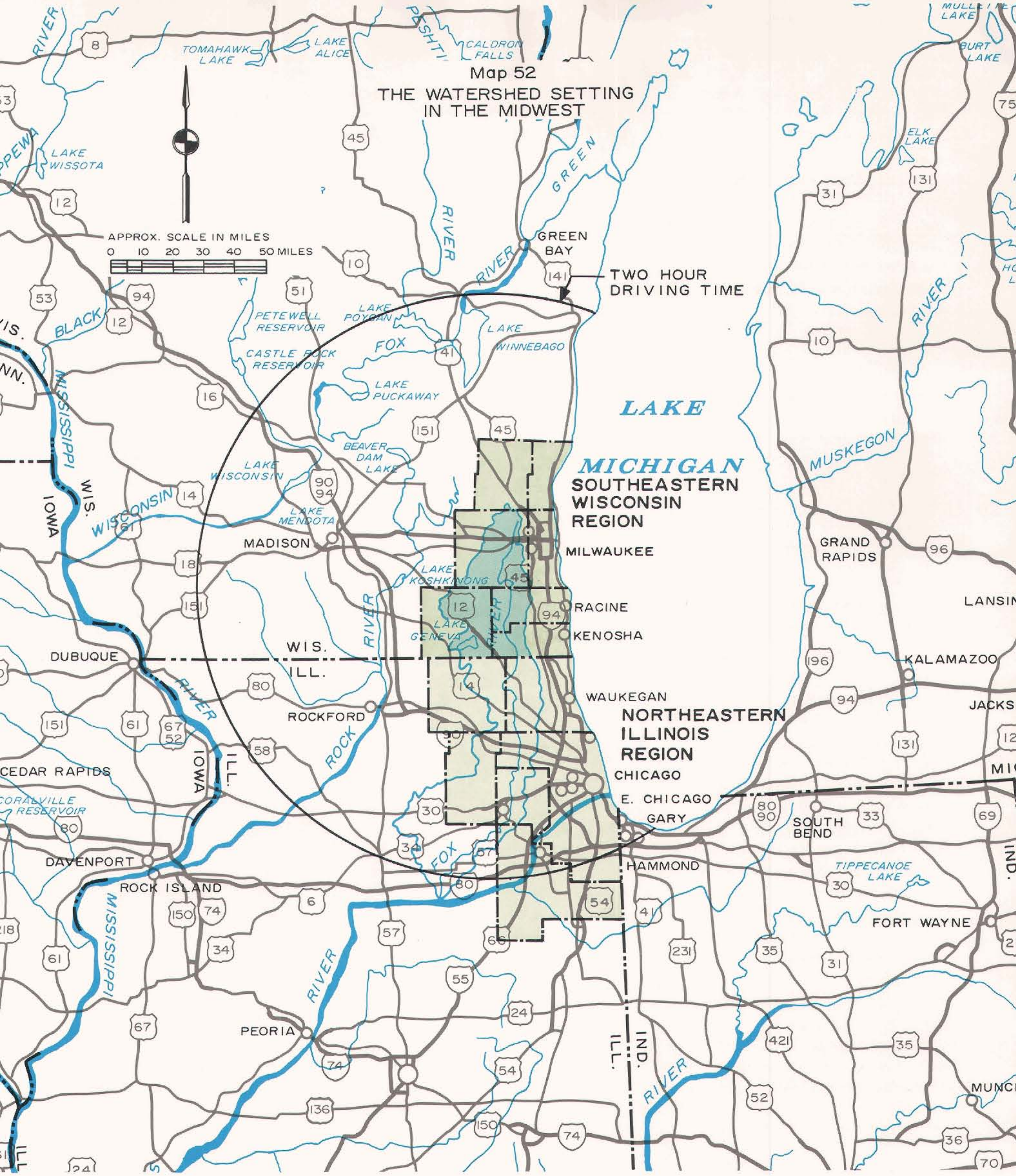
[g] *Interpolated by SEWRPC from 1985 and 1995 population forecasts prepared by NIPC and reported in NIPC Planning Paper No. 10.*

Source: NIPC and SEWRPC.

By 1990 over 350,000 people are expected to reside within the watershed. This forecast of growth represents an increase of 125 percent, or more than double the 1963 population of 159,500. This increase, while smaller in actual numbers than is expected in adjacent more intensely urbanized areas, is anticipated to have a significant effect on the recreational facilities and resources of the watershed. 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 persons residing in the watershed. This internal pressure on the recreational resources of the watershed may be expected to increase as population growth increases within the watershed. Moreover, the urban land development attendant to such population increases will not only result in increased pressures on recreational facilities but may also result in loss or irreparable damage to the recreation resource base.

In addition, intensified pressure on the recreational resources of the watershed is being generated by the rapidly increasing population within that portion of the Region lying outside the watershed, particularly within the urbanizing areas of Milwaukee, Racine, and Kenosha. Reduction of travel time between these urban centers and the recreational areas in the watershed through the construction of improved transportation facilities, particularly 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 may be 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.

The northeastern Illinois metropolitan region exerts an ever-increasing demand on nearby recreational areas, one of which is the Fox River watershed in Wisconsin. Data compiled by the Wisconsin Department of Natural Resources indicates that persons seeking day-use recreational activities will drive up to two hours from their place of residence to participate in one or more outdoor recreational activities. Such a driving time places all of southeastern Wisconsin and 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 52); and



The accessibility of the recreation resources of the Illinois - Fox River watershed 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 this day-use radius presently exceeds eight million and is expected to increase to well over twelve million by 1990.
Source: SEWRPC.

8.2 million people reside within this day-use area. Already evident is the intensive use of the recreational facilities in the Lake Geneva area of the watershed by Illinois residents. The heavy demand for summer weekend use is apparent at Big Foot Beach State Park, located on the east shore of Geneva Lake, where license plate checks reveal facilities are filled primarily by Illinois residents by midmorning on any Friday during the summer recreation season. The anticipated continued growth of this recreational demand is further evident in the recent development of new, large, multi-use privately financed recreational facilities within the southern half of the watershed. As population and, therefore, recreational demand continue to increase, the outdoor recreational facilities of the watershed will be subjected to increasing use pressure. Unless potential recreation areas are acquired and developed, overuse and deterioration or destruction of existing recreation areas and the recreation resource base will result.

EXISTING OUTDOOR RECREATIONAL ACTIVITY DEMAND—1967

Outdoor recreation demand within the watershed may be more specifically measured in terms of individual participation in each of the 16 major outdoor recreational activities experiencing the highest participation on an average seasonal Sunday[2] in the State of Wisconsin, as determined by 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 within the watershed, residents of Wisconsin outside the watershed, and residents of other states (see Table 90).

[2] *The term "average seasonal Sunday" has been defined by the Wisconsin Department of Natural Resources, in the case of 14 of the 16 major outdoor recreational activities, as a summer Sunday which does not coincide with a holiday weekend. An average seasonal Sunday in the case of hunting and skiing activities is defined as a non-holiday weekend Sunday during the legal Wisconsin hunting season and a non-holiday weekend Sunday during the winter months, respectively. For the seven-county 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.*

Water-Based Activities

Water-based outdoor recreational activities, as previously indicated, are those activities which require access to a body of water (see Table 85). Demand for water-based activities in the watershed currently accounts for over 45 percent of the total outdoor recreation demand. As shown in Table 91, three of the five highest ranked activities based on participation demand—swimming, boating, and fishing—require surface water area. These three activities alone account for over 44 percent of the outdoor recreation demand in the watershed. Despite this heavy demand, areas providing access to water bodies in the watershed total only 340 acres, or less than 1 percent of the total land area devoted to outdoor recreation. It should be noted that 124 acres, or 37 percent, of the total developed water-access points are either in private-restricted ownership or organizational ownership, which, as already mentioned, are not available for use by the general public and, therefore, increase the burden of demand on publicly and commercially owned and operated water-access areas. It is also important to note that, at present, local units of government in the watershed provide 83 acres, or 24 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 28,000 acres, or less than 5 percent of the total area of the watershed. Fortunately, the activity experiencing the highest participant demand—swimming—requires the least amount of 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. It is a fact, however, that such water quality levels are not being maintained. Meeting the demand for swimming, therefore, will require a rehabilitative effort with respect to water quality levels, as well as the provision of the necessary recreational facilities.

Demand for water-based activities has, on the other hand, already reached critical levels. Water surface area available for other water-based rec-

Table 90

EXISTING AVERAGE SEASONAL SUNDAY PARTICIPANT RECREATION DEMAND IN THE FOX RIVER WATERSHED BY MAJOR RECREATIONAL ACTIVITY AND RESIDENCE OF PARTICIPANT: 1967

Activity	Watershed Participant Demand						
	Watershed Residents		Out-Of-Watershed Wisconsin Residents		Out-Of-State Residents		
	Participants	Percent Of Total	Participants	Percent Of Total	Participants	Percent Of Total	Total Participants
Water-Based							
Swimming	17,158	30.7	18,264	32.6	20,579	36.7	56,001
Boating	3,540	16.9	4,535	21.7	12,852	61.4	20,927
Fishing	5,284	26.7	5,160	26.1	9,322	47.2	19,766
Canoeing	158	16.3	243	24.9	573	58.8	974
Water Skiing	683	26.0	876	33.5	1,059	40.5	2,618
Subtotal	*26,823*	*26.7*	*29,078*	*29.0*	*44,385*	*44.3*	*100,286*
Land-Based							
Site Activities							
Camping	288	6.5	1,303	29.7	2,801	63.8	4,392
Picnicking	4,973	40.6	4,333	35.3	2,956	24.1	12,262
Golfing	6,576	57.9	2,236	19.7	2,542	22.4	11,354
Hunting	1,331	34.2	2,371	60.9	189	4.9	3,891
Skiing	262	12.1	568	26.2	1,338	61.7	2,168
Road Activities							
Sightseeing	2,063	9.6	3,996	18.6	15,448	71.8	21,507
Pleasure Driving	20,143	36.3	14,443	26.1	20,842	37.6	55,428
Bicycling	3,129	93.6	214	6.4	--	--	3,343
Trail Activities							
Hiking	342	25.6	287	21.4	709	53.0	1,338
Nature Walking	1,380	46.7	88	3.0	1,484	50.3	2,952
Horseback Riding	492	84.2	92	15.8	--	--	584
Subtotal	*46,979*	*34.4*	*29,931*	*25.1*	*48,309*	*40.5*	*119,219*
Total	67,802	30.9	59,009	26.9	92,694	42.2	219,505

Source: Wisconsin Department of Natural Resources.

reational activities totals only 21,700 acres.[3] With a total participation demand of 44,285 participants for water-based activities other than swimming on an average seasonal Sunday, an average of only about 0.5 acre of available lake and stream and surface area can be allotted to each participant. If only one-fifth of the total participants are on the water at any one time, this allocation would be increased to 2.5 acres per participant, still far below the minimum lake and stream water use standard of five acres per participant recommended by the Wisconsin Department of Natural Resources to achieve good water resource management.

Considering the juxtaposition of the watershed and the urban centers of Milwaukee, Racine, and Kenosha in southeastern Wisconsin, it is interesting to note that over 44 percent of the total demand for water-based recreational activities in the watershed is generated by out-of-state users, while approximately 29 percent is generated from within the State of Wisconsin but outside the watershed. The remaining 27 percent of total demand for water use is generated within the watershed. As previously mentioned, over 72 percent of publicly owned water-based land development in the watershed is provided by local or county governments in the watershed, whose residents make the least use of the facilities provided.

Land-Based Activities

Land-based outdoor recreational activities include those activities which are participated in wholly on land. The current demand for land-based outdoor recreational activities is over 54 percent of the total demand. Two activities—pleasure driv-

[3]*According to state promulgated standards for lake development, the area extending 200 feet from the shoreline of all lakeshores should be allocated solely to swimming. In the Fox River watershed, this swimming area allotment totals 6,300 acres, or about 22 percent of the total water surface area in the watershed.*

Table 91

RANK ORDER OF EXISTING RECREATIONAL ACTIVITY DEMAND ON AN AVERAGE SEASONAL SUNDAY IN THE FOX 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 (20,143)[a]	Swimming (18,264)	Pleasure Driving (20,842)	Swimming (56,001)
2	Swimming (17,158)	Pleasure Driving (14,443)	Swimming (20,579)	Pleasure Driving (55,428)
3	Golfing (6,576)	Fishing (5,160)	Sightseeing (15,448)	Sightseeing (21,507)
4	Fishing (5,284)	Boating (4,535)	Boating (12,852)	Boating (20,927)
5	Picnicking (4,973)	Picnicking (4,333)	Fishing (9,322)	Fishing (19,766)
6	Boating (3,540)	Sightseeing (3,996)	Picnicking (2,956)	Picnicking (12,262)
7	Bicycling (3,129)	Hunting (2,371)	Camping (2,801)	Golfing (11,354)
8	Sightseeing (2,063)	Golfing (2,236)	Golfing (2,542)	Camping (4,392)
9	Nature Walking (1,380)	Camping (1,303)	Nature Walking (1,484)	Hunting (3,891)
10	Hunting (1,331)	Water Skiing (876)	Skiing (1,338)	Bicycling (3,343)
11	Water Skiing (683)	Skiing (568)	Water Skiing (1,059)	Nature Walking (2,952)
12	Horseback Riding (492)	Hiking (287)	Hiking (709)	Water Skiing (2,618)
13	Hiking (342)	Canoeing (243)	Canoeing (573)	Skiing (2,168)
14	Camping (288)	Bicycling (214)	Hunting (189)	Hiking (1,338)
15	Skiing (262)	Horseback Riding (92)	Bicycling --	Canoeing (974)
16	Canoeing (158)	Nature Walking (88)	Horseback Riding --	Horseback Riding (584)
Total	(67,802)	(59,009)	(92,694)	(219,505)

[a]*Numbers below each activity represent the 1967 estimated participation demand on an average seasonal Sunday in the Fox River watershed, expressed in number of persons.*

Source: Wisconsin Department of Natural Resources.

ing and sightseeing—account for over 64 percent of all land-based activity participation on an average seasonal Sunday. Neither of these recreational pursuits require the direct ownership of recreation land, but rather they require the provision of secondary highways as pleasure drives and the maintenance of the visual beauty of the countryside. While comprising the heaviest demand, these recreational pursuits, therefore, are also the easiest to provide for in terms of land acquisition and development, as long as the destruction of the beauty of the landscape through poor urban and rural development and through pollution can be halted, thereby assuring the continued availability of the landscape for aesthetic enjoyment.

Land developed for land-based outdoor recreational activities is in short supply considering the rapidly increasing demand for such activities. While total outdoor recreation land acreage in the watershed appears to be large, that portion of the total actually developed and, therefore, available to the general public for intensive use is limited, particularly when related to demand. Of the 21,245 acres of land devoted to land-based recreational activities, only 7,312 acres, or less than 33 percent, are developed for active outdoor recreation purposes; and only 764 acres, or less than 11 percent, of active recreation land in the watershed are publicly owned. Private-restricted ownership and organizational ownership account for 4,318 acres, or 59 percent, of active recreation land, which is not accessible to the general public. Of all public outdoor recreation land in the watershed, 13,933 acres are owned or leased primarily for protecting and enhancing their natural biotic values and secondarily for hunting use. State ownership or control of these wildlife areas totals 13,475 acres. It is important to emphasize that, for these lands to achieve their primary purpose, they must be maintained essentially in a natural condition. Therefore, with the exception of some extensive uses, such as hunting, hiking, and nature walking, they are generally not available for other outdoor recreational activities.

FORECAST OUTDOOR RECREATIONAL ACTIVITY DEMAND—1990

As already indicated, large and rapid increase in population within the watershed, as well as in adjacent urbanizing regions, is anticipated to have a significant impact on the recreational facilities and the recreation resource base of the watershed. This section summarizes that expected impact, as expressed in terms of participant demand forecast for each of the 16 major outdoor recreational activities in the watershed.

Water-Based Activities

Water-based activities are expected to account for 285,091 participants, or 51 percent of the total participant demand for outdoor recreation in the watershed by 1990. This not only represents an increase of 184,805 in total numbers of participants, or 184 percent over 1967 demand levels, but also an increase of 5 percent in the proportionate share of all outdoor recreation participants in the watershed. In other words, participant demand for water-based outdoor recreational activities in the watershed is not only expected to more than triple in 23 years but is also expected to become even more popular as a leisure time activity than is now the case. As indicated in Table 92, participation in swimming is expected to increase 230 percent; and swimmers will remain the largest single user group of outdoor recreational facilities. Swimming will account for 65 percent of all water-based recreational activity participants and 33 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 216 percent above the 1967 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 increase in water-based participant demand (249 percent), with 67 percent of the canoeing demand generated by out-of-state residents. Forecast of participant demand for fishing will show the smallest increase during the period 1967 to 1990. The 73 percent increase in fishing participation, expected by 1990, is large, however, considering the already intensive use of surface waters in the watershed.

It is evident that participation demand for water-based activities in the watershed will exert great pressures on water resources, which are already being used at a critical level in terms of maintaining a viable resource base. To meet 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,

Table 92

FORECAST AVERAGE SEASONAL SUNDAY PARTICIPANT DEMAND IN THE FOX RIVER WATERSHED BY MAJOR RECREATIONAL ACTIVITY AND RESIDENCE OF PARTICIPANT: 1990[a]

Activity	Watershed Participant Demand						Total Participants	Percent Increase In Total Participants (1967-1990)
	Watershed Residents		Out-Of-Watershed Wisconsin Residents		Out-Of-State Residents			
	Participants	Percent Of Total	Participants	Percent Of Total	Participants	Percent Of Total		
I. Water-Based								
A. Swimming	56,929	30.8	53,288	28.9	74,452	40.3	184,669	230
Boating	6,323	11.5	7,132	13.0	41,516	75.5	54,971	163
Fishing	8,904	26.1	7,378	21.6	17,883	52.3	34,165	73
Canoeing	469	13.8	636	18.7	2,292	67.5	3,397	249
Water Skiing	1,929	24.4	2,150	27.3	3,810	48.3	7,889	201
Subtotal	*74,554*	*26.2*	*70,584*	*24.8*	*139,953*	*49.0*	*285,091*	*184*
II. Land-Based								
A. Site Activities								
Camping	327	3.0	1,207	11.3	9,181	85.7	10,715	144
Picnicking	8,354	39.0	6,409	30.0	6,631	31.0	21,394	74
Golfing	10,687	51.2	3,328	17.8	4,669	25.0	18,684	65
Hunting	2,232	35.2	3,542	55.9	567	8.9	6,341	63
Skiing	747	15.0	809	16.2	3,432	68.8	4,988	130
B. Road Activities								
Sightseeing	4,675	6.0	11,867	15.3	61,202	78.7	77,744	261
Pleasure Driving	42,373	36.6	25,840	22.4	47,464	41.0	115,677	109
Bicycling	5,258	94.1	330	5.9	--[b]	--[b]	5,588	67
C. Trail Activities								
Hiking	974	21.4	756	16.6	2,820	62.0	4,550	240
Nature Walking	3,978	38.8	236	2.3	6,028	58.9	10,242	247
Horseback Riding	801	84.9	142	15.1	--[b]	--[b]	943	61
Subtotal	*80,406*	*29.0*	*54,466*	*19.7*	*141,994*	*51.3*	*276,866*	*132*
Total	154,960	27.6	125,050	22.3	281,947	50.1	561,957	156

[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.

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 measures, or others, 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

Similar to water-based activities, land-based participant demand for major recreational activities in the watershed is expected to experience significant increases in the 23-year period from 1967 to 1990. Participation in six of the 11 land-based activities will more than double in this period, and participation in three of the six will more than triple in this period. Land-based activities will in 1990 account for 276,866 participants, or 49 percent of the total demand for outdoor recreation in the watershed. This is an increase in total participation of 157,647, or 132 percent over 1967.

Pleasure driving will remain the most popular land-based activity, with sightseeing second in popularity. These two activities alone will generate an average seasonal Sunday participation demand of 193,421, or 70 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 92.

Expected ranking of recreational activity demand on an average seasonal Sunday in 1990 will change only slightly from the 1967 ranking, as shown in Table 93. Nature walking and water skiing are both anticipated to move up in rank, while bicycling and hunting both are anticipated to move down in rank. Hunting may be expected to remain an activity of relatively low demand, with participation within the watershed increasing from 3,891 participants per average seasonal Sunday to 6,341 by 1990. Thus, hunting may be expected to actually decline proportionately from 1.8 percent of the total participant demand in 1967 to 1.1 percent by 1990. Pressure on game species may be expected to increase, however, because of adverse land use development in areas adjacent to those specifically acquired for wildlife habitat values. Although the demand for hunting may be expected to remain low, it should be noted that wildlife areas provide significant values for such recreational activities as hiking and nature walking.

It is evident that land must be acquired and developed for intensive recreational use if expected demand for outdoor recreational activity is to be accommodated in the watershed. If the acquisition and development of such land cannot be accomplished, measures will be required to otherwise preserve the resource base in the face of expected intensive use including limitation of use.

OUTDOOR RECREATION LAND AND WATER NEEDS—1990

Thus far in this chapter, existing conditions and anticipated future activity demands have been discussed. This section is concerned with the conversion of the anticipated 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 alternative solutions for meeting the demand can be set forth, evaluated, and one 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 using minimum-area-use standards. Subtracting the total lands presently owned or developed for land and water activity from the results of this conversion will then provide a measure of the deficiencies of the presently developed land or 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 94, the 16 major outdoor recreational activities discussed previously in this chapter have been grouped into five classifications based on the type 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 accommodated on lands already developed or being used for other public or nonpublic uses.

The five major outdoor recreational activities in the first group, namely, swimming, picnicking, golfing, camping, and skiing, require specific intensive site development; and 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 be generally accommodated on hunting lands in private ownership and on lands

Table 93

RANK ORDER OF FORECAST RECREATIONAL ACTIVITY DEMAND ON AN AVERAGE SEASONAL SUNDAY IN THE FOX 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	Swimming (56,929)[b]	Swimming (53,288)	Swimming (74,452)	Swimming (184,669)
2	Pleasure Driving (42,373)	Pleasure Driving (25,840)	Sightseeing (61,202)	Pleasure Driving (115,677)
3	Golfing (10,687)	Sightseeing (11,867)	Pleasure Driving (47,464)	Sightseeing (77,744)
4	Fishing (8,904)	Fishing (7,378)	Boating (41,516)	Boating (54,971)
5	Picnicking (8,354)	Boating (7,132)	Fishing (17,888)	Fishing (34,165)
6	Boating (6,323)	Picnicking (6,409)	Camping (9,181)	Picnicking (21,394)
7	Bicycling (5,258)	Hunting (3,542)	Picnicking (6,631)	Golfing (18,684)
8	Sightseeing (4,675)	Golfing (3,328)	Nature Walking (6,028)	Camping (10,715)
9	Nature Walking (3,978)	Water Skiing (2,150)	Golfing (4,669)	Nature Walking (10,242)
10	Hunting (2,232)	Camping (1,207)	Water Skiing (3,810)	Water Skiing (7,889)
11	Water Skiing (1,929)	Skiing (809)	Skiing (3,432)	Hunting (6,341)
12	Hiking (974)	Hiking (756)	Hiking (2,820)	Bicycling (5,588)
13	Horseback Riding (801)	Canoeing (636)	Canoeing (2,292)	Skiing (4,988)
14	Skiing (747)	Bicycling (330)	Hunting (567)	Hiking (4,550)
15	Canoeing (469)	Nature Walking (236)	Bicyling --[c]	Canoeing (3,397)
16	Camping (327)	Horseback Riding (142)	Horseback Riding --[c]	Horseback Riding (943)
Total	(154,960)	(125,050)	(281,947)	(561,957)

[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 Fox River watershed, expressed in number of persons.*

[c] *Demand figures not available.*

Source: Wisconsin Department of Natural Resources.

Table 94

SUGGESTED MINIMUM LAND AREA REQUIREMENTS[a] FOR MAJOR OUTDOOR RECREATIONAL ACTIVITY IN THE FOX 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[b] Area		Backup Land Or Secondary Development[c] Area			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.*

in other uses, such as agricultural or other open spaces, on public wildlife areas or private shooting preserves and game farms which do not require intensive development. 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 in conjunction with other intensive water-based development. It is assumed that water surface areas in the watershed will not be increased appreciably. Therefore, the existing and forecast heavy demand for water use activities will not be entirely met in the watershed; and measures will have to be taken to limit use of the surface waters in order to protect the resource. It is anticipated that participant demand for the three activities in the fourth group—hiking, nature walking, and horseback riding—can be met in existing and future backup lands, as well as in nonpublic, agricultural, or other open-space lands. As indicated earlier, participation in the three activities in the fifth group—pleasure driving, sightseeing, and bicycling—can be accommodated for the most part in existing and future public highway rights-of-way.

Determination of Future Recreation Land Needs

Specific standards in terms of acres of area for each activity can be readily developed only for the five major activities in the first group. Demand for these five major activities, however, 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 94). 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 24,102 acres to accommodate the anticipated recreational activity demand (see Table 95). Subtracting existing land area, including assignable backup lands, as allocated in Table 88, from 1990 land demand will result in a total of 17,071 acres of additional land area required or land needed to facilitate the expected 1990 participant demand for each activity. This represents an increase of 141 percent in land devoted to these five major activities. Adding the 17,071 acres of additional land required to meet the 1990 participant demand for the five major outdoor recreational activities to the existing supply of 36,312 acres of outdoor recreation land (see Table 85) will total 53,383 acres. This required increase in land by 1990 represents an increase of 47 percent in total lands devoted to outdoor recreation in the watershed.

MEETING THE 1990 OUTDOOR RECREATION LAND DEMAND

Throughout this chapter it has been continually stressed that intensive pressure is being, and will continue to be, exerted on the outdoor recreation resources of the Fox River watershed by increased demand for both water-based and land-based activities. It has been shown that 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 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 recreation opportunities, is encompassed in the primary environmental corridors of the watershed. As indicated in Chapter XII, these primary environmental corridors encompass most of the surface water areas and best potential park and related open-space sites remaining in the watershed. Outside the corridor areas, only isolated potential park sites and minor surface water areas important to future recreation development are found.

The major lakes and rivers of the watershed form the basic framework of the corridor areas, and these surface waters offer the best development potential for meeting the water acreage needs generated by the rapidly increasing participants in water-based recreational activities. As previously indicated, use of 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

Table 95

EXISTING AND REQUIRED LAND FOR OUTDOOR RECREATION IN THE FOX RIVER WATERSHED BY ACTIVITY: 1967 AND 1990

Activity	1967	1990			
	Total Existing Recreational Land (In Acres)	Total Participant Demand[a] (Persons)	Minimum Land Requirement Per Participant Per Day[b] (In Acres)	Total Land Demand (In Acres)	Total Land Needs[c] (In Acres)
Swimming	310	184,669	0.0045	831	+ 521
Picnicking	851	21,394	0.1250	2,674	+ 1,823
Golf	2,494	18,684	0.3279	6,126	+ 3,632
Camping	3,191	10,715	1.3333	14,286	+ 11,095
Skiing	243	4,988	0.0370	185	- (58)[c]
Subtotal	*7,089*	*240,450*	--	*24,102*	*17,071*
Other Recreational Activities[d]	8,495	--	--	8,495	--[e]
Total	15,584	240,450	--	32,597	17,071

[a] *On an average seasonal Sunday.*

[b] *Includes required backup land acreage.*

[c] *The decrease in total skiing area is not included in the subtotal or total because no actual decrease is suggested.*

[d] *Does not include wild areas or unused (developable) acreage.*

[e] *Forecast needs for other recreation lands are 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.

areas can be established to provide better public access to the water for swimming, fishing, boating, water skiing, and canoeing. Provision of additional water surface area is another matter, however. The only means of securing such additional water surface area in the watershed is to create such areas through the construction of impoundments. The alternative 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 can 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 such lands are still available in the watershed which have recreation potential, are not now owned by either public or nonpublic recreation developers, and have not yet been developed for urban purposes. As indicated in Chapter IV, such land totals 36,860 acres. Of this total 23,206 acres, or about 63 percent, lie within the primary environmental corridors and, in some cases, include potential park sites which lie within the corridor. Another 13,654 acres, or about 37 percent of the total, are included in potential park sites within the watershed but outside the primary environmental corridors.

There are a total of 255 potential park sites within the watershed, encompassing a total of 36,860 acres (see Map 53). Of the 76 high-value sites within the watershed, four were recommended as new regional recreation areas on the adopted 1990 southeastern Wisconsin regional land use plan. Two of the four sites are located on Sugar Creek and Tichigan Lake, and the other two sites are being developed as Minooka Park in Waukesha County and Fox-Owen Park in Kenosha County. The remaining high-value potential park sites offer the best areas for development of additional multi-use outdoor recreation centers. Walworth and Waukesha Counties lead in the number of high-value potential park sites, with 31 and 24, respectively, and in the total number of acres available, with 9,370 acres and 5,762 acres, respectively. Of the total acres inventoried for possible use as outdoor facilities, the high-value sites total 19,559 acres, or 53.2 percent, of all potential park acreage. Many of these park facilities can be brought together within the framework of the primary environmental corridors, thereby developing an integrated framework of region-wide outdoor recreation and open-space lands.

The medium-value sites include 10,870 acres, or 28.9 percent of the land available for potential recreation development. These sites can provide many of the local or specialized recreational facilities. One or two use operations combining picnic areas with a boat launch area or a campground with hiking trails exemplify the types of development possible to meet the needs at these scattered smaller potential park sites.

The remaining potential park sites 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 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 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, some of the highest value potential recreation land in the Southeastern Wisconsin Region is found in the watershed in areas such as Sugar Creek Valley, adjacent to the main channel of the Fox River, and adjacent to the many lakes in the watershed. The primary environmental corridor lands are also a rich potential recreation resource. These corridor areas include not only the surface water areas of the watershed but also encompass the significant topographic and geo-

Map 53

POTENTIAL PARK SITES AND ENVIRONMENTAL CORRIDORS IN THE FOX RIVER WATERSHED (1967)

LEGEND

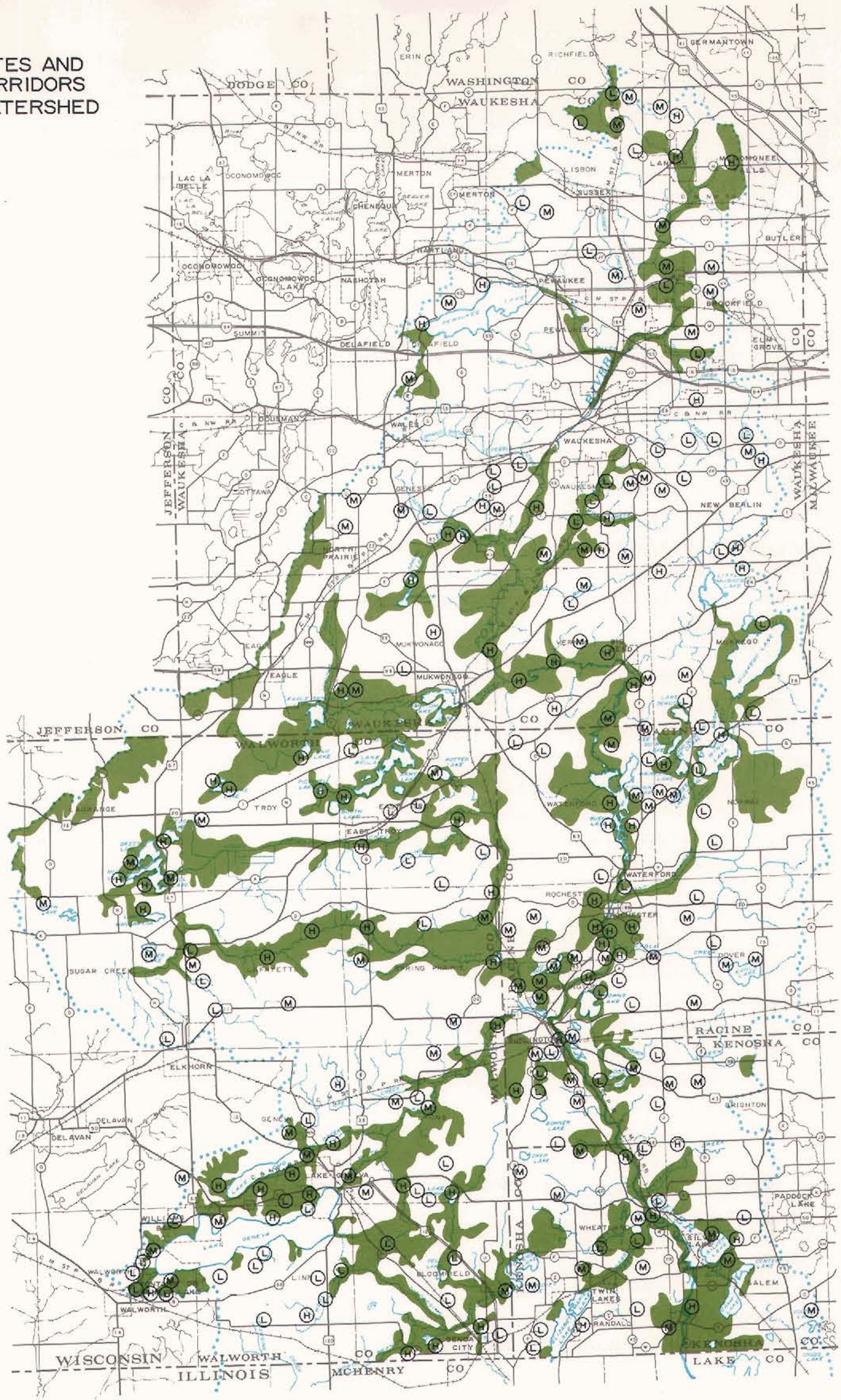
ENVIRONMENTAL CORRIDOR

POTENTIAL PARK SITES

(H) HIGH VALUE

(M) MEDIUM VALUE

(L) LOW VALUE



The value of the environmental corridors as a recreation resource is graphically illustrated on this map by the delineation and addition of potential park sites in the watershed as they relate to the environmental corridors. Of the 76 remaining high-value potential park sites in the watershed, 62 lie within or adjacent to the environmental corridors. Of the 255 potential sites in the watershed, 144, or 56 percent, lie within or adjacent to the environmental corridors. Preservation of the environmental corridor areas will, consequently, also preserve most of the valuable potential park sites which should be acquired and developed if minimum outdoor recreation facility demands are to be met in years to come.

Source: SEWRPC.

logic features, prime woodland areas, 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 use.

SUMMARY

A rapidly increasing demand for outdoor recreation in southeastern Wisconsin is being generated by the rapid population increase and urbanization, combined with rising income levels, increasing leisure time, and changing attitudes toward utilization of that leisure time. 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 Fox 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 area, as well as to the Milwaukee, Racine, and Kenosha 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 358 public and nonpublic recreational sites located within the Fox River watershed, encompassing a total area of 36,312 acres (56.7 square miles), or approximately 6 percent of the total watershed area. These sites represent about 32 percent of the total of such recreational sites and about 37 percent of the total area of such sites within the seven-county Region. Publicly controlled lands account for about 72 percent of the total acreage of recreation and related open-space sites within the watershed, with the remaining 28 percent being in private ownership.

A more detailed analysis of site activities, however, indicates that only 55 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 but used primarily for hunting comprise over 94 percent of this available area. Consequently, only 764 acres, or approximately 6 percent of the total publicly controlled recreational lands available for all 16 major recreation activities, are available for the remaining 15 major recreational activities.

Lands providing access to surface waters for water-based recreational activities that comprise over 45 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, 60 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. Total lake and stream surface area in the watershed totals approximately 28,000 acres, or less than 5 percent of the total area of the watershed. Of this total approximately 6,300 acres, or about 22 percent, are available for swimming, provided that water quality levels suitable for full-body-contact-recreation can be maintained; and 21,700 acres are available for all other water-based recreation uses. Of the total participation demand of 44,285 participants on an average seasonal Sunday, and with an average turnover rate of 5, only 2.5 acres 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 minimum standard of 5 acres per participant necessary to achieve good water resource management.

It is particularly important to note that over 44 percent of the total demand for water-based recreational activities within the watershed is generated by out-of-state users, while approximately 29 percent is generated from within the State of Wisconsin but outside the watershed. The remaining 27 percent is generated within the watershed. Yet, over 72 percent of the publicly owned water-based land development within the watershed is provided by local or county governments, whose residents make the least use of the facilities provided.

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 of 21,245 acres of land devoted to land-based recreational activities, less than 33 percent is developed for active use; and less than 11 percent, or 764 acres, of this developed land is in public ownership. It may be possible to develop a very limited acreage of the existing wildlife areas, comprising 57 percent of the total state ownership of outdoor recreation lands in the watershed for certain extensive recreational uses such as hiking, nature walking, sightseeing, pleasure driving and picnicking. Such development should not, however, be allowed to destroy the biotic values for which the lands were originally acquired.

Forecasts indicate that the participant demand for water-based outdoor recreational activities in the watershed may be expected to increase from 100,286 to 285,091 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 119,219 to 276,866 participants per average seasonal Sunday, more than doubling. 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 17,071 acres of land will have to be devoted to recreation use within the watershed, an increase of 47 percent over the present recreation acreage.

Although participant demand for outdoor recreational activities within the Fox River watershed may be expected to increase at an unprecedented rate, there are sufficient potential recreational land areas still available to meet this expected demand. In the absence of a sound resource management program, however, urbanization may encroach into, and destroy, many of the areas having high potential for recreation use. It is imperative, therefore, that all levels of government act to ensure that the future demand for outdoor recreation of the watershed can be met, both by protecting the quality of the recreational resource base and by acquiring the best remaining recreational sites.

Chapter XIV

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 Fox 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.

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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.*

Attention in this chapter is first focused upon those aspects of water law generally applicable to the planning and management of the water 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 Fox 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 or 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 Watercourse: 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 Fox 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 Fox 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 previous usage, and to the nature and condition of the improvements upon the stream; and so

[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).*

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 circumstances; 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 waterways 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,[6] has limited riparian land to that land bordering a lake or stream which has been in the same 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 Fox 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 and treat a municipal water utility as just another water user and point with disapproval to the distribution of water to non-riparian

[5] *Timm v. Bear. 29 Wis. 254 (1871).*

[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.*

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.

The irrigator who wants to use water from a stream must get 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 on 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 subject to the limitation. This line of reasoning would permit a holding that compensation need not be paid even though public uses impair private uses substantially.

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]

The stream, pond, or lake does not in order to qualify as navigable 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. By the recreational boating test, most natural ponds and lakes are navigable; and streams of even modest size may be navigable. Clearly the Fox 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

[7] *255 Wis. 252, 38 N.W. 2d712 (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).*

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 possible 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 proj-

[11] *Wisconsin Statutes 30.20(1)(b).*

[12] *Wisconsin Statutes 144.025 (2)(e). See Also Regulation of Well Drillers, Wis. 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).*

ect 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]

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 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]

In spite of 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.

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 Fox 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

[15] *Tiedeman v. Middleton*, 25 Wis. 2d 443 (1964).

[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).*

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.

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 is not available, by the maximum flood of record.

This delineation should be based upon careful hydrologic and hydraulic engineering studies, such as have been conducted under the Fox River watershed study for the Fox 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 mapping 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 state and local units of government 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 Regulations: Sections 30.11, 30.12, and 30.15 of the Wisconsin Statutes establish rules for

[19] *SEWRPC Planning Guide No. 5, Floodland and Shoreland Development Guide, November 1968.*

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. A Wisconsin Department of Natural Resources permit is required for deposit of material or the 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 costs 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 RD 16 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 power, for example, over single- or two-family housing units. It does have power 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-

[20] *This function was formerly assigned to the Wisconsin Public Service Commission.*

[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); Haberman and Hoefelt, ''The Wisconsin State Building Code,'' 1947 Wis. L. Rev., 373.*

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 the development of subdivision lots which have more than 10 percent of the minimum lot area less than two feet above the high-water 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 ground water level.[24] This regulation 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 recent 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 Fox 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 regulation 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.[27] The Commission also offers assistance to any local unit of government in the Region that desires to incorporate these provisions in its ordinances.

[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.*

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 consideration and adaptation by local units of government within the Region.[28] The Commission offers assistance to any local unit of government in the Region that desires to incorporate these provisions in its ordinances.

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.

4. Finally, the extraterritorial zoning powers available to cities and villages in Wisconsin under Section 62.23(7)(a) of the Wisconsin Statutes and extraterritorial land subdivision control powers available under Chapter 236 of the Wisconsin Statutes should be noted. These powers might be especially useful in regulating through local action floodplains lying outside municipal corporate limits.

To effectively regulate the use of land in the floodlands of the Fox 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 in the Southeastern Wisconsin Regional Planning Commission; in the hydrologic and hydraulic data and land use and water control facility plans prepared as a part of the Fox 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 Fox River.

POLLUTION CONTROL

Inasmuch as the Fox 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 Fox 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 governmental 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 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

[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.*

[30] *Chapter 614, Laws of Wisconsin 1965.*

[31] *Wisconsin Statutes 144.025 (1).*

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.

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 and furnish equipment 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 the discharge of untreated domestic sewage or pumpage from septic tanks, dry wells, or cesspools into any surface water or drainage ditch or any source of filth or cause of sickness caused 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 secured, altered, extended, replaced, or constructed 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, the Wisconsin Legislature recently created Section 144.46 of the Wisconsin Statutes, which prohibits 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 anal-

[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 RD 15.*

ses of the samples; an inventory of all possible 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 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 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. The extent to which this policy may have changed since the reorganization under the State Water Resources Act of 1965 is not as yet apparent.

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 had refused to grant or had 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.

The only other state agency now involved in state-level water pollution control is the Wisconsin Division of Health, formerly the State Board of Health. In performing its functions relating to the maintenance and promotion of the public health, the Division 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

[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.*

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.

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, by action of the County Board of Supervisors established 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 addition to the broad grant of authority to general-purpose units of local government, the Wisconsin Statutes provide for the creation of four types of special-purpose units of government through which water pollution can be abated and water quality protected. These are: 1) the Metropolitan Sewerage Commission of the County of Milwaukee, 2) other metropolitan sewerage districts, 3) town sanitary districts, and 4) cooperative action by contract.

Metropolitan Sewerage Commission of the County of Milwaukee: The Metropolitan Sewerage Commission of the County of Milwaukee, established in 1921 pursuant to Section 59.96 of the Wisconsin Statutes, has the power to establish and carry out a broad program of water pollution control. The legislative mandate to the Commission states that it shall 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. To assist the Commission in carrying out these functions, the Statutes further state that any town, city, or village in the discharge of sewage effluent into any river or canal within the county or drainage area may be subject to such regulations as the Commission may determine; and the Commission may make and promulgate and enforce such reasonable rules for the supervision, protection, management, and use of the entire sewerage system as it deems expedient. The enabling legislation contemplates that the county-wide Metropolitan Sewerage Commission would work closely with the Sewerage Commission of the City of Milwaukee, organized pursuant to Chapter 608, Wisconsin Laws of 1913. The older Sewerage Commission of the City of Milwaukee has broad regulative powers similar to those cited above. Thus, these two commissions have broad powers within their jurisdictional area to regulate all aspects of private, industrial, and municipal effluent discharges. Section 59.96(9)(c) of the Wisconsin Statutes permits the Metropolitan Sewerage Commission to contract with any city, village, town, town sanitary district, or metropolitan sewerage district organized pursuant to Section 66.20 of the Wisconsin Statutes for the transmission, treatment, and disposal of sewage. However, no such contracts are permitted with cities, villages, towns, town sanitary districts, or metropolitan sewerage districts lying outside the "same general drainage area" as that of the Metropolitan Sewerage Commission of the County of Milwaukee.

Since the Fox River watershed lies west of the subcontinental divide traversing the Southeastern Wisconsin Region and since the Metropolitan Sewerage Commission of the County of Milwaukee operates in watersheds lying east of the subcontinental divide, it would appear that the current enabling legislation would prohibit any direct involvement by the Commission in the abatement of the water pollution problems of the Fox River watershed. The vast experience and high level of staff expertise developed over 47 years by the Metropolitan Sewerage Commission of the County

[36] *Wis. Adm. Code, Chapter H65.*

of Milwaukee represent a substantial public investment that should not be disregarded when alternative organizational structures for water pollution abatement in other major watersheds of the Region are considered.

Other Metropolitan Sewerage Districts: Sections 66.20 through 66.209 of the Wisconsin Statutes authorize the creation of metropolitan sewerage districts consisting of entire cities and villages and entire towns or portions of towns. Such districts are created upon proper petition to, and hearing by, a county court. Recently (1965), such a district was created in the Fox River watershed. This district has been named the Western Racine County Metropolitan Sewerage District and consists of the entire Villages of Rochester and Waterford and parts of the Towns of Rochester and Waterford.

Metropolitan sewerage commissions organized under Sections 66.20 through 66.209 of the Wisconsin Statutes have the broad power to plan, construct, and maintain interceptor and main sanitary sewers, storm sewers, and sewage treatment plants. Section 66.205(7) of the Wisconsin Statutes apparently grants to these metropolitan sewerage commissions broad regulative powers not dissimilar to those granted to the Metropolitan Sewerage Commission of the County of Milwaukee, and these powers enable a program of water quality management and pollution control to be carried out by such commissions. There is, however, apparently contradictive language in Section 66.204(1)(b) to the effect that pollution control activities will be handled not by the commissions but by the regulating agencies; namely, the Wisconsin Department of Natural Resources.[37]

The future role of metropolitan sewerage districts organized under Sections 66.20 to 66.209 of the Wisconsin Statutes became clouded on April 1, 1969, when the Wisconsin Supreme Court struck down these sections of the Statutes on the ground that the Wisconsin Legislature, in providing for the creation of such metropolitan sanitary sewerage districts by county courts, had unconstitutionally delegated legislative authority to the judiciary.[38] The Court made it clear, however, that what was at issue in the cited case was not a question of a lack of legislative authority to provide for the creation of metropolitan sewerage districts but rather of the method by which legislative power had been exercised. If future metropolitan sewerage districts are to be created, then, the Wisconsin Legislature must now provide curative legislation designed to overcome the Supreme Court's objections.

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 sell its services outside its jurisdictional area. 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.

Cooperative Action by Contract: Section 66.30 of the Wisconsin Statutes permits the joint exercise by municipalities[39] of any power or duty required or authorized 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.

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

[37] *For further discussion of this statutory ambiguity, see Chapter VII of SEWRPC Technical Report No. 2, Water Law in Southeastern Wisconsin, January 1966.*

[38] *In re Petition for Fond du Lac Metropolitan Sewerage District, 42 Wis. 2d 323, (1969).*

[39] *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.*

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 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.

The Navigable Waters Protection Law[40] 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.[41] The Wisconsin Department 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 costs 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.[42] For further 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, see SEWRPC Planning Guide No. 5, Floodland and Shoreland Development Guide.

Federal Water Pollution Control Machinery

The United States Congress in 1965 enacted a Water Quality Act. Under the provisions of this Act, states were given until July 1, 1967, to establish satisfactory water quality criteria, or standards, to protect interstate waters. The Wisconsin Department of Natural Resources met this requirement by establishing such standards and incorporating them into the Wisconsin Administrative Code.[43] The Fox River is an "interstate water" under the Act, and the water use objectives and supporting water quality standards adopted by the state for this area are set forth in

[40] *Wisconsin Statutes 144.26.*

[41] *Wis. Adm. Code, Chapter RD 15.*

[42] *Wis. Adm. Code, Chapter RD 15.*

[43] *Wis. Adm. Code, Chapter RD 3.*

Chapter IX of this report. If pollutants in the Fox River as it flows into the State of Illinois adversely affect the quality of the river in that state, federal action to abate the pollution might ultimately be undertaken in the event that the State of Wisconsin should fail to take appropriate action.

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 Fox River are not foreclosed by the existence of federal, state, or local pollution control efforts from attempting to assert their common law rights in court. The court may ask the State 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[44] 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 was 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.

[44] *261 Wis. 492, 53 N.W. 2d 514 (1952).*

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."[45] This review contemplates eventual court determination under Chapter 227 of the Wisconsin Statutes 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 dealing 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 Fox 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.[46]

The 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) metropolitan and town sanitary sewerage districts, 4) flood control boards, and 5) county drainage boards and drainage districts. Of these special districts, only the comprehensive river basin district would be suitable for projects, such as flood control works, covering and serving an entire watershed.

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 such enabling legislation 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.[47] However, its broad approach and

[45] *Wisconsin Statutes 144.56.*

[46] *Wisconsin Statutes 66.30 (3M).*

[47] *Assembly Bill No. 108, offered January 30, 1969, represents the most recent attempt to enact enabling legislation dealing with the creation of special river basin authorities.*

long-run desirability may dictate that the Legislature be reapproached with strengthened legislation toward these ends.

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 are coterminous with county lines. There exists such a district in each county of the Fox 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 University 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 Fox River watershed can meet these requirements, these districts may serve as an agent for federal financing of the project.

Metropolitan and Town Sanitary Sewerage Districts: Section 66.204(1) of the Wisconsin Statutes authorizes metropolitan sewerage districts to "...project, plan, construct and maintain intercepting and other main sewers for the collection and disposal of storm water...." But, unlike the Metropolitan Sewerage Commission of the County of Milwaukee, such metropolitan sewerage districts have no specific authorization to improve watercourses by deepening, widening, or otherwise changing their course to carry off surface or drainage water. 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 formation 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;...[48]

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.

Little use has been made of this device historically largely because the entire cost of improvements was to be borne by the benefited property owners, and projects of this type are generally expensive. To encourage greater use of this device, the Wisconsin Legislature, in Chapter 481, Laws of Wisconsin 1965, has provided for a special procedure authorizing the Department of Natural Resources, upon petition and hearing, to order the creation of flood control boards and provide for financing of projects in whole or in part through funds to be received from municipalities, other governmental agencies, and other sources.

County Drainage Boards and Drainage Districts: 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 in 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.

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[48] *Wisconsin Statutes 87.02 (1).*

SPECIFIC LEGAL CONSIDERATIONS IN THE FOX RIVER WATERSHED

Certain specific and potential legal problems became apparent as work on the Fox River watershed study proceeded. These dealt with the backing of floodwaters into established agricultural drains, the location of the watershed boundary itself, interbasin water diversion, and private dams.

Legal Implications of Temporarily Backing Floodwaters Into Agricultural Drains

One type of water control facility being considered for incorporation in the Fox River watershed plan 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. It is doubtful that this inactive approach would be feasible under the provisions of Sections 31.14(2) and (3) of the Wisconsin Statutes as administered by the Wisconsin Department of Natural Resources.

The legal alternatives open to private individuals are identical with those described above wherein the drainage district was portrayed opposite a governmental unit. 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.

The Fox River Watershed-Root River Watershed Boundary

In its Root River watershed study, the Commission after careful study concluded that the true natural historic northwest boundary of the Root River watershed excluded the lands drained by, and the waters of, Muskego Lake and Little Muskego Lake in the City of Muskego.[49] Thus, the area in question, approximately 21,000 acres (32.8 square miles), was concluded to historically have been a part of the Fox River watershed. The question was of legal interest because it involved a possible diversion of international waters across the subcontinental divide traversing the Southeastern Wisconsin Region and thereby affected the practicality of certain proposals advanced in the Root River watershed study to utilize the Muskego Lakes as headwater pools for the Root River system.

The reasons for so concluding that the area in question was historically part of the Fox River watershed were fully set forth in Chapter VIII of SEWRPC Technical Report No. 2, Water Law in Southeastern Wisconsin, and will not be repeated here. The question remains of interest because of the potential effect upon the practicality of proposals for flood control and water pollution abatement in the Fox River watershed.

Interbasin Water Diversion

Another one of the more important legal problems in water resources planning concerns interbasin diversion. The traditional common-law riparian

[49] *SEWRPC Planning Report No. 9, A Comprehensive Plan for the Root River Watershed, July 1966.*

doctrine, which for the most part is still in effect today, forebade the transfer of water between watersheds. This was regarded as a non-riparian use of water and often gave rise to a per se violation. 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 have on occasion taken place. A prominent example is the diversion of water from the Lake Michigan-St. Lawrence River drainage basin to the Mississippi River drainage basin via the Chicago and Illinois Rivers.

Such diversions however, are not accomplished without great legal difficulty. Two major groups of individuals may be in a position, depending upon the quantity of water involved and the duration of the diversion, to assert their private property rights against the private or public agencies carrying out the diversion. The first group are those riparians along the stream from which the diversion is made. If the diversion is total, that is, if the entire flow is permanently terminated, courts will have little difficulty finding that a "taking" of private property had occurred. A buying out of these property interests would then almost certainly be required, regardless of the public benefit which might accrue from such a diversion. If less than the entire flow is diverted or if the entire flow is diverted, but for only limited and determinable periods of time, then the question of reasonableness enters in. If under the circumstances of a particular case the diversion is unreasonable, then compensation more than likely will have to be paid. If, too, the plaintiff can show damages as a direct result of either the less than total flow diversion or the total flow diversion which occurs only periodically, he may be able to recover these damages even though the diversion is otherwise termed reasonable.

The second group of individuals who may be in a position to assert legal rights are those whose lands abut the stream or lakeshore into which the diversion is made. The diverter is liable to these riparians for lands taken or damages caused as a consequence of the unnatural increased flow. If the increased flow is permanent and overflows property beyond the normal lake or stream high-water mark, a compensable "taking" of this newly overflowed property will have occurred. If the increased flow is minimal or occurs only occasionally, the question of reasonableness, to be determined in the context of all of the relevant facts in each particular case, is again present. If found unreasonable, compensation must be paid. Again, if the plaintiff can show damages, he will probably be compensated, though in other respects the increased flow may be deemed reasonable. Obviously, if an interbasin water diversion is of major proportions, the number of people in either or both of these two groups of riparians will be very large. Consequently, the amount of land involved and the total cost of compensation for land taken and/or for damages may be great. This can be and in fact is a major factor in preventing such interbasin diversions.

Another problem arises in Wisconsin with regard to interbasin navigable stream diversions. It would appear that the consent of the state as guardian "in trust" of public rights in all navigable waters of the state is necessary. Section 30.18 of the Wisconsin Statutes, dealing with water diversions, stipulates that "... no water shall be so diverted to the injury of public rights in the stream...." This certainly seems to preclude the diversion of the total flow of a stream because that would not just injure but would actually terminate public rights in that stream. In other words, consent for such a diversion could not legally be given. The diversion of less than the total flow would seemingly present a question of fact as to whether or not public rights had been injured—a question to be resolved by the courts in each individual instance. Section 30.18 of the Wisconsin Statutes, furthermore, seems to preclude interbasin diversion of any but surplus waters as defined in the statute.[50] Once again, the diversion of any major quantity of water must be considered unlikely under the provisions of this statute.

A last but important factor militating against interbasin stream diversions which in any way affect interstate or international waters, as might well be the case in southeastern Wisconsin, is the longstanding litigation between Wisconsin and Illinois in the Supreme Court of the United States concerning the Chicago diversion and developments arising therefrom. The most recent decree[51] entered by the U. S. Supreme Court in this

[50]*Wisconsin Statutes 30.18(2). Surplus water as used in this section means any water of a stream which is not being beneficially used. The Department of Natural Resources may determine how much of the flowing water at any point in a stream is surplus.*

[51]*Wisconsin, et al v. Illinois, et al, 388 U.S. 426 (1967).*

litigation occurred in 1967 when the State of Illinois and its political subdivisions were enjoined from diverting from the Great Lakes-St. Lawrence River drainage basin to the Mississippi River drainage basin more than 3,200 cubic feet per second for domestic use. The Court, however, indicated that the State of Illinois could make application for a modification of the decree to permit further diversion upon a showing that the reasonable needs of the northeastern Illinois metropolitan region for water for domestic use cannot be met from the surface and ground water resources of the region and from the current permitted diversion. Wisconsin has long argued in this litigation that interbasin diversions which reduce or alter the level or flow of waters in one state or country in favor of another state or country are illegal. The tactical position of Wisconsin, in light of its long-held position in this litigation, would be seriously weakened if it permitted a stream diversion within the Region which altered in favor of Wisconsin the natural flow of waters between Wisconsin and Illinois. The advantages that such a diversion would have to the Region and to the state as a whole would thus have to be weighed against the longstanding and apparently deeply felt issues involved in this past and probable future U. S. Supreme Court litigation.

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 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.[52]

[52] *Tiedeman v. Middleton*, 25 Wis. 2d 443 (1964).

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.

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 Fox 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 (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); and the floodplain, defined as that portion of the floodlands, excluding the floodway, subject to inundation by the 100-year recurrence interval flood or, where such data is not available, by the maximum flood of record.

In the State Water Resources Act of 1965, the Wisconsin Legislature recognized the need to encourage the regulation of floodland development. The Wisconsin Department of Natural 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 by the Wisconsin Legislature to enact special shoreland 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, while cities and villages are permitted to do so. 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 Commission, 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. 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 Fox River.

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 farm lands 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.

There are a number of legal impediments to large scale inter-watershed diversions. Two major groups of riparians, those from whom and those to whom water is being diverted, have legal rights which may well be infringed upon in such an undertaking. In addition, the legal problems of state consent, public rights in the diverted water, and the seemingly restrictive language of Section 30.18 of the Wisconsin Statutes must be faced. Finally, the tactical legal position which Wisconsin has taken in opposition to Illinois in the long-standing Chicago River diversion case before the U. S. Supreme Court seems to make unlikely, if not actually impossible, any project involving the diversion of a major quantity of water from one river basin to another.

The maintenance and upkeep 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 or the preservation of health, safety, and welfare.

Chapter XV

SUMMARY

STUDY ORGANIZATION AND PURPOSE

The Fox River watershed study, which resulted in the preparation of this report, is the second 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 on a portion of an interstate river basin. Although the study has focused primarily on the 942 square mile portion of the total Fox River basin, which lies within Wisconsin and comprises the headwater area of the total basin, the interrelationships existing between this headwater area and the remaining 1,640 square mile area of the basin lying in Illinois were considered throughout the study.

The Fox 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 from its inception guided by the Fox River Watershed Committee, an advisory committee to the Commission composed of 39 elected and appointed public officials, technicians, and citizen leaders from throughout the watershed. The technical work has been 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; and the Wisconsin Conservation Commission; and by 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, outdoor recreation and natural resource conservation, sanitary engineering, and control survey and photogrammetric engineering, as well as in comprehensive, areawide planning.

The study was founded upon the recognition by public officials, technicians, and citizen leaders within the watershed that problems, such as flood damage and water pollution, transcend local governmental boundaries and that solution to such areawide problems must be sought on a regional basis. Furthermore, it was recognized by those who initiated the study that the water and water-related resource problems of the Fox River basin are directly and inextricably related, not only to each other but also to urbanization and its associated increasing and often misdirected demands upon the natural resource base.

The primary objective of the Fox 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 Fox River basin by developing a workable plan to guide the staged development of multipurpose water resource-related facilities and related resource and conservation management programs for the watershed. The problems to be abated include flood damage, water pollution and conflicting water uses, soil erosion, deteriorating fish and wildlife habitat, and the complex effects of rapidly changing land use. If the watershed plan is to be effective, 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 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. Accordingly, the 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 forecast, 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 is concerned with watershed development objectives and standards, alternative land use and water control facility plan elements, and a recommended comprehensive watershed development 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, and forecasting phases of the Fox River watershed study. Although the reproduction of the complete study data files in published format is impossible, due to the volume and complexity of the data collected, 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 Fox River watershed within Wisconsin is a surface water drainage unit approximately 942 square miles in areal extent, located in the southwestern portion of the Southeastern Wisconsin Region. It is part of a 2,582 square mile interstate river basin, 1,640 square miles of which lie in Illinois. The watershed is the largest of 11 major natural surface water drainage units within the Region and comprises 35 percent of the total regional land and water area. The northern portion of the watershed is bounded on the east 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 portion of the watershed is bounded on the east by the Des Plaines River watershed, a portion of the Mississippi River drainage system. The northern headwater portion of the watershed lies in rapidly urbanizing Waukesha County, while the central and southern portions lie in the important agricultural and recreational areas of western Kenosha and Racine Counties and eastern Walworth County.

Superimposed upon the natural meandering watershed boundary is a rectangular pattern of local political boundaries. The watershed occupies portions of six of the seven counties comprising the Southeastern Wisconsin Region—Kenosha, Milwaukee, Racine, Walworth, Washington, and Waukesha—and portions or all of 9 cities, 19 villages, and 36 towns. Six soil and water conservation districts have jurisdiction over portions of the watershed. In addition, certain other special-purpose districts having important responsibilities for water resource management exist within the watershed, including portions of the Metropolitan Sewerage District of the County of Milwaukee, all of the Western Racine County Metropolitan Sewerage District, and all of three active 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 Wisconsin Department of Health and Social Services; the Cooperative Extension Service of The University of Wisconsin; the U. S. Department of Agriculture, Soil Conservation Service; the U. S. Department of the Interior, Federal Water Pollution Control Administration; and the U. S. Army Corps of Engineers.

Population and Economic Activity

The present (1963) population of the watershed is estimated at 159,500 persons, or about 9 percent of the total regional population of 1,674,000. The population of the watershed has increased steadily since 1850; and the rate of population growth has consistently exceeded that of the Region, the state, and the nation. The population of the watershed is anticipated to increase to 359,000 persons by 1990, an increase of 199,500 persons, or 125 percent, in approximately 25 years. The watershed is expected to account for an increasing proportion of the total regional population, increasing from about 9 percent in 1963 to over 13 percent by 1990.

Employment within the watershed presently (1963) totals 33,500 jobs. The largest concentration of industry within the watershed lies in the City of Waukesha and is comprised of 16 of the total of 25 industrial firms within the watershed which employ over 150 persons. Other industrial concentrations within the watershed are located in the Cities of Burlington, Elkhorn, and Lake Geneva. Most of the resident labor force of the watershed, estimated at 60,000 persons, however, finds employment in out-of-watershed industrial centers, primarily in the intensely urbanized areas of Milwaukee, Racine, and Kenosha Counties; and although the watershed contains approximately 9 percent of the regional population, it accounts for less than 6 percent of the total regional jobs. The economic forces influencing development within the watershed are expected to continue to be located primarily outside the watershed boundaries in the nearby metropolitan population and employment centers.

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. Over 50 percent of the agricultural lands of Kenosha, Racine, Walworth, and Waukesha Counties lie within the Fox River watershed, while over one-third of the agricultural lands of the entire seven-county Region lie within this 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 not only within the watershed but also in nearby but out-of-watershed metropolitan centers. Urbanization is particularly rapid in the headwater areas and adjacent to the major lakes and streams within the watershed. Forty percent of the watershed residents live within the headwater area upstream from the confluence of the Fox River and Pebble Creek, which area comprises only 14 percent of the total area of the watershed. This concentration of population and urban land uses in the headwater reaches and surrounding the major lakes within the watershed is a major factor contributing to a number of serious environmental and specific resource-related problems.

Agricultural use is still by far the predominant land use within the watershed, occupying almost 65 percent of the total watershed area. Although urban land uses within the watershed presently occupy only 11 percent of the total watershed area, the pattern of such land use is becoming increasingly diffused. Residential development devoted almost exclusively to single-family dwellings accounts for almost half of the total urban land uses within the watershed. Only 1 percent of the watershed area is presently devoted to active recreational use.

Continuation of present development trends within the watershed may be expected to result in an increase in urban land use from 105 square miles in 1963 to 201 square miles by 1990, an increase of 91.5 percent. Residential land use may be expected to increase from 48 square miles in 1963 to 109 square miles by 1990, an increase of 127 percent. All other urban land uses may be expected to increase from 58 square miles to 95 square miles over this same period of time, an increase of 64 percent. This demand for urban land would have to be satisfied primarily by the conversion of agricultural lands, woodlands, and wetlands, which collectively may be expected to decline from 833 square miles in 1963 to 737 square miles by 1990, a decrease of 12 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, the woodlands, the wetlands, and the wildlife habitat areas—nor to long-established public utility systems and service areas.

Public Utility Service

The construction of public sanitary sewer and water supply facilities has not 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. Presently only 32 percent of the developed area of the watershed and 41 percent of the total watershed population are served by public sanitary sewerage facilities. Public water supply systems presently serve only 34 percent of the total developed area of the watershed and only 45 percent of the total watershed population.

Detailed operational soil surveys indicate that almost 30 percent of the watershed is covered by soils which are poorly suited for urban development of any kind. Approximately 40 percent of the watershed is covered by soils which are poorly suited for residential development without public sanitary sewer service on lots of one acre or larger in size, and about 56 percent of the watershed is covered by soils poorly suited for urban development without public sanitary sewer service on lots smaller than one acre in size.

Wetlands

Wetlands having an individual surface area of 50 acres or more cover an aggregate area of 83 square miles, or about 8.6 percent of the total area of the watershed. Of this total area, only 8.3 square miles, or 10 percent, is in public ownership. It is estimated that at the time of settlement by Europeans approximately 217 square miles, or 23 percent of the total area of the Fox River watershed, were covered by such wetlands. Thus, over one-half of the original wetlands existing within the watershed have been destroyed. This destruction is continuing at the rate of approximately 1.8 square miles 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 toll. At the same time, the natural quality of the remaining wetlands is deteriorating as a result of human activities within the watershed. Yet, wetlands are among the most important elements of the natural resource base of the watershed. Wetlands are important not only to the hydrologic regimen of the watershed, attenuating flood flows, but important to the maintenance of the overall quality of the environment. Wetlands provide the 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 105 square miles, or about 11 percent of the total area of the watershed but constitute over 40 percent of the total regional woodland areas. 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 490 square miles, or 51 percent of the total area of the watershed, were covered by woodlands. Thus, over 78 percent of the original woodland cover of the watershed has been destroyed. It is estimated that the amount of woodland acreage being destroyed each year within the watershed for the construction of roads, buildings, and other purposes is presently about equal to that being planted to trees and totals approximately 350 acres. This balance cannot be expected to be maintained, however, unless a sound woodland management and active reforestation program is instituted within the watershed. This is so because the loss of woodlands may be expected to increase sharply in the future inasmuch as 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 11 percent is in public ownership. Thus, private action will be essential to the maintenance of woodland cover within the watershed.

Water Resources

The surface water resource in the form of lakes and streams provides the singularly most important natural landscape feature within the watershed and serves to enhance all proximate land uses. There are a total of about 300 lineal miles of perennial streams and watercourses within the watershed and 76 lakes, 45 of which have surface water areas 50 acres or more in extent. These 45 major lakes provide a combined surface water area of 34 square miles, or 3.6 percent of the total watershed area, and a total of 228 miles of shoreline. The 31 smaller lakes provide a combined surface water area of 0.9 square mile, or 0.1 percent of the total watershed area, and a total of 29 miles of shoreline.

Three ground water aquifers underlie the watershed: 1) the unconsolidated sand and gravel deposits of the glacial drift; 2) the shallow dolomite strata of the underlying and interconnected bedrock; and 3) the Cambrian and Ordovician strata composed of sandstone, dolomite, siltstone, and shale. The latter comprises the deepest and most dependable and productive of the three aquifer systems. Wells tapping this aquifer are sometimes more than 2,000 feet deep and are, therefore, very expensive to drill. This aquifer, except for minor leakage and the connection to the recharge area, is hydraulically separated from the remainder of the hydrologic system by overlying semipermeable shale formations. This separation makes the deep aquifer less susceptible to pollution. This aquifer is the principal source of water supply for municipalities and large industrial and commercial firms within the watershed. Because of their interconnection and relative nearness to the land surface, the shallow dolomite and overlying glacial drift aquifers are commonly considered to comprise a single aquifer commonly called the "shallow" aquifer.

The principal source of recharge to the sandstone aquifer is from percolation in recharge areas located in northwestern Walworth and western Waukesha Counties, largely outside the watershed boundaries. An estimated 12 million gallons per day of ground water move through the sandstone aquifer under the Fox River watershed, of which an estimated 6.9 million gallons per day move into the City of Waukesha pumpage center. Presently the rate of withdrawal of water from the sandstone aquifer exceeds the rate of recharge, resulting in declines in piezometric levels which average three to four feet per year.

The shallow aquifers are recharged locally, and the average annual recharge is estimated to be about 3.8 inches of water over the entire ground water basin, equivalent to about 125 million gallons per day, or 175,000 gallons per day per square mile, subject to seasonal and annual variation. This recharge rate represents the sustained yield of the shallow groundwater resources. Ground water pumpage affects local ground water movement and runoff, and shallow wells near streams, lakes, or wetlands directly or indirectly affect streamflow and the stages of lakes and wetlands. Ground water within the Fox River watershed is discharged both naturally and artificially to the lakes and streams. The long-term average discharge of ground water to the Fox River is estimated to be about 240 cfs as measured at the Wilmot stream gaging station, although discharge fluctuates from year to year with climatic conditions.

The ground water from both aquifers is chemically classified as very hard, containing relatively high concentrations of calcium and magnesium. Quality, however, is superior to stream water quality and, if protected from pollution, is well suited to domestic and industrial use. Pollution of the ground water in the shallow aquifer is a potential problem in many localized areas of the watershed, particularly in those areas where residential land uses are concentrated and wastes discharged into septic tank systems, the water supply is obtained from shallow wells, the water table is close to the land surface, and the soil is highly pervious or the aquifer is thin and underlain by impervious clay or crevised and extending near the land surface. Unless preventive measures are taken, pollution of the shallow aquifer may be expected to become a serious problem within the watershed. This aquifer 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.

Existing and Potential Park Sites

Three hundred fifty-eight park and related open-space sites exist within the watershed, totaling approximately 36,312 acres, or 56.7 square miles in area. Nearly 42 percent of these sites and 72 percent of this total acreage is in public ownership. About 90 percent of the sites held in public ownership are held by the state, consisting, however, primarily of large woodland and wildlife areas. Only 56 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 92 percent of this available area. Consequently, only 1,118 acres, or approximately 4 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, which activities comprise over 45 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, 92 percent is owned or operated by local units of government. Water surface area within the watershed is already inadequate when related to the existing demand for water-based recreational activities, with only 1.5 acres of lake and stream surface area being available to each participant on an average seasonal Sunday, far below the recommended standard of five acres per participant. Over 44 percent of the total demand for water-based recreational activities within the watershed is generated by out-of-state users, while approximately 29 percent is generated from within the state but outside the watershed. Yet, over 72 percent of the publicly owned water-based land development within the watershed is provided by local governments, whose residents make the least use of the facilities provided.

Forecasts indicate that the participant demand for water-based outdoor recreational activities in the watershed may be expected to increase from 100,286 to 285,091 participants on an average seasonal Sunday by 1990, almost tripling. 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 119,219 to 276,866 participants per average seasonal Sunday, also almost tripling. 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 land within the watershed, indicate that an additional 17,071 acres of land will have to be devoted to recreational use within the watershed by 1990, an increase of 47 percent over present levels.

Two hundred fifty-five potential park and related open-space sites, totaling 36,860 acres, or 57.5 square miles in area exist within the watershed, of which slightly less than one-third are considered to possess a high recreational resource value. These high-value sites, however, comprise over one-half of the total delineated potential park and open-space site acreage and constitute one of the most valuable resources of the watershed.

Fish and Wildlife

Every major lake within the watershed supports a fishery comprised of northern pike, largemouth bass, bluegills, and bullheads. Stream fisheries of consequence, however, exist on only seven streams within the watershed, including the main stem of the Fox River, Mukwonago River, Genesee Creek, White River, Palmer Creek, Sugar Creek, and Honey Creek. These streams have a combined length of 179.4 miles, or only 46 percent of the total stream channel mileage within the watershed. The principal warm-water fishery is the main stem of the Fox River below Waterford, with walleyes, northern pike, bass, perch, bluegills, catfish, and bullheads contributing to the fishery. Maintenance and improvement of these fishery resources is ultimately dependent on water pollution abatement and control of lake eutrophication.

The watershed contains an estimated 119,540 acres, or 187 square miles, of wildlife habitat, exclusive of cropland areas and urbanized areas and exclusive of open water areas exceeding 10 acres in surface area, or almost 40 percent of all the remaining wildlife habitat within the Region. Of the total within the watershed, 80 square miles, or 43 percent, are rated as high-value habitat areas; 60 square miles, or 32 percent, as medium value; and 47 square miles, or 25 percent, as low value. Wildlife in 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 economic activity within the watershed. It is important to recognize that the productivity of the remaining wildlife habitat areas is dependent upon the use of surrounding lands. Use of adjacent lands for agricultural purposes can abet wildlife habitat productivity. Use of adjacent lands for certain kinds of intense urban purposes can stifle such productivity. Competing land uses and improper development practices are continually lowering the quality, as well as quantity, of the remaining wildlife habitat; and many species of wildlife will be threatened with extinction within the watershed over the next two decades unless the remaining high-quality habitat 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 198 square miles, or about 21 percent of the total area of the watershed. These corridors contain, however, 164 lineal miles, or 66 percent, of the total lake shoreline and 277 miles, or 92 percent, of the major stream channel length within the watershed. The corridors encompass almost 82 percent of all the remaining wetlands and 40 percent of all the remaining woodlands within the watershed. The corridors also encompass 43 percent of the wildlife habitat areas remaining within the watershed.

Surface Water Hydrology

The Fox River watershed within Wisconsin is a composite hydrologic unit of 15 subwatersheds and flows in a generally southerly direction. The major axis of the watershed lies in an approximately north-south direction. The watershed has a continental climate with four distinct seasons and two distinct surface water runoff distributions. The six-month period from November 1 through April 30 is characterized by snowmelt and long-duration, low-intensity frontal type precipitation creating runoff hydrographs with a long time base, large volume, and relatively low peak rates of discharge. The six-month period from May 1 through October 31 generally produces hydrographs with a shorter time base, lower volumes, and relatively higher peak rates of discharge resulting from convective thunderstorm precipitation accompanying the movement of frontal systems in a generally southwest to northeast direction across the watershed.

The drainage pattern of the watershed is poorly developed and much of the channel system has been formed by glaciation. 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 river 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 peak travel times.

The average annual precipitation over the watershed ranges from just under 30 inches to over 32.5 inches, with the long-term average annual precipitation for the watershed being estimated at 31.8 inches. During the four-month period from December through March, a considerable accumulation of snow may occur on the ground, which, when coupled with spring rains, constitutes the principal flood hazard within the watershed.

Long-term average rate of annual water loss through evapotranspiration is estimated to be 25 inches for the watershed, or nearly 80 percent of the annual precipitation. Annual runoff from the watershed is estimated to average 6.8 inches per year, or about 20 percent of the precipitation. About 60 percent of this runoff occurs in the six-month period extending from November through April, although only about 40 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, the outflow from, and inflow to, the watershed have been about equal, indicating that there is no apparent long-term trend in the net gain or loss in the quantity of water in the basin. Low flows of only a few hundred cubic feet per second generally persist during much of the summer, fall, and winter months, with only minor rises after heavy rainfall. As already noted, high flows and floods are generally associated with snowmelt; and most critical flood flows result from rainfall during a snowmelt period, especially on frozen ground.

A profusion of surface water storage areas within the watershed serves to decrease peak discharges and increase the duration of runoff. There are 76 lakes within the Fox River watershed having a total surface area of about 35 square miles, or approximately 4 percent of the total watershed area. Forty-five of these lakes have areas of over 50 acres and together comprise about 98 percent of the total lake surface area of the watershed. An additional 83 square miles, or 8.6 percent of the watershed, are covered by permanent wetland areas, which also serve to attenuate runoff. Major wetland areas having an important effect on streamflows include the Tamarack Swamp and Capitol Drive areas above the City of Waukesha; the area along the Fox River from the confluence of the Mukwonago River to Waterford, including Tichigan Lake; large areas in the Wind Lake subwatershed; the Honey Lake region of the Sugar-Honey Creek subwatershed; and, most importantly, the Vernon Marsh area below the City of Waukesha. These lakes and wetlands, together with temporary floodplain overflow area storage, tend to provide a high degree of natural flood control within the basin through reduction of peak flood flows.

The naturally well-regulated nature of the Fox River hydraulic system is indicated by the fact that the peak discharge of a 100-year recurrence interval flood in the Fox River watershed at Wilmot, Wisconsin, is estimated at 9,400 cfs, or only 10.8 cfs per square mile of tributary drainage area, while similar flows on the Milwaukee River are estimated at 17,500 cfs, or 25.5 cfs per square mile of tributary drainage area, and on the Root River at 9,900 cfs, or 53 cfs per square mile of tributary drainage area. Actual recorded peak flood discharges of 7,520 cfs have been measured on the Fox River at Wilmot; of 15,100 cfs, on the Milwaukee River at Milwaukee; and estimated at 8,200 cfs, on the Root River at Racine.

Water Control Structures

The Fox River watershed contains 43 man-made water control structures, not including bridges and culverts, which serve to regulate or modify the natural flow regimen of the stream system by reducing to some degree peak flood discharges. Sixteen of these are located at natural lake outlets to regulate and control lake levels. Eight are located on the stream system and were originally constructed to impound water for power, recreational, and aesthetic purposes. These eight do not have enough storage to materially affect the peaks or durations of flood flows. Twenty were originally constructed for water power or water supply, including one industrial water supply impoundment at East Troy. These seven are also too small to provide any significant storage during major flood events. No structures presently exist within the watershed which have been constructed specifically and primarily for flood control purposes.

Approximately 65 miles, or 25 percent, of the perennial stream system studied within the Fox River watershed have been modified by straightening, deepening, or by increasing the cross-sectional area, by improving the horizontal grade line, or by diking, all of which result in increased velocities of flow and decreased times of concentration. Similar alterations have been made in nearly every subwatershed of the total basin totaling 390 miles of channel improvements on all streams; but the most intense improvement activity has occurred in the eastern part of the watershed, particularly in the Wind Lake subwatershed. The effects of the channel improvements on the flow regimen are exactly the reverse of the dams and impoundments previously described and tend to increase flood velocities and downstream flood peaks. It is apparent, therefore, that uncoordinated reservoir construction and channel modifications may cause compensating or negative overall effects on the surface water problems of the watershed, which emphasizes the need for proper water management practices based upon a comprehensive watershed plan.

Artificial subsurface drainage improvements for agricultural purposes are often closely associated with channel improvements. Approximately 165 square miles, or 17.5 percent of the total watershed area, have been so improved, with nearly 21 percent of this total lying within the Wind Lake subwatershed. It is doubtful, however, that this tiling has 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 251 highway and railroad crossings over the main channel system of the Fox River watershed, with the greatest number of crossings per river mile being 1.67 in the upper subwatershed and the least number being 0.40 per river mile in the lower 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 only two major floods in recent times. The record of river discharge maintained at Wilmot since 1940 indicates that over the past 28 years 16 of the yearly peak flood discharges, including the highest recorded, have occurred in March or April. The most damaging flood event occurred in March-April of 1960 as a result of a combination of heavy rainfall, frozen ground, and rapid snowmelt. The combination of climatological events which caused the 1960 flood was unusual. Measurement of snow cover indicated a depth of snow on the ground immediately prior to the flood of 24 inches, equivalent to 2.8 inches of water. Temperatures having been below normal for most of the month began to rise on the 27th of March and reached a high of 62°F on the 29th. Beginning on the evening of the 29th, rain fell intermittently over the watershed for a period of about 24 hours, with an average depth on the watershed of 1.5 inches. This combination of climatological events produced a peak flood flow of 7,520 cfs at Wilmot near the state line, a discharge which has a probability of occurrence in any given year of 2.7 percent, or a recurrence interval of 37 years. A discharge of 2,300 cfs was measured at Waukesha somewhat after the peak flow had passed. Although the 1960 flood was the highest recorded in the 28 years of record maintained at the U. S. Geological Survey gaging station at Wilmot, it was not an event of truly rare magnitude or severity. Analyses indicate that this flood event ranged from a 10-year recurrence interval on some tributaries to a 50-year recurrence interval in the upper Fox River watershed.

The July 1938 flood on the White River was produced by a rainstorm centered over the Village of Williams Bay in Walworth County, where 6.76 inches of rain were recorded in less than 24 hours. A discharge of 4,140 cfs was measured at the outlet of Echo Lake in Burlington following this storm. Although the rainfall, as recorded at Williams Bay, causing the flood had a recurrence interval in excess of 100 years, the flood discharge, as measured at Burlington, had a recurrence interval of only 10 years.

Extensive field surveys revealed that in recent decades flood damage potential and flood damage risk have risen from a nuisance level to substantial proportions as urban land use has increased in the floodways and floodplains of the watershed. These floodways and floodplains together comprise less than 7 percent of the total area of the watershed and lie almost entirely within the primary environmental corridors of the watershed. As of 1963 approximately 2.8 square miles, or 4 percent, of the total floodplains of the watershed had been developed for urban use. If existing land use development trends are allowed to continue unregulated in the riverine areas of the watershed, the urban land uses within the floodplains may be expected to increase by an additional 22.7 square miles; and total average annual flood damage risk may be expected to increase from the current 1968 level of approximately $77,000 per year to approximately $112,000 per year by 1990. Damages from a single 100-year recurrence interval flood could be expected to increase from a present level of $857,000 to over $1.5 million by 1990.

The 1960 flood caused total monetary damages of approximately $490,000 within the watershed. Approximately 18 percent of these total monetary losses were inflicted upon public property; and 78 percent, upon private non-agricultural property. About 62 percent of the potential flood damages are urban, and most of the urban damages occur to residences located on the floodplains. Reaches of particularly heavy flood damages included the City of Waukesha, with total damages exceeding $128,000; the City of Burlington, with total damages exceeding $29,000; the Town of Wheatland, with total damages exceeding $146,000; the Town of Salem, with total damages exceeding $57,000; and the Village of Silver Lake, with total damages exceeding $32,000.

Flood peaks may be expected to be increased somewhat as urbanization continues within the watershed. Although urbanization may be expected to increase snowmelt flood peaks by only 2 percent, summer flood peaks may be expected to be increased by as much as 50 percent in individual subwatersheds.

A mathematical model was developed and used to simulate the hydrologic performance of the river system. Using the model, stage-discharge curves were developed at 589 locations; and discharge-frequency relationships were established for all road crossings and water control structures. This information was used to identify and delineate those portions of the watershed that have experienced or could experience flood damage. All of the discharge-frequency relationships, except those that represent locations on the Fox River between Burlington and Wilmot, were developed synthetically. That is, frequency was assigned to a flood on the basis of the rainfall or snowmelt volume used to simulate the event. On the Fox River below Burlington, flood frequency was established by a statistical analysis of the U. S. Geological Survey streamflow records at Wilmot.

Stream Water Quality and Pollution

The quality of stream water resulting from natural environmental conditions within the Fox River watershed generally does not present any serious problems for most beneficial water uses. In the upper reaches of the watershed, drainage from the Tamarack Swamp causes a natural degradation of water quality. Waters draining from this swamp are frequently low in dissolved oxygen content and contain a relatively high concentration of organic materials with a high biochemical oxygen demand. The outflow is small, however, except after exceptionally heavy rainfalls, so that dilution water and natural stream purification improve the water quality downstream to a level acceptable for most uses.

The activities of man within the watershed have, however, created a serious water pollution problem by degrading the quality of the stream water to such an extent as to impair its usefulness for several important purposes. Twelve major municipal sewage treatment plants discharge treated wastes to surface waters of the Fox River watershed. The major pollutants associated with such effluent are oxygen demanding organic materials, pathogenic bacteria, and nutrients. All but one existing sewage treatment plant, located at Waterford, presently provide secondary treatment.[1] Almost 75 percent of the total pollution load, as measured by five-day biochemical oxygen demand, discharged to the surface waters of the basin enters the Fox River system at and above the City of Waukesha. This area also contains the reaches of lowest streamflow. Presently approximately 75 percent of the low flow of the Fox River just below Waukesha consists of effluent from the sewage treatment plants at Waukesha, Brookfield, Pewaukee, and Sussex.

Nineteen industrial waste sources exist in the Fox River basin, with a particularly heavy concentration in the vicinity of the City of Waukesha. 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 Fox River system. Four large resorts discharge or will discharge treated effluent to the Fox River system, including the Rainbow Springs Convention Center and the Lake Geneva Playboy Club International.

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.

About 41 square miles of the developed urban area of the watershed and all of the rural area, containing a combined population of almost 100,000 persons, rely primarily on individual septic tank soil absorption systems for the disposal of domestic wastes. As already noted, about 56 percent of the Fox 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.

[1] *The plant at Waterford was expanded to provide secondary treatment in 1968 and secondary treatment was being provided in 1969.*

Fox River—Headwater to Waukesha Dam: Existing water uses in the reach of the Fox River from its headwater to the Waukesha Dam include livestock and wildlife watering, maintenance of a warm-water fishery, partial-body-contact recreation, waste assimilation, and aesthetic uses. State-established water use objectives include all of the existing uses plus industrial and cooling water supply. Existing water quality in this reach, however, is suitable only for livestock and wildlife watering and waste assimilation. Minimum dissolved oxygen levels of less than 2 mg/l and an average summer level of less than 4 mg/l prohibit the maintenance of a warm-water fishery. Coliform concentrations well in excess of 5,000 MFCC/100 ml render the water unsuitable for any type of recreational activities. In addition, luxuriant growths of algae and other aquatic plants frequently cover the surface of the stream, particularly in the impoundment above the Barstow Street Dam in the City of Waukesha and in other sluggish reaches of the stream. Waste discharges in this reach include the sewage treatment plants at Brookfield, Sussex, and Pewaukee, serving a combined population of about 6,500 persons and discharging treated effluent at an average rate of 1.3 cfs. If existing development trends within the watershed continue, and if only secondary sewage treatment is provided, future water quality conditions in this reach may be expected to be unsuitable for all uses except waste assimilation. The sewage treatment plants at Brookfield, Sussex, and Pewaukee, together with new plants proposed to serve the Lannon and Poplar Creek areas, would be expected to serve a population of 98,600 persons by 1990. The average volume of waste discharge by these plants may be expected to reach an average daily flow by 1990 of 27.5 cfs, or over 20 times the volume discharged presently to the stream. These increased waste loadings may be expected to lower oxygen levels to below 2 mg/l during low-flow summer conditions over the entire reach of the Fox River from Lannon to the impoundment at Waukesha. Anaerobic conditions may be expected to develop in some reaches of the stream, particularly below the Brookfield and Poplar Creek sewage treatment plants. Approximately 90 percent of the low flow of the Fox River at Waukesha may be expected to consist of sewage treatment plant effluent by 1990; and the impoundment at Waukesha may be expected to function essentially as a large oxidation pond, receiving wastes from the upstream areas. The large additions of nutrients to the river will stimulate algae growth throughout this section and will preclude any recreational use of the river. In order to improve water quality in the Fox River from its headwaters to the Waukesha Dam to a level suitable for state-established water use objectives, it will be necessary to remove or dilute much of the organic waste present in the stream to maintain oxygen levels above 5 mg/l, to reduce coliform concentrations below 5,000 MFCC/100 ml, and to eliminate the nuisance of algae.

Fox River—Waukesha Dam to Waterford Dam: Existing water uses in the reach of the Fox River from Waukesha to Waterford include livestock and wildlife watering, maintenance of a warm-water fishery, partial- and whole-body-contact recreation, waste assimilation, and aesthetic uses. Existing water quality conditions in this reach vary from levels unsuitable for most uses below the Waukesha sewage treatment plant to levels suitable for most uses in the impoundment at Waterford. Minimum oxygen levels of less than 1.0 mg/l and average summer levels of less than 4.0 mg/l downstream from the outfall of the sewage treatment plant at Waukesha render the stream unsuitable for the maintenance of a balanced warm-water fishery in that section. Dissolved oxygen levels increase further downstream, however, to average concentrations in excess of 5.0 mg/l and minimum concentrations greater than 4.0 mg/l. Oxygen levels are sufficient to support a warm-water fishery throughout that section of the reach below the confluence with Genesee Creek.

Coliform counts in excess of 5,000 MFCC/100 ml render the stream unsuitable for any recreational activities from the Waukesha sewage treatment plant to the confluence with Pebble Brook. Coliform levels from Pebble Brook to the upstream end of the Waterford impoundment are generally between 1,000 and 5,000 MFCC/100 ml during the summer months, indicating that this section of the Fox River is suitable for partial-body-contact recreation during the summer. Higher coliform concentrations during the spring, fall, and winter seasons in this section indicate unsuitable water quality for recreational activities during these seasons. Coliform concentrations in the Waterford impoundment are generally on the order of 1,000 MFCC/100 ml during the summer and fall seasons and between 2,500 and 5,000 MFCC/100 ml during the winter and spring seasons. Thus, the water quality in the impoundment is suitable for partial-body-contact recreation throughout the year but is of questionable quality for whole-body-contact recreation during summer and fall and definitely unsuitable during winter and spring.

Algae and aquatic weeds represent a major problem affecting recreational and aesthetic uses of the stream, particularly in the Waterford impoundment. Nutrients contained in the sewage treatment plant effluent stimulate the growth of algae, which frequently results in a green scum on the surface of various sections of the impoundment. In addition, extensive slime and algae growths that detract from the aesthetic value of the stream are evident through the City of Waukesha and below the treatment plant outfall. Accumulations of black odorous sludge are present below the Waukesha Motor Company and below the sewage treatment plant.

The major waste discharge to this reach of the Fox River is from the Waukesha sewage treatment plant, which in 1966 served a population of about 37,500 persons and discharged treated effluent at an average rate of 11.6 cfs. A second waste source is the discharge from the Mukwonago sewage treatment plant, which served a population of about 2,000 persons and discharged treated effluent at an average rate of 0.3 cfs in 1966. Approximately 50 percent of the present average annual nitrogen contribution and 75 percent of the phosphorus contribution to the Waterford impoundment are from sewage treatment plant effluents discharged upstream from the impoundment.

The sewage treatment plant at Waukesha may be expected to serve a population of over 80,000 persons by 1990; and the plant at Mukwonago, nearly 7,000 persons. The estimated effluent discharge at Waukesha may be expected to reach an average flow of 28.6 cfs by 1990, or about 2.5 times the present waste discharge; and organic matter and nutrient discharges may be expected to increase in about the same proportion. The discharge from the Mukwonago sewage treatment plant may be expected to increase to about 1.9 cfs by 1990, or over 6 times the present discharge, with similar increases in organic matter and nutrient discharges. By 1990 the amount of organic matter discharged to the Fox River in, and upstream from, Waukesha will be equivalent to the raw sewage of a city of over 30,000 persons. At the same time, nutrient discharges to the river will have increased to over 4 times the present discharge.

Dissolved oxygen levels during low-flow summer conditions in 1990 may be expected to fall in the range of 3.0 to 5.0 mg/l, with minimum values on the order of 1.0 mg/l, from the Waukesha sewage treatment plant to the Mukwonago River, with the lowest levels generally occurring from 3 to 6 miles below the Waukesha sewage treatment plant outfall. Thus, water quality in this section of the Fox River will not be suitable for the maintenance of a warm-water fishery. Oxygen levels in that section of the river from the Mukwonago River to Waterford will generally be greater than 5.0 mg/l, and water quality will be suitable for the maintenance of a warm-water fishery.

If adequate disinfection of all sewage treatment plant discharges is provided, the 1990 coliform level should be below 1,000 MFCC/100 ml throughout the reach, indicating a water quality suitable for all types of recreational activities. It is to be expected, however, that the large quantities of nutrients being added to the river in the sewage treatment plant effluents will increase the frequency and severity of algal blooms throughout the reach, particularly in the Waterford impoundment and Tichigan Lake. The nuisances associated with these blooms and with increasing amounts of aquatic weeds may restrict recreational and aesthetic uses of this reach of the Fox River. Also the use of continued high levels of disinfectants may have harmful effects on desirable species of aquatic life.

State-established water use objectives for this reach require water quality levels suitable for all uses except public water supply from the Waterford Dam upstream to a point five miles below the Waukesha sewage treatment plant. From this point to the sewage treatment plant at Waukesha, water quality levels should meet the standards for industrial and cooling water supply and minimum conditions. Future (1990) water quality conditions may be expected generally to meet the standards in the section of the reach from the Waukesha treatment plant to a point five miles downstream, although the probable development of heavy algal growths may violate the standard for minimum conditions. In order to maintain water quality levels suitable for all uses except public water supply in the remainder of this reach, however, it will be necessary to maintain oxygen levels above 5.0 mg/l, to reduce coliform levels to less than 1,000 MFCC/100 ml, and to reduce or eliminate the heavy algal growths.

Fox River—Waterford Dam to State Line: Existing water uses in the reach of the Fox River from Waterford to the Wisconsin-Illinois State line include the maintenance of a warm-water fishery, partial- and whole-body-contact recreation, livestock and wildlife watering, waste assimilation, and aesthetic uses. State-established water use objectives for this reach of the Fox River include all of the existing uses plus irrigation and industrial and cooling water supply.

Existing water quality conditions throughout this reach are generally suitable for all of the present uses except recreation. The major waste discharges in this reach consist of treated effluent from the sewage treatment plants at Waterford, Burlington, Twin Lakes, and Silver Lake. These plants served a combined population of about 11,000 persons and discharged treated effluent at an average rate of 2.3 cfs in 1963. The waste discharges generally do not lower oxygen concentrations in the river to a level that would adversely affect any of the present uses of the river. Both average and minimum dissolved oxygen concentrations are in excess of 5.0 mg/l throughout the year, indicating the suitability of this reach for the preservation and enhancement of fish and other aquatic life. The discharge of inadequately disinfected effluent from the Waterford, Burlington, and Twin Lakes sewage treatment plants, however, results in high coliform concentrations throughout much of this reach of the river. Coliform bacteria levels are in excess of 5,000 MFCC/100 ml from the Waterford sewage treatment plant to Wheatland during the fall and winter months. The only section of this reach that is suitable for any recreational activity is that extending from Wheatland to the state line, where coliform levels in the range of 2,500 to 5,000 MFCC/100 ml during the spring and summer indicate a water quality suitable for partial-body-contact recreation. Discharge from the Burlington plant also results in extensive slime growths and accumulations of black odorous sludge along the west side of the Fox River below the plant outfall. Nutrients contained in the waste discharges presently stimulate algae growths throughout this reach of the Fox River.

By 1990 the four sewage treatment plants located within this reach may be expected to serve a combined population in excess of 25,000 persons; and the discharge of treated effluent may be expected to reach an average flow of 6.6 cfs by 1990, or almost 3 times the present discharge. If adequate secondary treatment is provided at each plant, the river will be capable of assimilating the resultant organic waste discharged without lowering the oxygen concentration below 5.0 mg/l, the standard for the maintenance of a warm-water fishery. Secondary treatment, however, will not reduce the amount of nutrients being discharged to the river.

State-established water use objectives for this reach of the Fox River require water quality levels suitable for all uses except public water supply. Future water quality may be expected generally to meet these standards, provided that adequate disinfection of all sewage treatment plant discharges is accomplished. A potential problem may develop in this reach, however, as a result of the large amounts of nutrients added to the river by discharges from sewage treatment plants upstream from, and within, the reach. Estimates of the nutrient contributions to this reach of the Fox River indicate that the total amounts of nitrogen and phosphorus discharged to the river may be expected to reach 3 times the present amount by 1990, with approximately 85 percent of the phosphorus and 65 percent of the nitrogen being derived from sewage treatment plant discharges upstream from, and within, the reach. These nutrients may stimulate excessive growths of algae, causing nuisances that would interfere with recreational and aesthetic uses of the stream. In addition to causing problems in the Fox River in Wisconsin, the nutrients will move down the river; and a portion will eventually reach the Fox Chain of Lakes in Illinois. These lakes, on the main channel of the Fox River, while intensively used for recreational purposes, are already in a highly eutrophic condition. The continued and increased inflow of nutrients to the lakes in the future will serve further to aggravate this problem.

Tributaries: Analyses of existing and probable future water quality levels similar to the foregoing relating to the main stem of the Fox River have also been prepared under the study for all major tributaries of the Fox River; namely, Sussex Creek, Poplar Creek, Pewaukee River, Pebble Creek, Genesee Creek, Mukwonago River, Wind Lake Drainage Canal, Muskego Canal, Honey Creek, Sugar Creek, White River, Bassett Creek, and Nippersink Creek. The data and analyses indicate that 10 of the 13 major tributaries are grossly polluted, the present level of stream water quality being inadequate to meet the state-established water use objectives if the supporting water quality standards are strictly interpreted and applied. Only Sussex Creek, Genesee Creek, and the Wind Lake Drainage Canal have water quality adequate to meet the established water use objectives.

Analyses indicate, moreover, that, if existing development trends continue within the watershed and a basin-wide water quality management plan and program is not instituted, none of the major tributaries except the Wind Lake Drainage Canal can be expected to meet the state-established water use objectives in the future. The water quality of four additional tributaries—Genesee Creek, Mukwonago River, Sugar Creek, and Nippersink Creek—could be improved sufficiently to meet the state-established water use objectives by the institution of relatively minor pollution abatement measures, including the disinfection of treated sewage effluent discharged to the streams. To meet the state-established water use objectives on the remaining eight tributaries, however, would require major efforts to eliminate the existing and potential sources of water pollution within their tributary drainage areas.

Lake Water Quality and Pollution

Lakes within the Fox River watershed are generally classified as being moderately hard, alkaline, fertile lakes. Of 12 major lakes in the watershed sampled, all but two—Eagle and Long Lakes—were found to have coliform bacterial levels exceeding 1,000 MFCC/100 ml, the maximum concentration permitted by the Wisconsin water quality standards for whole-body-contact recreation use. Of the 45 major lakes in the watershed, only eight contain dissolved phosphorus concentrations in the spring that are below the 0.015 mg/l threshold concentration for algal blooms. An additional 27 lakes are characterized by spring phosphorus concentrations that exceed the threshold concentration of 0.015 mg/l but less than the average regional dissolved phosphorus level of 0.05 mg/l. These lakes may be classified as moderately fertile, and problems of algae and weed growth may be expected in many of these lakes. The remaining 10 lakes contain dissolved phosphorus concentrations substantially in excess of the average regional level of 0.05 mg/l and may be classified as highly fertile. Frequent problems from nuisance growths of algae and aquatic weeds may be expected in these lakes. Of these 10 excessively fertile lakes, seven, including Wind, Tichigan, Pewaukee, Buena, Long, Little Muskego, and Browns, also contain levels of chloride ions indicative of pollution. Pesticide concentrations substantially higher than those observed in most other areas of the state and indicative of a significant level of contamination by DDT and dieldrin exist throughout the lakes of the Fox River watershed.

The relatively high phosphorus concentrations in 37 of the 45 major lakes, the summer depletion of oxygen in the hypolimnion of the 28 lakes which experience thermal stratification during the summer months, the winter depletion of oxygen in the unstratified lakes under ice cover, together with the frequent occurrence of large growths of algae and aquatic weeds, all indicate that the lakes of the Fox River watershed are in a relatively advanced state of eutrophication. Although eutrophication was in the past basically a natural phenomenon, nutrient inflow to lakes as a result of human activities in the watershed has increased the rate of eutrophication in recent years. Over three-fourths of the phosphorus and slightly less than one-half of the nitrogen presently entering the lakes are estimated to be derived from human activities in the watershed. Major artificial sources of nutrient contributions to lakes in the watershed are drainage from septic tanks and runoff from agricultural lands on which artificial fertilizer and manure have been spread while the soil is frozen. Unless effective water quality management programs are mounted, the rapid rate of eutrophication of the lakes within the watershed can be expected to continue; and the number of lakes suitable for recreation and aesthetic enjoyment will continue to decrease in the future.

Water Use and Supply

Ground water is presently the principal source of domestic, municipal, agricultural, and industrial water supply within the Fox River watershed. Water use within the basin in 1966 totaled 24.5 million gallons per day, of which 97 percent was obtained from ground water sources. The quantity of water used within the basin averaged 150 gallons per capita per day based upon the total 1966 resident population of the watershed, estimated as 160,000 persons, ranging from a high of 180 gallons per capita per average day in the highly industrialized City of Waukesha to 60 gallons per capita per average day in a typically rural-urban fringe area residential subdivision.

Municipal and private water utilities supplied 13.75 mgd, or 56 percent of the total use; self-supplied domestic and agricultural users, 8.00 mgd, or 33 percent of the total use; and self-supplied commercial and industrial users, 2.75 mgd, or 11 percent of the total use. About 35 percent of the total municipal and private utility supply was obtained from the shallow aquifer and about 65 percent from the deep aquifer. These two sources may be expected to continue to provide an adequate supply for municipal and private utility use to the year 1990, provided that an adequate ground water resource management program, including a plan for the proper spacing of wells, is effected throughout the watershed. Approximately 93 percent of the self-supplied domestic and agricultural water supplies were derived from the shallow aquifer and only 1.3 percent from the deep aquifer. Approximately 36 percent of the self-supplied commercial and industrial use was obtained from the deep aquifer, and 55 percent was pumped from the shallow aquifer.

The major water management problems of the rural portions of the watershed are more related to irrigation than to domestic and livestock watering needs. Agricultural irrigation is presently not extensively practiced within the watershed; and only 6,600 acres, or 1 percent of the total area of the watershed, is under agricultural irrigation. The area irrigated has increased rapidly in recent years, however; and if current trends continue, the number of acres irrigated in 1990 could reach 6 times the present amount. The necessary irrigation water will, because of potential use conflicts over surface waters, most probably have to be supplied almost entirely by the shallow ground water aquifer. The four to six inches of water applied to most irrigated crops in years with an average amount of seasonal distribution of precipitation is higher than the estimated 3.8 inches per year average recharge rate of the shallow aquifer. Thus, in the absence of a careful ground water resource management plan, local water supply conflicts and problems could develop in the rural, as well as urban, portions of the watershed.

Total water use may be expected to more than double within the watershed by 1990, reaching an approximate total pumping rate of 65 million gallons per day, or 23.7 billion gallons per year. Municipal use, dependent almost entirely upon the deep ground water aquifer for its supply, may be expected to comprise over 76 percent of this total water use. As already noted, the water supply available in the deep aquifer 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 this supply.

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 Fox River watershed planning program, marks the completion of the first phase of that program. That phase has, of necessity, been directed to careful research and forecast operations in order to provide the necessary definitive knowledge of the existing and probable future state of the 942 square mile watershed. The inventory findings and forecasts picture a dynamic and rapidly changing watershed, one in which the population may be expected to almost double within the next 25 years and one in which the area of land devoted to urban use may be expected to increase from 105 square miles in 1963 to 201 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 to 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.

Although 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 resource-related problems of the watershed, out of this documentation will grow definitive plans and concrete recommendations for both public works facility construction and for land and water management policies within the watershed. The alternative courses of action available for abating the problems of the Fox 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 and Planning, Wisconsin Department of Natural Resources
Kurt W. Bauer . . . . Secretary	Executive Director, SEWRPC
George F. Hanson	State Geologist and Director, University of Wisconsin Extension Division-Geological and Natural History Survey
Robert E. Hasselkus	Executive Director, Waukesha County Park and Planning Commission
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
James R. Price	Division Engineer, Sewer Construction and Maintenance, Sewerage Commission of the City of Milwaukee
Clifford Risley, Jr..	Director, Chicago Program Office, Federal Water Pollution Control Administration, Great Lakes Region
William 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
William F. Steuber	Assistant State Highway Engineer, Division of Highways, Wisconsin Department of Transportation
George B. Wesler	Chief, Planning and Reports Branch, U. S. Army Corps of Engineers
Donald G. Wieland	Division Engineer, Sewer Design, Sewerage Commission of the City of Milwaukee
Harvey E. Wirth	State Sanitary Engineer, Wisconsin Department of Health and Social Services
Theodore F. Wisniewski	Assistant to the Administrator, Division of Environmental Protection, Wisconsin Department of Natural Resources
K. B. Young	Associate Chief, Water Resources Division, U. S. Geological Survey

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Appendix B

FOX RIVER WATERSHED COMMITTEE

*William D. Rogan . . . . Chairman	County Agri-Business Agent, Waukesha County
*Lester Hoganson . . . . Vice-Chairman	Consulting Engineer, Burlington, Wisconsin
*Paul G. Jaeger . . . . Secretary	County Agri-Business Agent, Kenosha County
*Kurt W. Bauer	Executive Director, SEWRPC
Alexander H. Button	Inspector and Secretary, Linn Township Sanitary District
Arnold L. Clement	Planning Director and Zoning Administrator, Racine County
Willard R. Evans	Waukesha County Board Supervisor; Member, County Health Board; Chairman, Town of Pewaukee
Robert L. Frank	Citizen Member, Lake Geneva, Wisconsin
H. Copeland Greene	Citizen Member, Genesee Depot, Wisconsin
*Howard C. Hass	Area Conservationist, U.S. Soil Conservation Service
Robert E. Hasselkus	Executive Director, Waukesha County Park and Planning Commission
Eugene Hollister	Chairman, Walworth County Board of Supervisors; Chairman, County Park and Planning Commission; Chairman, County Executive Committee; Member, County Agricultural Committee; Member, County Sheriff Committee (CD); Commissioner, SEWRPC
V. H. Holtdorf	Citizen Member, Silver Lake, Wisconsin
Stanley W. Ihlenfeldt	County Agri-Business Agent, Walworth County
James A. Johnson	Zoning and Sanitation Supervisor, Walworth County
John E. Jones	Citizen Member, Genesee, Wisconsin
*Thomas A. Kroehn	Director, Region 2, Division of Environmental Protection, Wisconsin Department of Natural Resources
Elwin G. Leet	County Agricultural Agent, Racine County
Paul Lohaus	Chairman, Fox River Flood Control Committee, Burlington, Wisconsin
John H. Mielke	Consulting Engineer, Waukesha, Wisconsin
Bauer Mohr	Citizen Member, Rochester, Wisconsin
Roland F. Nicotera	District Game Manager, Division of Fish, Game, and Enforcement, Wisconsin Department of Natural Resources, Waterford, Wisconsin
*Benjamin Richason	Professor of Geography, Carroll College, Waukesha, Wisconsin
*Herbert E. Ripley	Director of Environmental Health Services, Waukesha County Health Department
Phil Sander	Kenosha County Conservation Warden; Executive Secretary, Southeastern Wisconsin Sportsmen's Federation
Dr. Bruno E. Schiffleger	Citizen Member, Elkhorn, Wisconsin

George L. Schlitz	Citizen Member, Burlington, Wisconsin
Wilbert Schrank	Racine County Agricultural Stabilization and Conservation Committee
Rodney Vanden Noven	Director of Public Works, City of Waukesha
Theodore Vogel	Citizen Member, Chenequa, Wisconsin
*Franklin Walsh	Walworth County Board Supervisor; Member, County Agricultural Committee; Chairman, County Counseling Center Committee; Member, County Executive Committee; Member, County Finance Committee; Chairman, County Social Services Committee; Chairman, Town of Linn
Franklin Wirth	Mayor, City of Brookfield
John R. Zillmer	Secretary, Ice Age Park and Trail Foundation

*Members of the Fox River Watershed Steering Committee

Appendix C

LAND USE IN THE FOX RIVER WATERSHED

Table C-1

SUMMARY OF EXISTING LAND USE IN THE FOX RIVER WATERSHED ABOVE THE WAUKESHA GAGING STATION, WAUKESHA, WISCONSIN:[a] 1963

Land Use Category	Area in Acres	Area in Square Miles	Percent of Major Category	Percent of Subwatershed Area
Urban Land Use				
Residential				
Under Development . .	1,998	3.12	10.1	2.4
Developed	7,612	11.89	38.4	9.0
Subtotal	*9,610*	*15.01*	*48.5*	*11.4*
Commercial	288	0.45	1.5	0.3
Industrial	379	0.59	1.9	0.4
Mining	1,085	1.70	5.5	1.3
Transportation and Utilities[b]	6,120	9.56	30.9	7.3
Governmental and Institutional	794	1.24	4.0	0.9
Recreational[c]	1,523	2.38	7.7	1.9
Total Urban Land Use	19,799	30.93	100.0	23.5
Rural Land Use				
Agricultural	47,698	74.53	74.0	56.7
Open Land				
Water and Wetland . .	8,959	14.00	13.9	10.6
Woodland	5,603	8.75	8.7	6.6
Unused Land	2,160	3.38	3.4	2.6
Total Rural Land Use	64,420	100.66	100.0	76.5
Total Land Use	84,219	131.59	---	100.0

[a] *To summarize existing land use as tabulated in the SEWRPC land use inventory, the subwatershed boundary was approximated by U. S. Public Land Survey quarter-section boundaries giving a total area for the subwatershed of 85,284 acres. The difference of 1,065 acres between this approximation and the actual area of the subwatershed was distributed by reducing the tabulated area in each land use category on the basis of the proportionate share which each land use category formed of the total subwatershed.*

[b] *Includes off-street parking.*

[c] *Includes major and neighborhood parks.*

Source: SEWRPC.

Table C-2

SUMMARY OF EXISTING LAND USE IN THE FOX RIVER WATERSHED
ABOVE THE WILMOT GAGING STATION, WILMOT, WISCONSIN
AND BELOW THE WAUKESHA GAGING STATION, WAUKESHA, WISCONSIN:[a] 1963

Land Use Category	Area in Acres	Area in Square Miles	Percent of Major Category	Percent of Subwatershed Area
Urban Land Use				
Residential				
Under Development . .	4,978	7.78	8.0	0.9
Developed	22,785	35.60	36.7	4.1
Subtotal	*27,763*	*43.38*	*44.7*	*5.0*
Commercial	949	1.48	1.5	0.1
Industrial	1,154	1.80	1.9	0.2
Mining	2,819	4.40	4.5	0.5
Transportation and Utilities[b]	21,474	33.55	34.6	3.9
Governmental and Institutional	2,020	3.16	3.3	0.4
Recreational[c]	5,879	9.19	9.5	1.1
Total Urban Land Use	62,058	96.96	100.0	11.2
Rural Land Use				
Agricultural	359,342	561.48	72.9	64.7
Open Land				
Water and Wetland. . .	70,524	110.19	14.3	12.7
Woodland	52,861	82.59	10.7	9.5
Unused Land.	10,302	16.10	2.1	1.9
Total Rural Land Use	493,029	770.36	100.0	88.8
Total Land Use	555,087	867.32[d]	---	100.0

[a]*To summarize existing land use as tabulated in the SEWRPC land use inventory, the subwatershed boundary was approximated by U. S. Public Land Survey quarter-section boundaries giving a total area for the watershed of 557,263 acres. The difference of 1,176 acres between this approximation and the actual area of the subwatershed was distributed by reducing the tabulated area in each land use category on the basis of the proportionate share which each land use category formed of the total subwatershed.*

[b]*Includes off-street parking.*

[c]*Includes major and neighborhood parks.*

[d]*Does not include 3.64 square miles in Jefferson County. This excluded area is entirely in rural land uses.*

Source: SEWRPC.

Appendix D

TYPICAL LAKE USE REPORT PREPARED BY THE WISCONSIN DEPARTMENT OF NATURAL RESOURCES FOR THE SOUTHEASTERN WISCONSIN REGIONAL PLANNING COMMISSION UNDER THE FOX RIVER WATERSHED STUDY

Lake use reports of this kind were prepared for each of the following forty-five lakes within the fox River watershed:

KENOSHA COUNTY

Benedict Lake
Camp Lake
Center Lake
Cross Lake
Dyer Lake
Elizabeth Lake
Lilly Lake
Marie Lake
Powers Lake
Silver Lake
Voltz Lake

RACINE COUNTY

Bohner Lake
Browns Lake
Buena Lake
Eagle Lake
Echo Lake
Kee Nong Go Mong Lake
Long Lake
Tichigan Lake
Waubeesee Lake
Wind Lake

WALWORTH COUNTY

Army Lake
Beulah Lake
Booth Lake
Como Lake
Geneva Lake
Green Lake
Lulu Lake
Middle Lake
Mill Lake
North Lake
Pell Lake
Peters Lake
Pleasant Lake
Potters Lake
Silver Lake
Wandawega Lake

WAUKESHA COUNTY

Big Muskego Lake
Denoon Lake
Eagle Springs Lake
Little Muskego Lake
Lower Phantom Lake
Pewaukee Lkae
Spring Lake
Upper Phantom Lake

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Lake Use Report No. FX-15

BROWNS LAKE

RACINE COUNTY, WISCONSIN

Department of Natural Resources
Madison, Wisconsin

1968

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BROWNS LAKE
Racine County

An Inventory With Planning Recommendations

This report is a product of the lake and stream classification activity pursued in accordance with Section 23.09 (7)(m), Wisconsin Statutes; and preparation of this report was financed in part through a planning grant to the Southeastern Wisconsin Regional Planning Commission from the U. S. Department of Housing and Urban Development under the provisions of Section 701 of the Housing Act of 1954, as amended.

Lake Use Report No. FX-15

Prepared By
Wisconsin Department of Natural Resources

For the

Southeastern Wisconsin Regional Planning Commission

1968

Contributors

Ronald Poff, C. W. Threinen, Ronald Piening, Henry Schwenn, Brian Belonger, and Warren Churchill for the Lake Classification Project, Bureau of Fish Management

D. John O'Donnell, Watershed Coordination Section, Ruth L. Hine, Editor—Bureau of Research

(This report is No. 7 in the Department of Natural Resources series of Lake Use Reports.)

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INTRODUCTION

Browns Lake is a medium-sized natural lake in the Town of Burlington, Racine County, Wisconsin. Its area is 396 acres, excluding island acreage; and its water volume is 3,134.6 acre feet at a water elevation of 769 feet above mean sea level. Of the lakes in the Fox River watershed, it ranks 15th in size and, therefore, represents an important segment of the recreational resource of the Region. Provisions for protection, development, and wise use of this resource are important to its proper management.

PHYSICAL DESCRIPTION

Lake Basin

Browns Lake lies on the eastern edge of the Kettle Moraine and was formed, in part, from a melting ice block buried in the glacial drift and, in part, by damming and mounding of glacial materials. The basin, therefore, has both a deep pit and extensive shallow water areas. The lake watershed area, excluding the lake surface, covers 914 acres. The ratio of watershed, including the lake surface, to lake area is only 3.06 to 1, quite low. A low-head structure on the outlet maintains the lake level by impounding spring runoff and serves to prevent further cutting at the outlet. A hydrographic map illustrates the irregular basin configuration and indicates the location of the outlet (see Map 1).

Basic hydrographic and morphologic data for Browns Lake are presented in Table 1. An island, a narrow peninsula, and extensive channeling increase appreciably the shore length relative to the area of water available. The lake has a shore development factor of 1.98, meaning it has nearly twice as much frontage as a circular lake with the same area.

Shore Characteristics

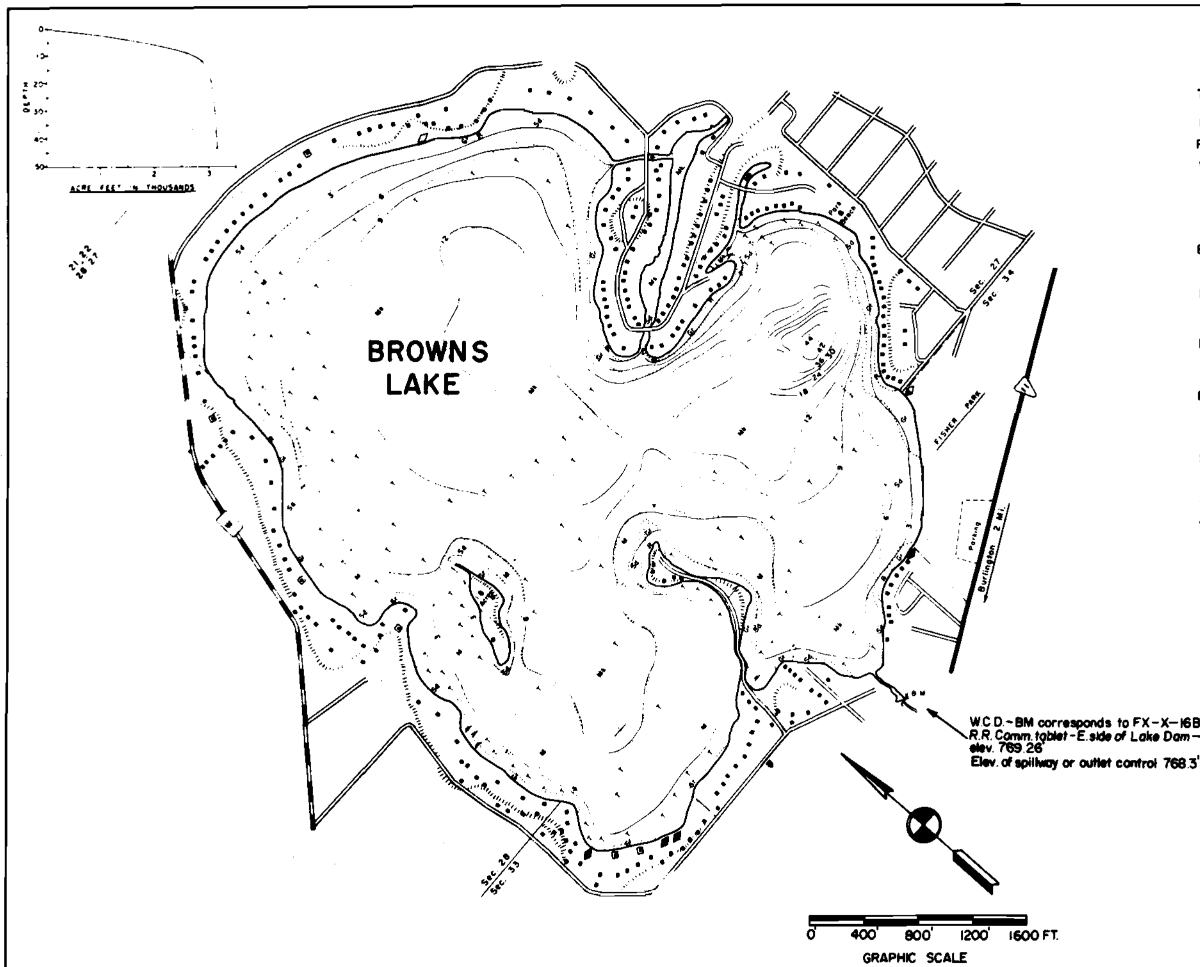
Sandy, firm bottom materials predominate around 52 percent of the shore, primarily on the north, south, and parts of the east shore. Extensive sand blanketing accounts for much of the sandy beach area on the north side and for scattered areas on the west shore. Most of the west and southwest shores are mucky. Prevailing winds have continually swept the east side of the lake, while fine sediments have been allowed to accumulate on the protected west shore. With more than a mile over which the wind can blow unobstructed, the theoretical maximum wave height is 1.35 feet; however, waves of this magnitude are unlikely because of the interference of the peninsula and island. Active sorting of beach materials is expected on the wave-washed shore to a depth of five to six feet, beyond which fine sediments cover the sand. Vegetation greatly reduces turbulence and permits sedimentation in the normally wave-washed zone.

Drainage Characteristics

The lake lies at the head of the western extension of the Hoosier Creek watershed and drains via this creek to the Fox River. Its principal water source is ground water from precipitation that has percolated through the sandy glacial deposits in the hilly area immediately east of the lake. Ground water and surface runoff are lost from Browns Lake by flow of the intermittent outlet stream southward. The lake also loses water to ground water seepage along the west and south lakeshore areas. The Fox River, west of the lake, is 17 feet lower than the lake surface; it is, therefore, the route for discharge of local ground water. South of the lake, extensive lowlands act as a discharge point.

Climate and Hydrology

Climatological data for Lake Geneva, Waukesha, and Racine approximate conditions at Browns Lake and are presented in Table 2. Lake Geneva is the nearest recording station; however, data from all stations have been used in this discussion. Runoff and evaporation data are from the nearest stations with such records. About 53 percent of the average annual precipitation falls as rain from May through September. About 30 percent occurs as snow in winter and contributes to spring runoff. The watershed of 914 acres, excluding the lake surface, receives 2,413 acre feet of precipitation each year. The lake surface receives an additional 1,045 acre feet; however, some 970 acre feet of this amount normally evaporate from the lake surface; and, therefore, the net contribution directly to the lake surface from precipitation is only 75 acre feet. Of that which falls on the watershed, about 23 percent, or 555 acre feet, runs off to the lake and supports a small seasonal flow from the outlet.



LEGEND

TOPOGRAPHIC SYMBOLS

- B BRUSH
- PW PARTIALLY WOODED
- W WOODED
- C CLEARED
- P PASTURED
- A AGRICULTURAL
- BM BENCH MARK
- DWELLING
- RESORT
- STEEP SLOPE
- INDEFINITE SHORELINE
- MARSH
- SPRING
- INTERMITTENT STREAM
- PERMANENT INLET
- PERMANENT OUTLET
- DAM

LAKE BOTTOM SYMBOLS

- P PEAT
- Mk MUCK
- C CLAY
- M MARL
- Sd SAND
- St SILT
- Gr GRAVEL
- R RUBBLE
- BR BEDROCK
- T SUBMERGENT VEGETATION
- ⊥ EMERGENT VEGETATION
- FLOATING VEGETATION
- STUMPS & SNAGS

◇ ACCESS ONLY ◆ ACCESS WITH PARKING ◆ BOAT LIVERY

SPECIES OF FISH	ABUNDANT	COMMON	RARE
MUSKIE			
N. PIKE		X	
WALLEYE			
L. M. BASS	X		
S. M. BASS			
PANFISH	X		
TROUT			

WATER AREA 396.0 ACRES (397.8 WITH ISLAND)
UNDER 3 FT. DEPTH 12%
OVER 20 FT. DEPTH 2%
VOLUME 3134.6 ACRE FT.
TOTAL ALK. 181 P.P.M.
SHORELINE 5.7 MILES
MAXIMUM DEPTH 44 FT.

MAPPED: FEB. 1953
REVISED: OCT. 1967
EQUIPMENT: THRU ICE
SURFACE WATER ELEVATION: 768.3'

MAP 1

HYDROGRAPHIC MAP

BROWNS LAKE, RACINE COUNTY, WISCONSIN

T-3-N R-19-E

D.N.R., JUNE 1968

Table I

HYDROGRAPHY AND MORPHOLOGY OF BROWNS LAKE,
RACINE COUNTY, WISCONSIN, 1967

Area = 0.62 sq. miles 396 acres
Shore length = 5.53 miles 29,198 feet (includes islands)
Shore development factor[a] = 1.98 (includes island shoreline)
Ratio of area (sq. miles) to shore length = .112
Maximum depth = 44 feet
Mean depth = 8 feet
Volume = 3,134.6 acre feet
Percent of area less than 3 feet deep = 12%
Percent of area more than 20 feet deep = 22%
Maximum length = 5,848 feet
Maximum width = 4,680 feet
Watershed area = 914 acres + 396 acres (lake surface) = 1,310 acres
Ratio of watershed area to lake area = 3.06 (excluding lake from watershed = 2.31)
Exchange time = not computed - intermittent drainage
Public frontage
Intensive use (beach, boat launching) = 662 feet
Wild frontage = none
Open space frontage = none

[a] *Shore development factor is defined as the ratio of shoreline to the circumference of a circle with the same area as the lake.*

Source: Wis. Dept. of Natural Resources.

Soils

Major soil groupings in the watershed are illustrated on Map 2. Most of the soils are Fox or Casco loams with moderate limitations for human use when considering the relatively flat terrain of the area. On the southeast shore, an area of soils with a seasonal high-water table exhibits severe limitations for most uses but only moderate limitations for extensive park use. This area is presently a county park. Inland from the east shore peninsula, an area of silt loam soil with moderate to severe limitations for cottages and homesites has been converted to housing and poses a threat to the lake in that sewage disposal is difficult. A small marsh pocket north of the lake possesses the only muck soil within the watershed. This area is commonly wet and is well separated from the lake.

WATER QUALITY

Selected chemical analyses for spring and midsummer of recent years are the basis for evaluation of the present water (see Table 3). The lake is moderately alkaline, has lower than average total alkalinity for this Region, and is rated on this basis as being moderately fertile. It is highly fertile when spring phosphate levels are considered, as these are commonly above the average for all lakes in the watershed. The potential aquatic nuisance hazard, as based on average chloride content, is considered medium, though the concentration is 1.8 times the regional average. Chlorides are considered as a reliable index to external sources of nutrients and an indicator of aquatic nuisance problems. Of the other ions indicative of pollution or nuisance problems, only sodium and sulphate are present in above average quantities.

Temperature and oxygen profiles taken in midsummer, 1966, in the deep basin indicated that there was relatively little anoxic water at that time (see Figure 1). A thermocline develops at 19 feet, and oxygen decreases below an assumed critical level of 2 mg/l at 21 feet. However, 99 percent of the total volume of the lake lies above this depth. Extensive, heavily vegetated shallows attest to the aquatic nuisance problem here. Over 87 percent of the lake area is less than 12 feet deep and heavily vegetated.

Table 2

CLIMATOLOGICAL DATA FOR THE BROWNS LAKE AREA, RACINE COUNTY, WISCONSIN

Station: Lake Geneva	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Year
Temperature (F) Mean monthly	21.6	24.8	33.5	47.6	58.1	68.4	73.2	72.1	63.3	53.5	36.8	24.3	48.1
Precipitation (inches) Mean monthly	1.7	1.3	2.6	3.2	3.4	4.3	4.4	3.5	2.0	2.2	2.1	2.2	32.9
Days with rain[a]	4	4	6	6	7	7	6	6	4	4	5	6	65
Station: Waukesha	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Year
Temperature (F) Mean monthly	20.7	23.1	32.1	45.4	56.5	66.9	72.1	70.8	62.4	51.3	36.4	24.9	46.9
Precipitation (inches) Mean monthly	1.7	1.3	2.2	2.5	3.5	3.7	3.3	3.1	2.9	2.1	2.3	1.6	30.2
Days with rain[a]	4	4	5	6	7	7	5	6	5	4	5	4	62
Station: Racine	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Year
Temperature (F) Mean monthly	24.2	26.2	34.5	45.9	56.1	67.0	73.1	72.3	64.7	53.4	39.0	27.9	48.7
Precipitation (inches) Mean monthly	2.0	1.5	2.7	2.8	3.8	3.5	3.1	3.2	3.0	2.0	2.4	2.0	31.9
Days with rain[a]	5	4	6	6	7	7	5	6	5	4	6	5	66

[a]*Precip. 0.10 inch or more*

Source: Wis. Climatological Data, U. S. Weather Bureau, 1961.

Monthly Average Runoff in Inches

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Total
Station: Fox River, Wilmot	0.52	0.48	1.43	1.10	0.74	0.58	0.39	0.33	0.27	0.40	0.51	0.44	7.19

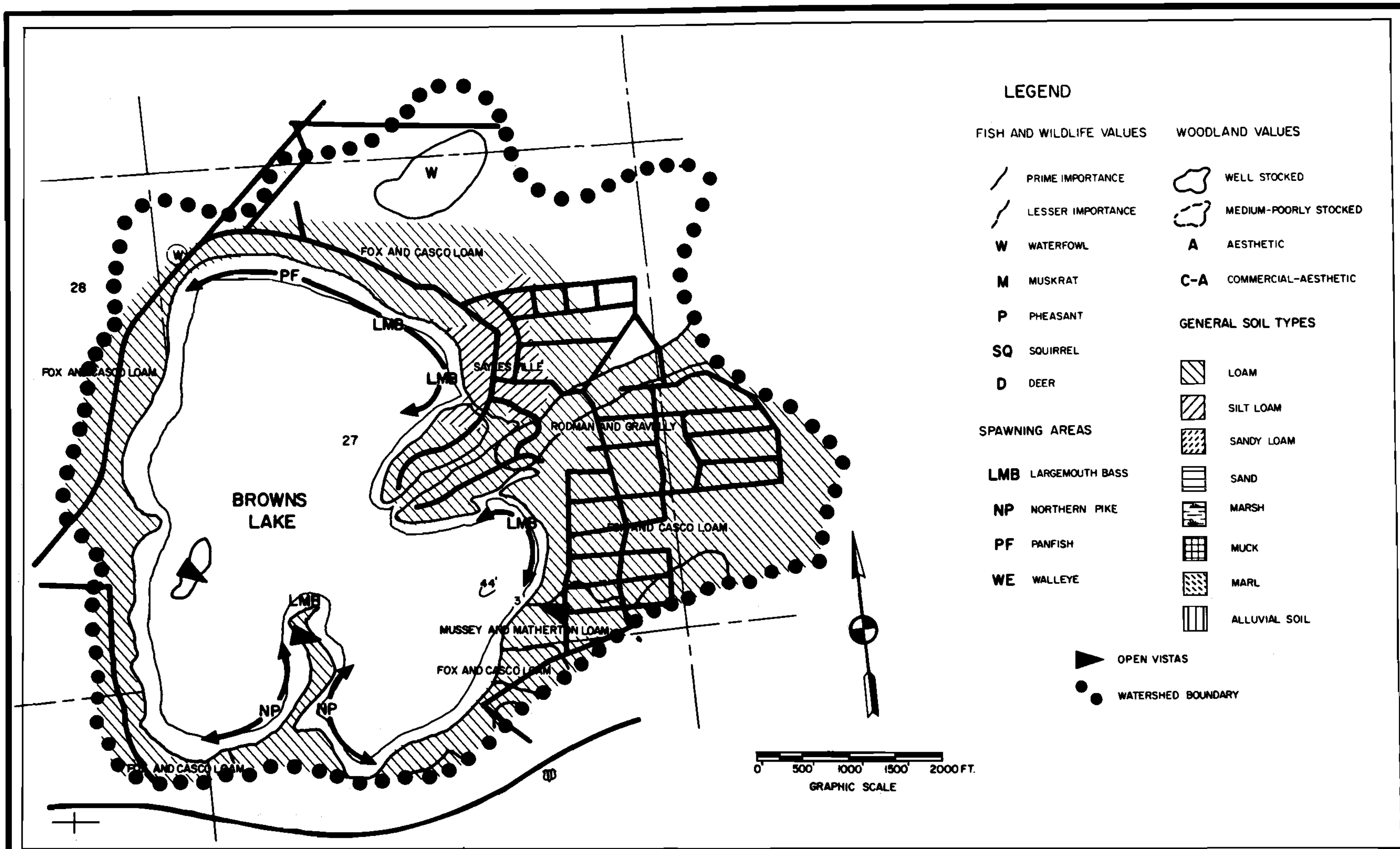
Ratio of Runoff to Rainfall

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
Station: Fox River, Waukesha	.35	.38	.66	.43	.21	.16	.12	.11	.09	.19	.22	.28	.24

Lake Evaporation in Inches

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Total
Station: Rockford, Illinois	0.31	0.57	1.75	2.90	4.03	4.37	5.09	4.05	2.95	2.15	0.89	0.34	29.40

Source: Roberts, W. J. and J. B. Stall. 1967, Lake evaporation in Illinois. Report of investigation No. 57, State of Illinois.



MAP 2

FISH, WILDLIFE AND WOODLAND VALUES AND BASIC SOIL TYPES

BROWNS LAKE, RACINE COUNTY, WISCONSIN

T-3-N R-19-E

D.N.R., JUNE 1968

Table 3

SELECTED WATER QUALITY PARAMETERS OF BROWNS LAKE, RACINE COUNTY, WISCONSIN, 1960, 1963 AND 1966

Parameter[a] — Depth: / Date:	Composite 4-15-60	Composite 4-15-63	3 ft. 4-14-66	15 ft. 8-23-66
pH (units)	8.1	8.1	8.5	8.6
Tot. Alk.	184.0	186.0	172.0	160.0
Sp. Cond. (micromhos/ cm @ 25° C.)	433.0	433.0	369.0	401.0
Ca	19.0	19.0	35.3	19.2
Mg	34.5	36.0	29.8	29.8
Na	4.6	4.6	8.0	9.3
K	0.5	0.5	1.1	1.0
Fe (T)	0.08	0.08	0.06	0.05
PO_4 (T)	0.53	0.57	--	0.86
PO_4 (D)	0.29	0.24	0.78	0.83
Cl	8.4	9.2	14.0	17.2
SO_4	21.0	23.0	36.3	48.5

[a] *All parameters expressed in mg/l unless otherwise noted.*

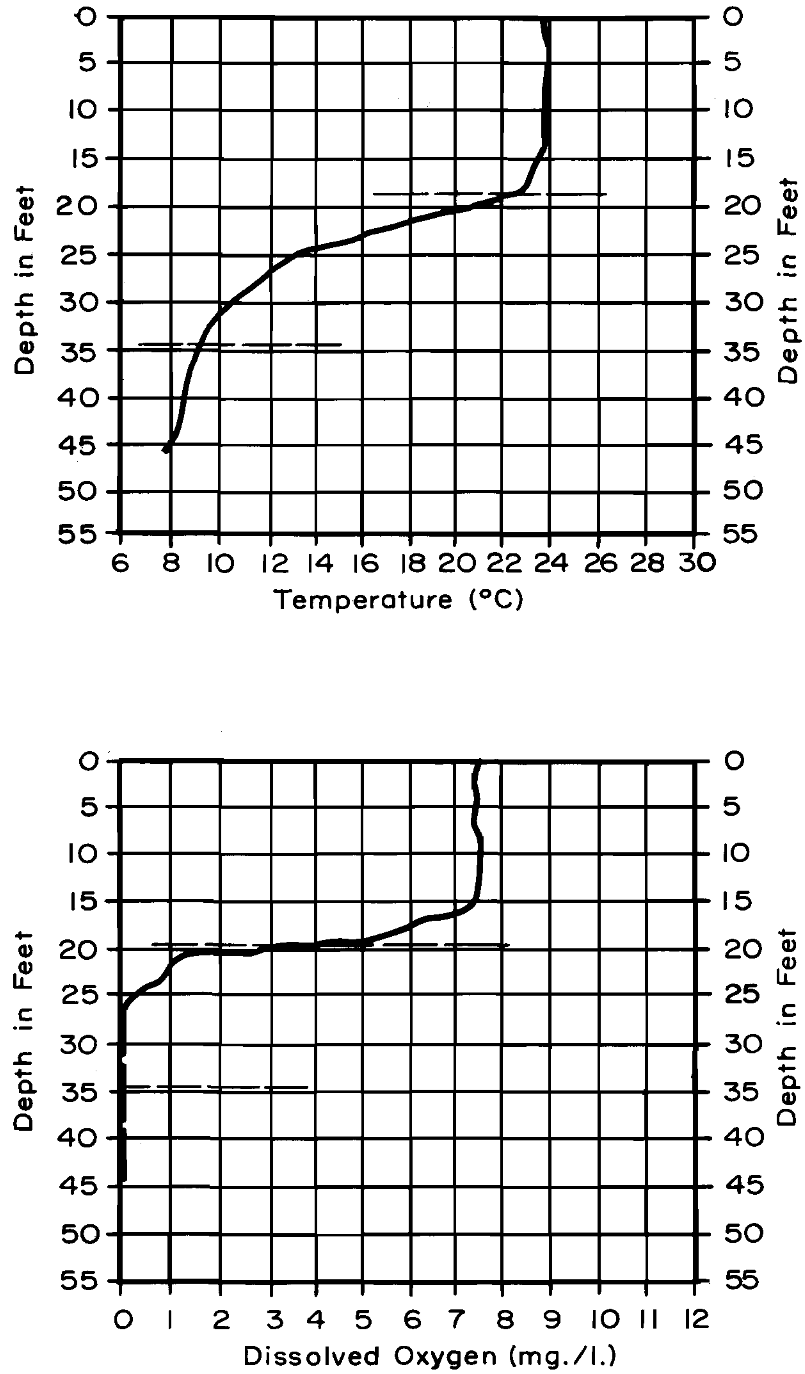
Source: Wis. Dept. of Natural Resources.

RESOURCES

Aquatic Plants
An intensive survey on July 12, 1967, revealed the extent of growth of rooted aquatic vegetation in Browns Lake. The general distribution of submergent, floating, and emergent-leaved vegetation is illustrated on the hydrographic map (see Map 1). Vegetation was found from shore to depths of 13 feet (89 percent of the basin). Chara was the most abundant plant in the southwest bay, covering the bottom in a dense mat. The rest of the lake was dominated by Ruppia maritima (widgeon grass), which was almost without exception the only plant found in water deeper than six feet. Scattered small amounts of pondweeds and water milfoil were also observed. Dominant species and the extent of their growth in the basin are presented in Table 4.

The lack of diversity in the aquatic plant community suggests that Browns Lake is quite eutrophic (well nourished) and that nutrients are inappropriately channeled for maintenance of desired conditions. Prior surveys noted a diverse plant community typical of moderately fertile lakes. Specific comments were made regarding the aesthetic value of the water lilies and hard-stem bulrush, which were common. The lake has been treated with sodium arsenite for control of rooted aquatic vegetation in seven years since 1950. Recently, because of the accumulation of arsenic in the water environment, this treatment has been discontinued on Browns Lake.

Fish Resources
The lake is best described as a bass-panfish lake with bluegills predominating among the panfish. Other species important in the catch are crappies, yellow perch, and rock bass. Over the years there has been evidence of somewhat poorer growth of Browns Lake fish when compared to the size of fish caught in other lakes. In the mid-1950's, the presence of excessive, slow-growing, small largemouth bass prompted investigations on the effect of size limit regulations here. Most recently, excessive numbers of small bluegills, a stunted population, have become a problem. With the lack of well-known predator fish, such as northern pike, it is tempting to assign the cause to inadequate predator populations and inadequate habitat. Detailed studies, however, might not offer so simple an explanation. The lake is productive, and it has desirable species, but there is a tendency toward imbalance. The best explanation may be the



August 11, 1966 — 11:45 A.M.
Wis. Dept. of Natural Resources

FIGURE I. Temperature and Oxygen Profiles

Table 4

DOMINANT SPECIES OF AQUATIC VEGETATION IN BROWNS LAKE, RACINE COUNTY, WISCONSIN, 1967[a]

Scientific Name	Common Name	Growth Character	Extent in Basin
Chara spp.	Muskgrass	Dense mats - submersed	Abundant SW bay
Ruppia maritima	Widgeon Grass	Submersed - slender	Dominates rest of lake
Potamogeton crispus	Curly-leaf pondweed	Submersed	Scattered amounts
P. pectinatus	Sago pondweed	Submersed - slender	Scattered amounts

[a]*Results of an intensive survey conducted July 12, 1967.*

Source: Wis. Dept. of Natural Resources.

lack of buffering, which provides a more diverse habitat. It lacks northern pike and predaceous rough fish species, such as gar or dogfish. The presence of dense extensive weed beds could also be a factor in the high survival of panfish.

At the present time, Browns Lake has no wild shore devoted to spawning grounds and nursery areas. The known spawning grounds are noted on the fish and wildlife resource map (see Map 2). Spawning requirements for common species consist of nesting sites and nursery sites for the young. Preferred nesting sites are the protected bays. Better habitat for spawning and nursery grounds would be desirable; the improved shores around the entire basin are not regarded as optimum habitat, although common species do reproduce.

Opportunities for fishing are facilitated by a large boat-launching site and several resort-boat rental services. Extreme competition and disruption are encountered from intensive pleasure boating. The amount of fishing taking place is inverse to the number of boats engaged in other activities.

Game Resource

The game resource is limited to waterfowl using the lake during migratory periods. There is no nesting on the lakeshore. Diver ducks find depths suitable and food resources fairly rich, but the opportunities for dabbling ducks are severely restricted by the lack of emergent plants and the intensive use of shallows for human recreation with its attendant sterility. In years past the waterfowl resource was thought to be deserving of protection from molestation in the fall by closure of fishing.

Pleasure Boating

Browns Lake is a medium-sized lake, which can be described as having inadequate space for scenic motorboating trips but space enough for rowing and canoeing and some space for fast boat activity, such as water skiing.

Aesthetic Features

Browns Lake has no spectacular hills or bluffs immediately adjoining it. Most of the shores have moderate slopes except for a small hill on the south shore. The real aesthetic resources here lie mostly in the extensive interaction of shore and water, particularly so with the presence of an island and two peninsulas. Since all of the shore is now occupied by buildings or developments—it is a disciplined shore—the aesthetic values are considerably dimmed. One cannot observe woods or wild plants from the shore or along the water's edge on this lake. An island with one house on it comes closest to providing this habitat.

LAKE USE

Fishing

Aerial boat counts and an intensive creel census provided data relative to fishing pressure on Browns Lake. On weekdays in midsummer, an average of 2.6 boats have been observed fishing on any one aerial count, while on weekends the average count has been 6.0 boats. Estimated summer fishing pressure is light with 31 hours per acre. Very little winter fishing occurs, and it appears that the fishery is lightly utilized throughout the year. Intensive summer pleasure boating definitely discourages heavier fishing pressure. Access is adequate with a public ramp and parking.

Hunting, Trapping, and Wildlife Observation

Very little opportunity exists for these activities, and a quantitative assessment has not been made. Hunting and trapping are generally impractical uses since the area is nearly urban in character. The islands and weedy bays offer wildlife observation opportunities during the off-season, when swimmers and boaters are inactive. There are few areas of undisturbed shores and resting areas in midsummer, when other activities prevail.

Swimming

This is perhaps the primary recreational attribute of Browns Lake as it is presently used. The county park on the south shore has as many as 4,000 users on a good summer day and 10,000 per summer weekend. All the resorts have swimming areas which are heavily used. The county park has about 500 feet of managed beach and accommodates over eight times the desired level of use (one lineal foot of shore per bather).

Cottages and Homesites

The entire shore of Browns Lake is now occupied. Most of the occupancy is for homesite or cottage use, followed by resort or business use and public land used for swimming.

This use of shore feasts on the open space of the lake common. As a medium-sized lake, a substantial amount of space is available. Its quality is not seriously impaired by water conditions, such as offensive odors from algae; but the space per person has shrunk substantially by the intensive and complete development that has taken place. A count of the number of units, both housing and commercial, now located around the shore, not including islands, indicates each unit has an average 83 feet of shore space and 1.24 acres of water space. The shores around the entire basin are basically suitable for building sites, but there are some substantial limitations because of soil types. Presently, there are 177 single-family or seasonal homes, 133 motel or cottage-type homes, and 10 resorts on the lakeshore that have been developed with little or no regard to soil capabilities.

Boating

Aerial boat counts and data from the public boat-launching ramp are the basis for evaluation. From 1964 through 1966, an average of 2,065 boats were launched at the ramp each year, of which about 15 percent were from out of state. As many as 60 boats have been counted on the lake at one time. The average number of boats engaged in activities other than fishing in the instantaneous counts is about 17 on weekends and holidays and about 6 on weekdays. Pleasure boating consistently outnumbers fishing 2 to 1; however, when activity increases beyond a total of 10 boats, fishing diminishes as pleasure boating increases. The lake accommodates about 15,000 hours of pleasure boating each summer.

RECREATIONAL RATING

Browns Lake has been rated in terms of its value for primary recreational uses. Rating and criteria are presented in Table 5. With 50 of a possible 72 points, the lake has a good but not high rating. Modest fishery problems and medium production detract from the fishery; weeds and somewhat limited sand shore detract from swimming; weeds and lake size detract from boating; and lack of wild shore limits significantly the desired aesthetic values.

Table 5

RECREATIONAL RATING OF BROWNS LAKE, RACINE COUNTY, WISCONSIN, 1967

Space: Total area - 396 acres — Total shore length - 5.00 miles

Ratio of total area to total shore length: 0.1238

Quality (18 points for each item)

Fish:		
___ 9 High production	_X_ 6 Medium production	___ 3 Low production
___ 9 No problems	_X_ 6 Modest problems such as infrequent winterkill, small rough fish problems	___ 3 Frequent and overbearing problems such as winter-kill, carp, excessive fertility
Swimming:		
___ 6 Sand or gravel (75% or more)	_X_ 4 Sand or gravel (25 - 50%)	___ 2 Sand or gravel (<25%)
_X_ 6 Clean water	___ 4 Moderately clean	___ 2 Turbid or darkly stained
___ 6 No algae or weed problems	_X_ 4 Moderate algae or weed problems	___ 2 Frequent algae or weed problems
Boating:		
_X_ 6 Adequate depths (75% of basin > 5')	___ 4 Adequate depths (50-75% of basin > 5' deep)	___ 2 Adequate depths (50% of basin)
___ 6 Adequate size for extended boating (> 1,000 acres)	_X_ 4 Adequate size for some boating (200-1,000 acres)	___ 2 Limit of boating challenge and space (< 200 acres)
___ 6 Good water quality	_X_ 4 Some inhibiting factors such as weedy bays, algae blooms, etc.	___ 2 Overwhelming inhibiting factors such as weed beds throughout
Aesthetics:		
___ 6 Existence of 25% or more wild shore	___ 4 Less than 25% wild shore	_X_ 2 No wild shore
___ 6 Varied landscape	_X_ 4 Moderately varied landscape	___ 2 Unvaried landscape
___ 6 Few nuisances such as excessive algae, carp dumps, etc.	_X_ 4 Moderate nuisance conditions	___ 2 High nuisance condition

Total quality rating: 50 out of a possible 72

EXISTING LAND USE

Land use in the watershed has been summarized for 1963 in Table 6. The lake surface and other open land constitute the largest portion of the watershed (40.4 percent). Agricultural cropland constitutes 32.2 percent. Residential uses and related transportation and commercial uses comprise 21.8 percent. The remaining 5.6 percent represents public park areas (3.2 percent), industrial uses (2.0 percent), and private recreation lands (0.4 percent). These data suggest that agricultural practices and urbanization play equally important roles in influencing the quality of Browns Lake. Existing land use is illustrated on a map of the lake and environs (see Map 3). The area encompassed in summarizing the land use of the watershed represents nine quarter sections and is based on total quarter-section area, provided more than one-half the total was within the true watershed.

Table 6

EXISTING LAND USE IN THE BROWNS LAKE WATERSHED,
RACINE COUNTY, WISCONSIN, 1963[a]

Land Use		Area in Acres	Total Acreage	Percent of Watershed
Major Category	Detailed			
Residential		237.06		16.56
Commercial		23.77		1.66
Industrial	Major Other Mining	 2.00 27.16	29.16	2.04
Transportation & Communication		50.56		3.53
Government or Institutional				
Recreation	Public Private	45.68 6.18	51.86	3.62
Open Land	Wet Unused Wooded	385.37 39.66 153.81	578.84	40.43
Agriculture	Crops Related	460.43		32.16
Total Acreage for Watershed Including Lake		1,431.68		100.00

[a] *Summarized to the nearest whole U. S. Public Land Survey quarter section.*

Source: SEWRPC Existing Land Use Inventory; March, 1963.

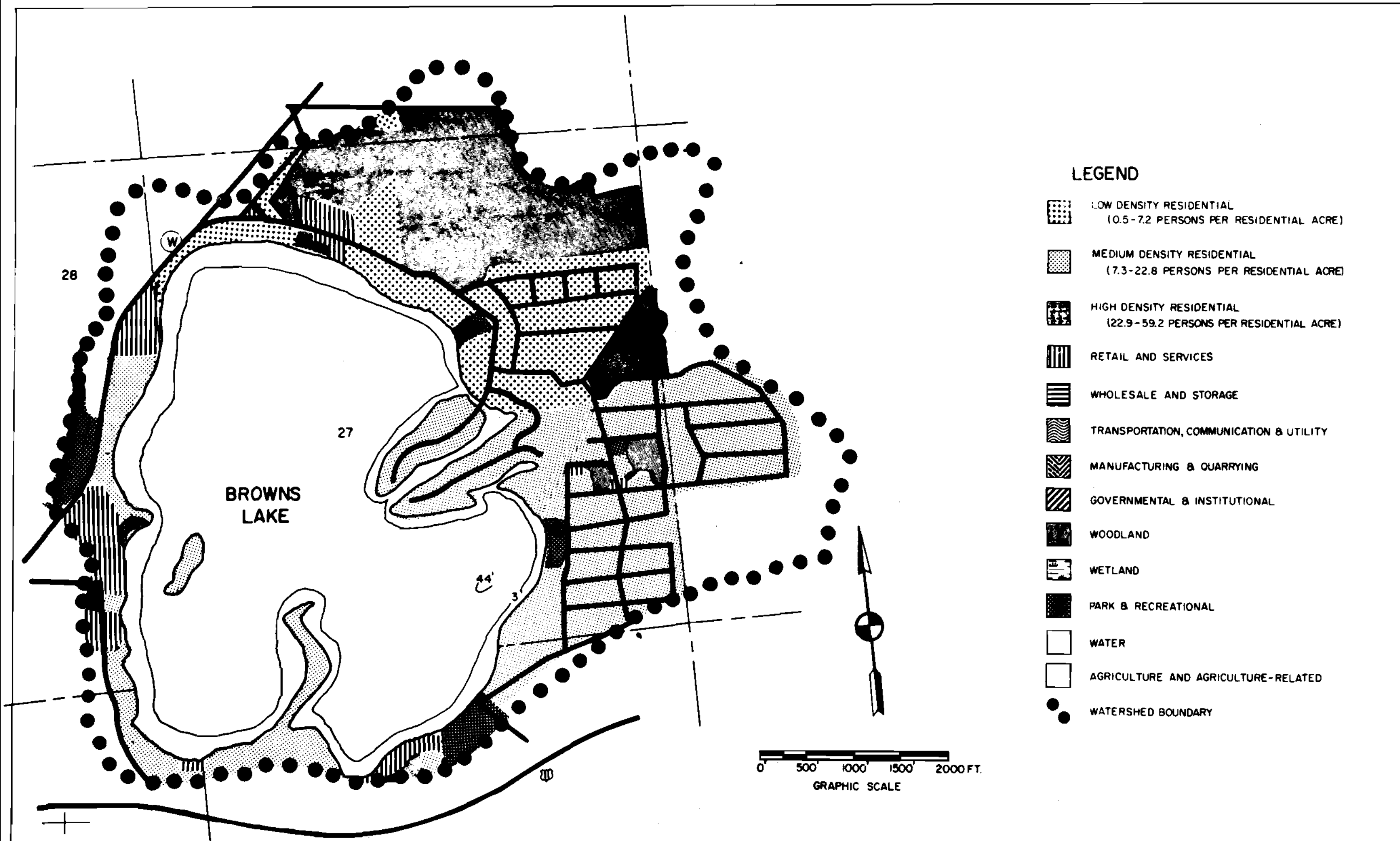
EXISTING PROTECTIVE MEASURES

Sewage Disposal

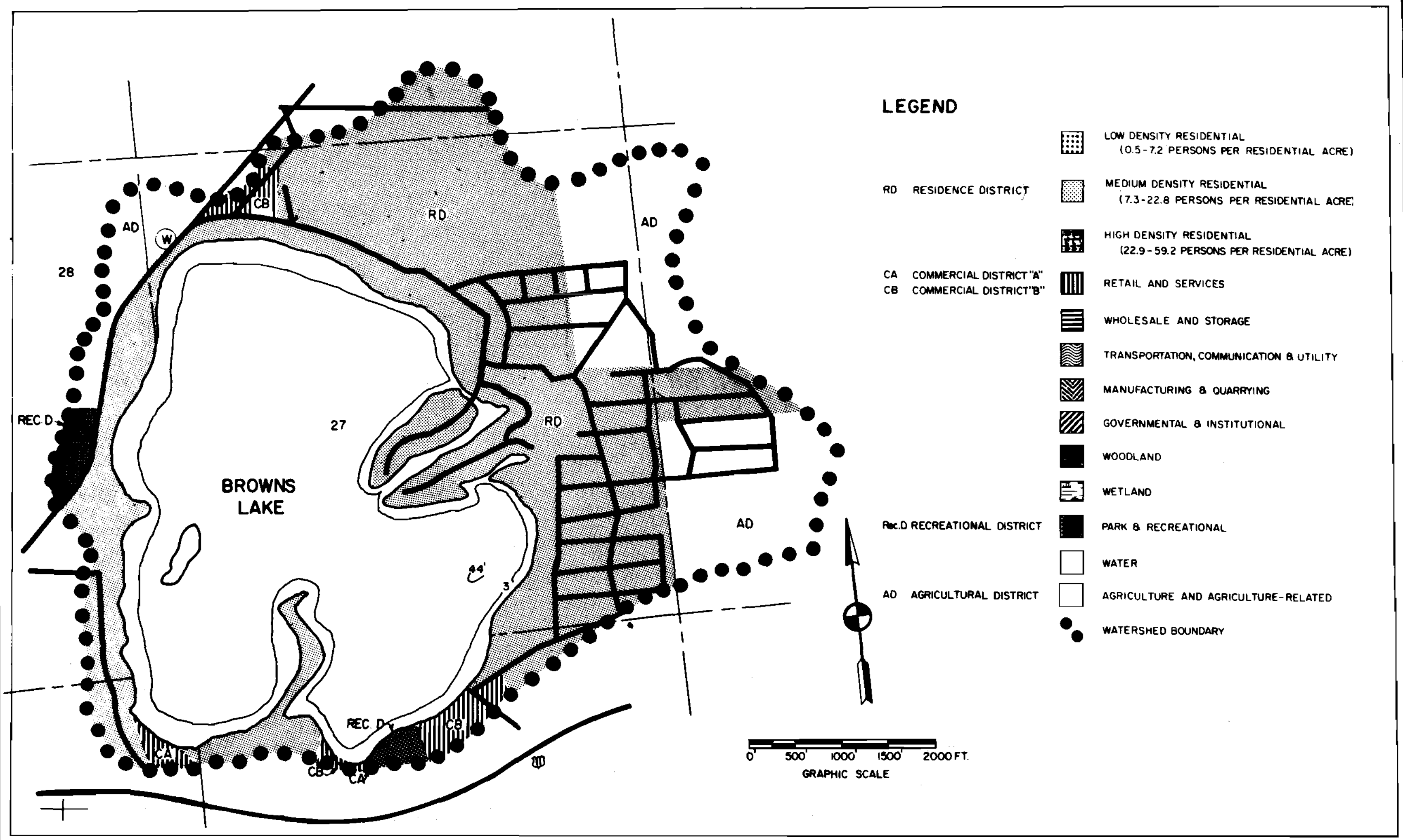
Public sewerage is lacking in the watershed. Private septic tank-tile field systems serve the lake community and have an immense potential to influence fertility of ground water supplies and the lake. East shore residents provide the greatest threat of increased nuisance problems since ground water movement is west toward the lake. Unfortunately, some areas of unsuitable soils have been developed for housing east of the lake. Very likely, Browns Lake would be in worse condition if it were not for its limited ground water drainage area.

Zoning

Zoning of shorelands in the Town of Burlington has been evaluated in Table 7 and is illustrated on Map 3A. Those measures considered essential to proper lake area development are adequate setback from shoreline to minimize pollution and fertilization and enhance aesthetics; spacing of units to avoid crowding, pollution, and damage to aesthetics; avoidance of development in high ground water and unstable soil areas; and providing adequate buffer areas with commercial and public park developments in order to pursue activities without interference and antagonism to private residents.



MAP 3	EXISTING LAND USE, 1963 BROWNS LAKE, RACINE COUNTY, WISCONSIN	T-3-N R-19-E D.N.R., JUNE 1968



MAP 3A

PRESENT ZONING, 1967

BROWNS LAKE, RACINE COUNTY, WISCONSIN

T-3-N R-19-E

D.N.R. JUNE 1968

Table 7
DEGREE OF PROTECTION AFFORDED BY LAND USE CONTROLS
TO BROWNS LAKE, RACINE COUNTY, WISCONSIN, 1967

Criterion (Suggested reservation)	Adequate	Inadequate	Remarks
Dwelling setback (at least 75' from high water and 3' above water level)		X	Waterfront not considered
Sewage disposal facilities (adequate lot size to permit desired positioning of septic tanks)		X	Just percolation test
Boathouses (not over water to extent they constitute a hazard - not used as dwellings)		X	Not considered
Refuse disposal (public or private refuse disposal areas not contiguous with the water or adjoining wetlands)	X		Restricted on recreational districts
Lot width (minimum set to enhance shoreline values - 75' or more)	X		100' would be more desirable
Bank/shore cover (discourage removal of cover where result is destruction of natural beauty)		X	Not considered
Grazing of shores (discourage indiscriminate grazing since it destroys spring areas and aids bank erosion - fencing is suggested)		X	Stock farms permitted in recreational "B"
Conservancy district (protect adjoining wetlands by a conservancy zoning program)		X	Not considered
Commercial facilities (adequate space required to buffer from private development and be serviceable)		X	Parking but little else in way of buffering
Slope protection (prohibit construction on slopes of 12% or more)		X	Not considered
Billboards (restrict billboard placement and size to protect scenic shores)	X		May not be placed in recreational districts
(some shore zoned commercial)			

Source: Wis. Dept. of Natural Resources.

Water Zoning

Boating on Browns Lake is now limited to idling speeds between the hours of sunset and 10:00 a.m. This timing of activity is a substantial consideration to fishermen. The only other specific water zoning measures call for prohibition of motorboating inside buoyed swimming areas and careful, prudent operation near persons and property. The town has not provided a restriction limiting speeds within the shore zone (200 feet from shore). The boat control ordinance has been evaluated in Table 8.

Table 8

DEGREE OF PROTECTION AFFORDED BY BOAT CONTROL ORDINANCE
TO BROWNS LAKE, RACINE COUNTY, WISCONSIN, 1967

Criterion (suggested reservations)	Adequate	Inadequate	Remarks
Motors (lakes less than 50 acres be limited to boats without motors L. C. #1).	X		
Shore Zone (speed be restricted to less than 5 mph within 200' of shore L. C. #2).		X	
Cabin Craft Mooring (boats on which persons are living, sleeping, camping are prohibited from mooring, drifting or overnight anchoring L. C. #3).		X	
Mooring at Landings (prohibited at public landings for more than 24 hrs., except in designated areas L. C. #4).		X	
Speed Limits (on lakes 50-200 acres speed limited to 5 mph or less L. C. #5).	X		
Passing (within 200; of another object speed is limited to 5 mph or less L. C. #6).		X	
Shore Preservation (25% of shore must remain in wild state L. C. #8).		X	
Weed Preservation (vital aquatic vegetation beds should be marked and boating therein prohibited)		X	

Civil Town of Burlington ordinance applies

General restrictions: No overpowering; need a permit to hold races; no boats in marked areas; motors must have mufflers to prevent excessive noise; lights on all craft and raft after dark.

Speed limit: Idle sunset to 10:00 a.m.

Water skiing: Two people in boat, must not pull more than two skiers.

Source: Wis. Dept. of Natural Resources.

RECREATION AND RESOURCE-RELATED PROBLEMS

Deteriorating Water Quality

Continued occupancy of the shore area by housing and businesses increases the level of fertility in the lake. Septic tanks on the east side of the lake are an especially significant source of nutrients and add to the aquatic vegetation problem. Development of soils unsuited to sanitary facilities is unfortunate. Immense use pressure concentrated at the county park is also a definite threat to water quality, both bacteriologically and in terms of overtaxing sanitary facilities.

Unstable Water Levels

The lake is subject to water level fluctuations due in part to its small watershed. Increased ground water pumpage from shallow aquifers north, west, and south of the lake will increase ground water drainage and aggravate this situation.

Deteriorating Wildlife Habitat

Present land use hinders any possibility of sustaining wildlife in the watershed save for a small wetland pocket north of the lake. The southwest bay, best suited for preservation, is unprotected by present land use controls. There are no zoned conservancy district lands in the watershed.

Poor Quality Fishery

Slow-growing panfishes, few large predators, and moderate harvest suggest a deteriorating fishery. The catch, though small, approaches the level of sustained yield in a lake with such problems.

Compounded User Conflicts

Browns Lake has now reached the saturation level for boating; has crowded, inadequately-sized beach areas; and lacks extensive use park lands. The county park presently is the only significant facility which provides public swimming on inland lakes in all of Racine County. Pleasure boating, at the use levels encountered here, deters fishing and thus narrows the recreational base.

RECOMMENDED RESOURCE PROTECTION AND ENHANCEMENT MEASURES

The following specific recommendations have been formulated for the recreational enhancement and resource protection of Browns Lake:

1. In order to preserve water quality and yet sustain present lake levels, further consideration of public sewerage for the Browns Lake watershed is warranted, combined with a public deep well water supply located most desirably east of the lake.

2. To preserve and enhance fish, wildlife, and aesthetic habitat, it is recommended that the southwest bay and its contiguous shore be protected from further development by conservancy zoning, acquisition, and establishment of a no-motorboating zone. The island and peninsula are prime aesthetic and recreational attributes and should be acquired for extensive park use.

3. An improved fishery is desirable to increase the recreational base of the lake. This may require employment of such measures as vegetation control in part of the basin, reduction of overly abundant species of fish, possibly deepening of part of the basin, predator species stocking, and rough fish control. If any or all of the above fail, chemical rehabilitation of the entire population may be warranted. By providing more deeper water on the north end, an auxiliary benefit of better swimming frontage and better boating conditions would be achieved.

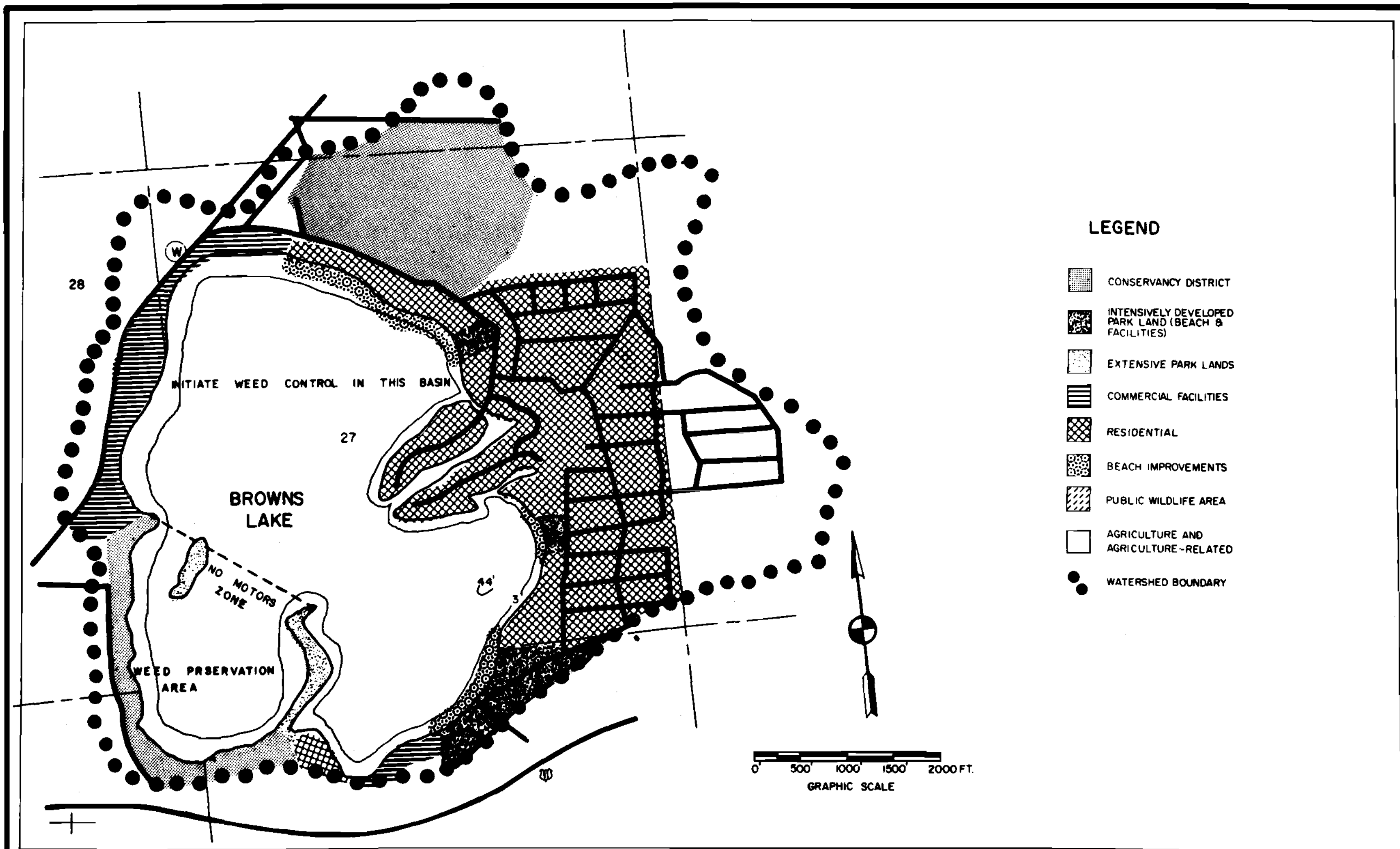
4. The existing county park is inadequate for the use it receives and should be enlarged to provide additional beach frontage and parking.

5. It is recommended that the wetland pocket and surrounding land north of the lake be protected from further development by conservancy zoning. A recreational complex of bathing beach, launching site, and parking would enhance the north shore in this area.

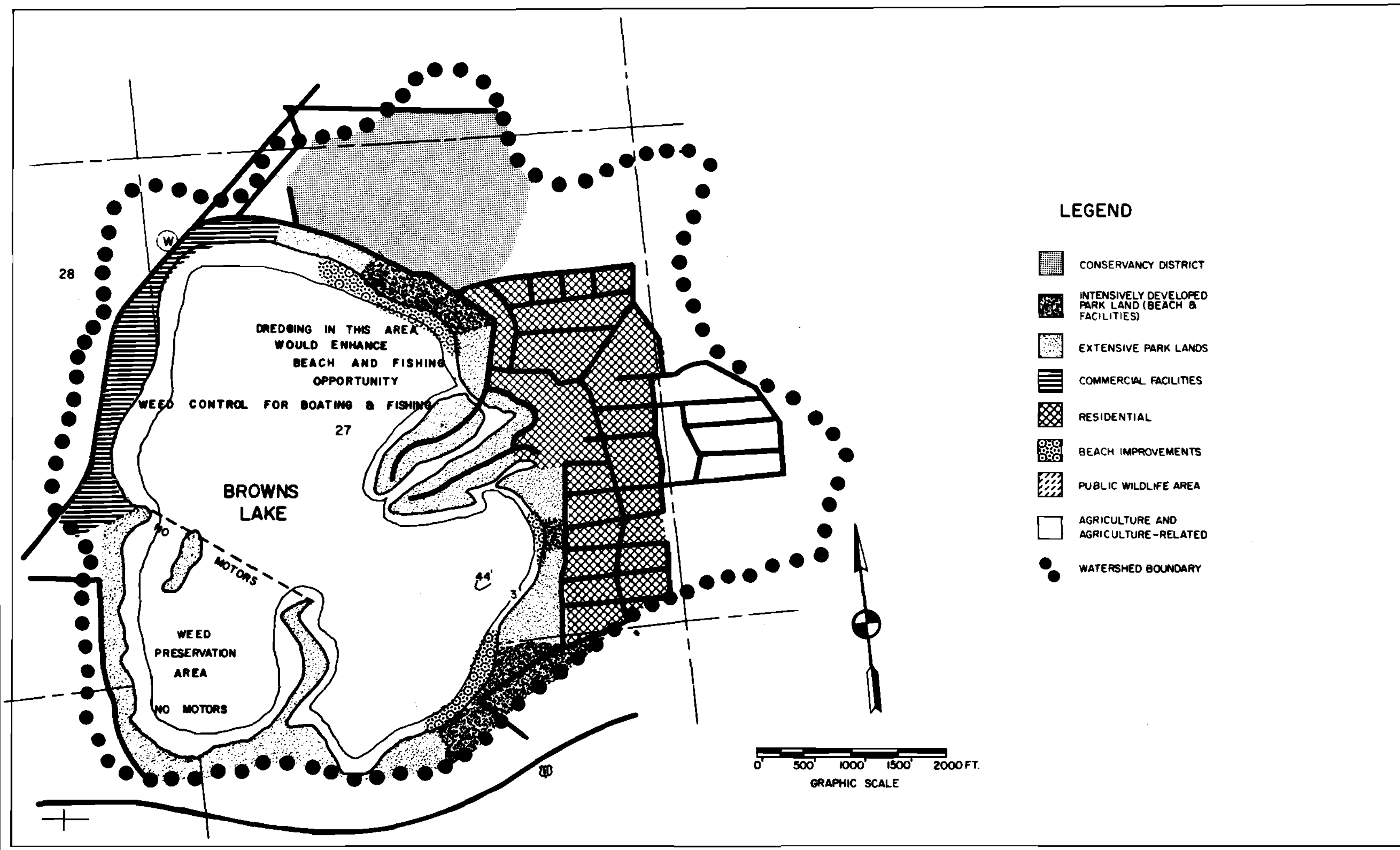
6. Ultimately, the entire shoreline should be either public or open to access by the public on so valuable a resource as this. It is, therefore, recommended in the long-run picture that the east shore peninsula be acquired and maintained as extensive park.

7. It is recommended that the large resort complexes, a desired use so long as it is adequately buffered from other developments, provide shoreline rights-of-way, making the entire shoreline available as a walkway. With the lakeshore suitably controlled, urbanization can continue east of the lake; and property values may be enhanced by a shoreline available to all.

8. A detailed study involving local interests to formulate land use objectives and develop an ultimate land use plan for the Browns Lake basin will be necessary and is recommended. Although such master plan development is beyond the scope of this lake plan, recreation-related plans have been formulated and are recommended. The resource conservation plans are presented on Map 4, representing intermediate objectives, and on Map 5, representing ultimate objectives.



MAP 4	INTERMEDIATE RECREATIONAL USE PLAN BROWNS LAKE, RACINE COUNTY, WISCONSIN	T-3-N R-19-E D.N.R., JUNE 1968



MAP 5	ULTIMATE RECREATIONAL USE PLAN BROWNS LAKE, RACINE COUNTY, WISCONSIN	T-3-N R-19-E D.N.R., JUNE 1968

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Appendix E

FLOOD DISCHARGE-FREQUENCY CURVES FOR SELECTED LOCATIONS IN THE FOX RIVER WATERSHED 1965 LAND USE AND 1990 LAND USE

Figure E-1
DISCHARGE-FREQUENCY, UPPER FOX SUBWATERSHED AT STRUCTURE NOS. 23, DUPLAINVILLE RD.; 71, USH 16; 75, BUSSE RD.

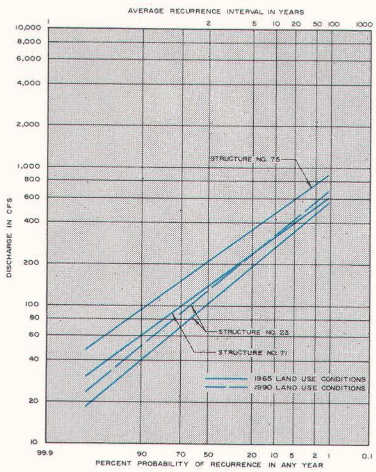


Figure E-2
DISCHARGE-FREQUENCY, UPPER FOX SUBWATERSHED AT STRUCTURE NOS. 31, CTH M; 38, STH 59; 52, DAVIDSON RD; 60, CTH SS

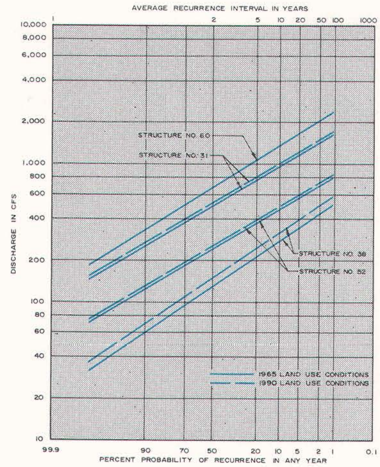


Figure E-3
DISCHARGE-FREQUENCY, UPPER FOX SUBWATERSHED AT STRUCTURE NOS. 13, CTH K; 45, IH 94; 56, CTH Y; 89, PRAIRIE AVE.

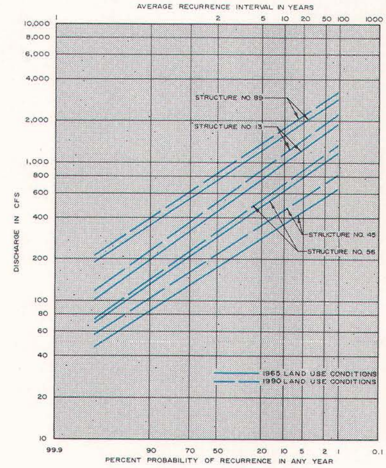


Figure E-4
DISCHARGE-FREQUENCY PEBBLE CREEK SUBWATERSHED AT STRUCTURE NO. 97, STH 59

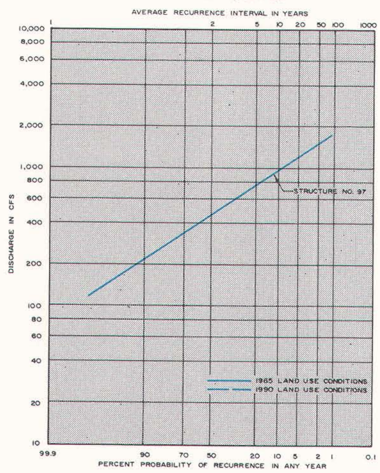


Figure E-5
DISCHARGE-FREQUENCY SPRING CREEK SUBWATERSHED AT STRUCTURE NOS. 104, HOLIDAY RD.; 107, CTH XI

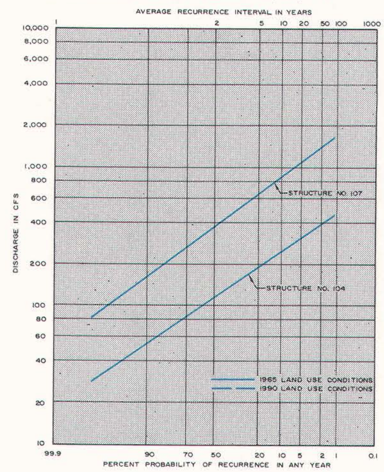


Figure E-6
DISCHARGE-FREQUENCY PEBBLE BROOK SUBWATERSHED AT STRUCTURE NO. 119, SOO LINE R.R. (Sec. 33; T. 6 N., R. 18 E.)

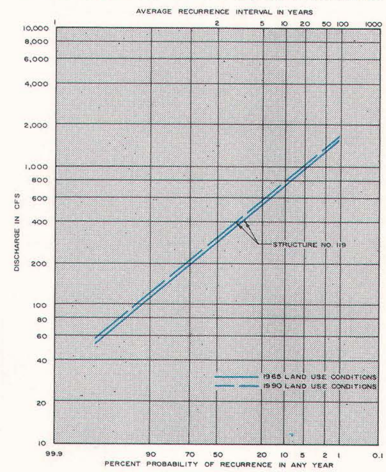
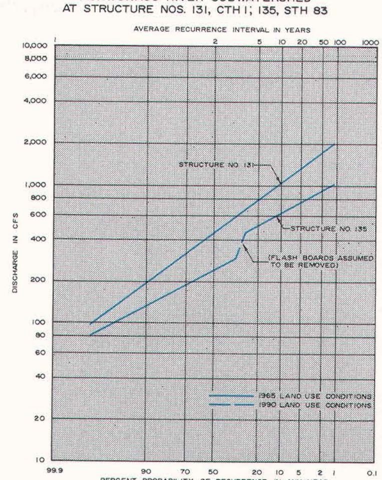


Figure E-7
DISCHARGE-FREQUENCY MUKWONAGO RIVER SUBWATERSHED AT STRUCTURE NOS. 131, CTH I; 135, STH 83



Source: U. S. Soil Conservation Service.

Figure E-8
DISCHARGE - FREQUENCY, MUKWONAGO RIVER SUBWATERSHED AT STRUCTURE NO. 123, STH 99; LAKE BEULAH OUTLET

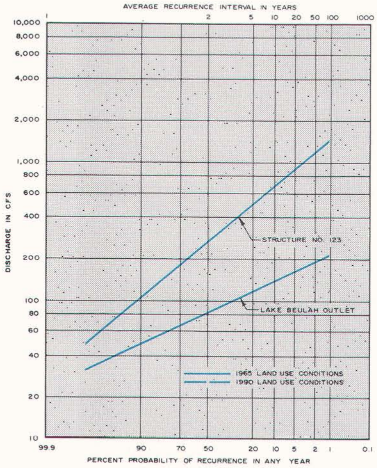


Figure E-9
DISCHARGE - FREQUENCY, WIND LAKE SUBWATERSHED AT STRUCTURE NO. 151, STH 36 AND LONG LAKE OUTLET

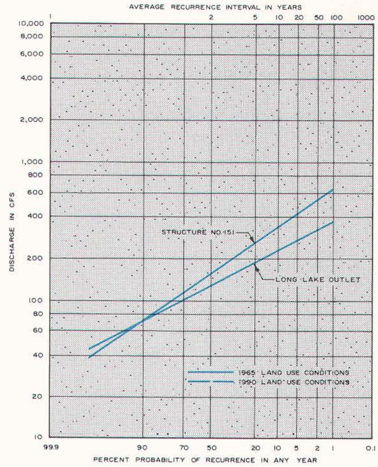


Figure E-10
DISCHARGE - FREQUENCY, EAGLE CREEK SUBWATERSHED AT STRUCTURE NO. 170, EAGLE RIVER RD.

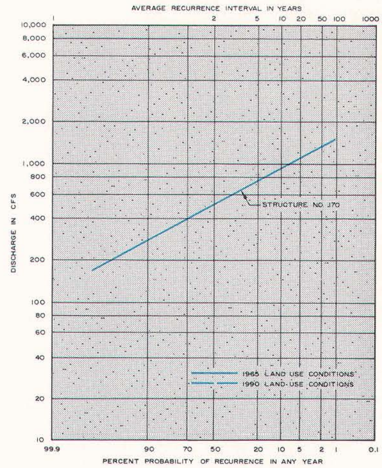


Figure E-11
DISCHARGE - FREQUENCY, SUGAR - HONEY SUBWATERSHED AT STRUCTURE NOS. 198, BOWERS RD.; 201, POTTER RD.

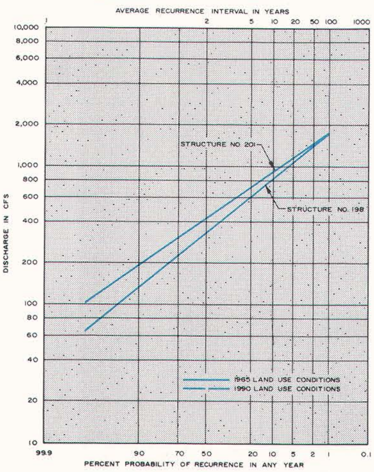


Figure E-12
DISCHARGE - FREQUENCY, SUGAR - HONEY SUBWATERSHED AT STRUCTURE NOS. 181; CTH G; 206, SPRING PRAIRIE RD.

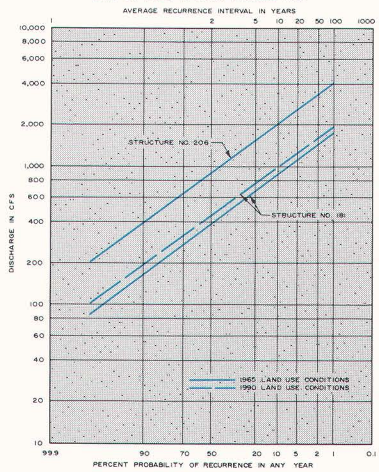


Figure E-13
DISCHARGE - FREQUENCY, WHITE RIVER SUBWATERSHED AT STRUCTURE NOS. 235, S. CHURCH ST.; 240, STH 11; 244, STH 36 AND 83

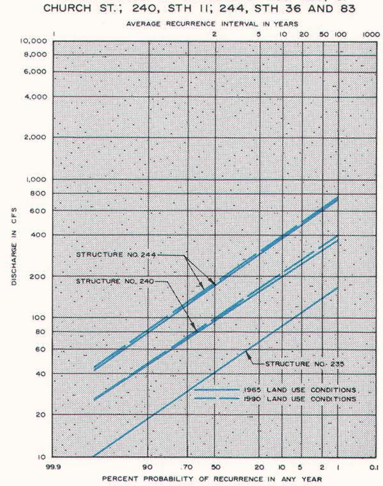
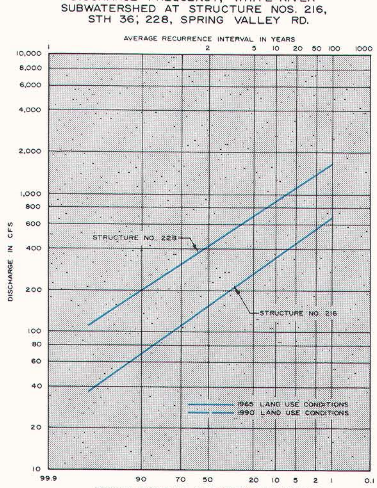


Figure E-14
DISCHARGE - FREQUENCY, WHITE RIVER SUBWATERSHED AT STRUCTURE NOS. 216, STH 36; 228, SPRING VALLEY RD.



Source: U. S. Soil Conservation Service.

Figure E-15

DISCHARGE-FREQUENCY, HOOSIER CREEK SUBWATERSHED AT STRUCTURE NOS. 252 AND 255, MT. TOM RD.; 257, BREVER RD.

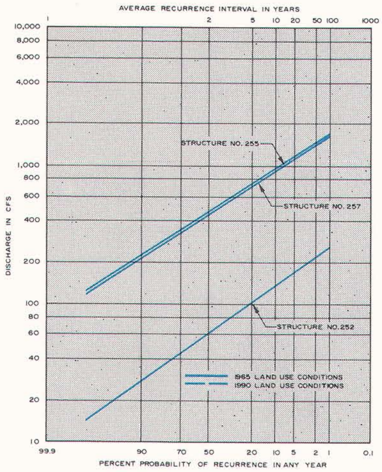


Figure E-16

DISCHARGE-FREQUENCY PETERSON CREEK SUBWATERSHED AT STRUCTURE NO. 264, CTH W

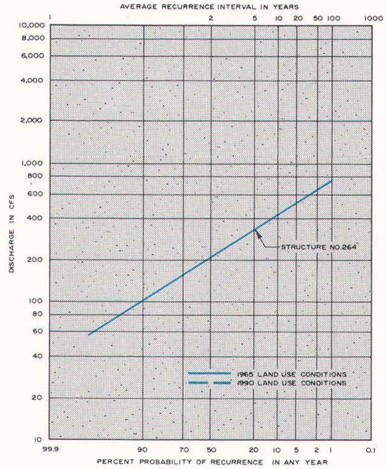


Figure E-17

DISCHARGE-FREQUENCY BASSETT CREEK SUBWATERSHED AT STRUCTURE NO. 268, FOX RIVER RD.

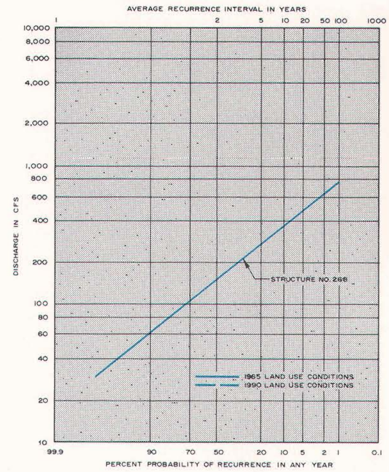


Figure E-18

DISCHARGE-FREQUENCY SILVER LAKE SUBWATERSHED AT STRUCTURE NO. 272, CTH B

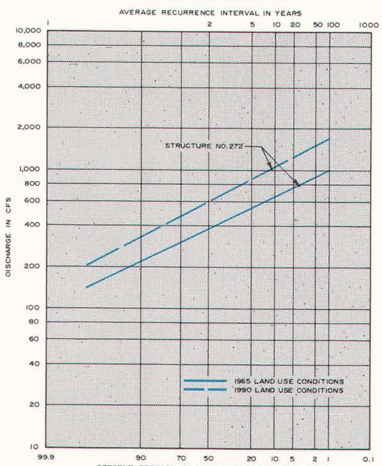


Figure E-19

DISCHARGE-FREQUENCY, LOWER FOX SUBWATERSHED AT STRUCTURE NOS. 121, STH 15; 145, STH 20 AND 36; 171, CTH W; 246, STH 11; 273, CTH C

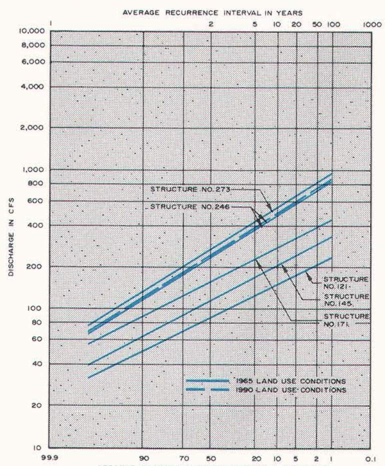
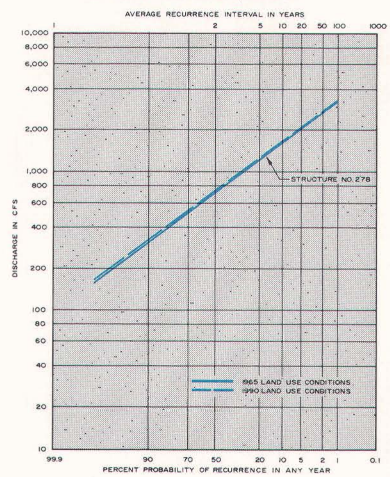


Figure E-20

DISCHARGE-FREQUENCY NIPPERSINK CREEK SUBWATERSHED AT STRUCTURE NO. 278, MAIN ST.



Source: U. S. Soil Conservation Service.

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FLOOD DISCHARGE-FREQUENCY CURVES FOR BRIDGES IN THE FOX RIVER WATERSHED

Figure F-1
DISCHARGE-FREQUENCY, UPPER FOX SUBWATERSHED AT STRUCTURE NOS. 13, CTH K; 31, CTH M; 38, STH 59; 45, IH 94; 52, DAVIDSON RD.; 56, CTH Y; 60, CTH SS; 89, PRAIRIE AVE.

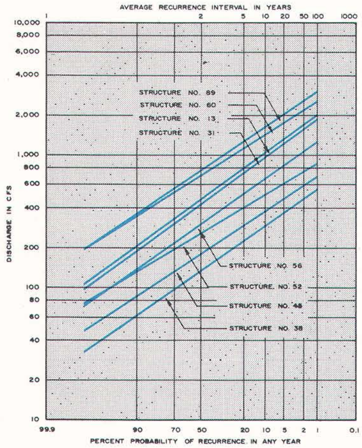


Figure F-2
DISCHARGE-FREQUENCY, UPPER FOX SUBWATERSHED AT STRUCTURE NOS. 23, DUPLAINVILLE RD.; 70, CLARK ST.; 75, BUSSE RD.

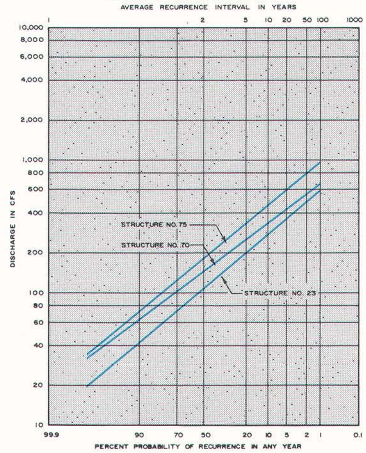


Figure F-3
DISCHARGE-FREQUENCY
PEBBLE CREEK SUBWATERSHED
AT STRUCTURE NO. 97, STH 59

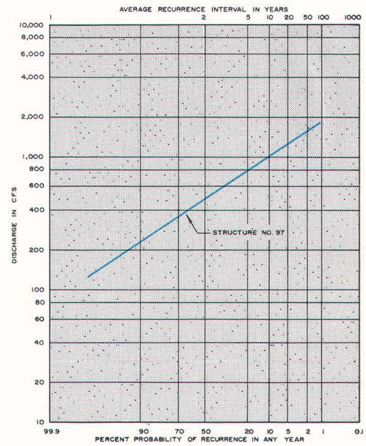


Figure F-4
DISCHARGE-FREQUENCY
SPRING CREEK SUBWATERSHED
AT STRUCTURE NOS. 104, HOLIDAY RD., 107, CTH XI

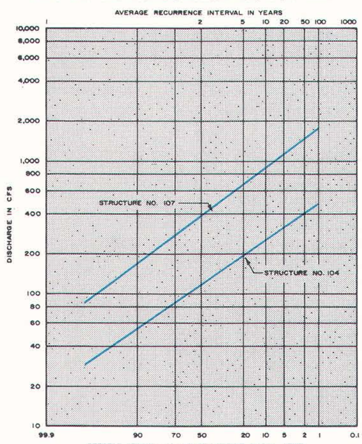


Figure F-5
DISCHARGE-FREQUENCY
PEBBLE BROOK SUBWATERSHED
AT STRUCTURE NO. 119, SOO LINE R.R. (Sec. 33; T. 6N., R. 18E.)

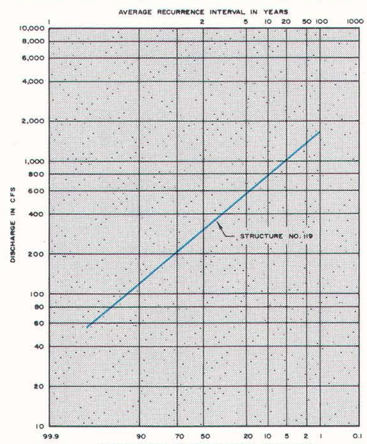


Figure F-6
DISCHARGE-FREQUENCY, MUKWONAGO RIVER SUBWATERSHED AT STRUCTURE NOS. 123, STH 99; 131, CTH I; 135, STH 83; LAKE BEULAH OUTLET

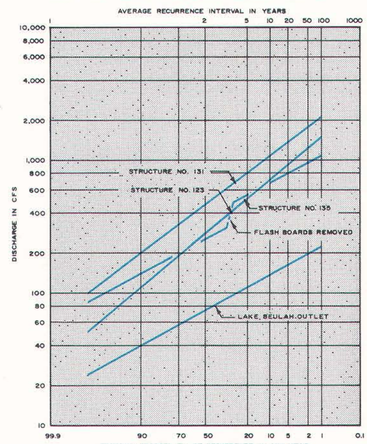


Figure F-7
DISCHARGE-FREQUENCY, WIND LAKE SUBWATERSHED AT STRUCTURE NOS. 151, STH 36; 162, STH 20; LONG LAKE OUTLET

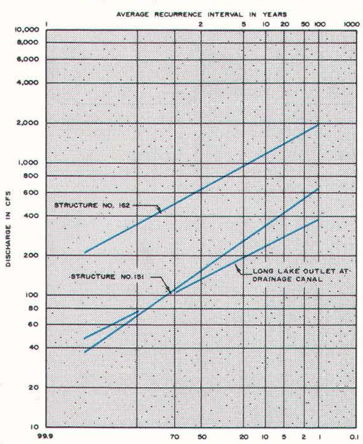


Figure F-8
DISCHARGE-FREQUENCY, EAGLE CREEK SUBWATERSHED AT STRUCTURE NO. 170, EAGLE RIVER RD.

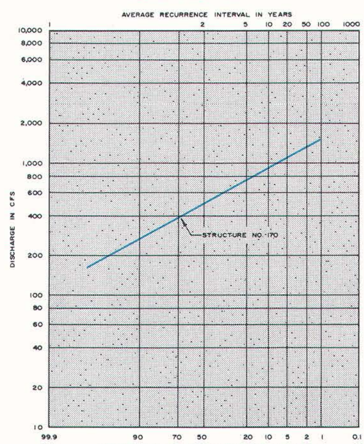
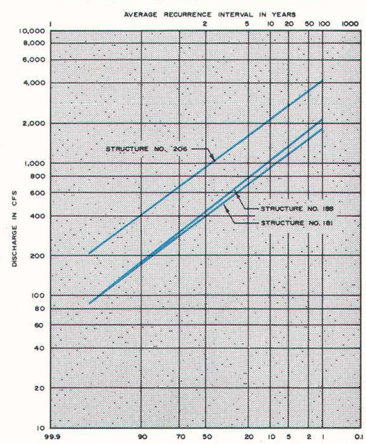


Figure F-9
DISCHARGE-FREQUENCY, SUGAR-HONEY SUBWATERSHED AT STRUCTURE NOS. 181, CTH G; 188, CTH D; 206, SPRING PRAIRIE RD.



Source: U. S. Soil Conservation Service.

Figure F-10
DISCHARGE-FREQUENCY, SUGAR-HONEY SUBWATERSHED AT STRUCTURE NOS. 198, BOWERS RD.; 201, POTTER RD.

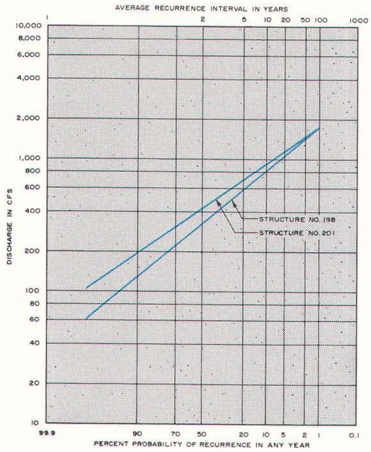


Figure F-11
DISCHARGE-FREQUENCY, WHITE RIVER SUBWATERSHED AT STRUCTURE NOS. 216, STH 36; 228, SPRING VALLEY RD.; 235, S. CHURCH ST.; 240, STH 11; 244, STH 36 AND 83

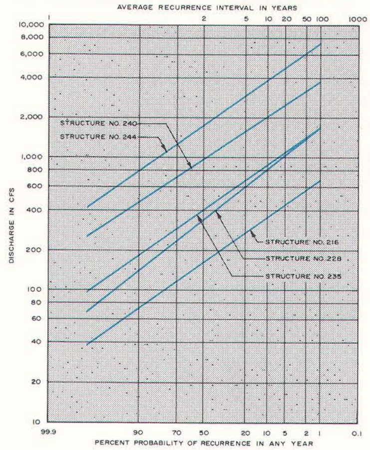


Figure F-12
DISCHARGE-FREQUENCY, HOOSIER CREEK SUBWATERSHED AT STRUCTURE NOS. 252 AND 255, MT. TOM RD.; 257, BREVER RD.

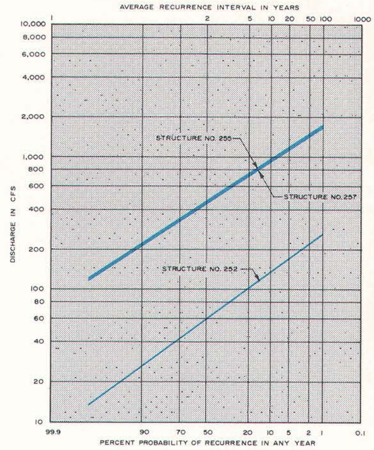


Figure F-13
DISCHARGE-FREQUENCY
PETERSON CREEK SUBWATERSHED
AT STRUCTURE NO. 264, CTH W

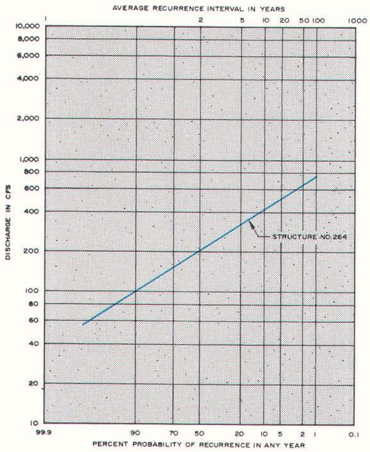


Figure F-14
DISCHARGE-FREQUENCY
BASSETT CREEK SUBWATERSHED
AT STRUCTURE NO. 268, FOX RIVER RD.

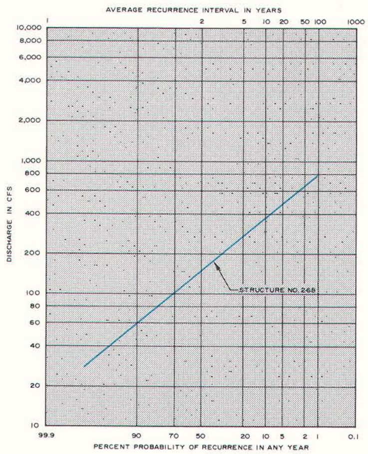


Figure F-15
DISCHARGE-FREQUENCY
SILVER LAKE SUBWATERSHED
AT STRUCTURE NO. 272, CTH B

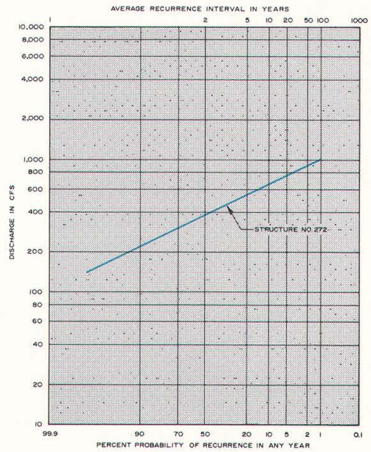


Figure F-16
DISCHARGE-FREQUENCY, LOWER FOX SUBWATERSHED
AT STRUCTURE NOS. 121, STH 15; 145, STH 20 AND 36;
171, CTH W; 246, STH 11; 273, CTH C

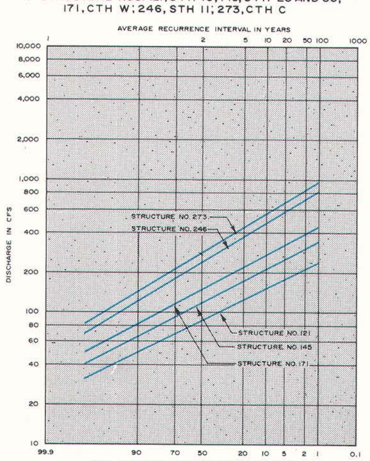
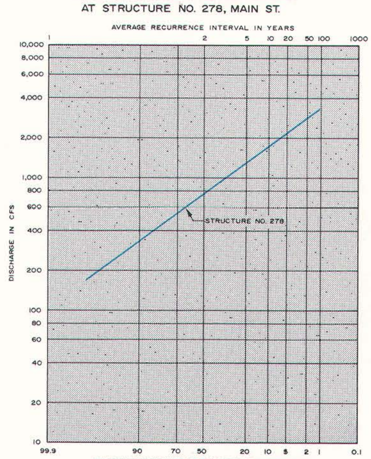


Figure F-17
DISCHARGE-FREQUENCY
NIPPERSINK CREEK SUBWATERSHED
AT STRUCTURE NO. 278, MAIN ST.



Source: U. S. Soil Conservation Service.

Appendix G

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 ______

Cost Estimates

Damage	Sub-total	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 2

RAILROADS

Serial Number ______

River ______ Period of Flood ______ Date of Crest ______ Flood Crest ______

County ______ Flood Zone ______ ft. on ______ gage ______ Other Zones Reported

Railroad ______ Person Interviewed ______

Section ______ to ______ Length of Section ______ Length Submerged ______ Depth Submerged ______ ft.

Cost Estimates

Damage	Sub-total	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 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 4

BRIDGES

Serial Number ______

River ______ Period of Flood ______ Date of Crest ______ Owner ______

County or City ______ Flood Zone ______ Flood Crest ______ ft. on ______ gage

Cost Estimates

Damage	Sub Total	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 | Name | Flood Stage

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 H

FLOOD DAMAGE DERIVATION DATA

Table H-1
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 H-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 H-1 (continued)
RESIDENCE FLOOD DAMAGE

Current Dollar Value	Items	Total Value of Furniture	Base-ment 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			1020	1210	1390	1560	1750	1940	2120	2300	2480	2670	2860	3030	3210	3400	4250	4250	4250	4250	4250
	Furniture	$5610		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			1080	1280	1480	1660	1850	2050	2250	2430	2630	2830	3020	3200	3400	3600	4500	4500	4500	4500	4500
	Furniture	5940		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			1140	1350	1560	1750	1960	2170	2380	2560	2770	2980	3190	3380	3590	3800	4750	4750	4750	4750	4750
	Furniture	6270		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			1200	1420	1640	1840	2060	2280	2500	2700	2920	3140	3360	3560	3780	4000	5000	5000	5000	5000	5000
	Furniture	6600		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			1260	1490	1720	1930	2160	2390	2625	2840	3070	3300	3530	3740	3970	4200	5250	5250	5250	5250	5250
	Furniture	6930		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			1320	1560	1800	2020	2270	2510	2750	2970	3210	3450	3700	3920	4160	4400	5500	5500	5500	5500	5500
	Furniture	7260		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			1380	1630	1890	2120	2370	2620	2875	3100	3360	3610	3860	4090	4350	4600	5750	5750	5750	5750	5750
	Furniture	7590		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			1440	1700	1970	2210	2470	2740	3000	3240	3500	3770	4030	4270	4540	4800	6000	6000	6000	6000	6000
	Furniture	7920		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			1500	1780	2050	2300	2580	2850	3120	3380	3650	3920	4200	4450	4720	5000	6250	6250	6250	6250	6250
	Furniture	8250		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			1560	1850	2130	2390	2680	2960	3250	3510	3800	4080	4370	4630	4910	5200	6500	6500	6500	6500	6500
	Furniture	8580		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			1620	1920	2210	2480	2780	3080	3380	3640	3940	4240	4540	4810	5100	5400	6750	6750	6750	6750	6750
	Furniture	8910		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			1680	1990	2300	2580	2880	3190	3500	3780	4090	4400	4700	4980	5290	5600	7000	7000	7000	7000	7000
	Furniture	9240		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			1740	2060	2380	2670	2990	3310	3625	3920	4230	4550	4870	5160	5480	5800	7250	7250	7250	7250	7250
	Furniture	9570		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			1800	2130	2460	2760	3090	3420	3750	4050	4380	4710	5040	5340	5670	6000	7500	7500	7500	7500	7500
	Furniture	9900		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 H-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.*

Table H-2
CURRENT AGRICULTURAL CROP PRICES

Commodity	Unit	Price[a] 1966	Remarks
Field Crops:			
Hay (all)	ton	$ 18.92	1963 Calendar Year Average
Oats	bu.	0.63	1963 Calendar Year Average
Corn (grain)	bu.	1.06	1963 Calendar Year Average
Soybeans (for beans)	bu.	2.41	1963 Calendar Year Average
Wheat (all)	bu.	1.85	1963 Calendar Year Average
Barley	bu.	0.99	1963 Calendar Year Average
Truck:			
Cabbage (all).	cwt	$ 1.85	1962 Season Average
Potatoes	cwt	2.19	1963 Calendar Year Average

[a]*Adjusted Normalized Price.*

Source: *U. S. Department of Agriculture.*

Appendix I

HYDROLOGIC SOIL GROUPS

SOIL GROUP A

Number	Name
14	Crestview loamy fine sand
75	Rodman gravelly loam
95	(See No. 75, Rodman gravelly loam)
96	(See No. 75, Rodman gravelly loam)
97	Hackett loamy sand
102	Vilas loamy sand
108	Lorenzo-Rodman loams (Rodman gravelly loam)
133	Spinks fine sand
133Z	(See No. 411, Spink fine sand, silty sub.)
134	Spinks loamy fine sand
195	Hackett loamy sand
250	Tedron sandy loam
250V	Tedron sandy loam, (silt & fine sand sub.)
250Y	Tedron sandy loam, loam sub.
251	Tedron loamy sand
251Y	Tedron loamy sand, loam sub.
270	Hackett sandy loam
271	Hackett loamy sand
281	Hackett loam
282	Casco-Rodman loams (Rodman gravelly loam)
288	Hackett loamy sand
289	Hackett sandy loam
410	Spinks loamy fine sand
411	Spinks fine sand, silty sub.
413	Crestview fine sandy loam
414	Crestview loamy fine sand
419	Beach sand

SOIL GROUP B

Number	Name
3	Stony Colluvium
7	Dorchester silt loam
10	Alluvial land
11	Alluvial land
12	Wea silt loam
16	Rome silt loam
16Z	(See No. 362, Theresa silt loam)
18	Sisson silt loam
18Y	Sisson silt loam, loam sub.
19	Sisson fine sandy loam
20	(See No. 120, Warsaw loam)
21	Hebron loam
21Y	Hebron loam, loam sub.
22	Hebron sandy loam
24	Hebron silt loam
31	Rome loam
32	Rome sandy loam

SOIL GROUP B (Continued)

Number	Name
33	Sisson fine sandy loam
33Z	Sisson fine sandy loam (clay sub.)
34	Sisson silt loam
39X	Saylesville loam, gravelly sub.
40R	(See No. 208, Knowles silt loam)
40V	Saylesville silt loam silt & fine sand sub.
40X	Saylesville silt loam (gravelly sub.)
40Y	Saylesville silt loam (loam sub.)
43	(See No. 206, Knowles silt loam, shallow variant)
43R	(See No. 206, Knowles silt loam, shallow variant)
44	Jericho silt loam
56	(See No. 357, Hochheim loam)
69	Casco-Fox silt loam
70	Fox sandy loam
70V	Fox sandy loam, silt & fine sand sub.
70Y	Fox sandy loam, loam sub.
70Z	Fox sandy loam, clay sub.
71	Casco-Fox loams
72	Fox loam
72R	Fox loam, rock sub.
72V	Fox loam, silt & fine sand sub.
72Y	Fox loam, loam sub.
72Z	Fox loam, clay sub.
73	Fox silt loam-Walworth County only
73R	Fox silt loam, rock sub.
73V	Fox silt loam, silt & fine sand sub.
73Y	Fox silt loam, loam sub.
73Z	Fox silt loam, clay sub.
74	(See No. 70, Fox sandy loam)
84	Ockley silt loam
84V	Ockley silt loam, silt & fine sand sub.
84R	Ockley silt loam, rock sub.
84Z	Ockley silt loam, clay sub.
86	Thackery silt loam
86V	Thackery silt loam, silt & fine sand sub.
90	(See No. 91, Parr silt loam)
91	Parr silt loam
91D	Parr silt loam
91N	(See No. 91, Parr silt loam)
92	Parr loam
92N	Parr loam
93	(See No. 73, Fox silt loam)
99	Kewaunee soils
100	Kewaunee silt loam
101	Kewaunee sandy loam

SOIL GROUP B (Continued)

Number	Name
102Z	(See No. 254, Tustin sandy loam)
103	Kewaunee silt loam (12-20% slopes)
103	(See No. 100, Kewaunee silt loam 12-20% slope moderately eroded)
106	Lorenzo silt loam
106Z	Lorenzo silt loam, clay sub.
108	Lorenzo-Rodman loam
110	Lorenzo loam
110R	Knowles silt loam
110Y	Lorenzo loam, loam sub.
110Z	Lorenzo loam, clay sub.
111	Dodge silt loam
112	Calamus silt loam
114	Miami silt loam
116	Celina silt loam
119	Warsaw silt loam
119V	Warsaw silt loam, silt & fine sand sub.
119Y	Warsaw silt loam, loam sub.
119Z	Warsaw silt loam, clay sub.
120	Warsaw loam
120V	(See No. 267, Sisson fine sandy loam)
120Y	Warsaw loam, loam sub.
120Z	Warsaw loam, clay sub.
121	Lorenzo-Rodman loams
122	Lorenzo loam
123	Tippecanoe silt loam
123V	Tippecanoe silt loam, silt & fine sand sub.
123Z	Tippecanoe silt loam, clay sub.
125	Knowles silt loam, shallow variant
151	(See No. 100, Kewaunee silt loam)
152	Lapeer loam, shallow variant
153	Lapeer loam
154	McHenry silt loam
155	McHenry silt loam
156	Lapeer sandy loam
157	Lapeer sandy loam
158	(See No. 152, Lapeer loam, shallow variant)
160	Hochheim-Casco-Sisson loams
161	Dodge silt loam
161R	Dodge silt loam, rock sub.
162	(See No. 362, Theresa silt loam)
170	Casco sandy loam
170V	Casco sandy loam, silt & fine sand sub.
170Y	Casco sandy loam, loam sub.
170Z	Casco sandy loam, clay sub.
172	Casco loam
172R	Casco loam, rock sub.
172V	Casco loam, silt & fine sand sub.
172Y	Casco loam, loam sub.
172Z	Casco loam, clay sub.
173	Casco silt loam
173V	Casco silt loam, silt & fine sand sub.
173Y	Casco silt loam, loam sub.
173Z	Casco silt loam, clay sub.
191	Parr silt loam, shallow variant
195V	Hackett loamy sand, silt & fine sand sub.
195Y	Hackett sandy loam, loam sub.
195Z	Hebron sandy loam
204	Knowles loam
206	Knowles silt loam, shallow variant

SOIL GROUP B (Continued)

Number	Name
208	Knowles silt loam
226	Keyser silt loam
226B	(See No. 91, Parr silt loam)
226D	Keyser silt loam
226N	(See No. 91, Parr silt loam)
226W	(See No. 91, Parr silt loam)
235	(See No. 73, Fox silt loam-Walworth County only)
243	Calamus silt loam
254	Tustin sandy loam
258	(See No. 510, Pecatonica silt loam)
260	(See No. 360, Hochheim silt loam)
261	Hackett sandy loam, wet variant
262	Hackett loamy sand, wet variant
262R	(See No. 208, Knowles silt loam)
265	(See No. 266, Sisson silt loam)
266	Sisson silt loam
266R	Sisson silt loam, rock sub.
266X	Sisson silt loam, sand & gravel sub.
266Y	(See No. 266, Sisson silt loam)
266Z	Sisson silt loam, clay sub.
267	Sisson fine sandy loam
268	Sisson loam
269	Warsaw sandy loam
269Y	(See No. 119, Warsaw silt loam)
270V	Hackett sandy loam
271Z	(See No. 22, Hebron sandy loam)
272	Tustin loamy fine sand
276	Boyer sandy loam
276V	(See No. 267, Sisson fine sandy loam)
276Y	Boyer sandy loam, loam sub.
276Z	Boyer sandy loam, clay sub.
277	Sumner sandy loam
277Y	Sumner sandy loam, loam sub.
277Z	Sumner sandy loam, clay sub.
279	Boyer sandy loam
280	Boyer loamy sand
281Y	(See No. 254, Tustin sandy loam)
282	Casco-Rodman loams (Casco part)
288V	Hackett loamy sand, silt & fine sand sub.
289Y	Hackett sandy loam, loam sub.
289Z	Hackett sandy loam, clay sub.
293	(See No. 243, Calamus silt loam-Washington County only)
297V	Morley silt loam, silt & fine sand sub.
297X	Morley silt loam, gravelly sub.
304	(See No. 206, Knowles silt loam, shallow variant)
305	Knowles silt loam
308	Knowles silt loam, shallow variant
314	Sumner loamy sand
315	Oshtemo loamy sand
316	Boyer loamy sand
316Y	Boyer loamy sand, loam sub.
316Z	Boyer loamy sand, clay sub.
317	Oshtemo loamy fine sand
317Y	(See No. 276Z, Boyer sandy loam, clay sub.)
318	(See No. 22, Hebron sandy loam)
320	Oshtemo sandy loam
323	Ionia sandy loam

SOIL GROUP B (Continued)

Number	Name
323V	Ionia sandy loam
323Y	(See No. 22, Hebron sandy loam)
324	Ionia loam
324V	Ionia loam, silt & fine sand sub.
324Y	Ionia loam, loam sub.
324Z	Ionia loam, clay sub.
325	Varna silt loam
333	Eagle silt loam
333Y	Warsaw silt loam, loam sub.
333Z	Warsaw silt loam, clay sub.
334	Warsaw loam
335	Ionia silt loam
335V	(See No. 266, Sisson silt loam)
335Y	Ionia silt loam, loam sub.
335Z	Ionia silt loam, clay sub.
343	Celina silt loam (on 0-6% slope)
343	Theresa silt loam (over 6% slope)
344	Ashford silt loam
346V	(See No. 266, Sisson silt loam)
348	(See No. 323, Ionia sandy loam)
348	(See No. 343, Theresa silt loam-Washington County only)
352	Lapeer loam
355	Lapeer sandy loam
356	Lapeer sandy loam
357	Hochheim loam
357R	Hochheim loam, rock sub.
357X	Hochheim loam, gravelly sub.
358	Miami loam
359	Hennepin loam
360	Hochheim silt loam
360R	Hochheim silt loam, rock sub.
360V	Hochheim silt loam, silt & fine sand sub.
360X	Hochheim silt loam, gravelly sub.
360Y	(See No. 360, Hocheim silt loam)
361	Miami silt loam
362	Theresa silt loam
362R	Theresa silt loam, rock sub.
362V	Theresa silt loam, silt & fine sand sub.
362X	Theresa silt loam, gravelly sub.
362Z	Theresa silt loam, clay sub.
363	Mayville silt loam
363X	Mayville silt loam, gravelly sub.
363Y	Mayville silt loam
363Z	Mayville silt loam, clay sub.
365	Hocheim-Hennepin loams
365X	Hocheim-Hennepin loams gravelly sub.
366	Hochheim-Theresa loams
367	Hochheim fine sandy loam
377	(See No. 276, Boyer sandy loam)
380	Sumner loamy sand
380Z	(See No. 254, Tustin sandy loam)
391	Wea sandy loam
392	Ockley loam
393	Ockley sandy loam
394	Parr sandy loam
397R	Ozaukee silt loam, rock sub.
397X	Ozaukee silt loam, gravelly sub.
413Z	Crestview fine sandy loam, clay sub.

SOIL GROUP B (Continued)

Number	Name
417	Terrace escarpment outwash
420	Miami silt loam
421	Dodge silt loam
431	Knowles stony silt loam, shallow variant
502	Flagg silt loam
504	Flagg silt loam
504	(See No. 84, Ockley silt loam)
508	Pecatonica silt loam
510	Pecatonica silt loam
512	(See No. 516, Westville silt loam)
514	Westville silt loam
516	Westville silt loam
557	Miami loam
560	Miami silt loam

SOIL GROUP C

Number	Name
2	Stinson silt loam
11WR	(See No. 306, Knowles silt loam, wet variant)
23	(See No. 82, Juneau silt loam)
26	Wauconda fine sandy loam
27	Wauconda silt loam
27Y	(See No. 27, Wauconda silt loam)
27Z	Wauconda silt loam, clay sub.
35	Yahara very fine sandy loam
35Z	Yahara very fine sandy loam, clay sub.
36	Yahara silt loam
37	Kibbie fine sandy loam
37Z	Kibbie fine sandy loam, clay sub.
38	Kibbie silt loam
38R	Kibbie silt loam, rock sub.
38X	(See No. 233, Matherton silt loam)
38Z	Kibbie silt loam, clay sub.
39	Saylesville loam
40	Saylesville silt loam
41	Tichigan silt loam
41N	(See No. 42, Tichigan silt loam)
42	Tichigan silt loam
42R	Tichigan silt loam, rock sub.
42V	Tichigan silt loam, silt & fine sand sub.
42X	Tichigan silt loam, gravelly sub.
42Y	Tichigan silt loam, loam sub.
45	Yahara silt loam
45Z	Yahara very fine sandy, clay loam, clay loam sub.
46	Yahara silt loam
47	Yahara loam
47Z	Yahara loam, clay sub.
51	Aztalan loam
52	Aztalan sandy loam
53	Aztalan silt loam
59Z	Dousman sandy loam, clay sub.
60	Dousman loam
60Z	Dousman loam, clay sub.
77Z	Dousman sandy loam, clay sub.
78	Dousman loam
78V	Dousman loam, silt & fine sand sub.
78Y	Dousman loam, loam sub.

SOIL GROUP C (Continued)

Number	Name
82	Juneau silt loam
83	(See No. 82, Juneau silt loam)
87	Sleeth silt loam
87Z	Sleeth silt loam, clay sub.
89	Briggsville silty clay loam
109	Fabius loam
109R	(See No. 306, Knowles silt loam, wet variant)
109V	Fabius silt loam, silt & fine sand sub.
109Y	Matherton loam, clay sub.
109Z	Fabius silt loam, clay sub.
113	Clyman silt loam
118	Crosby silt loam
124	Crane silt loam
124V	(See No. 38, Kibbie silt loam)
142	Manawa silt loam
143	(See No. 142, Manawa silt loam)
144	Matherton loam, clay sub.
174	Fabius loam
174V	(See No. 38, Kibbie silt loam)
174Y	(See No. 174, Fabius loam)
175	Fabius sandy loam
175V	(See No. 37, Kibbie fine sandy loam)
175Z	Fabius sandy loam, clay sub.
178	Crosby silt loam
182	Fabius silt loam
182V	Fabius silt loam, silt & fine sand sub.
182Y	Fabius silt loam, loam sub.
182Z	Fabius silt loam, clay sub.
184	(See No. 182, Fabius silt loam)
188	Crosby silt loam
189	Bristol silt loam
198	(See No. 178, Crosby silt loam)
203	Matherton loam
203V	Matherton loam, silt & fine sand sub.
203Y	Matherton loam, loam sub.
203Z	Matherton loam, clay sub.
223	(See No. 233, Matherton silt loam)
233	Matherton silt loam
233V	Matherton silt loam, silt & fine sand sub.
233Y	Matherton silt loam, loam sub.
233Z	Matherton silt loam, clay sub.
234	Matherton sandy loam
234V	Matherton Sandy loam, silt & fine sand sub.
234Y	Matherton sandy loam, loam sub.
234Z	(See No. 51, Aztalan loam)
235	(See No. 233, Matherton silt loam)
238	(See No. 328, Pistakee silt loam)
241	(See No. 46, Yahara silt loam)
250Z	Tedrow sandy loam, clay sub.
251Z	Tedrow loamy sand, clay sub.
261Z	(See No. 51, Aztalan loam)
263	(See No. 45, Yahara silt loam)
278	Clyman silt loam
283	Mosel sandy loam
284	Mosel sandy loam
293	(See No. 297, Morley silt loam)
294	(See No. 297, Morley silt loam)
295	Morley-Beecher silt loams
297	Morley silt loam
297S	Morley sandy loam
297Y	Morley silt loam
299	Blount silt loam
300	Ashkum-Beecher silt loams
306	Knowles silt loam, wet variant
307	Knowles silt loam, wet variant
311	Manawa loam
328	Pistakee silt loam
328W	(See No. 328, Pistakee silt loam)
328Y	(See No. 328, Pistakee silt loam)
328Y	Pistakee silt loam
331	Markham-Elliott silt loam
332	Kane silt loam
332V	Kane silt loam, silt & fine sand sub.
332Y	Kane silt loam, loam sub.
332Z	Kane silt loam, clay sub.
336	Markham silt loam
340R	(See No. 306, Knowles silt loam wet variant)
345	Nenno silt loam
345X	(See No. 233, Matherton silt loam)
346	Kane loam
346Y	Kane loam, loam sub.
363R	Mayville silt loam, rock sub.
364	Lamartine silt loam
364V	Lamartine silt loam, silt & fine sand sub.
364X	Lamartine silt loam, gravelly sub.
364Z	Lamartine silt loam, clay sub.
369	Mosel silt loam
369Z	(See No. 51, Aztalan loam)
370	Mosel sandy loam
371	Mosel loam
387V	Granby loamy sand silt & fine sand sub.
397	Ozaukee silt loam
397V	Ozaukee silt loam, silt & fine sand sub.
397Y	Ozaukee silt loam, loam sub.
399	Mequon silt loam
416	Terrace escarpment till
501	(See No. 505, Flagg silt loam, wet variant)
505	Flagg silt loam, wet variant
511	Flagg silt loam, wet variant
3251	Elliott silt loam
3251V	Elliott silt loam, silt & fine sand sub.
3261	(See No. 3361, Beecher silt loam)
3361	Beecher silt loam
3975	(See No. 397, Ozaukee silt loam)

SOIL GROUP D

Number	Name
4	Marsh
5	Lawson silt loam
5W	Sawmill silt loam
7W	Lawson silt loam
9	(See No. 450, Houghton Muck)
10W	Alluvial land, wet
11W	Alluvial land, wet
15	Hillside seepage
23	Lawson silt loam

SOIL GROUP D (Continued)

Number	Name
28	Colwood fine sandy loam
28Z	Colwood fine sandy loam, clay sub.
29	Colwood silt loam
29C	(See No. 29, Colwood silt loam)
29V	Colwood silt loam
29X	Colwood silt loam, gravelly sub.
29Z	Colwood silt loam, clay sub.
30	Colwood silt loam
48	Keowns silt loam
48Z	Keowns silt loam, clay sub.
49	Keowns fine sandy loam
49Y	Keowns fine sandy loam, loam sub.
50	(See No. 48, Keowns silt loam)
54	Lawson silt loam
59	Dousman sandy loam
63	Brookston silt loam
63V	(See No. 29, Colwood silt loam)
63W	(See No 231, Brookston silt loam)
64	Brookston silt loam
66	Granby fine sandy loam
67	Granby fine sandy loam
76	Sebewa silt loam
76R	Sebewa silt loam, rock sub.
76V	Sebewa silt loam, silt & fine sand sub.
76W	(See No. 76, Sebewa silt loam)
76Y	Sebewa silt loam, loam sub.
76Z	Sebewa silt loam, clay sub.
77	Dousman sandy loam
79	Waukechon loam
79Z	(See No. 330, Navan loam)
80	Sebewa loam
80V	Sebewa loam, silt & fine sand sub.
80W	(See No. 80, Sebewa loam)
80Y	Sebewa loam, loam sub.
80Z	Sebewa loam, clay sub.
81	Sebewa sandy loam
81Z	(See No. 330, Navan loam)
126	Westland silt loam
126V	Westland silt loam, silt & fine sand sub.
126Y	Westland silt loam, loam sub.
126Z	Westland silt loam, clay sub.
127	(See No. 126, Westland silt loam)
128	(See No. 126, Westland silt loam)
165	Poygan silt loam
171	Poygan silty clay loam
176	Mussey loam
176V	Mussey loam
176Z	Mussey loam, clay sub.
179	Brookston silt loam
180	Mussey sandy loam
181	Mussey silt loam
181V	Mussey silt loam, silt & fine sand sub.
181Y	Mussey silt loam, loam sub.
181Z	Mussey silt loam, clay sub.
212	Ehler silt loam
212R	Ehler silt loam, rock sub.
212X	Ehler silt loam, gravelly sub.
212Y	Ehler silt loam
213	Ehler silt loam
213C	(See No. 212, Ehler silt loam)

SOIL GROUP D (Continued)

Number	Name
213R	Ehler silt loam, rock sub.
213V	Colwood silt loam
213W	(See No. 212, Enler silt loam)
213Y	(See No. 213Y, Ehler silt loam)
214	Ehler silt loam
215	Ehler silt loam
215C	(See No. 212, Ehler silt loam)
216	Ehler silt loam
217	Bono silty clay loam
217Y	(See No. 217, Bono silty clay loam)
218	Bono silty clay loam
218V	Bono silty clay loam
218Y	Bono silty clay loam
228	Rollin muck, shallow phase
228C	(See No. 458, Rollin muck, shallow)
231	Brookston silt loam
231Z	Brookston silt loam, clay sub.
232	(See No. 231, Brookston silt loam)
285	Mussey loam
286	Mussey silt loam
287	Mussey loam
290	(See No. 29, Colwood silt loam)
290X	(See No. 76, Sebewa silt loam)
296	(See No. 298, Ashkum silty clay loam)
298	Ashkum silty clay loam
300	Ashkum-Beecher silt loam
302	Rollin muck
303	Alluvial land, rock sub.
326	Abington silt loam
326C	(See No. 326, Abington silt loam)
326W	(See No. 326, Abington silt loam)
326Z	Abington silt loam, clay sub.
327	Wallkill silt loam
329	(See No. 340, Navan silt loam)
330	Navan loam
338	Ashkum silty clay loam
339	Abington silty clay
340	Navan silt loam
340W	(See No. 330, Navan loam)
340Z	(See No. 330, Navan loam)
368	(See No. 386, Granby fine sandy loam)
386	Granby fine sandy loam
386Y	Granby fine sandy loam, loam sub.
386Z	Granby fine sandy loam, clay sub.
387	Granby loamy sand
398	Ashkum silty clay loam
449	Houghton mucky peat
450	Houghton muck
450C	(See No. 450, Houghton muck)
450W	(See No. 450, Houghton muck)
451	Houghton mucky peat
451W	(See No. 451, Houghton mucky peat)
452	Adrian muck
452C	(See No. 452, Adrian muck)
452Z	Adrian muck, clay sub.
453	Adrian mucky peat
454	Palms muck
454C	(See No. 454, Palms muck)
454W	(See No. 454, Palms muck)
455	Palms mucky peat

SOIL GROUP D (Continued)

Number	Name
455V	(See No. 455, Palms mucky peat
456	Ogden muck
456C	(See No. 456, Ogden muck)
456W	(See No. 456, Ogden muck)
457	Ogden mucky peat
458	Rollin muck, shallow
459	Rollin muck

SOIL GROUP D (Continued)

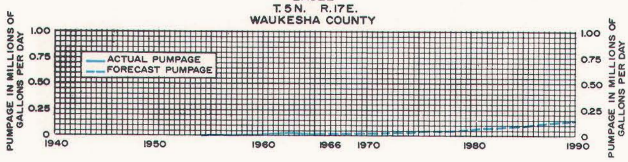
Number	Name
460	Rollin mucky peat
461	Muskego muck
461Y	(See No. 454, Palms muck)
462	Houghton peat, acid variant
465	(See No. 456, Ogden muck)
550	Ehler silt loam, rock sub.
1151	(See No. 451, Houghton mucky peat)

Source: U. S. Soil Conservation Service.

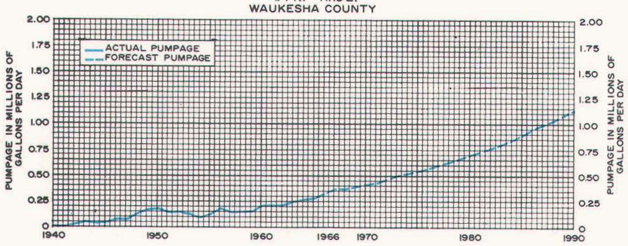
Appendix J

FORECAST TRENDS FOR INDIVIDUAL MUNICIPAL PUMPAGES FOR THE FOX RIVER WATERSHED

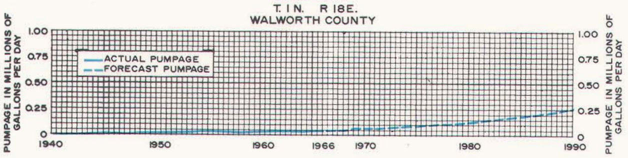
EAGLE
T. 5 N. R. 17 E.
WAUKESHA COUNTY



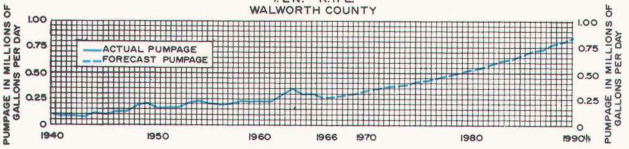
PEWAUKEE
T. 7 N. R. 19 E.
WAUKESHA COUNTY



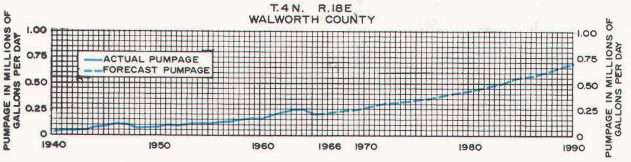
GENOA CITY
T. 1 N. R 18 E.
WALWORTH COUNTY



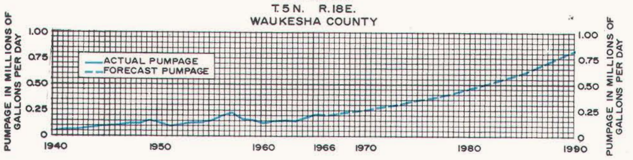
WILLIAMS BAY
T. 2 N. R. 17 E.
WALWORTH COUNTY



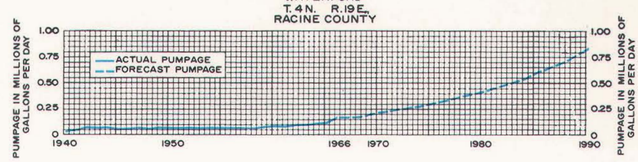
EAST TROY
T. 4 N. R. 18 E
WALWORTH COUNTY



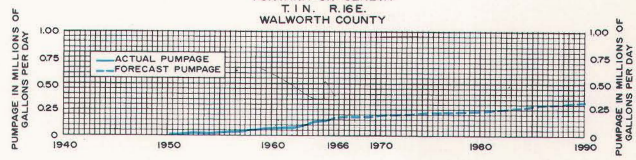
MUKWONAGO
T 5 N. R. 18 E.
WAUKESHA COUNTY



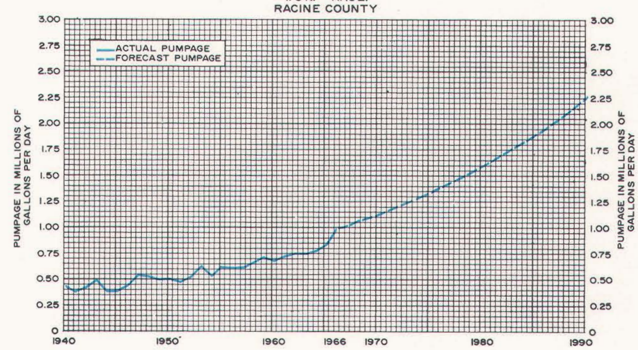
WATERFORD
T. 4 N. R. 19 E.
RACINE COUNTY



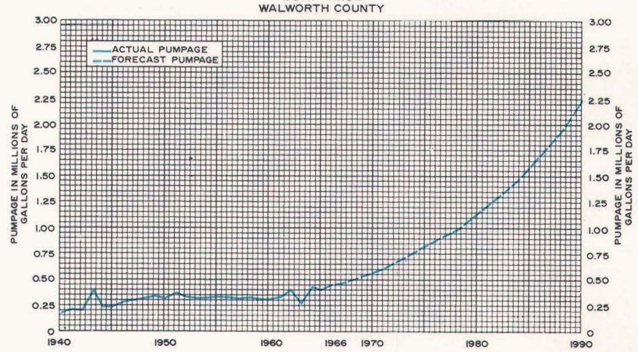
FONTANA-ON-GENEVA
T. 1 N. R. 16 E.
WALWORTH COUNTY



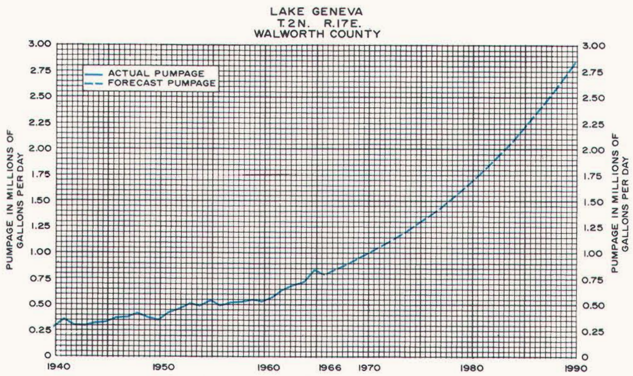
BURLINGTON
T. 3 N. R. 19 E.
RACINE COUNTY

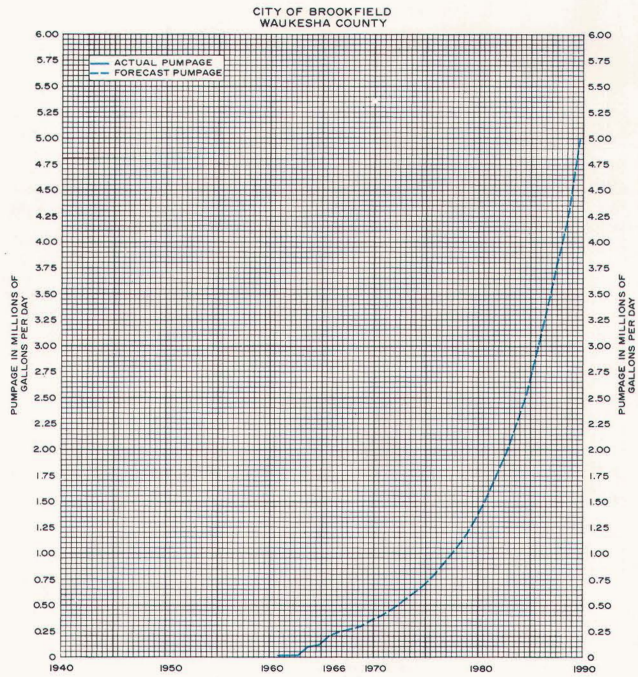


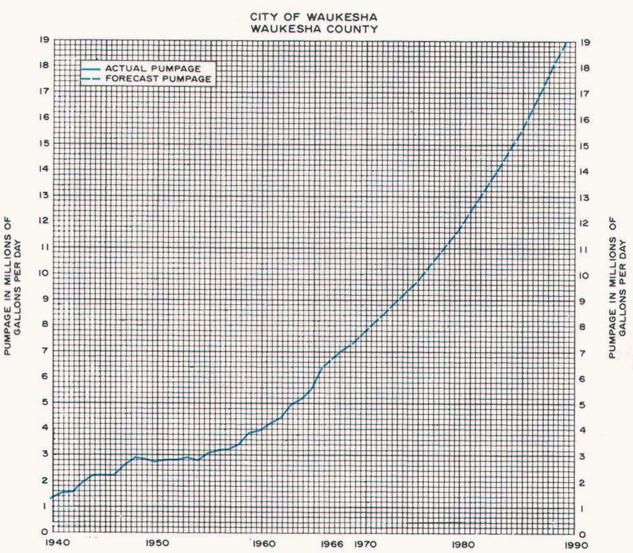
ELKHORN
T. 3 N. R. 16 E.
WALWORTH COUNTY



Source: U. S. Geological Survey.







Source: U. S. Geological Survey.

Appendix K

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.

Source: Wisconsin Department of Natural Resources.

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Appendix L

DEFINITION OF WETLAND TYPES IN WISCONSIN

A wetland, as defined for the 1961 State 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, 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 cattails, river rush, bulrushes, and spikerushes.

4. Deep Marsh
   Water from six inches to three feet in depth during growing season. Vegetation of cattails, reeds, bulrushes, spikerushes, and pondweed.

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, cranberries, and labrador tea.

The correlation between the U. S. Department of 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 203 numbered wetland units studied in the Fox 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 203 numbered wetland units identified in the Fox 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 203 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 955 points for types yielded the following data:

Wisconsin Wetland Type Number	Wetland Type Name	Number Of Points	Percent Of Total Points
2	Meadow	395	41.3
1, 3, 4, 7	Marsh	296	31.0
5	Shrub swamp	141	14.8
6	Timber Swamp	123	12.9
Total		955	100.0

The marsh category (wetland types 1, 3, 4, and 7) included the shallow and deep marsh calles, 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 22 percent shallow marsh, 8 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 31 percent. The remaining categories are drier types and comprise 69 percent.

Appendix M

WETLAND UNITS IN AND MANAGEMENT RECOMMENDATIONS FOR THE FOX RIVER WATERSHED

Table M-1

Wetland Unit Number[a]	Area in Acres[b]	Major Species[c] To Be Managed	Quality Rating[d]	Recommended Management[e]
1	87	D	3	Pothole
2	150	D	2	Pothole
3	145	P,D,W,M	2	Pothole
4	48	P	3	Pothole
5	51	P	3	Dike
6	393	D	1	Pothole
7	896	P,W,D	1	Pothole
8	256	W,M	1	Pothole
9	243	P,W,M	2	Pothole
10	231	P,W	2	Pothole
11	267	P,W,M	1	Pothole
12	391	W,M,P	1	Pothole
14	1,426	P,D,W,M	1	Pollution Control
15	290	W,M,P	1	Pollution Control
16	102	P,W	1	
17	343	W,D	1	Pothole
18	185	P,W	2	Pothole
20	216	D,W,M,P	2	Pothole
21	248	P,W,M	2	Pothole
22	219	W,M,S,P	2	Pothole
23	183	W,M	3	Pothole
24	271	P	2	Plug Ditches
25	188	P	3	Pothole
26	299	P,R	2	
27	145	P	3	
28	284	P	2	
29	261	W,P	2	Pothole
30	74	P	3	
31	160	P,D	3	Pothole
34	188	P	2	Pothole
36	208	W	2	Pothole
37	73	P	3	Pothole
39	155	W	2	Pothole
40	332	W,P,M	2	Pothole
41	351	W,M,P,D	2	Pothole
42	343	P,D,P	1	Pothole
43	803	M,W,P,D	1	Pothole
44	241	P,D	2	Pothole
46	246	P,D	3	Pothole
47	170	D,P	3	Pothole
49	54	D	3	Pothole
50	172	P,D	3	
51	43	P,W,M	3	Pothole
52	233	P,D	2	Pothole
53	333	P,D	2	
54	299	P,D,W,M	1	Pothole
55	165	W	2	Flood Part
56	672	Public Hunting Ground	1	Pothole
57	784	Public Hunting Ground	1	
58	1,543	Public Hunting Ground	1	
59	120	M,W	2	Pothole
60	297	W,M	1	Pothole
61	196	W,M	1	
62	79	W,D	2	Pothole
63	393	W,M	1	Pothole
64	274	W,M	1	
65	587	P,D	1	Pothole
66	500	W,M	1	Dike-Pothole
67	38	P,W	3	Pothole
68	61	P,W	3	Low Dike
70	571	M,W	1	Pothole
71	167	M,W	2	Pothole
72	419	W,M	1	Pothole
73	91	P,W,M	2	Pothole
74	84	P,D	2	
75	160	P,W	2	Pothole
76	140	P,W	3	Pothole
77a	1,196	W,M	1	Pothole
77b	1,289	W,M	1	
77c	1,186	W,M	1	
78	23	P	3	
79	64	W,M	2	
80	106	P,D	2	
81	36	W	2	
82	170	P,W	2	Pothole
83	21	W,M	2	
84	48	W,M	1	Add 25 Potholes
85	130	W,M	1	Potholes
86	153	W,M	2	Potholes
87	33	W,M	2	Potholes
88	142	W,M	2	Potholes
89	417	W	1	Potholes
90	375	W,M	1	Potholea
91	21	W,M	2	
92	327	W,M	1	
93	132	W	2	Pothole
94	50	W	1	Pothole
95	960	Public Hunting Ground	1	
96	358	Public Hunting Ground		
97	71	P	2	
98	152	P,D	2	Pothole
99	97	W,M	2	Pothole
100	254	W,M	1	Pothole
101	165	W,M	1	Pothole
102	211	P,W	2	Pothole
103	325	W,M,P	2	Pothole
104	221	Public Hunting Ground	2	
105	693	Public Hunting Ground	1	
106	366	P,W,M	1	Pothole
107	391	P,W	2	Pothole
108	71	P,W	3	Pothole
109	325	W,M	1	Pothole
110	132	W,M	1	Pothole
111	842	Public Hunting Ground	2	
112	102	W,M	2	
113	429	P,D,W	1	Pothole
114	396	P,W,D	1	Pothole
115	327	P,W,M,D	2	Low Dam
116	516	P,D,W	1	Pothole
117	244	P,W,M	2	Pothole
118	178	Public Hunting Ground	2	
119	59	W,P	2	Pothole
120	396	W,M,P	2	Pothole
121	64	W,M,P	1	Pothole
122	91	W,M	3	
123	413	P,W	2	Pothole
124	483	P,W	1	Pothole
125	271	W,M,P	1	Pothole
126	233	W,M	2	Pothole
127	233	P,W	2	Pothole
128	257	W,M,P	2	Pothole
129	36	P,D	3	Pothole
130	381	P,W,D	2	Pothole
131	79	W,M,P	2	
132	290	W,M,P	1	Pothole
133	464	W,P	2	Pothole
134	137	W	2	Pothole
135	728	P,W	1	Pothole
136	233	P,W	2	Pothole
137	576	P,D,W	1	Pothole
138	251	P,W	2	Pothole
139	355	P,M,W	2	Pothole

Source: Wisconsin Department of Natural Resources.

Table M-I (Continued)

Wetland Unit Number[a]	Area in Acres[b]	Major Species[c] To Be Managed	Quality Rating[d]	Recommended Management[e]
140	333	P,W	2	Pothole
141	115	W,M	2	
142	162	P,W	2	Pothole
143	102	W,M	2	
144	36	W,D,M	3	
145	251	W,M,P	1	
146	678	Public Hunting Ground	1	
147	183	Public Hunting Ground	2	
148	158	W,M	1	Pothole
149	104	W,M	2	Pothole
150	188	P,W	2	Pothole
151	160	W,M	2	Pothole
152	195	Public Hunting Ground	2	
153	73	P,D	3	
154	285	P	2	
155	81	P	2	
156	112	P	3	
157	63	P	3	
158	677	P,D	1	
159	228	P	2	Shooting Preserve
160	36	P,D	3	
162	213	P,D	3	Pothole
163	51	W,M	2	
164	271	Public Hunting Ground	2	
165	114	Public Hunting Ground	2	
166	469	Public Hunting Ground	2	
167	30	Public Hunting Ground	2	
168	567	Public Hunting Ground	2	
169	71	Public Hunting Ground	3	
170	188	W,P,D	2	Pothole
171	66		3	Pothole
172	152	W,M	2	Pothole
173	196	W,M	2	Pothole
174	160	P	3	Pothole
175	69	P,W,M	3	Pothole
176	40	P,W	3	Pothole
177	124	P,W,M	1	Pothole
178	73	P,D,W	2	Pothole

Wetland Unit Number[a]	Area in Acres[b]	Major Species[c] To Be Managed	Quality Rating[d]	Recommended Management[e]
179	78	W,M	3	Pothole
180	81	W,M	2	Pothole
181	106	P	2	Pothole
182	54	P,W	3	Pothole
183	317	Public Hunting Ground	1	
184	338	P	1	Pothole
185	96	P	3	
186	74	P,W	2	
187	96	P,W	2	Pothole
188	185	W,M,P	2	Pothole
189	87	Public Hunting Ground	2	
190	350	P,W,M	2	Pothole
191	106	W,P	3	
192	865	P,D,W	1	Pothole
193	417	Public Hunting Ground	1	
194	332	Public Hunting Ground	1	
195	83	W,M	2	
196	46	W	3	Pothole
197	142	P,W	2	Pothole
198	58	W,M,P	2	Pothole
199	122	P,D	2	
200	78	P,W	3	Pothole
201	120	P,W,M	2	Pothole
202	165	P,W	2	Pothole
203	307	P,W	2	Pothole
204	153	P,W	2	Pothole
205	66	M	3	
206	130	W,M,P,D	1	Pothole
207	134	W,P	2	Pothole
208	106	W,P	2	Pothole
209	229	W,M,P	1	Pothole
210	193	W,M	1	Pothole
211	455	W,M	1	Pothole
212	439	P,W	3	Pothole
213	132	P,W	3	Pothole
Total	53,226			

[a] *Number: See Index Map. 21*

[b] *Acreage was determined by dot counts of area, as outlined at a scale of 1:24000. 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 an East-West axis or two miles on a North-South axis were subdivided to conform to this limit. Also, a break was made at town or county lines.*

[c] *The listing 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. No species are stated for state-owned wildlife areas.*

[d] *The quality evaluation is not done in a sense of priority for preservation, since all the designated areas are needed. Rather, the rating should serve as a guideline to the degree to which management effort must be made. (In some cases of lower indicated quality, no management specification has been made. Here the ''space'' aspect of the area is of sufficient importance to warrant protection, although the intrinsic ''quality'' may be low. Also, no management is specified for state wildlife areas.) The rating is based on the following guidelines:*

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 b).

2) Vegetation – this factor is a major contributor to wildlife production and use potential. Certain types also greatly enhance the aesthetic appeal of an area. Tamarack swamps and other lowland timber types are rated highly.

Marsh types of vegetation are especially valuable. Sedge meadows are of value for certain species of birds but of lower general value than some of the mixed vegetation types.

3) Wetness–usually animal productivity is highest per unit area when wetlands have some small portion of their area deep enough to permit aquatic vegetative growth and to prevent solid stands of emergent vegetation from developing. Hence the axiom, the deeper the water on a wetland, the higher the rating.

4) Location–areas immediately adjacent to urban expansion were rated lower than those more removed from urban encroachment; areas within environmental corridors were rated higher than those outside; and areas in or adjacent to public lands were rated somewhat higher than those outside, especially those in or near existing wildlife areas. Nearness to stream course or lakes often boosted the rating.

[e] *Many wetlands are in excellent balance and condition. Preservation of the present conditions is the only requirement. Those of poorer quality should be maintained as is. No practical management techniques are applicable to those wetlands at this time. Their submarginal water supply is the factor usually limiting improvement possibilities.*

1) Restriction of Grazing–Excessive grazing may destroy so much cover as to make a wetland almost valueless for wildlife, especially during fall and winter. Species most affected include deer, pheasants, and cottontails.

To provide protection from the heavy snows in most winters, patches of heavy brush or trees may provide desirable cover in wetlands. Such cover will usually establish itself naturally if grazing is limited or if burning is practiced for a few years. Too heavy a cover over a large part of a wetland is not good either. Restricted grazing may be permitted to open up the heavier stands. In general, light grazing is preferable to no grazing, but excessive grazing is usually highly detrimental to wildlife interests.

2) Ponds and Potholes–Creation of small, open water areas is recommended for many wetlands. No other management technique will *give comparable benefits over such a long period of time with little or no maintenance required. One or more of the following values may be associated with any one pond, depending on yearly and seasonal variation:*

(1) Increase in the variety and concentration of wildlife for general nature study and enjoyment.

(2) Increase in duck nesting.

(3) Provision of watering and feeding areas for wildlife, that is, providing water which might not be available during drouth periods. Ponds are important feeding sites for many birds, such as swallows, as in early spring when the only place food insects may be found is over water.

(4) Ponds may be designed for fish production, including production of sport fishing or minnows. When licensed as a fish hatchery, these fish may be sold and will probably always have a ready market. Special designs are needed when fish production is desired.

(5) Increased populations of insects and amphibians known to feed heavily on mosquitos. Ponds often produce hellgrammites which are predators on mosquito larvae and which serve as fish bait. Upon maturing, hellgramites become dragonflies, which also eat mosquitos. Dragonflies and their smaller relatives, the damsel flies, have some aesthetic value because of their coloration and unique methods of flight. They are enjoyed by most everyone that observes them. Deeper ponds may also ensure the survival of fish which help control mosquitos. Mosquito production is generally low from permanent bodies of water, although a local water area may be blamed due to popular misconception.

(6) Increase in hunting and trapping opportunities.

(7) Provision of other recreational aspects, including possible swimming and skating.

(8) Provision of a source of water for fighting fires in rural areas, including the construction of water areas.

Bulldozer and heavy earth moving equipment may sometimes be used to construct ponds in temporarily dry situations. Draglines, however, are most commonly used. Potholes can be blasted relatively cheaply with the use of ammonium nitrate, but this method has only limited use in south-eastern Wisconsin with its concentration of homes, roads, and utility lines.

Costs of construction can be reduced by various means. Private ponds for wildlife in some counties may obtain cost sharing up to 50 percent from the federal government. Tax concessions may be obtained if the pond is part of a business venture, such as a fish hatchery. Ponds needed in school, park, and other public programs may obtain cost sharing from the county bounty conservation fund, LAWCON, education act funds, and so forth.

Impoundments made by diking form another type of pond or small lake. Technical specifications for dikes and control structures can be obtained from SCS offices. Locations of suggested ponds is only approximate. Depending on which wetland is involved, as many as 10 ponds might be desirable for every pond shown on the management maps. Size of ponds may be as small as 20x20 feet or up to several acres in size. Several small ponds can be considered the equivalent of one large pond, the size and number used depending on finances, objectives, and character of the wetland. Special consideration should be given to creation of ponds where they will increase recreational opportunities, even though no public access is involved. Thus, ponds along highways may provide opportunities for bird watching if parking facilities are available. Off-shoulder parking, waysides and so forth, could be provided at many places to broaden the recreational base.

Source: Wisconsin department of Natural Resources.

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Appendix N

LIST OF MAMMALS OF THE FOX RIVER WATERSHED (ARRANGED SYSTEMATICALLY)

Virginia Opossum
Prairie Mole
Star-Nosed Mole
Cinereous Shrew
Smoky Shrew
Hoy's Pigmy Shrew
Least Shrew
Kirtland's Short-Tailed Shrew
Little Brown Bat
Say's Bat
Silver-Haired Bat
Georgian Bat
Big Brown Bat
Red Bat
Hoary Bat
Upper Mississippi Valley Raccoon
Ermine
Least Weasel
New York Weasel
Mississippi Valley Mink
Minnesota Skunk
Illinois Skunk
Jackson's Badger
Eastern Red Fox
Wisconsin Gray Fox
Rufescent Woodchuck
Striped Ground Squirrel
Franklin's Ground Squirrel
Ohio Chipmunk
Northern Gray Squirrel
Western Fox Squirrel
Little Flying Squirrel
Michigan Beaver
Prairie Deer Mouse
Northern White-Footed Mouse
Cooper's Lemming Mouse
Gapper's Red-Backed Mouse
Meadow Vole
Prairie Vole
Northern Pine Mouse
Common Muskrat
House Mouse
Norway Rat
Meadow Pimping Mouse
White-Tailed Jackrabbit
Mearns' Cottontail
Northern White-Tailed Deer

SOURCE: Wisconsin Department of Natural Resources.

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Appendix O

LIST OF BIRDS OF THE FOX RIVER WATERSHED (ARRANGED SYSTEMATICALLY)

	Migrant	Breeder
Common Loon	M	
Horned Grebe	M	
Pied-Billed Grebe		B
White Pelican	M	
Double Crested Cormorant	M	
Great Blue Heron		B
American Egret	M	
Green Heron		B
Black Crested Night Heron		B
American Bittern		B
Least Bittern		B
Whistling Swan	M	
Canada Goose	M	
Lesser Snow Goose	M	
Blue Goose	M	
Mallard		B
Black Duck		B
Gadwall	M	
Baldpate	M	
Pintail		B
Green-Winged Teal	M	
Blue-Winged Teal		B
Shoveller		B
Wood Duck		B
Redhead		B
Ring-Necked Duck		B
Canvas-Back Duck	M	
Greater Scaup Duck	M	
Lesser Scaup Duck	M	
American Golden-Eye	M	
Buffle-Head	M	
Old Squaw	M	
White-Winged Scoter	M	
Ruddy Duck		B
Hooded Merganser		B
American Merganser	M	
Red-Breasted Merganser	M	
Turkey Vulture		B
Goshawk	M	
Sharp-Skinned Hawk	M	
Cooper's Hawk		B
Red-Tailed Hawk		B
Red-Shouldered Hawk		B
Broad-Winged Hawk	M	
American Rough-Legged Hawk	M	
Golden Eagle	M	

	Migrant	Breeder
Bald Eagle	M	
Marsh Hawk		B
Osprey	M	
Duck Hawk	M	
Pigeon Hawk	M	
Sparrow Hawk		B
Ruffed Grouse		B
Hungarian Partridge		B
Bobwhite		B
Ring-Necked Pheasant		B
Sandhill Crane	M	
King Rail		B
Virginia Rail		B
Sora		B
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	
Knot	M	
Pectoral Sandpiper	M	
White-Rumped Sandpiper	M	
Baird's Sandpiper	M	
Least Sandpiper	M	
Red-Backed Sandpiper	M	
Dowitcher	M	
Semipalmated Sandpiper	M	
Sanderling	M	
Northern Phalarope	M	
Wilson's Phalarope		B
Herring Gull	M	
Ring-Billed Gull	M	
Bonaparte's Gull	M	
Forster's Tern		B
Common Tern	M	
Caspian Tern		B
Black Tern		B

	Migrant	Breeder
Rock Dove		B
Mourning Dove		B
Yellow-Billed Cuckoo		B
Black-Billed Cuckoo		B
Barn Owl		B
Screech Owl		B
Great Horned Owl		B
Snowy Owl	M	
Barred Owl		B
Long-Eared Owl		B
Short-Eared Owl	M	
Saw-Whet Owl		B
Whip-Poor-Will		B
Night Hawk		B
Chimney Swift		B
Ruby-Throated Hummingbird		B
Belted Kingfisher		B
Flicker		B
Pileated Woodpecker	M	
Red-Bellied Woodpecker		B
Red-Headed Woodpecker		B
Yellow-Bellied Sapsucker		B
Hairy Woodpecker		B
Downy Woodpecker		B
Kingbird		B
Crested Flycatcher		B
Phoebe		B
Yellow-Bellied Flycatcher	M	
Arcadian Flycatcher		B
Alder Flycatcher		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		B
Purple Martin		B
Blue Jay		B
Crow		B
Black-Cap 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	
Prairie Marsh Wren		B
Short-Billed Marsh Wren		B

	Migrant	Breeder
Catbird		B
Brown Thrasher		B
Robin		B
Wood Thrush		B
Hermit Thrush	M	
Olive-Backed Thrush	M	
Gray-Cheeked Thrush	M	
Veery		B
Bluebird		B
Blue-Gray Gnatcatcher		B
Golden-Crested Kinglet	M	
Ruby-Crowned Kinglet	M	
American Pipit	M	
Bohemian Waxwing	M	
Cedar Waxwing		B
Northern Shrike	M	
Migrant Shrike		B
Starling		B
Yellow-Throated Vireo		B
Blue-Headed Vireo	M	
Red-Eyed Vireo		B
Philadelphia Vireo	M	
Warbling Vireo		B
Blue and 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	
Blue-Throated-Blue Warbler	M	
Myrtle Warbler	M	
Blue-Throated-Green Warbler	M	
Cerulean Warbler		B
Blackburnian Warbler	M	
Chestnut-Sided Warbler		B
Bay-Breasted Warbler	M	
Black-Poll Warbler	M	
Pine Warbler	M	
Palm Warbler	M	
Oven-Bird		B
Grinnell's Water Thrush		B
La. Water Thrush	M	
Connecticut Warbler	M	
Mourning Warbler		B
Northern Yellow-Throat		B
Yellow-Breasted Chat	M	
Wilson's Warbler	M	
Canada Warbler	M	

	Migrant	Breeder
Redstart		B
English Sparrow		B
Bobolink		B
Eastern Meadowlark		B
Western Meadowlark		B
Yellow-Headed Blackbird		B
Redwing		B
Orchard Oriole		B
Baltimore Oriole		B
Rusty Blackbird	M	
Brewer's Blackbird	M	
Bronzed Grackle		B
Cowbird		B
Scarlet Tanager		B
Cardinal		B
Rose-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

	Migrant	Breeder
Red Crossbill	M	
White-Winged Crossbill	M	
Red-Eyed 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	
Chipping Sparrow		B
Clay-Colored Sparrow		B
Field Sparrow		B
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.

INTERAGENCY STAFF
FOX RIVER WATERSHED STUDY

U. S. DEPARTMENT OF AGRICULTURE, SOIL CONSERVATION SERVICE

William W. Russell
State Conservationist

Curt Lindholm
Assistant State Conservationist

Carl K. Otte
Watershed-River Basin Staff Leader

Dale D. Secher
Civil Engineer

Thomas J. Faliski
Hydraulic Engineer

HARZA ENGINEERING COMPANY

V. A. Koelzer
Vice-President

James C. Ringenoldus
Head, Water Resources Division

Richard E. Fedler
Water Resources Engineer

H. J. Day
Head, Water Planning Department

U. S. GEOLOGICAL SURVEY

Charles L. R. Holt, Jr.
District Chief, Water Resources Division

Kenneth B. Young
Associate District Chief, Water Resources Division

Jack H. Green
Assistant District Chief, Ground Water Branch

Richard D. Hutchinson
Geologist, Ground Water Branch

Dale Cotter
Hydrologist, Ground Water Branch

WISCONSIN DEPARTMENT OF NATURAL RESOURCES

Cyril Kabat
Assistant Director, Bureau of Research, Division of Services

D. John O'Donnell
Supervisor, Watershed Development Unit

D. R. Thompson
Supervisor, Technical Services Section
Bureau of Research

Robert L. Fisher
Assistant Watershed Coordinator

Ruth L. Hine
Editor

Theodore Kouba
Specialist, Bureau of Research

Ronald Poff
Natural Resource Specialist, Bureau of Fish Management

C. W. Threinen
Natural Resource Specialist, Bureau of Fish Management

SOUTHEASTERN WISCONSIN REGIONAL PLANNING COMMISSION

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Senior Planner

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Executive Secretary-Editor