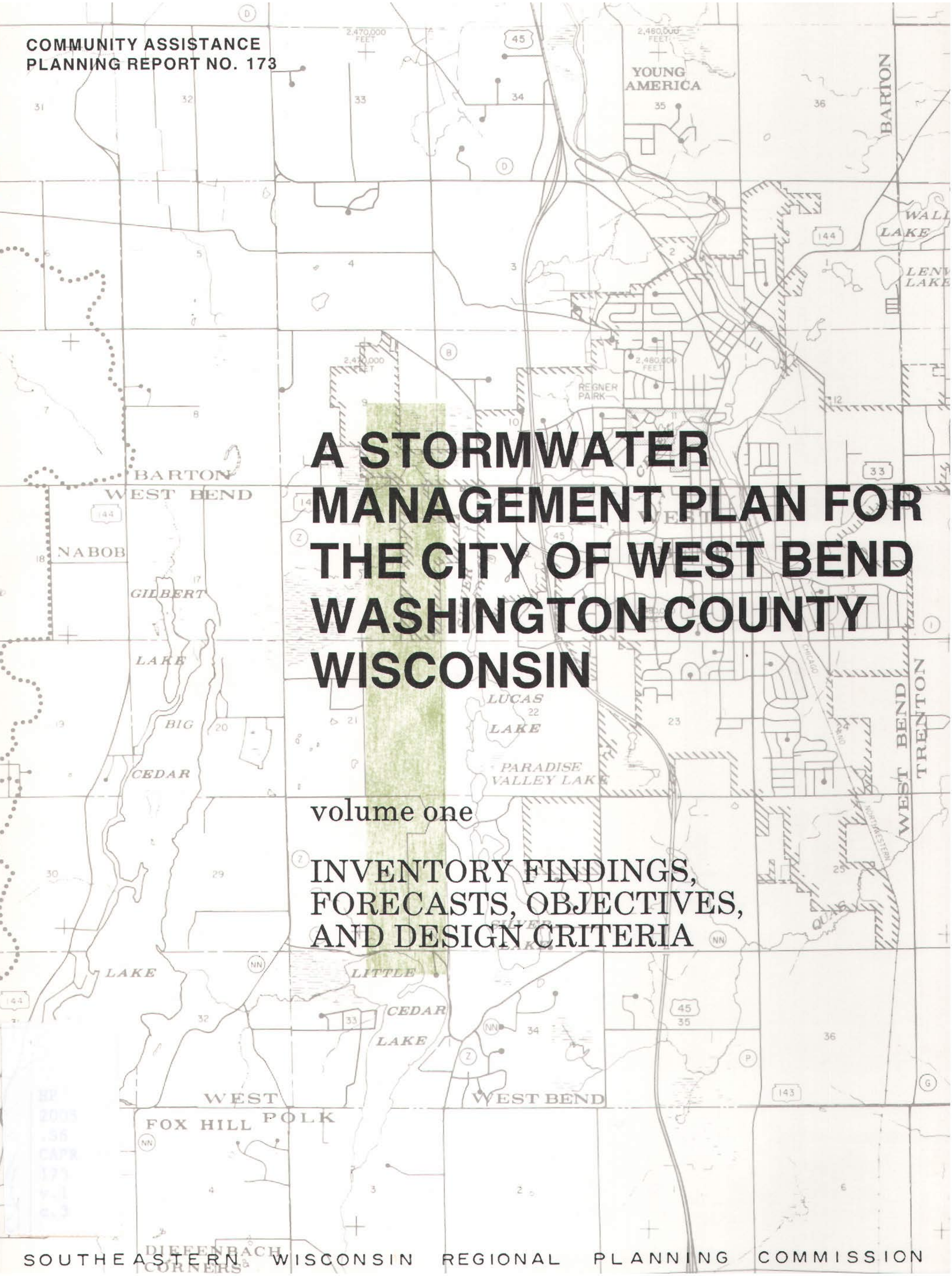
COMMUNITY ASSISTANCE
PLANNING REPORT NO. 173

A STORMWATER MANAGEMENT PLAN FOR THE CITY OF WEST BEND WASHINGTON COUNTY WISCONSIN

volume one

INVENTORY FINDINGS, FORECASTS, OBJECTIVES, AND DESIGN CRITERIA



SOUTHEASTERN WISCONSIN REGIONAL PLANNING COMMISSION

Special acknowledgement is due Mr. Allen S. Wojtasiak, Civil Engineer II, for his contribution to the preparation of this report.

Special acknowledgement is due Mr. Michael G. Hahn, SEWRPC Principal Engineer, for his contribution to the preparation of this report.

COMMUNITY ASSISTANCE PLANNING REPORT
NUMBER 173

A STORMWATER MANAGEMENT PLAN FOR THE CITY OF WEST BEND

CITY OF WEST BEND
WASHINGTON COUNTY, WISCONSIN

Volume One

INVENTORY FINDINGS, FORECASTS, OBJECTIVES, AND DESIGN CRITERIA

Prepared by the
Southeastern Wisconsin Regional Planning Commission
P. O. Box 1607
Old Courthouse
916 N. East Avenue
Waukesha, Wisconsin 53187-1607

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SOUTHEASTERN WISCONSIN REGIONAL PLANNING COMMISSION

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October 12, 1989

Mayor, City Council, and
City Plan Commission
c/o City Clerk
City of West Bend
100 N. Sixth Avenue
West Bend, Wisconsin 53095

Ladies and Gentlemen:

In January 1985, the City of West Bend requested the Southeastern Wisconsin Regional Planning Commission to assist the City in the preparation of a stormwater management plan for the City of West Bend and environs. This volume is the first in a series of four volumes, which together present the major findings and recommendations of the resulting stormwater management planning program. This volume sets forth the basic principles and concepts underlying the planning effort; presents existing and forecast resident population levels and land use within the study area; describes the existing stormwater drainage system; and identifies general stormwater management problems. This volume also describes the various components of a typical stormwater management system and presents a set of stormwater management objectives, standards, and design criteria for use in plan design, test, and evaluation.

The second volume presents the findings of an evaluation of the existing stormwater management system serving that portion of the planned urban service area of the City of West Bend lying within the Silver Creek subwatershed; describes and evaluates alternative stormwater management plans designed to serve that subwatershed through the design year 2010; and recommends a stormwater management system plan for the subwatershed. Subsequent volumes present similar information and recommendations for the Quaas Creek subwatershed and the Milwaukee River direct drainage area.

The information presented herein is consistent with regional as well as local land use development, water quality management, and flood control objectives, and is intended to serve, along with the subsequent volumes, as a guide to City officials in the making of sound decisions over time concerning the development of stormwater management facilities in the City of West Bend.

The Regional Planning Commission is appreciative of the assistance offered by city officials and staff in the preparation of this report. The Commission staff stands ready to assist the City in the adoption and implementation of the plan over time.

Sincerely,

Kurt W. Bauer
Executive Director

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Chapter I

INTRODUCTION

This volume is the first in a series of four volumes which together present the major findings and recommendations of a stormwater management planning program for the City of West Bend and environs. This volume sets forth the basic principles and concepts underlying the planning effort; presents forecasts of anticipated future land use within the study area; describes the existing stormwater drainage system; and identifies generally existing stormwater management problems. This volume also describes the various components of a typical stormwater management system and presents the stormwater management objectives, standards, and design criteria applied in the synthesis of the stormwater management plan for the City of West Bend.

The second volume presents the findings of an inventory and evaluation of the existing stormwater management system serving that portion of the planned urban service area of the City of West Bend which lies within the Silver Creek subwatershed; describes and evaluates alternative stormwater management plans designed to serve that subwatershed through the design year 2010; and recommends a stormwater management system plan for the subwatershed. Subsequent volumes present similar information and recommendations for the Quaas Creek subwatershed and the Milwaukee River direct drainage area.

STUDY BACKGROUND

The City of West Bend is located in north-central Washington County within the Milwaukee River watershed. In 1985 the resident population of the stormwater management study area, which includes the city proper and portions of the surrounding Towns of Barton, Farmington, Jackson, Polk, Trenton, and West Bend, was approximately 26,930 persons. The projected year 2010 population of this same area is approximately 35,180 persons, an increase of about 8,250 persons, or about 31 percent, over the 1985 level. To accommodate this projected increase in population, urban land use within the area may be expected to increase from a total of about 8.3 square miles in 1985 to about 17.2 square miles over the next two decades—an increase of about 8.9 square miles, or about 107 percent, over the 1985 level. In the absence of adequate planning, this conversion of land from rural to urban use may be expected to aggravate existing and create new stormwater management problems. Recognizing the need for a systematic plan to address existing stormwater management problems and to avoid the creation of new problems as urban development proceeds in the area, in January 1985 the City asked the Southeastern Wisconsin Regional Planning Commission to assist in the preparation of such a plan. The planning work was funded by the City of West Bend.

The purpose of this report is to present the resulting stormwater management plan. The plan seeks to promote the development of an effective stormwater management system, adequate to serve the City at least through the year 2010. To the extent practicable, the plan is intended to ameliorate existing stormwater drainage problems, to avoid the creation of new stormwater drainage problems as the area continues to develop, to mitigate the effects of nonpoint source pollution on surface water quality, and to help reduce downstream flooding. More specifically, this report:

1. Describes the existing stormwater management system and the existing stormwater management problems in the City and environs and identifies the causes of these problems;

2. Describes existing and planned land use conditions and identifies related stormwater management requirements;

3. Provides a set of objectives and supporting standards to guide the development of an effective stormwater management system;

4. Presents alternative stormwater management plans;

5. Provides a comparative evaluation of the technical, economic, and environmental features of the alternative plans;

6. Recommends a cost-effective stormwater management plan for the City and environs consisting of various structural and nonstructural measures; and

7. Identifies the responsibilities of, and actions required by, the various governmental units and agencies that will implement the recommended plan.

This report was prepared by the staff of the Southeastern Wisconsin Regional Planning Commission in cooperation with the staffs of the City of West Bend and the Wisconsin Department of Natural Resources (DNR). The recommended stormwater management plan for the City, as presented herein, is properly set within the context of broad flood control and water quality management plans for the Milwaukee River watershed.[1] The findings and recommendations of urban nonpoint source pollution control studies recently conducted by the DNR for the West Bend area as part of the Milwaukee River Priority Watersheds Program are also reflected in the alternative stormwater management plans and the recommended plan presented in this report.

DISTINCTION BETWEEN STORMWATER DRAINAGE, STORMWATER MANAGEMENT, AND FLOOD CONTROL

The distinction between stormwater drainage, stormwater management, and flood control is not always clear. For the purposes of this report, flood control is defined as the prevention of damage from the overflow of natural streams and watercourses. Drainage is defined as the control of excess stormwater on the land surface before such water has entered stream channels. The term "stormwater management" encompasses both stormwater drainage and nonpoint source pollution control measures. This report focuses on stormwater management, and addresses flood control only as necessary to avoid the intensification of existing, or the creation of new, flood control problems along the natural streams and watercourses of the study area which must receive the discharge from the existing and proposed stormwater drainage facilities.

NEED FOR AND IMPORTANCE OF STORMWATER MANAGEMENT PLANNING

Stormwater management—the collection, storage, transport, treatment, and disposal of excess stormwater—is one of the most important and costly requirements of sound urban development. Good stormwater management is essential to the provision of an attractive and efficient, as well as safe and healthful, environment for urban life.

Inadequate stormwater management can be costly and disruptive. Inadequate stormwater management can disrupt the safe and efficient movement of people and goods essential to the proper functioning of an urban area; undermine the structural stability of pavements, utilities, and buildings, requiring costly maintenance and reconstruction; and depreciate and destroy the market value of real property, with an attendant loss of tax base. Inadequate stormwater management can result in the excessive infiltration and flow of clear water into sanitary sewerage systems, with attendant surcharging of sanitary sewers, the backing of sanitary sewage into residential and commercial buildings, the bypassing of raw sewage to streams and watercourses through sanitary sewer system flow relief devices, and the attendant creation of serious hazards to public health. In extreme situations, inadequate stormwater management can also cause serious and costly soil erosion and sedimentation, create unsightly depositions of debris, and promote the breeding of mosquitoes and other troublesome insects, with attendant hazards to the health of humans and of domestic animals.

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[1] *See SEWRPC Planning Report No. 13, A Comprehensive Plan for the Milwaukee River Watershed, March 1972; and SEWRPC Planning Report No. 30, A Regional Water Quality Management Plan for Southeastern Wisconsin: 2000, Volume One, Inventory Findings, September 1978, Volume Two, Alternative Plans, February 1979, and Volume Three, Recommended Plan, June 1979. The Milwaukee River watershed plan has been formally adopted by the Wisconsin Department of Natural Resources and Washington County, as well as by the Regional Planning Commission. The regional water quality management plan has been adopted by the Wisconsin Department of Natural Resources, as well as the Commission. Also, see the Milwaukee River Priority Watersheds Program Prospectus, Wisconsin Department of Natural Resources and Southeastern Wisconsin Regional Planning Commission, March 1985.*

Municipal officials have long recognized the hazards to human health and safety, and the economic losses, caused by inadequate stormwater management. Such officials are increasingly recognizing the adverse ecological and environmental impacts of improperly managed stormwater runoff, including the pollution of surface waters, the reduction of groundwater recharge, and the adverse effects on desirable forms of plant and animal life.

Because of its important social, economic, and environmental impacts, stormwater management is a problem which requires sound resolution through fairly sophisticated planning and engineering. The factors which must be considered in the planning and design of stormwater management facilities are complex and highly interrelated. Perhaps the most important of these factors is the magnitude and frequency of the flows that must be accommodated. Yet, this variable cannot be determined with certainty since it is dependent on the occurrence of random meteorological events, as well as on topographic, soil, and land use conditions. Moreover, the factors determining the quantity and quality of the runoff to be accommodated by an urban stormwater management system are altered by urbanization itself, which particularly affects the overall imperviousness of the catchment areas concerned, reducing the infiltration capacity of soils, the amount of natural depression storage, and the flow times in the drainage system, thereby significantly increasing the rate and volume of stormwater runoff.

Careful application of the sciences of hydrology and hydraulics, as well as the art of urban engineering, is therefore important to the sound planning and design of urban stormwater management systems. Hydrology may be defined as the study of the physical behavior of the water resource from its occurrence as precipitation to its entry into streams and watercourses or its return to the atmosphere via evapotranspiration. The application of hydrology to the planning and design of urban stormwater management systems requires the collection and analysis of definitive information on precipitation, soils, and land uses, and on the volume and timing of that portion of precipitation which ultimately reaches the surface water system as runoff.

Hydraulics may be defined as the study of the physical behavior of water as it flows within pipes and natural and artificial channels; under and over bridges, culverts, and dams; and through lakes and impoundments. The application of hydraulics to the planning and design of stormwater management systems requires the collection and analysis of definitive information on the configuration of the natural and artificial stormwater management systems of the study area, including information on the shape and dimensions of the cross-sectional areas, on the longitudinal gradients, and on the roughness and attendant hydraulic performance of the collection, storage, and conveyance facilities involved.

Thus, stormwater management planning and design requires knowledge and understanding of the complex relationships existing among the many natural and man-made features that together comprise the hydrologic-hydraulic system of the study area, and of how these relationships may change over time. In addition, knowledge of the economic and environmental impacts of such systems, and of the public attitudes involved, is required.

BASIC CONCEPTS INVOLVED

The basic concept underlying urban stormwater management is undergoing reexamination. The old concept sought to remove excess surface water during and after a rainfall as quickly as possible through the provision of an efficient drainage system, a system usually consisting of enclosed conduits, although sometimes consisting of improved open channels. The problems created by application of this traditional approach to urban stormwater drainage were more or less acceptable when urban development was compact and confined to relatively small areas. These problems have become increasingly aggravating and unacceptable as the pattern of urban development has changed, and urban land uses have diffused over ever-larger areas.

The new concept emphasizes storage as well as conveyance, with the objectives of reducing the peak rate of runoff and in some cases the total volume of runoff; reducing the transport of sediment and other water pollutants to downstream surface waters; and protecting against increased downstream flooding. Therefore, the new concept also looks to controlling the quality, as well as the quantity, of runoff.

Regardless of the concept, urban stormwater management systems are generally designed to fulfill four basic objectives: 1) to prevent significant damage to buildings, other structures, and other forms of real property from relatively infrequent major rainfall events; 2) to maintain reasonably convenient access to and egress from the various land uses of an urban area during relatively frequent minor rainfall events; 3) to avoid undue hazards to public safety and health; and 4) to mitigate the effects of nonpoint source pollutants on receiving watercourses. Thus, the total stormwater management system of an urban area may be conceived of as consisting of a major element operating infrequently and a minor element operating frequently. Both of these elements can, under certain conditions, utilize stormwater retention or detention, as well as conveyance, as a potential design solution. The benefits of stormwater storage may include a reduction in the high kinetic energy of surface runoff; a reduction in both the total volume and peak rate of discharge; the provision of multiple-use opportunities for recreational and aesthetic purposes; the provision of groundwater recharge; the entrapment of some pollutants; and a reduction in the adverse impacts of the remaining pollutants by controlled release.

For predominantly developed parts of urban communities—such as the established areas of the City of West Bend—the development of stormwater storage and nonpoint source pollution control measures is difficult, such development being constrained by the availability of open land on, or adjacent to, the drainage system. Some storage potential may exist within the developed areas such as on parking lots in commercial and industrial areas and on-site in residential and recreational areas. Successful efforts have been made to integrate stormwater storage facilities into the existing urban environment; however, such efforts have been costly and difficult to implement because of the existing development pattern and public concerns. Nevertheless, the practice of detaining or retaining stormwater runoff within the confines of an urban area, as well as in developing areas, to mitigate flooding, soil erosion, sedimentation, and surface water pollution deserves careful consideration as a part of any sound stormwater management planning effort. In outlying, developing areas, the incorporation of stormwater storage facilities and nonpoint source pollution control measures may be more feasible owing to the availability of land and the opportunity to plan for such facilities as an integral part of the urban development process.

Facilities designed solely for the control of stormwater quantity, including storm sewers, concrete-lined drainage channels, and dry detention basins which drain completely between storms, provide little or no reduction in nonpoint source pollutant loadings to receiving watercourses. However, when such facilities are integrated with nonpoint source pollution control measures such as wet detention basins, infiltration trenches, percolation basins, grass swales and waterways, regular street sweeping, and catch basin cleaning, a significant reduction in pollutant loadings may be achieved.

SCOPE OF THE STORMWATER MANAGEMENT PLAN

The recommended stormwater management plan for the City of West Bend, as set forth in the four volumes of this report, incorporates compatible multiple-use planning concepts and recognizes the constraints imposed by other community needs, such as park and open space, transportation, sanitary sewerage, and water supply. Drainage requirements under existing and plan year 2010 land use conditions are evaluated. Flood control, drainage, and nonpoint source pollution control problems are addressed as necessary. The plan encompasses the existing and planned future urban service area of the City, and considers the hydrologic and hydraulic effects of the entire upstream watersheds of the natural streams and watercourses which flow into and through the study area and which must receive the discharge of the engineered urban drainage systems.

The primary focus of the stormwater management plan is the 20.1-square-mile area contained within the existing and planned urban service area of the City of West Bend, as shown on Map 1.[2] The planning effort considered both the

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[2]*The planned urban service area used in the preparation of the stormwater management plan is basically the same as that presented in SEWRPC Community Assistance Planning Report No. 35, Sanitary Sewer Service Area for the City of West Bend, December 1983, as amended by Amendment to the Regional Water*

(Footnote continued on page 5)

stormwater management facilities needed to serve areas that are planned to be converted from rural to urban land uses and the degree of rehabilitation needed to properly maintain, improve, or extend the existing stormwater management system serving the City. Stormwater runoff from the planned urban service area is drained to six separate surface water drainage systems—those systems being the intermittent and perennial streams of 1) the Silver Creek subwatershed; 2) the Quaas Creek subwatershed; 3) the Wingate Creek subwatershed; 4) a portion of the Middle Milwaukee River subwatershed; 5) a portion of the Milwaukee River North Branch subwatershed; and 6) overland drainage to a 0.30-square-mile internally drained area within the Upper Milwaukee River subwatershed. While the plan recommendations do not extend to the Milwaukee River, which flows through the study area and receives runoff from the entire study area, the effects on the Milwaukee River of future flows and nonpoint source pollutant loadings from tributary streams were considered. In addition to serving as outlets for stormwater runoff from within the urban service area of the City, the surface water systems considered receive runoff from areas within the Towns of Barton, Polk, Trenton, and West Bend. This report recommends comprehensive stormwater management system plans for the six subwatersheds concerned.

(Footnote continued from page 4)
Quality Management Plan—2000, City of West Bend, SEWRPC, June 1987. In order to better reflect the most likely extent of future urban development, the urban service area presented in Community Assistance Planning Report No. 35 and the amendment to the regional water quality management plan was revised to reflect those areas that have been proposed for addition or deletion by the City of West Bend. The areas proposed for addition are located in U. S. Public Land Survey Sections 3 and 22 of Township 11 North, Range 19 East. The areas proposed for deletion are located in U. S. Public Land Survey Sections 35 and 36 of Town 11 North, Range 19 East. These additions and deletions are shown on Map 1. The Amendment to the Regional Water Quality Management Plan—2000, City of West Bend/Town of West Bend, September 1988, added to the planned urban service area a site in the east one-half of U. S. Public Land Survey Section 29, Township 11 North, Range 19 East, Town of West Bend. Runoff from that relatively small site does not drain to the established study area, and the site is not contiguous with the remainder of the planned urban service area; therefore, the site was not included in the planned urban service area used for this stormwater management system plan.

REVIEW OF PREVIOUS STUDIES

One of the first steps in the preparation of the stormwater management plan was a careful review of the findings and recommendations of previous stormwater drainage and nonpoint source pollution control studies affecting the study area. The studies reviewed are listed below and their salient findings and recommendations summarized.

1. Stormwater Management Plan for the City of West Bend Industrial Park-South, Phase I & II, May 1985, prepared by the City of West Bend Engineering Department.

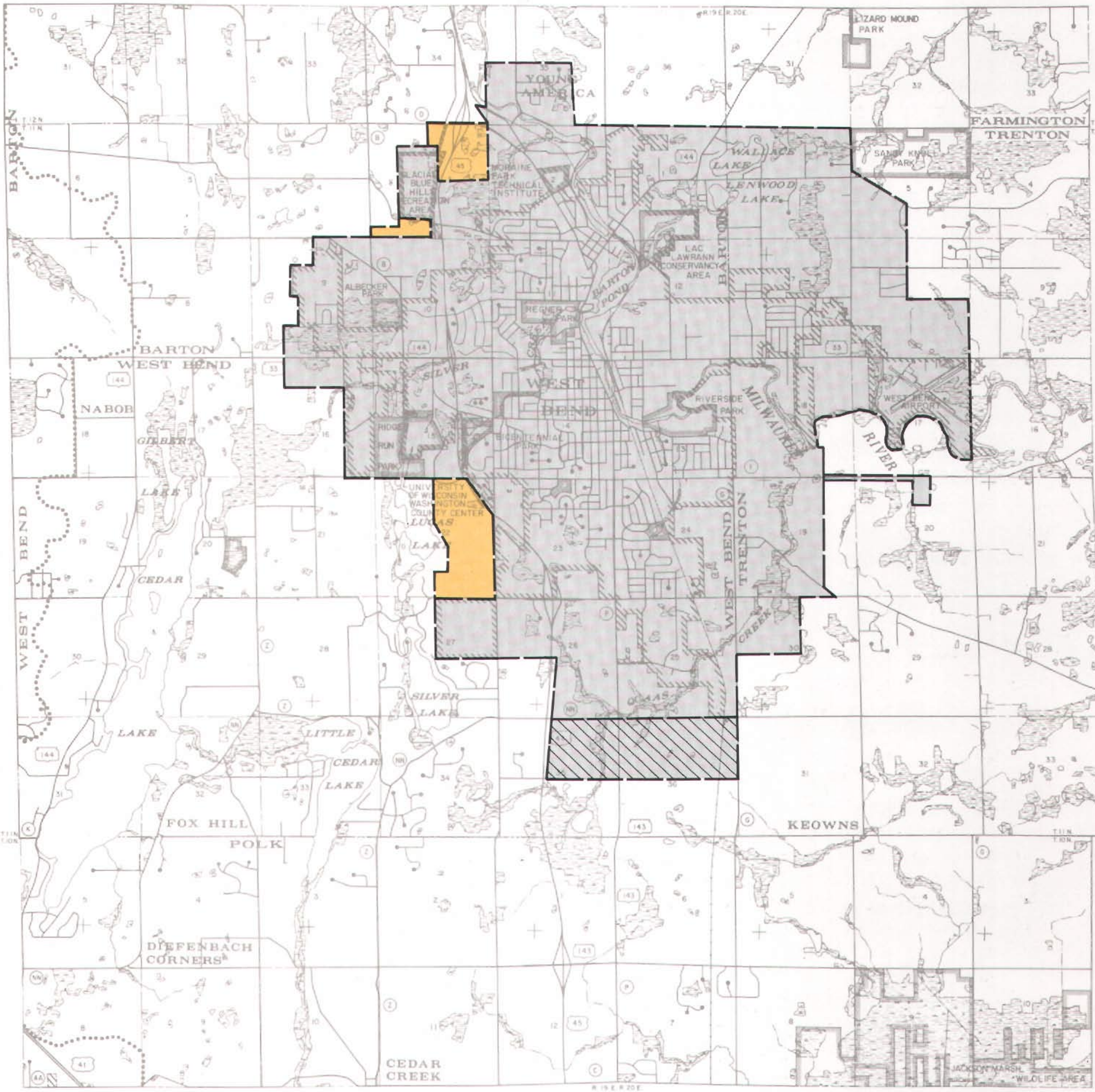
   This plan recommends a system of stormwater detention basins and improved drainage channels to manage runoff from an industrial park proposed to be located in the Quaas Creek subwatershed in the southern part of the City, south of Paradise Drive between Main Street and the tracks of the Chicago & North Western Railway. The plan recommended construction of three wet detention basins, one combined basin consisting of a wet and a dry basin in series, and three smaller dry silt ponds with a system of improved interconnecting open channels. The performance of the ponds was evaluated for storms having recurrence intervals of 10 years and 50 years. Subsequent to preparation of the plan, the size of the industrial park was reduced. A 1.2-acre wet detention pond; a wet detention pond in series with a dry detention pond, including an infiltration ditch, all with a total area of 1.4 acres; and three smaller, dry silt ponds were constructed in 1987 in accordance with the plan.

2. Julia Schloemer Farm Stormwater Management, December 1983, prepared by Ronald A. Weis.

   This report recommends a stormwater management system for the developed area in the Middle Milwaukee River sub-

Map 1

PROPOSED REVISIONS TO THE ADOPTED CITY OF WEST BEND PLANNED URBAN SERVICE AREA



LEGEND

EXISTING WEST BEND PLANNED URBAN SERVICE AREA

AREAS PROPOSED TO BE ADDED TO THE WEST BEND PLANNED URBAN SERVICE AREA

AREAS PROPOSED TO BE DELETED FROM THE WEST BEND PLANNED URBAN SERVICE AREA

Source: SEWRPC.

watershed located to the north of STH 33 (W. Washington Street) and to the east of CTH B. The major development in this area is the Westwood Mall Shopping Center. The performance of the proposed system was evaluated for storms having recurrence intervals of 10, 25, 50, and 100 years. Peak flows were calculated using the Rational Method. The stormwater management system consists of open channels and culverts to convey runoff to natural kettles, or depressions, which will serve as retention basins. The system was constructed in 1983.

3. Hydraulic Report Perennial Stream in the City of West Bend (Silver Creek) Section 10 and 15, Town 11 North, Range 19 East, USH 45, Washington County, September 1976, prepared by the Wisconsin Department of Transportation, Division of Highways.

   This report recommends the sizing of the culverts which pass flow from Silver Creek beneath STH 33 at the USH 45 overpass. The culverts were designed to pass the 100-year recurrence interval flood as determined by the Regional Planning Commission for that location on Silver Creek. The twin 60-inch-diameter reinforced concrete culvert pipes recommended in the report were installed in 1985.

4. Public Review Draft of a Nonpoint Source Control Plan for the East and West Branches of the Milwaukee River Priority Watershed, February 1989, prepared by the Wisconsin Department of Natural Resources.

   This report includes discussions of surface water resource conditions, water resource objectives, and nonpoint pollution sources and control goals in the East and West Branches of the Milwaukee River, which includes the West Bend stormwater management study area. The report recommends general programs for the control of nonpoint source pollution within the watershed and discusses implementation of control programs. The primary water resource-related objective for streams in the West Bend study area is to enhance existing recreational and aquatic life uses. A secondary objective is to protect those uses if the enhancement objective cannot be attained. In the context of urban nonpoint source pollution control, the proposed means of attaining those objectives include a reduction in the quantities of sediment delivered from uplands and stream banks; control of construction erosion; a reduction in runoff pollution from the areas of existing urban development in the West Bend area; and control of potential runoff pollution from areas of new urban development. An additional water resource-related objective is the protection of valuable wetlands from the effects of sedimentation where the pollution attenuation capacity of the wetlands is overloaded. Nonpoint source pollution control measures that were considered for the West Bend area include wet detention, infiltration, and street sweeping.

In addition to these studies, flood insurance studies were prepared for the City and for Washington County by the Federal Emergency Management Agency as documented in Flood Insurance Study, City of West Bend, Washington County, Wisconsin, February 1982; and Flood Insurance Study, County of Washington, Wisconsin, Unincorporated Areas, March 1983. The studies describe the existence and severity of flood hazards within the City and County, including portions of the planned urban service area outside the present corporate limits of the City. Hydrologic-hydraulic simulation models were used to determine the 10-, 50-, 100-, and 500-year recurrence interval flood discharges and associated stages. Flood insurance rate maps in the reports show the flood insurance zones and the boundaries of the 100- and 500-year flood hazard areas. The results of the studies enabled property owners within the City and County to participate in the Federal Insurance Administration's flood insurance program.

SUMMARY

The City of West Bend is located in north-central Washington County within the Milwaukee River watershed. The continued conversion of land from rural to urban use in the West Bend area may be expected to aggravate existing stormwater management problems and, in the absence of sound planning, create new problems. The need to resolve existing problems and to avoid the occurrence of new problems dictates the need to prepare a long-range stormwater management plan for the City of West Bend and environs.

This report presents such a stormwater management plan. The plan seeks to promote the development of an effective stormwater management system for the study area through at least the year 2010, a system that will minimize damages attendant to poor drainage while reducing downstream flooding, and that will protect and enhance surface water quality.

More specifically, Volume One of this report describes the existing stormwater drainage system and the existing stormwater management problems of the West Bend area, and identifies the causes of these problems; describes existing and planned future land use conditions and identifies related stormwater management requirements; and provides a set of objectives and supporting standards to guide the development of an effective stormwater management system for the area. Volumes Two, Three, and Four of this report present alternative stormwater management system plans for each subwatershed in the study area; provide a comparative evaluation of the technical, economic, and environmental features of these plans; recommend a cost-effective stormwater management plan for the City and environs; and set forth a plan implementation program.

The plan focuses on stormwater management as opposed to flood control problems, addressing the latter only as necessary to avoid the intensification of existing, or the creation of new, flood control problems along the natural streams and watercourses of the study area which must receive the discharge from existing and proposed urban drainage facilities. The plan recognizes that good stormwater management is essential to the provision of an attractive and efficient, as well as safe and healthful, environment for urban life; and that inadequate stormwater drainage can be costly and disruptive, can create hazards to public health and safety, and can have adverse ecological and environmental impacts. Because of the technical complexity of the problem and the important social, economic, and environmental impacts involved, the plan recognizes that stormwater management planning must be based upon knowledge of the art of urban engineering and of the sciences of hydrology and hydraulics; an understanding of the social, economic, and environmental impacts involved; and information on the public attitudes toward stormwater drainage.

The recommended stormwater management plan presented herein also recognizes that the basic concept underlying urban stormwater management is undergoing reexamination. The old concept sought to eliminate excess surface water during and after a rainfall as quickly as possible through the provision of an efficient drainage system, a system consisting of enclosed conduits and improved open channels. The new concept emphasizes storage as well as conveyance of runoff, with the objectives of reducing the peak rate of runoff, and, in some cases, the total volume of runoff; reducing the transport of sediment and other water pollutants to downstream surface waters; and protecting against increased downstream flooding. The new concept also looks to controlling the quality, as well as the quantity, of runoff.

The plan presented herein regards the stormwater runoff system of the area as consisting of a major element operating infrequently and a minor element operating frequently, with both of these elements incorporating, to the extent practicable, the storage as well as conveyance of excess runoff. The recommended stormwater management plan set forth herein thus incorporates compatible multi-use planning concepts and recognizes the opportunities provided as well as the constraints imposed by other community needs, such as park and open space, transportation, and water supply. Stormwater management requirements are evaluated under both existing and planned future land use conditions, and flood control problems are addressed as necessary. Finally, the plan encompasses not only the existing and future urban service area of the City but the entire upstream watersheds of the natural streams and watercourses flowing through the study area, which must constitute the outlets for the engineered urban drainage system of the area.

Chapter II

INVENTORY AND ANALYSIS

INTRODUCTION

Information on certain pertinent natural and man-made features of the study area is essential to sound stormwater management planning. Accordingly, the collation and collection of definitive information on key hydrologic and hydraulic characteristics, on the existing stormwater drainage system, and on erosion and sedimentation characteristics constitute an important step in the stormwater management planning process. The resulting information is essential to the planning process, because alternative stormwater management plans cannot be formulated and evaluated without an in-depth knowledge of the pertinent conditions in the planning area. This is particularly true for stormwater management planning, which must address the complex interaction of natural meteorologic events, key hydrologic and hydraulic characteristics of the planning area, and certain man-made physical systems.

Accordingly, this chapter presents data on the hydrologic phenomena governing the magnitude and frequency of stormwater flows; on existing stormwater drainage and flood control problems; on the anticipated type, density, and spatial distribution of land uses in the study area; and on the impact of the anticipated changes in land use on the stormwater management needs of the study area. Because water quality impacts are becoming increasingly of concern in stormwater management, this chapter also presents data on surface water quality conditions in the West Bend area and identifies those sources of pollution related to stormwater management.

STORMWATER MANAGEMENT STUDY AREA

The subwatersheds, or partial subwatersheds, which constitute the study area for stormwater management planning are shown on Map 2, and the drainage areas are quantified in Table 1.

The total areal extent of the study area is approximately 30.6 square miles, of which 20.1 square miles, or about 66 percent, lie within the limits of the planned urban service area for the City of West Bend, and 10.5 square miles, or about 34 percent, lie outside the urban service area. As set forth in Table 1, about 9.03 square miles, or 30 percent of the total study area, lie within the Silver Creek subwatershed. Of that area, 2.86 square miles are internally drained and would not contribute runoff to Silver Creek under existing conditions. About 8.74 square miles, or 29 percent of the total study area, lie within the Quaas Creek subwatershed. Of that area, 0.29 square mile is internally drained and would not contribute runoff to Quaas Creek under existing conditions. About 1.69 square miles, or 5 percent of the total study area, drain to Wingate Creek. About 9.56 square miles, or 31 percent of the total study area, lie within the Middle Milwaukee River subwatershed. Of that area, 0.95 square mile is internally drained and would not contribute runoff to the Milwaukee River under existing conditions. About 0.98 square mile, or 3 percent of the total study area, lies within the Milwaukee River North Branch subwatershed. Of that area, 0.02 square mile is internally drained and would not contribute runoff to the Milwaukee River under existing conditions. About 0.30 square mile, or 1 percent of the total study area, lies within the Upper Milwaukee River subwatershed. That entire area is internally drained and would not contribute runoff to the Milwaukee River under existing conditions. The remaining 0.31 square mile, or 1 percent of the total study area, is the surface water area of the Milwaukee River.

SURFACE WATER DRAINAGE IN THE STUDY AREA

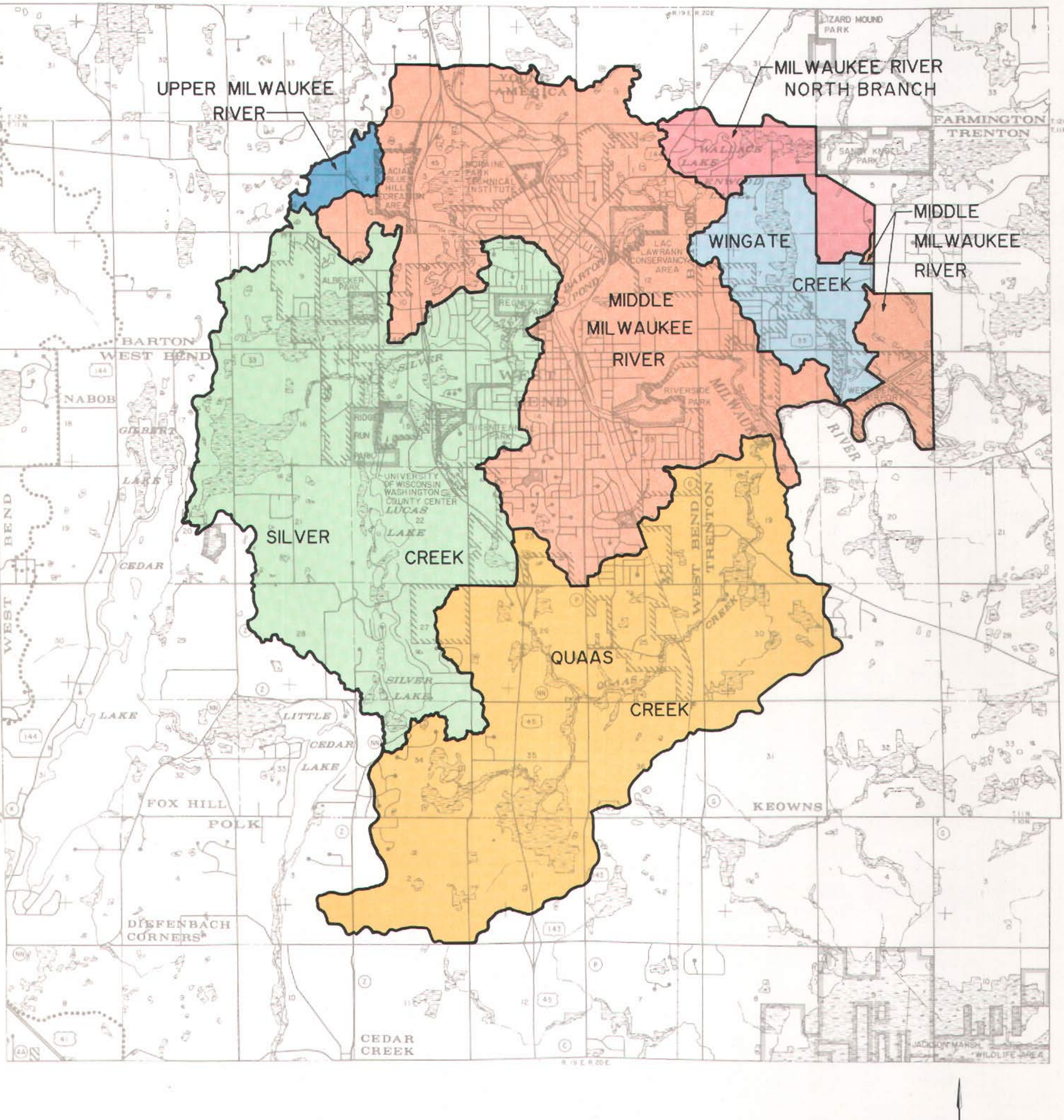
Selected characteristics of the surface water drainage system of the study area, including certain related features, are shown on Map 3. More specifically, shown on this map are subwatershed and floodplain boundaries, perennial and intermittent streams and watercourses, lakes and ponds, and the area served by storm sewer systems.

LAND USE

The City of West Bend stormwater management plan is intended to identify the stormwater

Map 2

SUBWATERSHEDS WITHIN THE CITY OF WEST BEND STORMWATER MANAGEMENT PLAN STUDY AREA



Source: SEWRPC.

Table 1

AREA AND PROPORTION OF THE SILVER CREEK, QUAAS CREEK, WINGATE CREEK, MIDDLE MILWAUKEE RIVER, MILWAUKEE NORTH BRANCH, AND UPPER MILWAUKEE RIVER SUBWATERSHEDS WITHIN THE CITY OF WEST BEND CORPORATE LIMITS, THE CITY OF WEST BEND PLANNED URBAN SERVICE, AND THE STUDY AREA

Subwatershed	City of West Bend 1987 Corporate Limits		City of West Bend Planned Urban Service Area Including Area Within the City Corporate Limits		Study Area Outside the Planned Urban Service Area		Total Study Area	
	Area (square miles)	Percent of Total	Area (square miles)	Percent of Total	Area (square miles)	Percent of Total	Area (square miles)	Percent of Total
Silver Creek	2.96	30	4.59	23	4.44	42	9.03[a]	30
Quaas Creek	1.08	11	3.86	19	4.88	46	8.74[b]	29
Wingate Creek	0.34	4	1.69	9	0.00	0	1.69	5
Middle Milwaukee River	5.15	53	8.68	43	0.88	9	9.56[c]	31
Milwaukee River North Branch	0.00	0	0.94	5	0.04	- -	0.98[d]	3
Upper Milwaukee River	0.00	0	0.02	- -	0.28	3	0.30[e]	1
Milwaukee River Surface Water	0.19	2	0.30	1	0.01	- -	0.31	1
Total	9.72	100	20.08	100	10.53	100	30.61	100

[a]*2.86 square miles are internally drained.*

[b]*0.29 square mile is internally drained.*

[c]*0.95 square mile is internally drained.*

[d]*0.02 square mile is internally drained.*

[e]*0.30 square mile is internally drained.*

Source: SEWRPC.

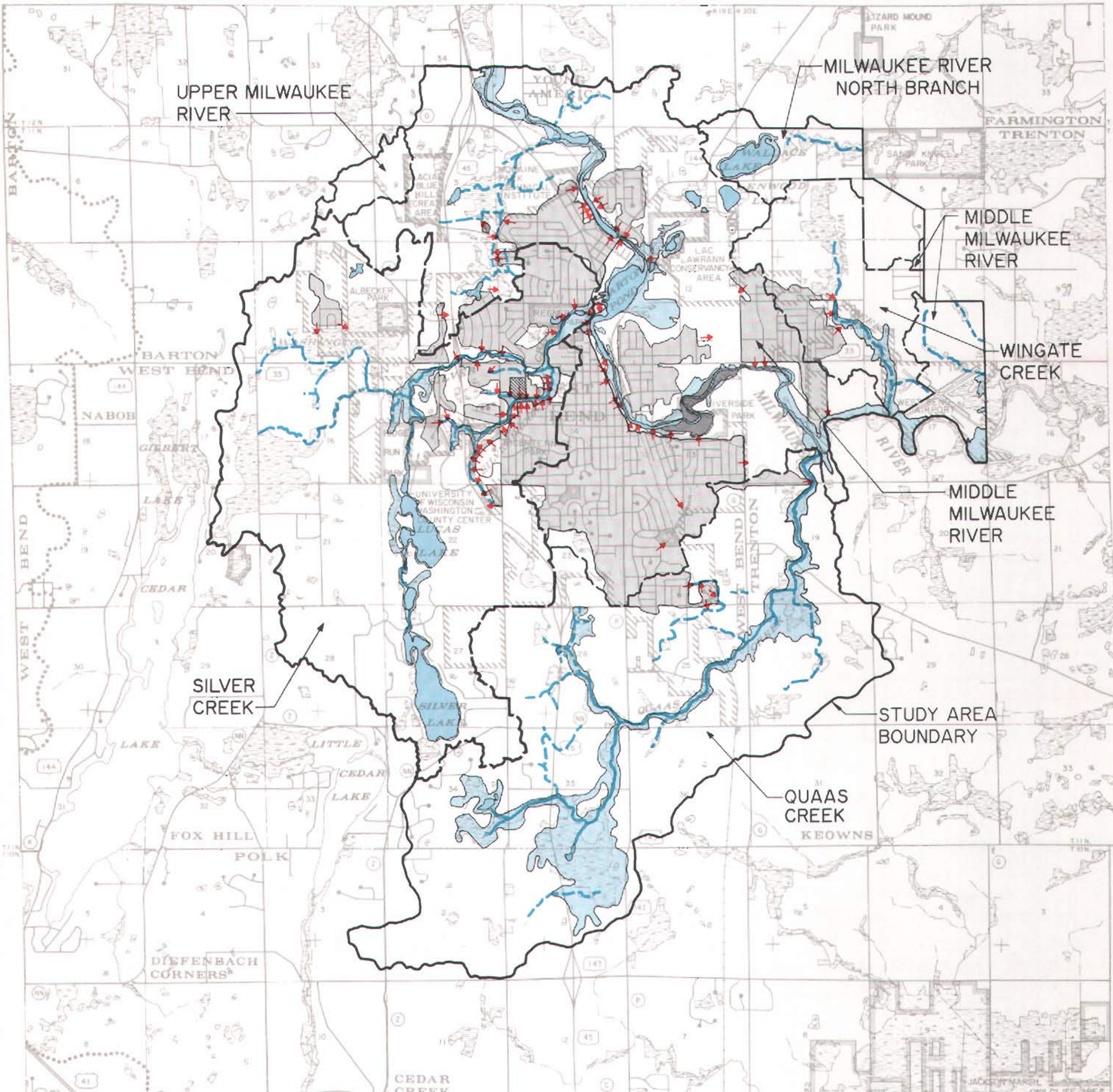
management needs of the City of West Bend through the year 2010 and to propose the best means of meeting those needs. In the case of the City, the land use pattern utilized as a basis for the stormwater management plan may be considered to represent an ultimate development pattern, barring any significant changes in community development objectives and attendant major redevelopment. Accordingly, the plan should serve the City as an effective guide to stormwater management system development well beyond the nominal design year of 2010.

It should be noted that the land use changes occurring within the City and environs are, in part, the result of an aggressive city development program. This program includes the establishment of a tax incremental finance district to fund and support, through public infrastructure development, desired land use development and redevelopment; the aggressive pursuit of state economic grants and loans; and the provision by the City of services encouraging development. This city development program gives impetus to the need to develop a stormwater management system plan.

Probable future, as well as existing, land use must be considered in any sound stormwater management planning effort. Accordingly, a design year 2010 land use pattern was developed for the stormwater management planning area. This pattern was based on the adopted year 2000 sewer service area plan; the development objectives implied by the existing zoning ordinance of the City of West Bend and of the other municipalities having jurisdiction in the study area; discussions with officials of the City of West

Map 3

SELECTED CHARACTERISTICS OF THE CITY OF WEST BEND STORMWATER MANAGEMENT STUDY AREA SURFACE WATER DRAINAGE SYSTEM: 1987



LEGEND

- SUBWATERSHED BOUNDARY
- INTERMITTENT STREAM
- PERENNIAL STREAM
- LAKES AND PONDS
- 100-YEAR RECURRENCE INTERVAL FLOODPLAIN UNDER EXISTING LAND USE AND CHANNEL CONDITIONS BASED ON 1982 AND 1983 FEMA FLOOD INSURANCE STUDIES
- AREAS SERVED BY EXISTING STORM SEWERS
- AREAS IN THE 100-YEAR RECURRENCE INTERVAL FLOODPLAIN UNDER EXISTING LAND USE AND CHANNEL CONDITIONS AND SERVED BY EXISTING STORM SEWERS
- STORM SEWER OUTFALL
- AREAS OF DISTURBED TOPOGRAPHY LIMITS OF FLOODPLAIN UNDETERMINED AS OF DATE OF PUBLICATION OF THIS REPORT

Source: City of West Bend and SEWRPC.

Table 2

EXISTING AND PROBABLE FUTURE LAND USE IN THE CITY OF WEST BEND PLANNED URBAN SERVICE AREA: 1985 AND 2010

Land Use Category	Existing 1985		Planned Increment		Total 2010	
	Acres	Percent of Total	Acres	Percent Change	Acres	Percent of Total
Urban						
Residential	2,107	16.4	3,295	156.4	5,402	42.0
Commercial	159	1.2	208	130.8	367	2.8
Industrial	172	1.3	431	250.6	603	4.7
Governmental and Institutional	333	2.6	73	21.9	406	3.2
Transportation	1,478	11.5	1,458	98.6	2,936	22.8
Communication and Utilities	45	0.4	40	88.9	85	0.7
Recreational	148	1.2	198	133.8	346	2.7
Subtotal	4,442	34.6	5,703	128.4	10,145	78.9
Rural						
Woodlands	994	7.7	-72	-7.2	922	7.2
Wetlands	1,177	9.1	-29	-2.5	1,148	8.9
Surface Water	342	2.7	- -	- -	342	2.7
Agricultural and Other Open Lands	5,900	45.9	-5,602	-94.9	298	2.3
Subtotal	8,413	65.4	-5,703	-67.8	2,710	21.1
Total	12,855	100.0	- -	- -	12,855	100.0

Source: SEWRPC.

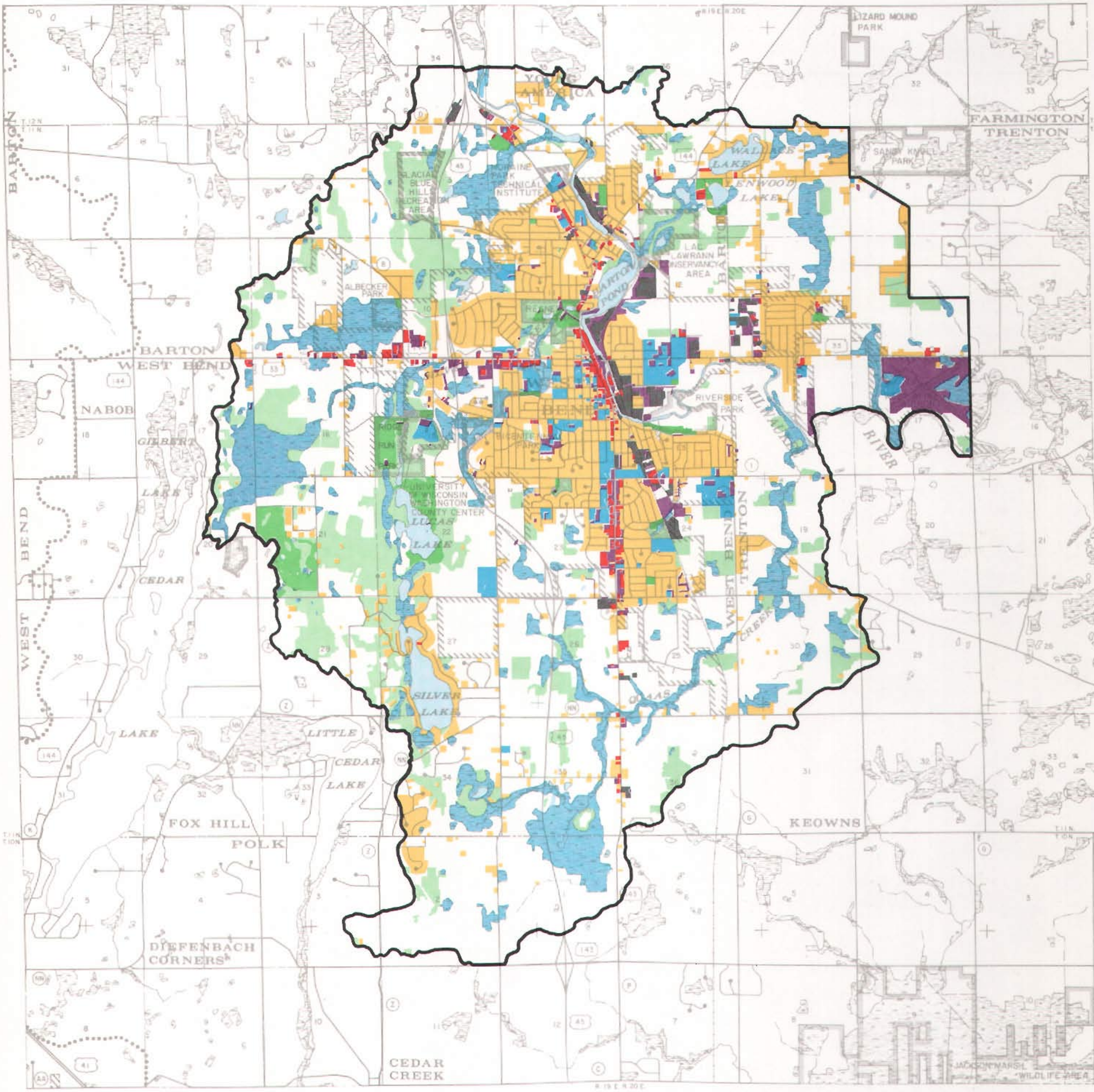
Bend to identify development opportunities and constraints; and preliminary work completed on a year 2010 sewer service area plan.

Probable future land use patterns are presented herein for two different geographic areas. First, a future land use pattern is presented for the City of West Bend planned urban service area. Land use changes in this area are clearly of direct concern in the stormwater management planning effort. In addition, the probable future land use pattern in the drainage area upstream of, and tributary to, the natural surface water drainage channels within the planned urban service area must be considered in any stormwater management plan development effort. Therefore, a probable future land use pattern in the tributary drainage areas concerned is also presented.

The total area contained within the planned urban service area of the City of West Bend in 1985 was 12,855 acres, or about 20.1 square miles. The existing 1985 and design year 2010 areas associated with each of the various land uses in the planned urban service area are set forth in Table 2. The year 1985 land use pattern is shown on Map 4. As indicated in the table, about 5,700 acres of rural land, or about 44 percent of the total area of the urban service area, may be expected to be converted from rural to urban uses over the approximately 25-year plan design period. This conversion would increase the amount of land in urban use within the planned urban service area by about 128 percent. Of the total area to be converted, about 3,300 acres, or 57 percent, would be converted to residential use; about 430 acres, or 8 percent, to industrial use; and about 1,970 acres, or 35 percent, to other urban uses.

Map 4

EXISTING LAND USE IN THE WEST BEND STUDY AREA: 1985



LEGEND

RESIDENTIAL	RECREATIONAL
COMMERCIAL	WATER
INDUSTRIAL	WETLANDS
TRANSPORTATION, COMMUNICATION AND UTILITIES	WOODLANDS
GOVERNMENTAL AND INSTITUTIONAL	AGRICULTURAL AND OTHER OPEN LAND

GRAPHIC SCALE
0 — 1 MILE
0 2000 4000 6000 FEET

Source: SEWRPC.

Table 3

EXISTING AND PROBABLE FUTURE LAND USE IN THE CITY OF WEST BEND STORMWATER MANAGEMENT STUDY AREA: 1985 AND 2010

Land Use Category	Existing 1985		Planned Increment		Total 2010	
	Acres	Percent of Total	Acres	Percent Change	Acres	Percent of Total
Urban						
Residential	2,516	12.8	3,295	131.0	5,811	29.7
Commercial	167	0.9	208	124.6	375	1.9
Industrial	179	0.9	431	240.8	610	3.1
Governmental and Institutional	336	1.7	73	21.7	409	2.1
Transportation	1,779	9.1	1,458	82.0	3,237	16.5
Communication and Utilities	46	0.2	40	87.0	86	0.4
Recreational	314	1.6	198	63.1	512	2.6
Subtotal	5,337	27.2	5,703	106.9	11,040	56.3
Rural						
Woodlands	2,083	10.7	-72	-3.5	2,011	10.3
Wetlands	1,962	10.0	-29	-1.5	1,933	9.9
Surface Water	548	2.8	- -	- -	548	2.8
Agricultural and Other Open Lands	9,663	49.3	-5,602	-58.0	4,061	20.7
Subtotal	14,256	72.8	-5,703	-40.0	8,553	43.7
Total	19,593	100.0	- -	- -	19,593	100.0

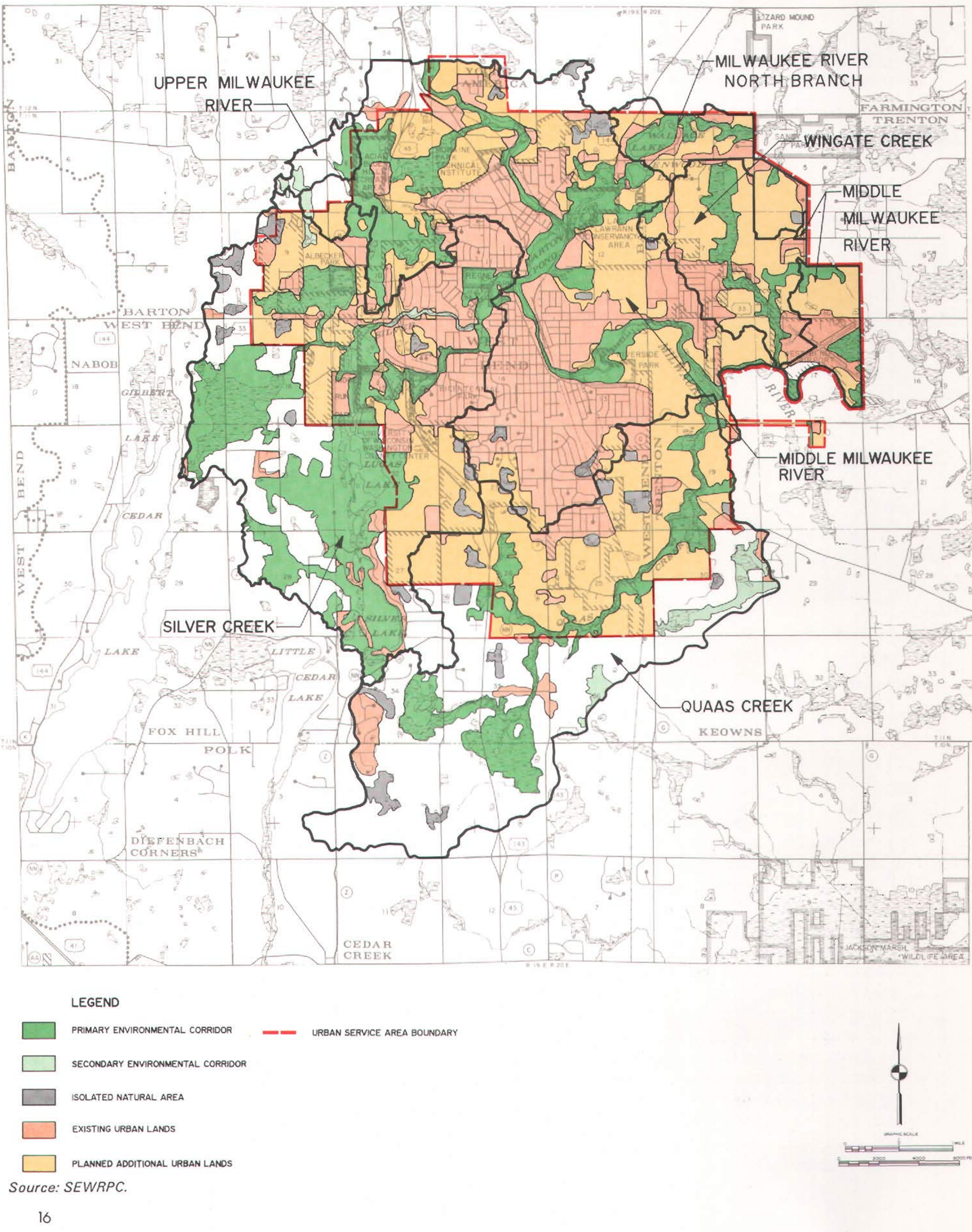
Source: SEWRPC.

As indicated in Table 2, under year 2010 conditions, urban land uses would account for about 10,140 acres, or about 79 percent, of the total area of the planned urban service area. Of the planned urban service area lands, residential uses would occupy about 5,400 acres, or about 42 percent, while the remaining urban land uses—commercial, industrial, transportation, communication and utilities, governmental and institutional, and recreational—would occupy 4,740 acres, or the remaining 37 percent. Under year 2010 conditions, rural land uses would still be expected to account for about 2,710 acres, or about 21 percent of the total area of the planned urban service area. Woodlands would occupy about 920 acres of that total, or about 7 percent; agricultural and other open lands about 300 acres, or about 2 percent; and other rural land uses, including wetlands and open water, about 1,490 acres, or 12 percent.

The entire stormwater management study area encompasses about 19,600 acres, or about 30.6 square miles. The existing 1985 and design year 2010 areas of land associated with each of the various land uses within the study area are set forth in Table 3. The year 2010 areas of planned development within the study area are shown on Map 5. As indicated in the table, about 5,703 acres of rural land, or about 29 percent of the total study area, may be expected to be converted from rural to urban uses over the approximately

Map 5

AREAS OF EXISTING AND PLANNED DEVELOPMENT IN THE WEST BEND STUDY AREA: 2010



Source: SEWRPC.

25-year plan design period, with all of such conversion envisioned to occur within the City of West Bend urban service area as previously described. This conversion would increase the amount of land in urban use within the study area by about 107 percent.

As indicated in Table 3, under year 2010 land use conditions, urban land uses would account for about 11,040 acres, or 56 percent, of the total study area. Of the study area lands, residential uses would occupy about 5,810 acres, or about 30 percent, and the remaining urban land uses—commercial, industrial, transportation, communication and utilities, governmental and institutional, and recreational—would occupy about 5,230 acres, or the remaining 26 percent. Under year 2010 conditions, rural land uses would still account for about 8,550 acres, or about 44 percent of the study area. Woodlands would occupy about 2,010 acres of the study area, or about 10 percent. Other rural land uses, including agricultural and other open lands, wetlands, and open waters, would occupy about 6,540 acres, or about 34 percent.

A comparison of Tables 2 and 3 shows that, between the years 1985 and 2010, the projected increase in urban land within the study area is expected to occur in the planned urban service area adopted for this study. Although it is possible that some land development may occur outside the planned urban service area boundaries, without the provision of urban services it is unlikely that such development would be intensive enough to have a significant effect on the downstream stormwater management facilities recommended for the planned urban service area. If areas of intensive development outside the planned urban service area were to occur in the future, it would be necessary to reevaluate the elements of the plan that could be affected by that development.

Because of the direct relationships that exist between resident population levels and land use patterns, the historical and probable future resident population levels in the City of West Bend stormwater management study area were evaluated as a part of the stormwater management planning effort. This evaluation was used to check the land use analyses. As indicated in Table 4, from 1963 to 1980 the resident population of the City of West Bend planned urban service area increased by about 58 percent, to 24,298 persons. This was a much higher rate of population increase than experienced by the Southeastern Wisconsin Region, but a lower rate than experienced by Washington County, over the same time period. Since 1980, the resident population of the planned urban service area has increased at about the same rate as the resident population of Washington County. Forecasts of population growth to the year 2010 indicate that the population of the planned urban service area may be expected to increase to about 33,250 persons—an increase of about 8,220 persons, or about 33 percent, over the 1985 population level.

As indicated in Table 4, from 1963 to 1980 the population within the stormwater management study area increased by about 63 percent, to 26,150 persons. Since 1980, the resident population of the study area has increased 3 percent, to 26,930. Forecasts of population growth to the year 2010 indicate that the population of the study area may be expected to increase to about 35,180—an increase of about 8,250 persons, or about 31 percent, over the 1985 population level. A graphic comparison of historical, existing, and forecast population levels for the City of West Bend planned urban service area, the stormwater management study area, Washington County, and the Southeastern Wisconsin Region is set forth in Figure 1. The anticipated increase in population within the planned urban service area, as well as within the entire stormwater management study area, can readily be accommodated by the increase in residential lands anticipated within the planned urban service area and study area over the 1985-2010 time period.

Within the City of West Bend planned urban service area, the forecast year 2010 population level of 33,250 persons would result in the need for approximately 11,875 housing units—assuming a household size of 2.8 persons per housing unit. Such housing units, if uniformly distributed over the 5,402 acres of residential land anticipated to be within the planned urban service area by the year 2010, would result in a density of approximately 2.2 housing units per net residential acre.

LAND USE REGULATIONS

Pertinent land use regulations in the study area include zoning and land division ordinances. Comprehensive zoning represents one of the most important tools available to local units of government for controlling the use of land in the

Table 4

HISTORICAL AND PROBABLE FUTURE RESIDENT POPULATION LEVELS FOR THE SOUTHEASTERN WISCONSIN REGION, WASHINGTON COUNTY, THE CITY OF WEST BEND PLANNED URBAN SERVICE AREA, AND THE CITY OF WEST BEND STORMWATER MANAGEMENT STUDY AREA

Year	Southeastern Wisconsin Region		Washington County		City of West Bend Planned Urban Service Area		Stormwater Management Study Area	
	Population	Percent Change	Population	Percent Change	Population	Percent Change	Population	Percent Change
1900	501,808	- -	23,589	- -	- -	- -	- -	- -
1910	631,161	25.8	23,784	0.8	- -	- -	- -	- -
1920	783,681	24.2	25,713	8.1	- -	- -	- -	- -
1930	1,006,118	28.4	26,551	3.3	- -	- -	- -	- -
1940	1,067,699	6.1	28,430	7.1	- -	- -	- -	- -
1950	1,240,618	16.2	33,902	19.2	- -	- -	- -	- -
1960	1,573,614	26.8	46,119	36.0	15,370[a]	- -	16,027[a]	- -
1970	1,756,083	11.6	63,839	38.4	18,959	23.4	20,045	25.1
1980	1,764,919	0.5	84,848	32.9	24,298	28.2	26,148	30.4
1985	1,742,742	-1.3	87,249	2.8	25,029	3.0	26,930	3.0
2010	1,872,333	7.4	111,723	28.1	33,251	32.8	35,180	30.6

[a]Represents 1963 population levels as determined under the 1963 SEWRPC origin-destination travel survey.

Source: U. S. Bureau of the Census, Wisconsin Department of Administration, and SEWRPC.

public interest, and such zoning has important implications for stormwater management. Zoning is exercised by each of the seven municipalities within the study area, which includes all of the City of West Bend and parts of the Towns of Barton, Farmington, Jackson, Polk, Trenton, and West Bend.

The current City of West Bend zoning ordinance provides for six residential districts, three business districts, two commercial districts, three manufacturing districts, and one wetland and floodplain district. Each of the districts includes adjoining streets.

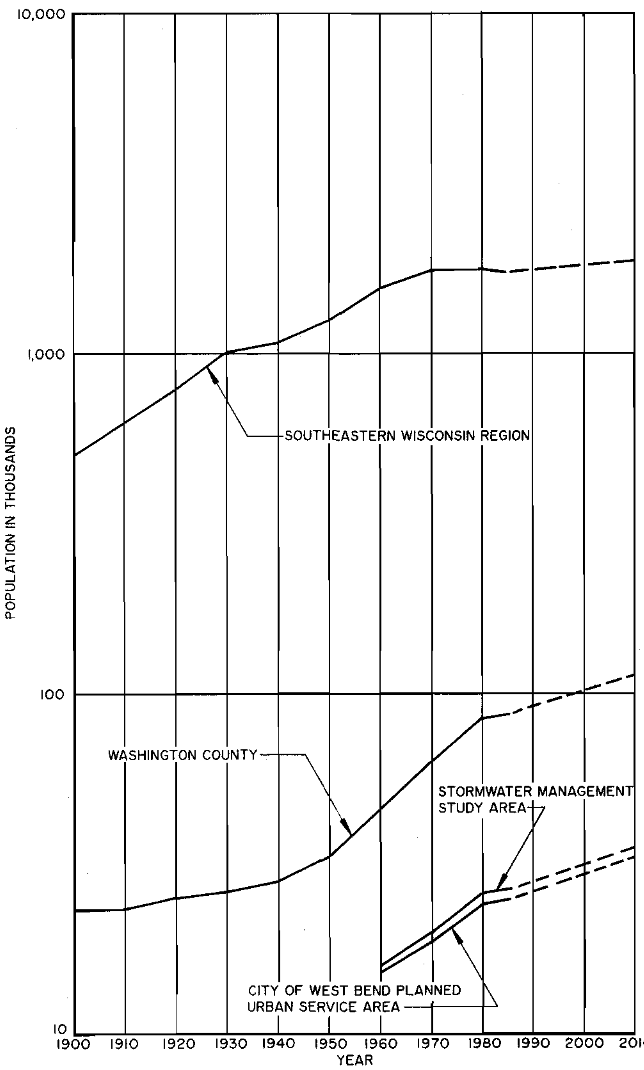
The subdivision and development for urban use of land within the City of West Bend is regulated by the City of West Bend subdivision and platting ordinance. The ordinance requires that preliminary and final subdivision plats be filed for all divisions of land which create five or more parcels of land 1.5 acres or less in area. It further requires that a certified survey map be filed for all divisions of land which create at least two but not more than four parcels of land, any of which are 10 acres or less in area. The ordinance sets forth specific design and improvement requirements for preliminary and final plats, and requires the subdivider to install subdivision improvements, including concrete curbs and gutters, drainage channels, culverts, and other surface drainage facilities, to city specifications prior to final plat approval. The subdivision control ordinance requires that a stormwater management plan be prepared showing a method for managing proposed stormwater runoff, subject to the approval of the City Plan Commission. The city land subdivision control ordinance provides that a waiver of the street improvement requirements may be granted by the City, permitting rural street cross-sections with roadside swales in commercial areas, industrial areas, and planned unit developments. Such waivers, however, are not routinely granted by the City.

The subdivision and development for urban use of the remainder of land within the study area is regulated by the land subdivision control ordinances of the Towns of Barton, Farmington, Jackson, Polk, Trenton, and West Bend. The Towns of Polk and West Bend require that preliminary and final subdivision plats be filed for all divisions of land which create five or more parcels of land, each 1.5 acres or less in area. The Towns of Barton and Farmington subdivision control ordinances require that preliminary and final plats be filed for all divisions of land which create five or more parcels of land, each 5.0 acres or less in area. The Town of Jackson requires that preliminary and final subdivision plats be filed for all divisions of land which create three or more parcels of land, each 5.0 acres or less in area, while the Town of Trenton requires that preliminary and final subdivision plats be filed for all divisions of land which create five or more parcels of any size. All six ordinances require a subdivider to install subdivision improvements, including stormwater drainage facilities, prior to final plat approval, the design of the facilities being subject to the approval of the municipality.

The zoning and subdivision control ordinances exercised by each of the seven municipalities within the study area serve to regulate the type, location, and intensity of the various land uses, and the improvements provided for new urban development. These ordinances regulate aspects of development which influence both the amount and rate of stormwater runoff, as well as the quality of runoff. For example, the size of lots and the placement and size of structures on those lots, as regulated by the zoning ordinances, affect the proportion of the land surface covered by impervious surfaces. Generally, as imperviousness increases, the rate and amount of stormwater runoff increase and the water quality of the runoff decreases. The type and design of the stormwater drainage system, as regulated by the subdivision control ordinances, also affect the quantity and quality of stormwater runoff. For example, storm-sewered urban areas usually generate higher runoff rates and amounts, and a lower quality of runoff, than do areas drained by vegetated open channels.

Figure 1

COMPARISON OF HISTORICAL, EXISTING, AND FORECAST POPULATION TRENDS FOR THE SOUTHEASTERN WISCONSIN REGION, WASHINGTON COUNTY, THE CITY OF WEST BEND PLANNED URBAN SERVICE AREA, AND THE CITY OF WEST BEND STORMWATER MANAGEMENT STUDY AREA



Source: SEWRPC.

IMPACT OF CHANGED LAND USE ON STUDY AREA STORMWATER MANAGEMENT SYSTEMS

Land use and cover in the study area markedly influence the stormwater runoff process. Land cover differs from land use in that it describes the types of surface—for example, roofed, paved, grassed, or wooded—whereas, land use describes the function or activity served by the land—for example, residential, commercial, or recreational. The conversion of land from rural to urban use and the associated increase in impervious area will tend to increase both the rate and volume of stormwater runoff for a given rainfall event and decrease the time of runoff. Such increases in rates and volumes of runoff can increase bank erosion and bed scour in receiving streams. In addition, increased imperviousness in areas of groundwater recharge may cause a reduction in stream baseflow. Stormwater runoff from urban lands also carries different types and increased amounts of pollutants as compared to runoff from rural lands.

Table 5

RANGE OF SURFACE IMPERVIOUSNESS FOR LAND USE AND LAND COVER CONDITIONS

Description	Range of Percent Imperviousness	Typical Corresponding Land Use/Cover Combinations
Rural	0-8	Agricultural lands, woodlands, wetlands, and unused lands
Low Imperviousness	9-20	Low-density residential with supporting urban uses and associated land cover
Low to Medium Imperviousness	21-33	Low- to medium-density residential with supporting urban uses and associated land cover
Medium Imperviousness	34-45	Medium-density residential with supporting urban uses and associated land cover
High Imperviousness	46-65	High-density residential with supporting urban uses and associated land cover
Very High Imperviousness	66-100	Commercial and industrial, and associated land cover

Source: SEWRPC.

Land use—and probable changes in such use over time—affects the stormwater runoff process, and therefore existing and probable future changes in the loadings on the stormwater management system; therefore, that system must serve to support existing, and promote desirable, land use development in the planning area. Therefore, consideration of both the probable future and existing land use pattern of an area is necessary for the effective development of alternative stormwater management plans and for the selection of a recommended plan.

The conversion of rural land to urban uses would result in about 10,140 acres, or about 79 percent of the planned urban service area, being devoted to urban land uses by the year 2010. This compares to the 4,440 acres, or 35 percent of the planned urban service area, in urban land use under existing 1985 conditions, and indicates an increase of approximately 128 percent in the amount of land in urban use. This change in land use will have a direct impact upon the quality, amount, and rate of stormwater runoff.

The percent of impervious surface in a given area is an important factor in determining both the amount of stormwater runoff and the rate at which stormwater runoff is generated. Table 5 lists the imperviousness ranges defined for various land use and land cover conditions. As indicated by that table, more than 65 percent of the total area of industrial and commercial areas may be impervious surface, while from 10 to 65 percent of the total area of residential areas may be impervious surface, depending upon the density of the development. Generally, less than 10 percent of the total area of rural areas is impervious surface. The impact of the planned changes in land use on the volume and rate of stormwater runoff from each of the drainage subbasins established for this study is set forth in Volumes Two, Three, and Four of this report, which discuss the results of the stormwater drainage system hydrologic-hydraulic simulation modeling work.

CLIMATE

Air temperatures and the type, intensity, and duration of precipitation events affect the extent of areas subject to inundation and the type and magnitude of stormwater problems throughout the study area. The study area has a typical continental-type climate characterized primarily

Table 6

AVERAGE MONTHLY AIR TEMPERATURE AT WEST BEND: 1951 THROUGH 1980

Month	Average Daily Maximum (°F)	Average Daily Minimum (°F)	Mean[a] (°F)
January	25.4	8.8	17.1
February	29.6	13.0	21.3
March	39.3	22.7	31.0
April	54.9	34.7	44.8
May	67.3	44.5	55.9
June	76.7	54.1	65.4
July	81.1	59.6	70.3
August	79.3	58.4	68.9
September	71.6	50.7	61.2
October	60.1	41.0	50.5
November	44.5	28.5	36.5
December	31.1	16.0	23.6
Annual	55.1	36.0	45.5

[a]*The monthly mean temperature is the mean of the average daily maximum temperature and the average daily minimum temperature for each month.*

Source: National Weather Service and SEWRPC.

by a continuous progression of markedly different seasons and a wide range in monthly temperatures. The study area lies in the path of both low-pressure storm centers moving from the west and southwest and high-pressure fair weather centers moving in a generally southeasterly direction. The confluence of these air masses results in frequent weather changes, particularly during spring and winter. These temporal weather changes consist of marked variations in temperature, precipitation, relative humidity, wind speed and direction, and cloud cover. The meteorologic events influence the rate and amount of stormwater runoff, the severity of storm drainage problems, and the required capacities of stormwater conveyance and storage facilities. Definitive, long-term meteorologic data are available from the West Bend National Weather Service station.

Temperature and Seasonal Considerations

Air temperatures, which exhibit a wide monthly range, are relevant to stormwater management planning in that they determine whether precipitation occurs as rainfall or snowfall, whether the ground is frozen and therefore essentially impervious, and the rate of snowmelt and attendant runoff. Table 6 presents average monthly air temperature variations at the West Bend National Weather Service station for the 30-year period from 1951 through 1980. The 30-year period of meteorologic record of 1951 through 1980 corresponds to the World Meteorological Organization's normal climatic period. Summer temperatures, as measured by the monthly means for June, July, and August, average from 65°F to 70°F. Winter temperatures, as measured by the monthly means for December, January, and February, average from 17°F to 24°F. For the period 1930 through 1980 at West Bend, the maximum recorded temperature was 107°F in July 1936, and the lowest recorded temperature was -30°F in January 1979. The growing season, which is defined as the number of days between the last 32°F temperature reading in spring and the first in fall, averages about 151 days for the study area. The last frost in spring normally occurs in early May, whereas, the first freeze in fall usually occurs during the first half of October. Streams and lakes begin to freeze over in late November and ice breakup usually occurs in late March or early April. Ice jams at bridges in spring can be a major cause of localized flooding. Such occurrences can be severe when combined with spring rainfall periods.

Precipitation

Precipitation within the study area takes the form of rain, sleet, hail, and snow, and ranges from gentle showers of trace quantities to brief but intense and potentially destructive thunderstorms or major rainfall-snowmelt events causing property damage, inundation of poorly drained areas, stream flooding, street and basement flooding, and severe soil erosion and sedimentation. Average monthly and annual total precipitation and snowfall data from the West Bend National Weather Service station for the period 1951 through 1980 are presented in Table 7. The average annual total precipitation in the West Bend study area based on the West Bend National Weather Service station is 30.65 inches, expressed as water equivalent, while the average annual snowfall and sleetfall measured as snow and sleet is 49.1 inches. Assuming that 10 inches of measured snowfall and sleetfall are equivalent to one inch of water, the average annual snowfall of 49.1 inches is equivalent to 4.91 inches of water; therefore, only about 16 percent of the average annual total precipitation occurs as snowfall and sleet. Average total monthly precipitation for the West Bend study

Table 7

AVERAGE MONTHLY PRECIPITATION AND SNOW AND SLEET AT WEST BEND: 1951 THROUGH 1980

Month	Average Total Precipitation (inches)	Average Snow and Sleet (inches)
January	1.31	12.3
February	0.95	9.0
March	1.99	9.8
April	2.97	1.7
May	2.97	0.1
June	3.65	0.0
July	3.97	0.0
August	3.37	0.0
September	3.48	0.0
October	2.48	0.2
November	1.97	3.5
December	1.54	12.5
Year	30.65	49.1

Source: National Weather Service and SEWRPC.

area ranges from 0.95 inch in February to 3.97 inches in July. The principal snowfall months are December, January, February, and March, during which 89 percent of the average annual snowfall may be expected to occur.

An important consideration in stormwater drainage is the seasonal nature of precipitation patterns. Based on historical observations, flooding along the streams in the study area, excluding the Milwaukee River, is likely to occur at any time throughout the year except during winter. This is because the drainage areas of those streams are relatively small and flood peaks are influenced by the effects of urban development. The relatively large proportions of impervious surfaces in urban areas inhibit infiltration, thereby significantly increasing surface runoff during even minor rainfall events. Because the dampening effects of infiltration, including leaf interception during summer months, are diminished in urban areas, the annual distribution of flood events in urbanized watersheds is similar to the annual distribution of significant rainfall events, and significant flood events may be expected to occur during spring, summer, and fall.

Extreme precipitation data for southeastern Wisconsin, based on observations for stations located throughout the Region that have relatively long periods of record, are presented in Table 8. The minimum annual precipitation within southeastern Wisconsin, as determined from the tabulated data for the indicated observation period, occurred at Waukesha in 1901, when only 17.30 inches of precipitation occurred, or 55 percent of the average annual precipitation of 31.30 inches for southeastern Wisconsin. The maximum annual precipitation within southeastern Wisconsin occurred at Milwaukee in 1876, when 50.36 inches of precipitation was recorded, equivalent to 161 percent of the average annual precipitation.

Based on a period of record from 1922 through 1986 at West Bend, the minimum annual precipitation was 19.72 inches recorded in 1901, and the maximum annual precipitation was 41.43 inches recorded in 1984. The maximum monthly precipitation was 13.14 inches recorded in August 1924, and the maximum 24-hour precipitation was 7.58 inches recorded on August 4, 1924. The maximum monthly and 24-hour precipitation amounts recorded at West Bend are also the maximums for the Region.

Stormwater drainage system design must also consider the characteristics of rainfall events for periods of time substantially shorter than 24 hours. The characteristics of rainfall events over these shorter peak precipitation periods are discussed in Chapter IV of this volume.

Snow Cover and Frost Depth

The likelihood of snow cover and the depth of snow on the ground are important precipitation-related factors that influence the planning, design, construction, and maintenance of stormwater management facilities. Snow cover in the West Bend study area is most likely during the months of December, January, and February, during which at least a 0.5 probability exists of having one inch or more of snow cover. The amount of snow cover influences the severity of spring snowmelt-rainfall flood events, which usually occur during March.

The depth and duration of ground frost, or frozen ground, influences hydrologic processes, particularly the proportion of rainfall or snowmelt that will run off the land directly into storm sewerage systems and surface watercourses. The amount of snow cover is an important determinant of frost depth. Since the thermal conductivity of snow cover is less than one-fifth that of moist soil, heat loss from the soil to the colder

Table 8

EXTREME PRECIPITATION PERIODS IN SOUTHEASTERN WISCONSIN: SELECTED YEARS 1870 THROUGH 1986

Observation Station		Period of Precipitation Records	Total Precipitation						
			Maximum Annual		Minimum Annual		Maximum Monthly		
Name	County		Amount	Year	Amount	Year	Amount	Month	Year
Mitchell Field	Milwaukee	1870-1986	50.36[a]	1876	18.69[a]	1901	10.03	June	1917
Racine	Racine	1895-1986	48.33	1954	17.75	1910	10.98	May	1933
Waukesha	Waukesha	1892-1986	43.57	1938	17.30	1901	11.41	July	1952
West Bend	Washington	1922-1986	41.43	1984	19.72	1901	13.14[b]	August	1924
West Allis	Milwaukee	1954-1986	42.85	1960	17.49	1963	9.63	June	1954
Mount Mary College	Milwaukee	1954-1986	41.25	1965	18.50	1963	10.17	June	1968

[a]*Based on the period 1941-1986.*

[b]*Based on the period 1895-1959 in A Survey Report for Flood Control on the Milwaukee River and Tributaries, U. S. Army Engineer District, Chicago, Corps of Engineers, November 1964.*

Source: U. S. Army Corps of Engineers, National Weather Service, Wisconsin Statistical Reporting Service, and SEWRPC.

atmosphere is greatly inhibited by the insulating snow cover. Frozen ground is likely to exist throughout the study area for approximately four months each winter season, extending from late November through March, with frost penetration to a depth ranging from six inches to more than four feet occurring in January, February, and the first half of March.

SOILS

Soil properties are an important factor influencing the rate and amount of stormwater runoff from land surfaces. The type of soil is also an important consideration in the evaluation of shallow groundwater aquifer recharge and stormwater retention and infiltration facilities. The soil characteristics and the slope and vegetative cover of the land surface also affect the degree of soil erosion which occurs during runoff events.

In order to assess the significance of the diverse soils found in southeastern Wisconsin, the Southeastern Wisconsin Regional Planning Commission, in 1963, negotiated a cooperative agreement with the U. S. Soil Conservation Service under which detailed operational soil surveys were completed for the entire Planning Region. The results of the soil surveys have been published in SEWRPC Planning Report No. 8, Soils of Southeastern Wisconsin. The regional soil surveys have resulted in the mapping of soils within the Region in great detail. At the same time, the surveys have provided data on the physical, chemical, and biological properties of the soils, and, more importantly, have provided interpretations of the soil properties for planning, engineering, agricultural, and resource conservation purposes, and for underlying stormwater management purposes. Detailed soils maps of the study area are available for use in stormwater management planning.

With respect to watershed hydrology, the most significant soil interpretation for stormwater management is the categorization of soils into hydrologic soil groups A, B, C, and D. In terms of runoff characteristics, these four hydrologic soil groups are defined as follows:

- Hydrologic Soil Group A: Very little runoff because of high infiltration capacity, high permeability, and good drainage.

- Hydrologic Soil Group B: Moderate amounts of runoff because of moderate infiltration capacity, moderate permeability, and good drainage.

- Hydrologic Soil Group C: Large amounts of runoff because of low infiltration capacity, low permeability, and poor drainage.

- Hydrologic Soil Group D: Very large amounts of runoff because of very low infiltration capacity, low permeability, and extremely poor drainage.

The spatial distribution of the four hydrologic soil groups within the study area is shown on Map 6. Hydrologic soil groups A, B, C, and D comprise less than 0.5 percent, 79 percent, 5 percent, and 16 percent, respectively, of the study area. Seventy-nine percent of the study area is covered by soils having good drainage characteristics, which therefore may be expected to generate moderate amounts of stormwater runoff if unpaved.

BEDROCK

Bedrock formations underlying the study area generally lie at a depth of 50 to 400 feet below the surface, with overlying unconsolidated glacial deposits. It is therefore not anticipated that bedrock would be encountered during construction of stormwater management facilities.

WATER QUALITY

The quality of the surface waters in the study area, primarily Silver Creek, Silverbrook Creek, Washington Creek, Wingate Creek, Quaas Creek, and several lakes, ponds, and wetlands, is an important concern of this study. Improper stormwater management may result in pollutant contributions from the watershed to the streams and also in high flow velocities and volumes which can cause erosion of stream banks and scour of the streambed. Under these conditions, high pollutant loadings are contributed, some of which are deposited in downstream beds, thereby potentially influencing water quality conditions over a relatively long period of time. Erosion and the resulting sediment contributed to the stream systems can destroy important stream and riparian fish and aquatic life habitat and result in the discharge of pollutants, such as nutrients, pesticides, and metals, which are transported in the stream system attached to sediment particles. Stormwater runoff from urban lands, including lawns and pavements, can contain relatively high concentrations of water pollutants, such as organic substances, nutrients, fecal coliform organisms, metals, and sediment. High pollutant concentrations and excessive erosion and sedimentation in the streams and ponds also reduce the suitability of these surface waters for recreational uses, such as swimming, fishing, and boating; limit the ability of the water body to support desirable forms of fish and other aquatic life; adversely affect the aesthetics of the water resource; reduce the hydraulic capacity of drainage channels and streams; and result in the loss of, or damage to, public and private shoreline property.

There are no known point sources of water pollution to the receiving streams in the study area other than the Milwaukee River. Sanitary sewage from the City of West Bend is treated by the city wastewater treatment plant, which discharges its treated effluent to the Milwaukee River near the downstream boundary of the study area. In addition, there are no known industrial wastewater discharges to surface waters in the study area other than to the Milwaukee River.

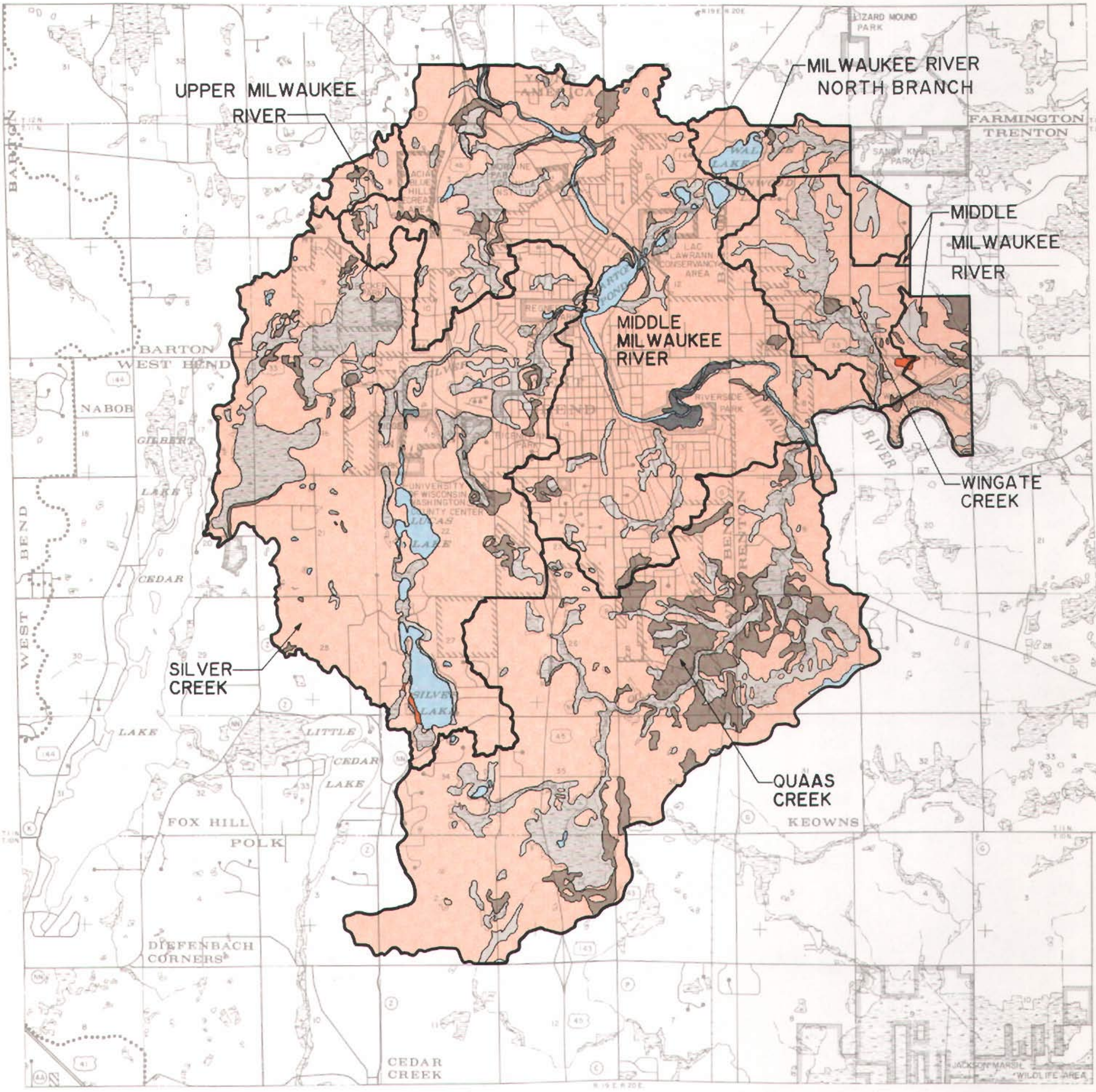
The Nonpoint Source Control Plan for the East and West Branches of the Milwaukee River Priority Watershed, as drafted by the Wisconsin Department of Natural Resources in February 1989, describes the water resources contained in the West Bend area; sets forth potential water use objectives; and identifies factors which currently limit water uses. The report documenting the plan indicates that the surface waters of the West Bend area are limited by degraded water quality conditions, excessive sedimentation, stream bank and channel erosion, and a loss of aquatic habitat.

Silver Creek currently supports a warmwater fish community dominated by forage species considered intolerant to very tolerant of poor water quality and degraded habitat conditions. Based on fishery survey information, the report documenting the plan indicates that since the mid-1970's, there has been a decrease in the number of intolerant fish species and their relative abundance as compared to pollution-tolerant fish species. For example, the least darter was collected from Silver Creek during the period 1976 through 1978, but not during the period 1986 through 1988. The change in the fish community over the past decade is coincidental with urbanization of much of the contributing watershed.

Silverbrook Creek currently supports a somewhat unique "coldwater" forage fish community, including species intolerant to very tolerant of

Map 6

HYDROLOGIC SOIL GROUPS IN THE WEST BEND STUDY AREA



LEGEND

- GROUP A WELL DRAINED SOIL
- GROUP B MODERATELY DRAINED SOIL
- GROUP C POORLY DRAINED SOIL
- GROUP D VERY POORLY DRAINED SOIL
- SURFACE WATER
- MAN MADE FEATURES OR DISTURBED SOILS

Source: SEWRPC.

poor water quality and degraded habitat conditions. Prior to 1963, fishery surveys documented natural reproducing populations of brook trout. Local residents have indicated that trout have been caught in the creek as recently as 1982. Fishery surveys conducted in 1986 through 1988, however, indicated that naturally reproducing trout populations are no longer present in Silverbrook Creek. Although trout populations are now absent, mottled sculpin have recently been collected. The presence of this coldwater and pollution-intolerant forage fish species indicates that marginal water temperatures for coldwater fish species may still exist along localized reaches, including the Bicentennial Park Pond. In addition, marginal habitat areas for coldwater species apparently still exist.

Washington Creek currently supports a warmwater forage fish and aquatic life community tolerant to very tolerant of poor water quality and degraded habitat conditions. The fishery resources in Washington Creek are therefore more limited and of lower quality than the fishery resource in Silver Creek or Silverbrook Creek.

The Regner Park Fish Pond is a shallow and heavily silted impoundment located near the mouth of Silver Creek. Carp are the predominant fish species present. The pond contains excessive aquatic plant growth, and the habitat is suitable for only the most tolerant forms of fish and aquatic life.

Quaas Creek currently supports a diverse population of forage fish and aquatic life intolerant to very tolerant of degraded water quality and habitat. The headwaters of the north and south branches of Quaas Creek downstream to CTH G are classified as Class II trout streams.

Based on the biological appraisals conducted under the priority watershed planning program, it appears that Silver Creek and portions of Silverbrook Creek support generally healthy populations of warmwater fish and aquatic life. Pollution-intolerant populations of coldwater fish are present in portions of Silverbrook Creek and in the upper reaches of Quaas Creek. Washington Creek and the Regner Park Fish Pond appear able to support populations of only limited pollution-tolerant fish and other limited aquatic species. There are indications that the overall quality of the fishery resources in the West Bend area has declined over the past 10 to 25 years.

STORMWATER DRAINAGE SYSTEM

The existing stormwater drainage system serving the study area consists of the streams and watercourses of the area together with certain constructed drainage facilities. The performance of this system is influenced by, among other factors, the topography of the land surface and the location and extent of the tributary drainage areas, as well as by the characteristics of the streams and watercourses, and related manmade drainage facilities.

Topography

Topography, or the relative elevation of the land surface within the study area, is one of the most important considerations in the planning and design of a stormwater management system. The topography of the land surface defines drainage areas, influences the rate and magnitude of surface water runoff and soil erosion, and determines both the uses to which the land can be put and the related stormwater management needs.

The elevation of the study area ranges from a low of about 858 feet above National Geodetic Vertical Datum (NGVD) in the southeast one-quarter of U. S. Public Land Survey Section 17, Township 11 North, Range 20 East, in the City of West Bend, to a high of about 1,182 feet NGVD in the southeast one-quarter of U. S. Public Land Survey Section 3, Township 10 North, Range 19 East, in the Town of Polk. Land surface slopes range from a low of about 0.09 percent for a portion of a drainage area located in the southwest one-quarter of U. S. Public Land Survey Section 10, Township 11 North, Range 19 East, to a high of about 60 percent for a portion of a drainage area located in the northwest one-quarter of U. S. Public Land Survey Section 27, Township 11 North, Range 19 East. In general, areas with slopes greater than 12 percent have severe limitations for urban residential development, and, if developed, present serious potential drainage and erosion problems.

Much of the currently rural, western part of the study area, including portions of the Silver Creek, Upper Milwaukee River, and Middle Milwaukee River subwatersheds, is covered by the relatively deep depressions characteristic of the Kettle Moraine area. In general, the storage volumes of those depressions are great enough to store all of the surface runoff from their tributary drainage area for storms up to, and in some cases exceeding, a recurrence interval of 100 years and a duration of 24 hours. The areas tributary to such deep depressions are classified as being internally drained and are quantified in Table 1.

With proper planning, the deep depression storage areas can be utilized as natural retention basins for runoff from areas undergoing conversion to urban uses. As land development occurs in areas that are currently internally drained, the stormwater runoff volume to the deep depression storage areas would increase; however, if the density of the development is such that the runoff volume does not exceed the depression storage capacity, the area will remain internally drained and downstream flood flows will not be increased by the additional development. It is also possible that, in some areas, conversion of land to urban uses will result in the filling of deep depression storage areas to such a degree that they are no longer effective for the storage of stormwater runoff. In those cases, the area tributary to the receiving stream will be increased and flood flows may also increase. The effects of planned development on internally drained areas and the potential for utilization of existing deep depression areas for stormwater retention were considered in the evaluation of the stormwater management alternatives developed for this plan.

Watershed Subbasins

Stormwater from the entire study area, as delineated on Map 2, is drained to six separate surface water systems—those systems being the intermittent and perennial streams of 1) the Silver Creek subwatershed, 2) the Quaas Creek subwatershed, 3) the Wingate Creek subwatershed, 4) the Middle Milwaukee River subwatershed, 5) the Milwaukee River North Branch subwatershed, and 6) overland drainage to a 0.30-square-mile internally drained area within the Upper Milwaukee River subwatershed. In addition to serving as outlets for stormwater drainage from within the planned urban service area for the City, Silver Creek and Quaas Creek drain areas located upstream of the planned urban service area. These upstream tributary drainage areas must be considered in the proper design of a stormwater management system for the City.

For stormwater management planning purposes, the subwatersheds and partial subwatersheds within the study area were divided into smaller hydrologic units called subbasins. The subbasin boundaries are shown in Chapter II in Volumes Two, Three, and Four of this report. The delineation of these subbasins permits a more accurate representation of the watershed hydrology in the computer models used to simulate stormwater runoff. The subbasin was thus the basic inventory unit within which watershed hydrologic characteristics were quantified prior to hydrologic modeling.

A number of considerations entered into the delineation of the subbasins. Using the available large-scale topographic maps prepared to Commission standards, supplemented by U. S. Geological Survey quadrangle maps in areas where there has been no large-scale topographic mapping, the subbasins were delineated so as to provide desired areas above discharge points at confluences of tributaries and main stems; at, or near, bridges and culverts; and at selected storm sewer inlets and outlets.

Within the total study area, there are 427 subbasins, of which 104 are internally drained under existing conditions. The subbasins range in size from about 1 acre to 932 acres. The average subbasin size, excluding internally drained areas, is 51 acres. The average subbasin size, considering all subbasins, is 46 acres.

Streams, Drainage Channels, Storm Sewers, Ponds, and Lakes

The intermittent and perennial streams in the study area serve as the major drainage outlets for the storm sewers and drainage ditches. As such, they are important components of the drainage system which must be characterized in order to properly plan a stormwater management system. All known intermittent and perennial streams, lakes, and ponds in the study area are shown on Map 3.

Perennial streams or watercourses which maintain a continuous flow throughout the year serve as the major drainage outlets for the storm sewers, drainage ditches, open channels, and intermittent streams of the study area. Intermittent streams are those watercourses which do not sustain continuous flow during dry periods. The network of streams serves a vital function by providing natural drainage for those areas not drained by engineered stormwater drainage facilities, and by receiving the discharge of the engineered facilities. Both perennial and intermittent streams constitute important components of the existing and planned stormwater management systems of the study area. The importance of these streams to future stormwater management is primarily due to two factors: 1) the streams accommodate surface runoff and provide outlets for engineered stormwater drainage systems, and 2) the streams carry flows from upstream areas into and through the urban service area, transmitting flows from both the upstream areas and the urban service area to downstream areas.

The Silver Creek subwatershed contains 4.92 miles of perennial streams and 4.39 miles of intermittent streams. The two major perennial streams tributary to Silver Creek are Silverbrook Creek and Washington Creek. Runoff from the upstream portions of the Silver Creek subwatershed drains to a chain of lakes with a total area of about 212 acres. From upstream to downstream, the lakes are Silver Lake (119.5-acre surface area), Paradise Valley Lake (10.4-acre area), Lucas Lake (68.2-acre area), Ridge Run Park Lake (7.2-acre area), Pick Lake (2.8-acre area), and an unnamed lake (3.7-acre area). Because much of the upper portion of the subwatershed is internally drained, the ratio of lake area to direct drainage area is relatively large. As a result, the available storage volumes of the lakes, in conjunction with their limited outflow capacities, attenuate peak inflows, reducing downstream flood flows. The areas tributary to the three largest lakes—Silver, Paradise Valley, and Lucas—lie outside the planned urban service area; therefore, these lakes are not available for detention of stormwater runoff from developing areas.

Bicentennial Park Pond, with a surface area of 1.3 acres, is located on Silverbrook Creek. Schumacher Pond, with an area of 1.8 acres, is located on a tributary to Silverbrook Creek. The West Bend Swimming Pond, with a surface area of about 2.1 acres, is located just west of Silver Creek in Regner Park. The Regner Park Fish Pond, with a surface area of 2.4 acres, is located on Silver Creek near its mouth.

The Quaas Creek subwatershed contains 8.22 miles of perennial streams and 7.01 miles of intermittent streams. Quaas Lake, with a surface area of 6.3 acres, is located in the headwaters area of the south branch of the creek.

The Wingate Creek subwatershed contains no perennial streams and 1.85 miles of intermittent streams.

Excluding the Milwaukee River, the portion of the Middle Milwaukee River subwatershed within the study area contains no perennial streams and 8.46 miles of intermittent streams. Rainbow Lake and Lenwood Lake are located within the subwatershed, and have surface areas of 8.8 acres and 16.1 acres, respectively. There are also several small ponds in the subwatershed.

Excluding the Milwaukee River, the portion of the Milwaukee River North Branch subwatershed within the study area contains no perennial streams and 0.76 mile of intermittent streams. Wallace Lake has a surface area of 55.6 acres.

There are no perennial or intermittent streams in that portion of the Upper Milwaukee River subwatershed within the study area. That entire area is internally drained, with runoff reaching depression areas through overland flow.

Engineered stormwater drainage facilities within the study area as of 1987—defined as constructed channels, storm sewers, and appurtenances, as opposed to natural watercourses—had a combined service area of about 3,371 acres, or 17 percent of the total study area. As presented in Table 9, about 3,049 acres, or 90 percent of the total area served by engineered stormwater drainage facilities, were tributary to drainage systems relying primarily on storm sewers for conveyance. The remaining 322 acres, or 10 percent, were tributary to drainage systems relying primarily on open drainage channels and associated culverts. In addition to the areas enumerated above, USH 45, which runs in a north-south direction through the western part of the study area, is drained by a system of storm sewers, culverts, and roadside swales.

Aside from USH 45, the portions of the study area served by storm sewers are located entirely within the existing corporate limits of the City of West Bend. They comprise 24 percent of the planned urban service area and 16 percent of the study area. The existing storm sewer system, which actually consists of 91 individual subsystems, serves tributary drainage areas ranging in size from about 1 to 417 acres. As shown in Table 9, the total length of existing storm sewers

Table 9

CHARACTERISTICS OF SUBWATERSHED STORM SEWER SYSTEM WITHIN THE CITY OF WEST BEND

Subwatershed	Tributary Area (acres)	Length of Storm Sewer (feet)	Range of Storm Sewer Sizes (inches)	Range of Storm Sewer Slopes (ft/ft)
Wingate Creek	132	11,180	12 to 57 x 43 CMPA	0.0026-0.0868
Quaas Creek	165	18,930	12 to 60 x 36 CMPA	0.0009-0.1385
Silver Creek	454	48,260	10 to 60 x 40 CMPA	0.0002-0.1917
Silverbrook Creek	243	31,040	12 to 54 x 38 CMPA	0.0001-0.1152
Washington Creek	39	3,470	12 to 36	0.0021-0.0929
Middle Milwaukee River	2,016	217,150	8 to 72 x 48 CMPA	0.0003-0.2791
Milwaukee River North Branch	No Storm Sewer Systems			
Upper Milwaukee River	No Storm Sewer Systems			
Total	3,049	330,030	18 to 72 x 48 CMPA	0.0001-0.2791

NOTE: CMPA = Corrugated metal pipe arch.

Source: SEWRPC.

in the study area is about 330,030 feet, or 62.5 miles. The slopes of the sewers range from 0.0001 foot per foot to 0.2791 foot per foot. Volumes Two, Three, and Four of this report, which present the evaluations of both the existing stormwater management system and alternative future stormwater management plans, and set forth the recommended plans for each subwatershed, contain more detailed descriptions of the storm sewer system within each subwatershed.

The storm sewer systems are maintained by the Public Works Department of the City of West Bend. Maintenance activities include sewer inspection; sewer, culvert, catch basin, and channel cleaning; and minor repair work on sewers, manholes, basins, and inlets.

Estimates of the peak flows and average total annual flows discharged from the existing storm sewer system to receiving streams are set forth in Volumes Two, Three, and Four of this report. A description of the design rainfall recurrence interval used to estimate those flows is presented in Chapter IV of this volume.

Wetlands

Wetlands are natural areas in which the groundwater table lies near, at, or above the surface of the ground, and which support certain types of vegetation. Wetlands are usually covered by organic soils, silts, and marl deposits. Wetlands provide valuable ecological habitats and stabilize streamflows by storing peak discharges and releasing water during low-flow conditions. Wetlands also have important recreational, educational, and aesthetic values.

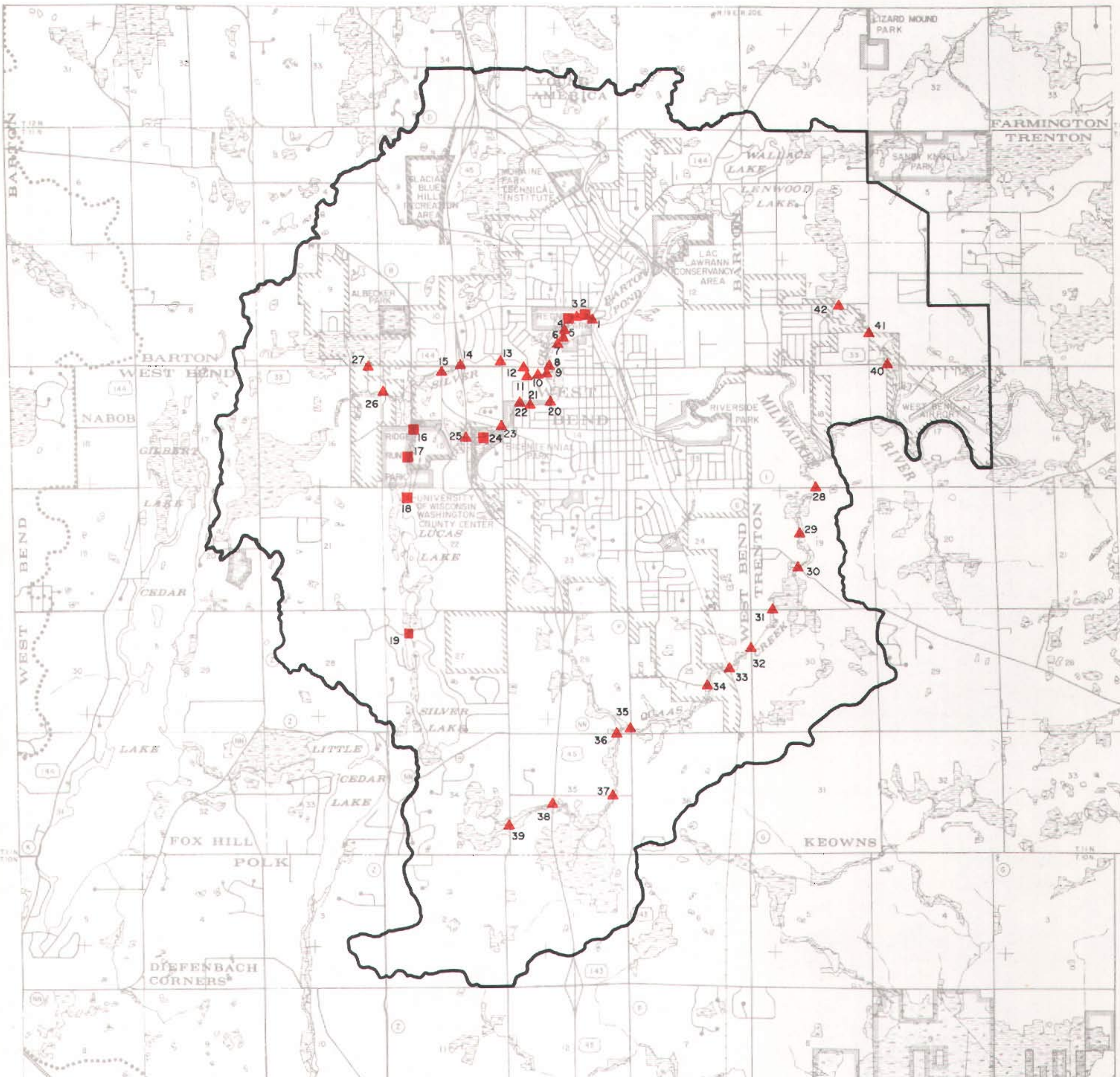
A sound stormwater management plan should, to the extent practicable, utilize the stormwater storage capacity of any existing natural wetlands, while preserving the quality of the wetlands. Thus, wetland preservation should be an integral part of a stormwater management plan. Wetlands in the study area were identified in a special inventory conducted by the Commission using aerial photographic interpretation and field inspection supplemented by analysis of mapped soil data. The location and extent of wetlands in the study area are shown on Map 4 and quantified in Tables 2 and 3. In 1985, there were approximately 1,962 acres of wetlands in the study area, comprising about 10 percent of the area. Within the planned urban service area for the City of West Bend, there were about 1,177 acres of wetlands, comprising about 9 percent of that area.

Bridges, Culverts, and Other Structures

Bridges and culverts significantly influence the hydraulic behavior of a stream system. Constric-

Map 7

LOCATION OF BRIDGES, CULVERTS, AND DAMS IN THE CITY OF WEST BEND STUDY AREA: 1988



LEGEND

▲ BRIDGE OR CULVERT

■ DAM

16 IDENTIFICATION NUMBER (SEE TABLE 10)

NOTE: BRIDGES, CULVERTS, AND DAMS ALONG THE MILWAUKEE RIVER ARE NOT IDENTIFIED

Source: SEWRPC.

tions caused by inadequately designed bridges and culverts can, during storm events, result in large backwater effects, thereby creating a floodland area upstream of the structure that is significantly larger than that which would exist in the absence of the bridge or culvert.

Map 7 shows the location of bridges, culverts, and dams in the study area. Table 10 indicates the hydraulic significance of each existing structure. A structure is classified as hydraulically significant if it has a significant effect on the peak discharges and/or stages of a stream.

A bridge or culvert is likely to be hydraulically insignificant if it spans a stream from bank to bank, has approach roadways with little or no fill on the floodplain, and has a relatively small superstructure.

Flood Discharges and Natural Floodlands

Flood insurance studies were prepared for the City of West Bend and for Washington County by the Federal Emergency Management Agency as documented in Flood Insurance Study, City of West Bend, Washington County, Wisconsin, February 1982; and Flood Insurance Study, County of Washington, Wisconsin, Unincorporated Areas, March 1983.

The studies used estimated peak 10-, 50-, 100-, and 500-year recurrence interval flood discharges at selected locations along Silver and Silverbrook Creeks as determined by the Regional Planning Commission for 1990 planned land use conditions. The studies also included 10-, 50-, 100-, and 500-year recurrence interval flood discharges at selected locations along Washington, Quaas, and Wingate Creeks based on the land use conditions existing at the times the studies were issued. The flood discharges used for the studies are given in Table 11.

Those flood flows were reviewed in conjunction with the preparation of estimated flows in the existing stormwater drainage system under this study. Volumes Two, Three, and Four of this report present refined estimates of the flood flows under planned land use and channel conditions.

The federal flood insurance study reports include flood insurance rate maps which show the expected surface elevations of the base 100-year flood and the attendant flood hazard areas under existing land use and channel conditions. Map 2 shows the flood hazard areas as delineated in the federal flood study. About 1,510 acres—not including 467 acres of surface water in lakes and the existing channels of rivers and streams—or about 8 percent of the total study area, are located within the 100-year recurrence interval flood hazard areas. About 1,047 acres, or 69 percent of the lands within flood hazard areas, are attributable to overland flooding from Silver, Silverbrook, Washington, Quaas, and Wingate Creeks. The remaining 463 acres, or 31 percent of the total, are attributable to overland flooding and the backwater effects of the Milwaukee River.

STORMWATER DRAINAGE PROBLEMS

Known areas with drainage problems as identified by the City of West Bend Engineering and Public Works Departments are shown on Map 8. The storm-sewered areas shown on the map experience street flooding created by undersized storm sewers, storm sewer outlets below streambeds, or insufficient inlet hydraulic capacity. Drainage problems in the West Bend Industrial Park-North, which is the easternmost problem area on the map, are associated with inadequate drainage swale capacity and lack of cross culverts in areas upstream of storm sewer inlets.

Additional areas of potential drainage problems, which were identified through the analyses conducted for the system plan, are discussed in Volumes Two, Three, and Four of this report.

Information on existing and potential drainage problems was considered in the evaluation of the existing stormwater drainage system and of alternative future plans; and although improvements recommended to the city stormwater drainage system should help to resolve some of these problems, other problems which affect isolated, individual properties may not be able to be fully solved through public drainage system improvements.

Infiltration of groundwater and inflow of stormwater into sanitary sewers is a problem related to stormwater drainage. Guidelines published by the U. S. Environmental Protection Agency define infiltration as water that leaks into a sanitary sewerage system through defective pipes, pipe joints, connections, or manhole walls.

Table 10

STRUCTURE INFORMATION FOR SILVER CREEK, SILVERBROOK CREEK, WASHINGTON CREEK, QUAAS CREEK, AND WINGATE CREEK

Stream	Number on Map 7	Structure Identification	U. S. Public Land Survey Section	Structure Type			Estimated Hydraulically Significant
				Bridge	Culvert	Dam	
Silver Creek	1	Main Street	NW ¼, SE ¼, S11, T11N, R19E	- -	X	- -	Yes
	2	Regner Park Fish Pond	NW ¼, SE ¼, S11, T11N, R19E	- -	- -	X	No
	3	City Park Drive	NW ¼, SE ¼, S11, T11N, R19E	X	- -	- -	Yes
	4	Low dam	NW ¼, SE ¼, S11, T11N, R19E	- -	- -	X	No
	5	Pedestrian bridge	NW ¼, SE ¼, S11, T11N,R19E	X	- -	- -	Yes
	6	Pedestrian bridge	NW ¼, SE ¼, S11, T11N, R19E	X	- -	- -	Yes
	7	Silverbrook Drive	SE ¼, SW ¼, S11, T11N, R19E	- -	X	- -	Yes
	8	Washington Avenue	SE ¼, SW ¼, S11, T11N, R19E	- -	X	- -	Yes
	9	Silverbrook Drive	NE ¼, NW ¼, S14, T11N, R19E	- -	X	- -	Yes
	10	Pedestrian and access bridge	NE ¼, NW ¼, S14, T11N, R19E	X	- -	- -	Yes
	11	15th Avenue	NW ¼, NW ¼, S14, T11N, R19E	- -	X	- -	Yes
	12	Washington Street	SW ¼, SW ¼, S11, and NW ¼, NW ¼, S14, T11N, R19E	- -	X	- -	Yes
	13	18th Avenue	SE ¼, SE ¼, S10, T11N, R19E	- -	X	- -	Yes
	14	Washington Street at USH 45 overpass	NW ¼, NE ¼, S15; SW ¼, SE ¼, S10, T11N, R19E	- -	X	- -	Yes
	15	University Drive	NE ¼, NW ¼, S15, T11N, R19E	- -	X	- -	Yes
	16	Pick Lake	NE ¼, SW ¼, S15, T11N, R19E	- -	- -	X	Yes
	17	Ridge Run Park Lake	SW ¼, SW ¼, S15, T11N, R19E	- -	- -	X	Yes
	18	Lucas Lake	NW ¼, NW ¼, S22, T11N, R19E	- -	- -	X	Yes
	19	Silver Lake	NW ¼, NW ¼, S27, T11N, R19 E	- -	- -	X	Yes
Silverbrook Creek	20	Silverbrook Drive	SE ¼, NW ¼, S14, T11N, R19E	- -	X	- -	Yes
	21	15th Avenue	SW ¼, NW ¼, S14, T11N, R19E	- -	X	- -	Yes
	22	16th Avenue	SW ¼, NW ¼, S14, T11N, R19E	- -	X	- -	Yes
	23	Intersection of 18th Avenue and Chestnut Street	NE ¼, SE ¼, S15, T11N, R19E	- -	X	- -	Yes
	24	Bicentennial Park Pond	NE ¼, SE ¼, S15, T11N, R19E	- -	- -	X	Yes
	25	USH 45	NW ¼, SE ¼, S15, T11N, R19E	- -	X	- -	Yes

Table 10 (continued)

Stream	Number on Map 7	Structure Identification	U. S. Public Land Survey Section	Structure Type			Estimated Hydraulically Significant
				Bridge	Culvert	Dam	
Washington Creek	26	Valley Avenue	NW ¼, NW ¼, S15, T11N, R19E	- -	X	- -	Yes
	27	Washington Avenue	SE ¼, SE ¼, S9, T11N, R19E	- -	X	- -	Yes
Quaas Creek	28	Decorah Road	NW ¼, NE ¼, S19, T11N, R20E	X	- -	- -	Yes
	29	Private drive	SE ¼, NW ¼, S19, T11N, R20E	- -	X	- -	Yes
	30	Sand Drive	NE ¼, SW ¼, S19, T11N, R20E	X	- -	- -	Yes
	31	Paradise Drive	NW ¼, NW ¼, S30, T11N, R20E	X	- -	- -	Yes
	32	CTH G	SE ¼, NE ¼, S25, T11N, R19E	- -	X	- -	Yes
	33	Chicago & North Western Railway	SE ¼, NE ¼, S25, T11N, R19E	X	- -	- -	Yes
	34	Progress Drive—Proposed to be Constructed in 1989	NW ¼, SE ¼, S25, T11N, R19E	- -	X	- -	Yes
	35	CTH P	SE ¼, SE ¼, S26, T11N, R19E	- -	X	- -	Yes
	36	CTH NN	NE ¼, NE ¼, S35, T11N, R19E	- -	X	- -	- -
	37	Mile View Road	NE ¼, SE ¼, S35, T11, R19E	- -	X	- -	Yes
	38	USH 45	NE ¼, SW ¼, S35, T11, R19E	- -	X	- -	Yes
	39	18th Avenue	SE ¼, SE ¼, S34, T11N, R19E	- -	X	- -	Yes
Wingate Creek	40	Washington Street	SW ¼, SW ¼, S8, T11N, R20E	- -	X	- -	Yes
	41	Trenton Road	NE ¼, SE ¼, S7, T11N, R20E	- -	X	- -	Yes
	42	Creek Road	SE ¼, NE ¼, S7, T11N, R20E	- -	X	- -	Yes

Source: SEWRPC.

The guidelines define inflow as water discharged into a sanitary sewerage system from such sources as roof leaders; cellar, yard, and area drains; foundation drains; cooling water discharges; drains from springs and swampy areas; manhole covers; cross connections from storm sewers and combined sewers; catch basins; storm waters; surface runoff; street wash waters; or drainage.

A report entitled Sanitary Sewer System Infiltration/Inflow Analysis, May 1974, was prepared for the City of West Bend by Donohue & Associates, Inc., Consulting Engineers. The report estimated that infiltration occurs at a maximum rate of 2.97 million gallons per day (mgd) in the city sanitary sewerage system, and that inflow occurs at a maximum rate of 0.5 mgd. The report considered the following three alternatives for handling infiltration and inflow: 1) treatment of all flows including infiltration/inflow; 2) measures to reduce infiltration/inflow and treatment of reduced flows; and 3) provision of flow equalization facilities. The report concluded that the expanded city wastewater treatment plant, which had been designed at the time the report was issued and has since been constructed, had adequate capacity to treat estimated year 1994

Table 11

FLOOD DISCHARGES FOR SILVER CREEK, SILVERBROOK CREEK, WASHINGTON CREEK, QUAAS CREEK, AND WINGATE CREEK

Stream	U. S. Public Land Survey Section	Discharge Location	Peak Discharges (cubic feet per second)			
			10-Year Recurrence Interval Flood Event	50-Year Recurrence Interval Flood Event	100-Year Recurrence Interval Flood Event	500-Year Recurrence Interval Flood Event
Silver Creek[a]	NW ¼, SE ¼, S11, T11N, R19E	City Park Drive	540	730	820	1,030
	NE ¼, NW ¼, S14, T11N, R19E	Confluence with Silverbrook Creek	510	690	770	970
	NE ¼, NW ¼, S15, T11N, R19E	University Drive	365	520	590	740
	SE ¼, NW ¼, S15, T11N, R19E	Upstream from Confluence with Washington Creek	20	30	30	40
Silverbrook Creek[a]	NE ¼, NW ¼, S14, T11N, R19E	Confluence with Silver Creek	200	300	350	460
	NE ¼, SE ¼, S15, T11N, R19E	Intersection of 18th Avenue and Chestnut Street	200	300	350	460
Washington Creek[b]	SW ¼, NW ¼, S15, T11N, R19E	Upstream from Confluence with Silver Creek	260	540	600	900
	NE ¼, NE ¼, S16, T11N, R19E	City of West Bend Corporate Limits	90	150	180	270
Quaas Creek[b]	SW ¼, SE ¼, S18, T11N, R20E	Above Confluence with Milwaukee River	620	1,200	1,400	2,050
	NE ¼, SE ¼, S25, T11N, R19E	Chicago & North Western Railway	500	950	1,100	1,600
	SE ¼, SE ¼, S26, T11N, R19E	Old USH 45	350	710	800	1,200
Wingate Creek[b]	SW ¼, NW ¼, S17, T11N, R20E	Above Confluence with Milwaukee River	135	270	325	490

[a] *Discharges based on 1990 planned land use.*

[b] *Discharges based on existing land use when city and county flood insurance studies were issued (1982 and 1983).*

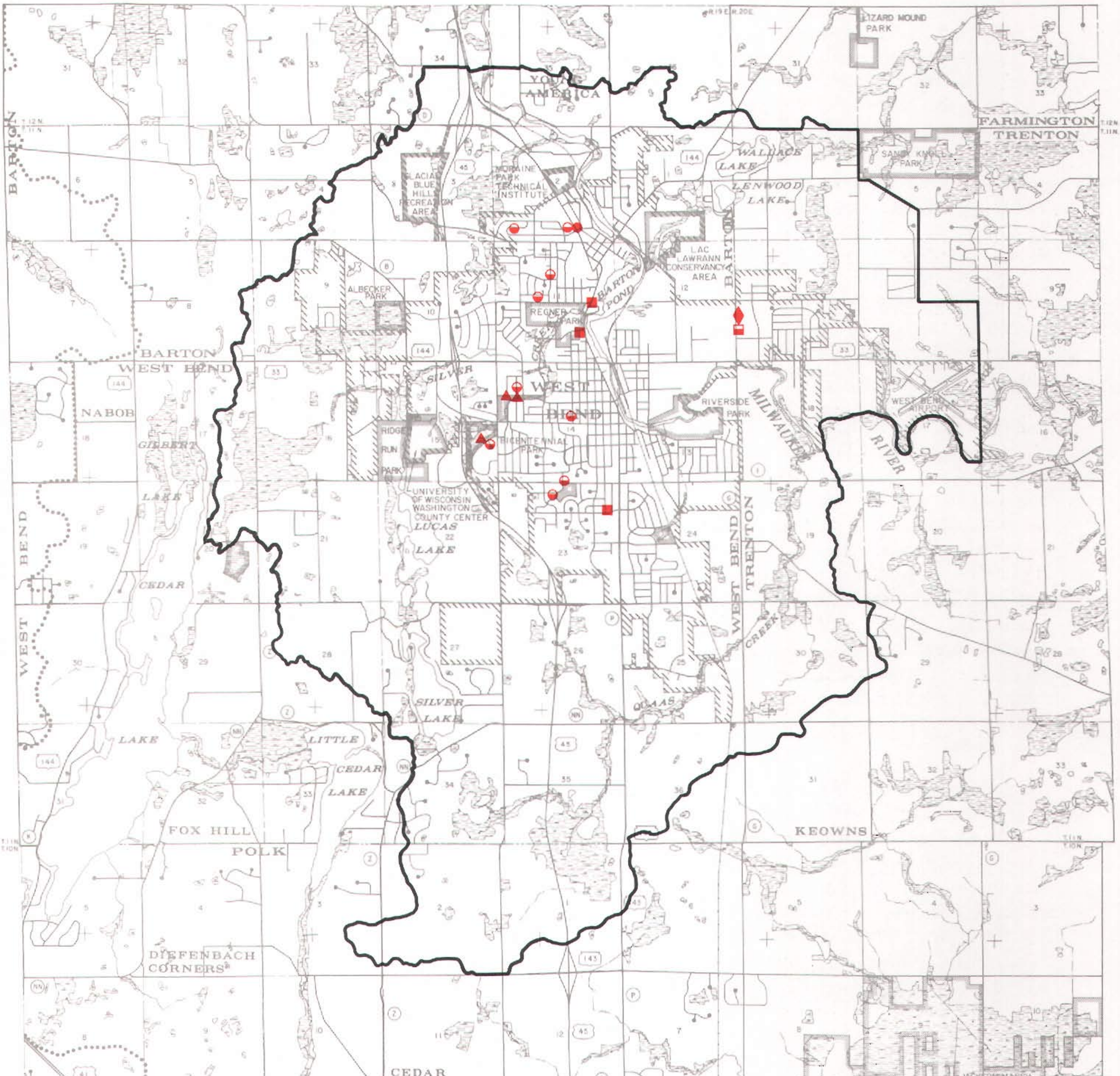
Source: Federal Emergency Management Agency 1982 and 1983 flood insurance studies, and SEWRPC.

average daily and total peak flows, including infiltration/inflow, and that treatment of all flows was the least costly of the three alternatives considered.

A provision in the city plumbing code which prohibits the connection of newly constructed clearwater drains to the sanitary sewer system should help limit inflow to sanitary sewers as urban development proceeds in the area. The City has no ordinance requiring that existing drains be disconnected from sanitary sewers. Newly constructed clearwater drains in the City generally discharge to the land surface. In isolated instances when such discharge creates a nuisance due to ponding or ice formation on sidewalks, connection of the drains to storm sewers may be required.

Map 8

EXISTING STORMWATER DRAINAGE PROBLEM AREAS IN THE CITY OF WEST BEND STUDY AREA: 1988



LEGEND

- ▲ STORM SEWER OUTFALL IS BLOCKED OR IS LOCATED BELOW STREAMBED
- ● IRREGULAR STORM SEWERS BLOCK FLOW
- ⊖ UNDERSIZED STORM SEWER
- ■ INSUFFICIENT INLET CAPACITY
- ♦ INADEQUATE DRAINAGE SWALE CAPACITY
- ⊟ LACK OF CROSS CULVERTS

Source: City of West Bend and SEWRPC.

STREAM BANK EROSION AND DEGRADATION PROBLEMS

Stream bank erosion destroys aquatic habitats at the erosion site, contributes to downstream water quality degradation by releasing sediments to the water, and provides material for subsequent sedimentation downstream which covers valuable benthic habitats, impedes navigation, and fills downstream stormwater storage basins, wetlands, ponds, and lakes.

The Nonpoint Source Control Plan for the East and West Branches of the Milwaukee River Priority Watershed presents data on stream bank erosion sites within the West Bend stormwater management study area. The priority watershed plan identifies 31 stream bank degradation sites with a total length of 8,070 lineal feet along Quaas Creek and one 1,400-foot-long site along Silverbrook Creek in the reach between the intersection of 18th Avenue and Chestnut Street and 16th Avenue. Twelve percent of the total length of stream bank degradation along Quaas Creek is attributed to cattle access. The remainder of the degraded stream bank length along Quaas Creek, and all of the degraded stream bank length along Silverbrook Creek, is attributable to several factors, including hydraulic scour, steep bank slopes, soil conditions, and the lack of stabilizing vegetative cover.

SUMMARY

The primary focus of the stormwater management plan presented in this report is the 20.1-square-mile area contained within the planned urban service area of the City of West Bend. The plan, however, considers, as may be necessary, drainage areas of the natural watersheds which lie upstream of, and are tributary to, the urban service area. About 30 percent of the study area lies in the Silver Creek subwatershed, about 29 percent lies in the Quaas Creek subwatershed, about 5 percent lies in the Wingate Creek subwatershed, about 31 percent lies in the Middle Milwaukee River subwatershed, about 3 percent lies in the Milwaukee River North Branch subwatershed, and about 1 percent lies in the Upper Milwaukee River subwatershed. One percent is the surface water of the Milwaukee River.

An accurate inventory of certain hydrologic and hydraulic characteristics of the study area and related natural and man-made features is an essential step in the stormwater management planning process. Data on the existing stormwater drainage system, existing drainage and flooding problems, and erosion and sedimentation problems are accordingly presented in this chapter. Also presented are data on land use and land use regulations, climate, soils, and water quality.

Land use characteristics, including impervious area, the type of storm drainage system, the level and characteristics of human activity, and the type and amount of pollutants deposited on the land surface, greatly influence the quantity and quality of stormwater runoff. Urban land uses within the planned urban service area of the City of West Bend are expected to increase from a total of 4,440 acres in 1985 to about 10,140 acres in the year 2010, an increase of about 128 percent. Urban land uses are expected to occupy about 79 percent of the total planned urban service area by the plan design year 2010, as opposed to about 35 percent in 1985. The residential land use category is expected to experience the largest absolute increase—about 3,300 acres—for a total in the plan design year of about 5,400 acres. Within the study area, urban land uses are expected to increase from a total of about 5,340 acres in 1985 to about 11,040 acres in the year 2010, an increase of about 107 percent. Urban land uses are thus expected to occupy about 56 percent of the total study area by the design year 2010, as opposed to about 27 percent in 1985.

Attendant to this increase in urban land use is an anticipated increase in the resident population of the planned urban service area and the study area. The 1985 resident population of the planned urban service area was 25,029 persons; the resident population is expected to increase to about 33,251 persons by the year 2010. The 1985 resident population of the stormwater management study area was 26,930 persons; it is expected to increase to about 35,180 persons by the year 2010. The anticipated increase in population within the planned urban service area, as well as within the entire stormwater management study area, can readily be accommodated by the increase in residential land anticipated within that area and the study area over the 1985 to 2010 time period.

The anticipated change in land use will directly impact the amount and quality of stormwater runoff. Increased rates and volumes of runoff result from the higher proportion of impervious areas—such as streets, parking lots, and rooftops. Thus, urban development can increase flood flows, stages, stream bank erosion, and streambed scour in downstream watercourses. Such development can also increase the downstream surface-water pollutant loadings and may reduce stream baseflows. Therefore, careful planning of urban stormwater management systems to meet sound water resource and related management objectives is essential.

Existing pertinent land use regulations include zoning and land division ordinances. These land use regulations, summarized in this chapter, represent important tools for local units of government in directing the use of land in the public interest. Such zoning has important implications for stormwater management.

Climatological factors affecting stormwater management include air temperature and the type and amount of precipitation. Air temperature affects whether precipitation occurs as rainfall or snowfall; whether the ground is frozen, and therefore essentially impervious; and the rate of snowmelt and attendant runoff. The seasonal nature of precipitation patterns is an important consideration in stormwater drainage. Flooding along the major streams in the study area, excluding the Milwaukee River, is likely to occur at any time throughout the year except during winter because of the relatively small drainage areas and the impacts of urban development. The maximum monthly precipitation recorded at West Bend was 13.14 inches in August 1924 and the maximum 24-hour precipitation was 7.58 inches, also recorded in August 1924. The amount of snow cover influences the severity of snowmelt flood events and the extent and depth of frozen soils.

Soil properties influence the rate and amount of stormwater runoff from land surfaces. About 79 percent of the study area is covered by soils which generate moderate amounts of runoff.

The water quality impacts of stormwater management are of increasing concern. High surface runoff and erosion can result in high pollutant concentrations in surface waters, reducing the suitability of the waters for recreational use and limiting the ability of the water to support desired forms of fish and other aquatic life. There are no point sources of water pollution discharging to the streams tributary to the Milwaukee River within the study area. Therefore, the sources of water pollution to those tributary streams are all nonpoint. The abatement of nonpoint pollution sources requires careful consideration in any stormwater management planning effort.

For planning purposes, the study area was divided into 427 drainage subbasins. These subbasins range in size from about 1 to 932 acres, with an average size of 45 acres. These subbasins are drained by a total of 13.14 miles of perennial streams and 22.47 miles of intermittent streams.

The existing City of West Bend storm sewer system—which actually consists of 91 individual subsystems—serves a combined drainage area of about 3,049 acres, or about 16 percent of the study area, all of which lie within the City of West Bend.

Most stormwater drainage problems within the study area are related to street flooding created by undersized storm sewers, storm sewer outlets below streambeds, or an insufficient number of inlets.

The Nonpoint Source Control Plan for the East and West Branches of the Milwaukee River Priority Watershed identified 31 stream bank degradation sites with a total length of 8,070 lineal feet along Quaas Creek and a 1,400-foot-long site along Silverbrook Creek.

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Chapter III

STORMWATER MANAGEMENT SYSTEM COMPONENTS

INTRODUCTION

A stormwater management system plan seeks to combine drainage, flood control, and water quality management system components in a manner that will cost-effectively meet agreed-upon stormwater management objectives. This chapter describes, to the extent required for system planning purposes, five stormwater management system components and the function of these components within a stormwater management system. Each component or element is described, its function identified, and its relationship to the overall stormwater management system discussed.

SYSTEM COMPONENTS

There are two distinct drainage systems to be considered in the development of a stormwater management plan for the City of West Bend: the minor system and the major system. The minor stormwater drainage system is intended to minimize the inconveniences attendant to inundation from more frequent storms, generally up to the 10-year recurrence interval storm event. The minor drainage system consists of side yard and back yard drainage swales, street curbs and gutters, roadside swales, storm sewers and appurtenances, and some storage facilities. It is composed of the engineered paths provided for the stormwater runoff to reach the receiving streams and watercourses during these more frequent storm events.

The major stormwater drainage system is designed for conveyance of stormwater runoff during major storm events—that is, generally, for storms exceeding the 10-year recurrence interval—when the capacity of the minor system is exceeded. The major stormwater drainage system consists of the entire street cross-section and interconnected drainage swales, watercourses, and stormwater storage facilities. Portions of the streets, therefore, serve as components of both the minor and major stormwater drainage systems. When providing transport of overland runoff to the piped storm sewer system, the streets function as a part of the minor drainage system; when utilized to transport overflow from surcharged pipe storm sewers and culverts and overflowing roadside swales, the streets function as a part of the major drainage system. Major drainage system components must be carefully studied to identify areas subject to inundation during major storm events.

The minor and major systems are comprised of four basic types of facilities: overland flow, collection, conveyance, and storage. The storage component of the stormwater quantity management system may also perform a water quality management function.

<u>Overland Flow</u>

When precipitation and snowmelt occur in amounts that exceed the infiltration capacity of the ground surface, the stormwater first accumulates on the ground surface, filling the depression storage, and then begins to flow down slope. In an area served by a traditional urban stormwater management system, this overland flow carries the stormwater runoff to a collection facility. Thus, overland flow serves to concentrate stormwater from its initially more diffuse form. In an urban area, the pattern of overland flow is determined by the siting of buildings and the grading of the surrounding sites, so that such siting and grading become an important part of the design of the stormwater management system. Proper siting and grading of buildings is important in order to provide proper drainage and to provide access to and from buildings during and after foreseeable rainstorm and snowmelt events.

Overland flow may develop relatively high velocities if it occurs over smooth surfaces such as rooftops or paved driveways or parking lots, or only relatively low velocities if it occurs over rough surfaces such as vegetated areas. In addition, stormwater may either accumulate pollutants as overland flow occurs, such as in flow across a paved parking lot, or actually lose pollutants, such as in flow over a vegetated area where sediment may be trapped, deposited, or infiltrated.

Urbanization generally entails a conversion of rough vegetated surfaces with water- and pollutant-absorbing and energy-dissipating characteristics to smooth paved surfaces with significantly reduced water-absorbing and energy-dissipating characteristics. This change in surface configuration will produce a greater quantity and generally a lower quality of stormwater at higher velocities for a given storm. Thus, following urbanization it is necessary to significantly increase the capacity and efficiency of natural drainage systems by providing artificial stormwater collection and conveyance facilities.

Overland flow is an important component of the overall stormwater management system, and has a direct and significant relationship to several of the overall system objectives. Overland flow patterns in urbanizing areas should be designed to maximize the inlet time of stormwater runoff without adversely affecting urban structures or disrupting human activities. Thus, while providing adequate urban drainage, overland flow patterns should be designed to minimize the total volume of stormwater runoff by allowing maximum infiltration of the stormwater; to reduce the peak rate of discharge of stormwater to the collection and conveyance facilities; and to reduce the velocity of overland flow, thereby reducing the energy level of flowing stormwater and its ability to disturb sediment particles and surface pollutants.

The velocity of overland flow can be controlled by minimizing the amounts of paved surfaces and, where possible, draining paved surfaces to pervious grassed areas rather than directly to paved gutters. Various detention and retention storage techniques are also effective in reducing the velocity of overland flow. Such systems are discussed later in this chapter. These management techniques can also reduce the overall volume of stormwater runoff by increasing infiltration and thereby reducing downstream stormwater management requirements.

Because overland flow has a broad impact on the overall system objectives, it was considered to be an important and essential component of the stormwater management system for the West Bend area. Specific arrangements for overland flow, however, cannot be addressed at the systems level of planning. The design of such arrangements must be done on a site-specific basis as urban development or redevelopment takes place, and especially during the land subdivision process attendant to urbanization. Overland flow was considered in the systems planning process, however, through the development of the general guidelines set forth in Chapter IV, which includes a description of practical techniques for minimizing the rate and volume of runoff. In the evaluation of alternative stormwater management systems, it was assumed that these general guidelines would be followed to the extent practicable as land is converted from rural to urban, or as existing urban uses are redeveloped.

Collection

Stormwater collection is the process of further concentrating stormwater flowing overland and transmitting it to conveyance facilities. Stormwater collection facilities may include drainage swales, roadside swales, roadway gutters, stormwater inlets, and inlet leads in which stormwater is collected and then transmitted to surface or subsurface conveyance systems.

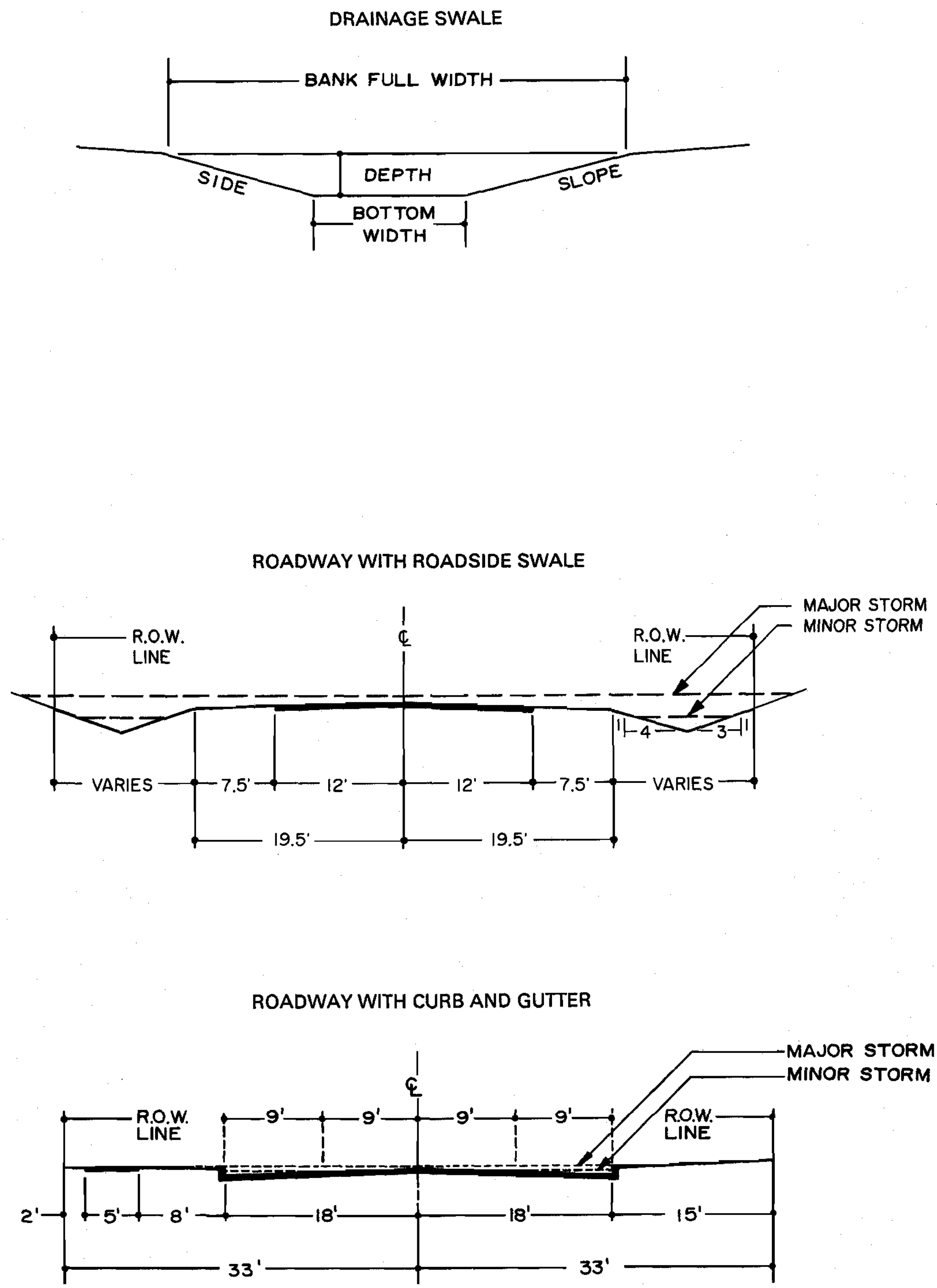
The stormwater collection system may also provide some conveyance and storage functions in the stormwater management system. For minor precipitation events, drainage swales, roadside swales, and roadway gutters collect and transmit stormwater to the stormwater conveyance facilities. Subsurface conveyance facilities—storm sewers—are designed to accommodate minor runoff events only. During major runoff events, the stormwater collected will, by design, exceed the capacity of the subsurface conveyance facilities, with the excess stormwater being temporarily stored on and conveyed over collector and land access roadways, and interconnected surface drainageways which comprise the major conveyance system.

Drainage Swales: A stormwater drainage swale is a small depression or valley in the land surface. The purpose of a drainage swale is to collect overland flow from areas such as front, side, and back yards and transmit it to larger, open stormwater drainage channels or to subsurface conveyance facilities. Drainage swales are generally grass lined, but may be paved to prevent erosion on steep slopes, or to avoid standing water on flat slopes. A typical drainage swale is shown in Figure 2.

Drainage swales cannot be specifically addressed at the systems level of planning. The design of such components must be done on a site-specific basis as urban development or redevelopment takes place. The design of swales, then, like the design of overland flow, is considered in the systems planning process using the

Figure 2

TYPICAL SWALE AND ROADWAY CROSS-SECTIONS SHOWING WATER COLLECTION AREAS



Source: City of West Bend and SEWRPC.

criteria provided in Chapter IV of this volume for detailed design.

Roadside Swales: A roadside swale is a long, narrow, shallow depression or valley running parallel and adjacent to a roadway providing longitudinal drainage. Roadside swales in urban areas are generally grass lined, but also may be paved to prevent erosion on steep slopes, or to avoid standing water on flat slopes. The roadside swale can serve as either a collection component or a conveyance component, or a combination of such components, of the stormwater management system. A typical residential roadway and swale combination is shown in Figure 2. The swale collects stormwater runoff from the roadway surface and the tributary overland flow areas of abutting lands. The collected stormwater is then transmitted to open channel or subsurface conveyance facilities. Roadside swales are generally less expensive than curb-and-gutter collection systems. They also provide lower runoff velocities and can provide for stormwater infiltration and for storage capacity. Nonpoint source water pollution loadings carried by stormwater are generally reduced as flows are collected in swales. Partial or full paving of swales may reduce or eliminate nonpoint source pollution control benefits due to infiltration and thus should be avoided where possible. Through the use of roadside swales, stormwater runoff can be managed entirely in a surface drainage system, and the construction of storm sewers can be avoided. Such surface drainage systems are the most practical in areas developed at relatively low densities, since each intersecting private driveway, as well as public roadway, must be provided with a culvert pipe to carry the drainage. As densities increase, lot areas and widths decrease and front yard setbacks decrease, and a point is reached where the provision of a storm sewer becomes more economical, desirable, and maintainable than the provision of roadside swales and culverts. The use of roadside swales provides a "rural," "suburban," or "estate" appearance and is desired by some communities for this reason. Roadway pavements with roadside swales are often called ribbon pavements.

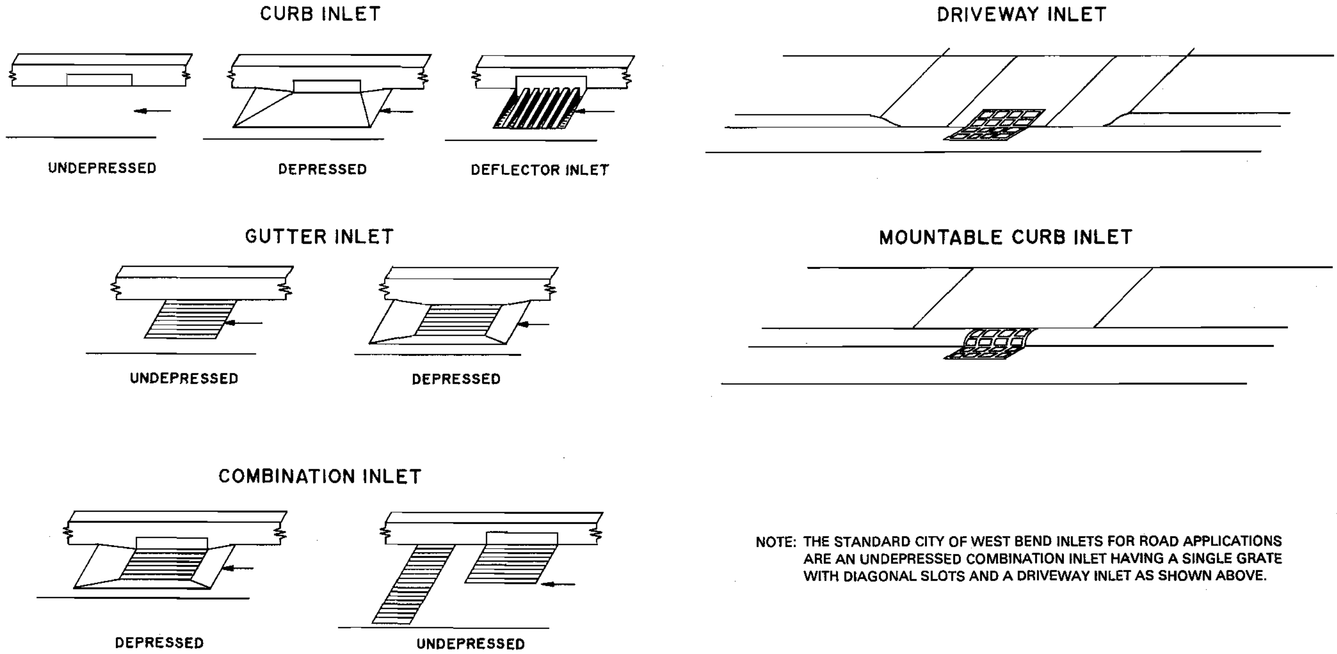
Under some conditions, as, for example, very close driveway culvert spacing or minimum longitudinal gradient, culvert headwater elevations and entrance losses may dictate the design. In areas with limited right-of-way, a rectangular, concrete-lined channel may be required. In other reaches, the channel can more typically be triangular or trapezoidal in shape with grassed bottom and side slopes. In areas of minimum longitudinal gradient, a paved channel bottom may be necessary. The stormwater management plan assumes the use of roadside swales with a cross-section similar to that shown in Figure 2 in certain areas of the City. Systems level design criteria for roadside swales are provided in Chapter IV of this volume.

Roadway Curbs and Gutters: A roadway curb and gutter is a low vertical surface with attendant depression in the roadway cross-section adjacent to the curb line. This stormwater management plan assumes the use of a typical roadway cross-section with curb and gutter similar to that shown in Figure 2 in certain areas of the City. The roadway gutter collects stormwater from the roadway surface and from the tributary overland flow areas of abutting lands. The collected stormwater is typically discharged from the roadway gutters into stormwater inlets or catch basins that transmit the stormwater to subsurface conveyance facilities. Curbs and gutters are required in higher density urban areas where the use of roadside swales and culverts becomes impractical. Curbs and gutters reduce the potential for stormwater infiltration, increase stormwater runoff flow velocity, and limit the removal of nonpoint source water pollution loadings.

It is important to note that curbs and gutters serve certain important functions in addition to the drainage function. Curbs and gutters perform a structural function in supporting pavement edges and protecting those edges against the effects of traffic and moisture. Water seeping into the pavement and subbase along the unprotected edges can shorten pavement life and increase maintenance costs. Curbs and gutters also perform a safety function, defining the pavement edge for drivers and pedestrians; help protect street lights, fire hydrants, and signs from damage by vehicles; and help to keep dirt and litter contained on pavement where mechanical sweepers can collect it. Dirt and litter must be hand collected on unpaved shoulders. Finally, roadway cross-sections with curbs and gutters require less right-of-way than such sections with roadway ditches.

Figure 3

TYPICAL STORMWATER INLET DESIGNS



Source: American Society of Civil Engineers and SEWRPC.

<u>Stormwater Inlets</u>: A stormwater inlet is a device through which stormwater is transmitted from the surface collection facilities to subsurface conveyance facilities. Stormwater inlets are placed at strategic locations along drainage swales, roadside swales, and gutters for the purpose of transmitting collected stormwater into subsurface conveyance facilities. The inlet structure includes a stormwater grate, drop structure, and connection to the underground conveyance facility.

The three basic types of inlets commonly used in stormwater management systems are:

1. The curb inlet, which consists of a relatively large, vertical opening in the curb face extending up from the base of the curb face or gutter line through which stormwater can flow (see Figure 3).

2. The gutter inlet, which consists of an opening in the roadway gutter that is covered by a cast iron grate (see Figure 3). Stormwater is allowed to flow into the gutter inlet while large debris is trapped by the iron grate, which also prevents pedestrian, cycle, and vehicular traffic from dropping into the inlet.

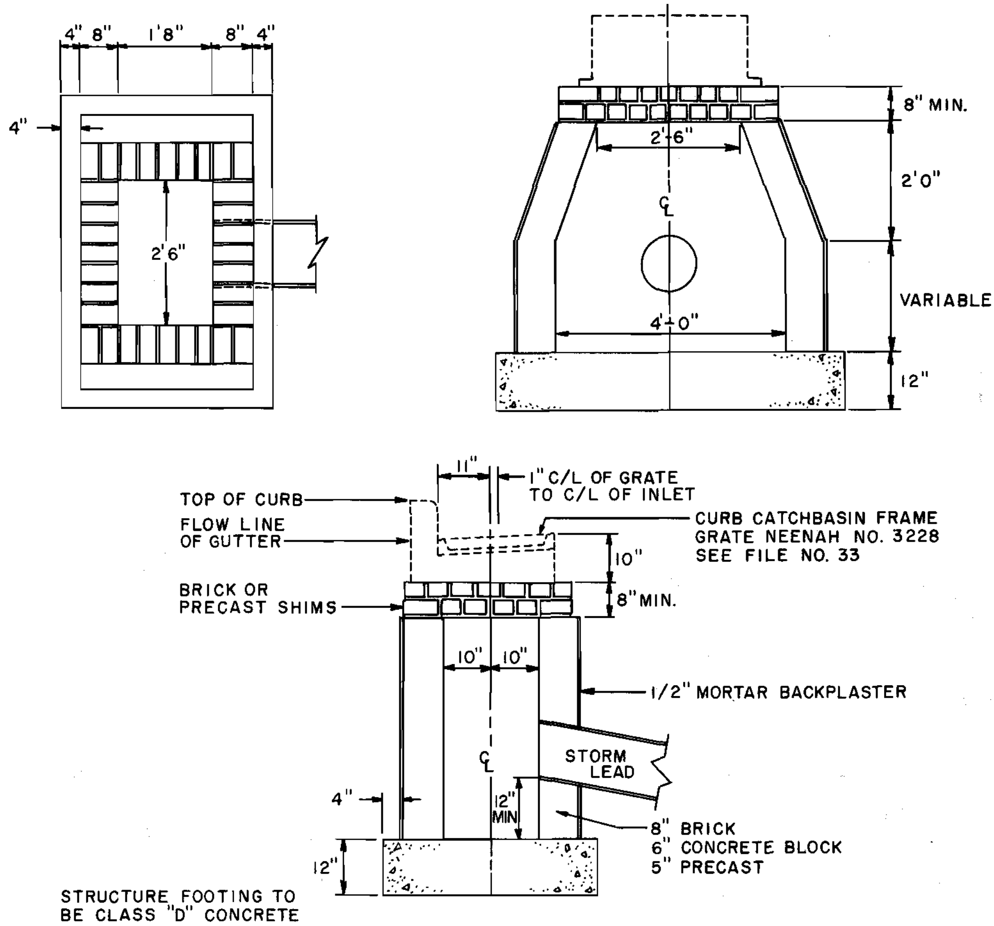
3. The combined curb inlet and gutter inlet, which is referred to as a combination inlet (see Figure 3). The City of West Bend standard inlet is a combination inlet.

Many variations of these basic inlet designs are used in stormwater management systems. For example, the three basic inlet types may be either set at grade in the gutter line (undepressed inlet) or set slightly below grade in the gutter line (depressed inlet), which improves hydraulic efficiency and gutter flow capture. The City of West Bend standard inlet grate types are shown in the City's <u>Standard Specifications for Public Works Construction</u>.

<u>Catch Basins</u>: A catch basin is a stormwater inlet equipped with a small sedimentation basin or grit chamber. The purpose of a catch basin is to remove sediment and debris from stormwater before it is transmitted to the subsurface conveyance facilities. A typical catch basin is shown in Figure 4. Stormwater enters through the surface inlet and drops to the lower basin area. Heavy sediment particles and other debris are collected in the basin area. This debris is then removed during maintenance operations. The catch basin is designed to reduce the maintenance requirements for the underground conveyance system,

Figure 4

TYPICAL CATCH BASIN



Source: Standard Specifications for Sewer and Water Construction in Wisconsin, *Fourth Edition.*

particularly in areas where heavy sediment loads may otherwise be carried into the conveyance system. Catch basins provided a form of nonpoint source water pollution abatement in the period before the automobile, when large quantities of horse manure were deposited on street surfaces. The use of catch basins fell into disfavor because of the cost of the periodic cleaning required. Nonpoint source pollution abatement, however, may warrant the reintroduction of the catch basin in urban areas.

Properly maintained, the catch basin is an effective sediment trap. Improperly or inadequately cleaned catch basins may have a negative impact on receiving water quality. Decaying organic material trapped in the basin may produce noxious odors, and the basin water may become rich in organic material and nutrients and low in dissolved oxygen content. This basin water becomes a part of the first flush of stormwater from subsequent storm events. Basin waters may also provide a place for mosquitoes to breed. Thus, improperly cleaned and maintained catch basins are not beneficial components of the overall stormwater management system.

Collection Elements Applicable to the City of West Bend Stormwater Management System: The general policy of the City of West Bend is to provide full curb and gutter and storm sewers for the collection of stormwater in developing residential and commercial areas. As already noted, the city land subdivision control ordinance provides that waiver of the street improvement requirements may be granted by the City, permitting rural street cross-sections with roadside swales in commercial areas, industrial areas, and planned unit developments. Such waivers, however, are not routinely granted by the City. The recently constructed West Bend Industrial Park-South and parts of the West Bend industrial park on the east side of the City utilize roadside swales and culverts for stormwater collection. The Industrial Park-South also utilizes wet and dry detention ponds, an infiltration ditch, and dry silt ponds to achieve joint stormwater collection and nonpoint control objectives.

In the preparation of the stormwater management plan, consideration was given to the use of both an urban street cross-section with a curb and gutter collection system and a rural street cross-section with roadside swales and culverts. Rural cross-sections were considered only in areas proposed for relatively low-density development, where there would be adequate right-of-way for roadside swales and where the number of driveway culverts would be minimized. Such areas include residential developments with lot sizes of 0.5 acre or greater, and industrial park of office park developments.

Conveyance

Conveyance facilities are normally the most costly component of the stormwater management system. The conveyance components of a stormwater management system may include both open channels and subsurface conduits—storm sewers—designed to receive and transport stormwater runoff from or through urban areas to a receiving stream or watercourse. Stormwater conveyance facilities may also be used to transport nonpolluted wastewaters, such as spent industrial cooling waters.

In most urban settings, it is not possible to maintain the natural stormwater conveyance system because of the increase in the volume and rate of stormwater runoff attendant to the conversion of land from rural to urban use. In addition, landfilling and drainageway excavation are frequently required to facilitate the use of land and roadways unencumbered by stormwater. Therefore, significant modifications are usually made to the natural drainage system to meet the increased stormwater conveyance and vertical separation requirements.

Open Channel Conveyance: Open channel conveyance facilities generally follow the natural surface drainage pattern. In some instances, the natural channel configuration can be maintained with only minor modifications such as removing obstructions and reducing the overall channel roughness. In certain areas it may be necessary to "improve" the existing channel by widening, deepening, and realigning, or to construct an entirely new channel, in order to provide the required conveyance capacity. Man-made open channel conveyance facilities may be grass lined, concrete lined, riprap lined, or composite lined, depending on the need to prevent erosion or avoid standing water. Typical open channel cross-sections are shown in Chapter IV of this volume.

When compared to subsurface storm sewer conveyance facilities, open channel surface conveyance facilities are generally less costly for high flow rates; provide a greater degree of nonpoint source water pollutant removal; and are more adaptable to providing inline storage. Grass-lined conveyance facilities reduce the overall velocity of stormwater runoff, reduce the peak discharge rate from the drainage basin, and allow stormwater to recharge the groundwater reservoir. Open channel conveyance facilities, if poorly designed, may be aesthetically less desirable, may constitute a safety hazard, and may have higher maintenance requirements than storm sewer conveyance facilities. Criteria for design of open channels are provided in Chapter IV of this volume.

Culverts: A culvert is a closed conduit used to convey stormwater under a street, highway, railway, or other embankment. Culverts are a common and hydraulically important feature of open channel drainage systems.

The locations and sizes of existing and proposed culverts in the City of West Bend and environs are set forth in the stormwater management system plan. Hydraulic conditions affecting culvert discharge and culvert design criteria are discussed in Chapter IV of this volume.

Storm Sewer Conveyance: A storm sewer is defined as an underground conduit that transports stormwater runoff from collection facilities to an ultimate point of disposal. The purpose of a storm sewer is to receive stormwater runoff from stormwater inlets and catch basins, and convey that runoff to surface water drainage facilities. The storm sewer provides a rapid conveyance route for stormwater to a point of disposal on a receiving surface watercourse. Subsurface storm sewer systems are generally more costly to construct than surface conveyance facilities; however, they are often required in order to meet stormwater management objectives.

Prefabricated Portland cement concrete pipe is the most commonly used material for the construction of storm sewers in the City of West Bend and in the Region. Concrete pipe is commercially available in standard lengths ranging from four feet to eight feet, and in circular, elliptical, and arch pipe sections, with circular sections ranging from 6 inches to 108 inches in diameter. Nonreinforced concrete pipe is commercially available in diameters ranging from 6 to 18 inches, while reinforced concrete pipe is commercially available in diameters ranging from 12 inches to 108 inches. Fittings for concrete pipe such as wyes, tees, and manholes are readily available. Concrete provides a high-strength, widely used and accepted storm sewer pipe. Prefabricated galvanized steel pipe such as corrugated metal pipe and corrugated metal pipe arch is also used in stormwater management systems. The most common application of these materials is in culvert installations, but, in some cases, corrugated metal pipe is used for storm sewer construction. Corrugated metal is lightweight, strong, and flexible, and is manufactured in generally longer lengths than is concrete pipe. It is more difficult to connect inlets to corrugated metal pipe. Polyvinylchloride (PVC) pipe, also referred to as plastic pipe, is lightweight, is manufactured in generally longer lengths than concrete pipe, and is more hydraulically efficient than corrugated metal pipe. Although most readily available in diameters up to 12 inches, PVC pipe can be obtained in diameters up to 30 inches. There is only limited experience with PVC pipe for storm sewer application; therefore, its long-term performance characteristics are not known. Criteria for the hydraulic design of storm sewers are provided in Chapter IV of this volume.

Other pipe materials such as corrugated polyethylene pipe, asbestos-cement pipe, vitrified clay pipe, ductile iron pipe, and welded steel pipe are also available. These materials are not commonly used for gravity flow storm sewers in the Region. There are limited applications for asbestos-cement pipe and ductile iron pipe as pressure stormwater conveyance facilities.

Manholes: A manhole is a structure which provides an access way to the underground storm sewer system for observation and maintenance. Manholes are typically placed at all junctions in the sewer system, at changes in horizontal or vertical alignment, and from 300 to 600 feet apart along the sewers. Smaller size sewers are normally laid in straight lines between manholes; larger sewers may be laid on curves. Greater manhole spacing distances are allowable for sewers large enough to allow entrance by maintenance personnel. Junctions for smaller size storm sewers can be accommodated within ordinary manholes. Larger sewers, however, may require the provision of special junction chambers. Typical storm sewer manhole designs utilized by the City of West Bend are given in Figure 5.

Recommendations for the locations and spacing of manholes are provided in the stormwater management plan. The type of manhole is a local design consideration which does not affect the system plan.

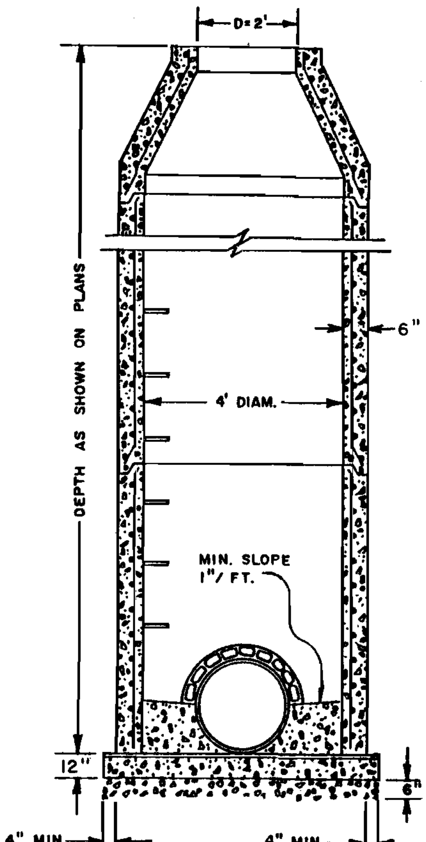
Junction Chambers: A junction chamber is a structure which both provides access to an underground sewer and accommodates changes in the size and junctions of storm sewers. Junction chambers are intended to provide a large underground structure to accommodate conduit size and direction changes. Typically, they are unique cast-in-place reinforced concrete vaults. The type of junction chamber is dependent upon the sewer sizes and alignment conditions at each point in the system. Accordingly, the details of any proposed junction chamber must be determined in the detailed design phase preceding construction.

Conduit End Structures: A conduit end structure is a structure used to make the transition between a culvert or storm sewer and a swale, channel, or other surface watercourse. The primary purpose of an end structure is hydraulic control and efficiency. This includes preventing scour before the pipe inlet and scour and undermining beyond the pipe outlet, and providing a hydraulically efficient pipe entrance. Conduit end structures also provide structural support for the pipe end and stabilization and protection of the embankment slope. The end structure provides protection from, and dissipation of, the excess energy due to the velocity change and turbulence associated with these flow transitions. Typical end structures are given in the Wisconsin Department of Transportation Facilities Development Manual. The details of any end

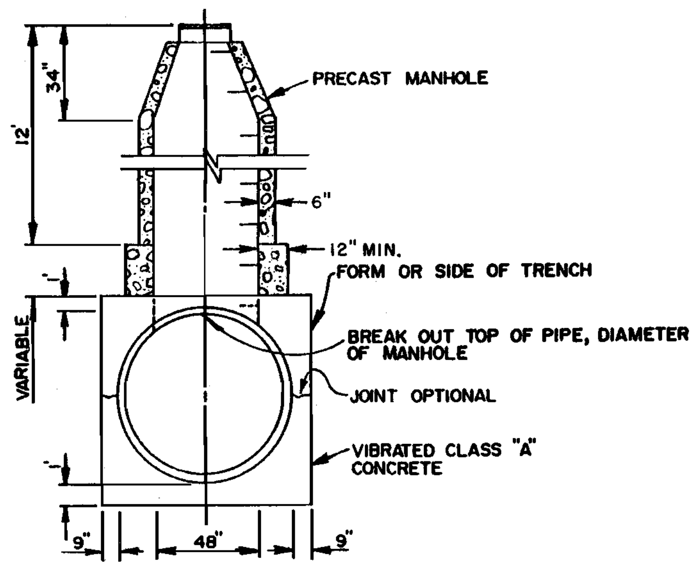
Figure 5

TYPICAL PRECAST REINFORCED CONCRETE MANHOLES FOR STORM SEWERS

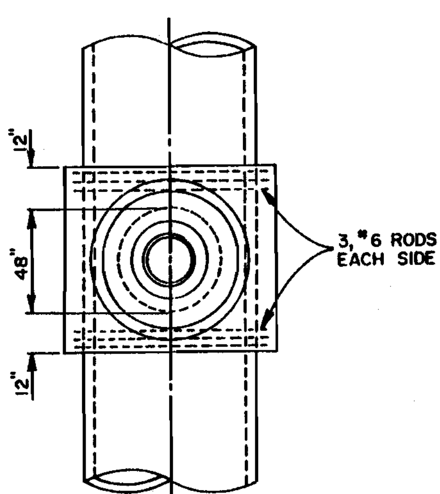
TYPICAL MANHOLE FOR
PIPES UP TO 48-INCH DIAMETER



TYPICAL MANHOLE FOR
PIPES OVER 48-INCH DIAMETER



SECTION



PLAN

MANHOLE FRAME
AND VENTED LID

HEIGHT 7" WT. 400 LBS.

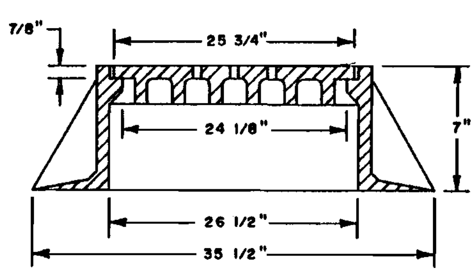
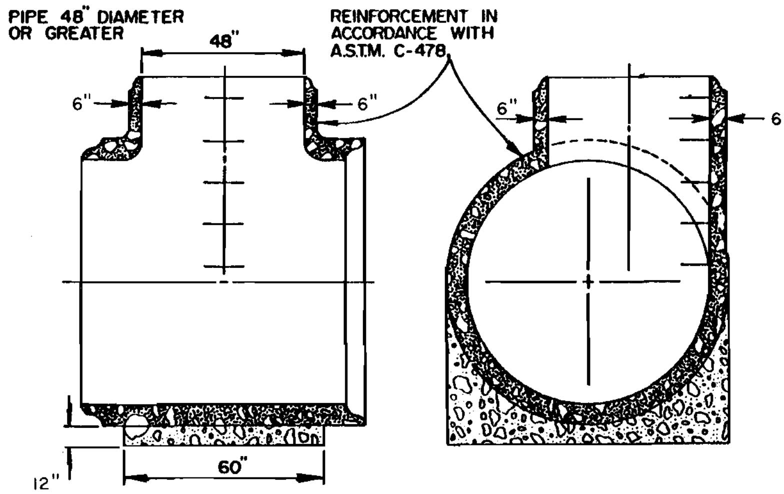


Figure 5 (continued)

TYPICAL MANHOLE FOR
PIPES OVER 48-INCH DIAMETER
WITH SHALLOW COVER



TYPICAL MANHOLE WITH INLET

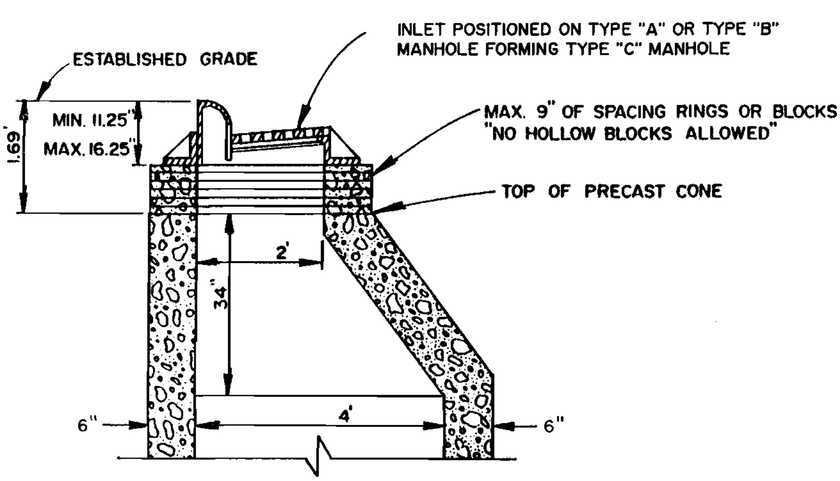
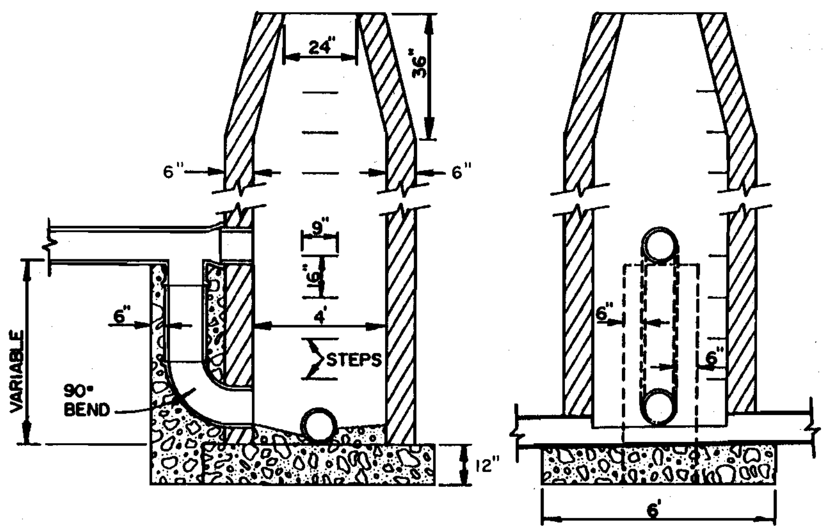


Figure 5 (continued)

TYPICAL DROP MANHOLE



Source: City of West Bend and SEWRPC.

structure must be determined on a site-specific basis in the detailed design phase preceding construction.

Stormwater Pumping Stations: A stormwater pumping station is a mechanical device that lifts and transports stormwater under pressure. The purpose of a stormwater pumping station is to remove stormwater from a low-lying area that cannot be effectively drained by gravity. Stormwater pumping stations are commonly associated with stormwater storage facilities that have limited land surface available, and therefore require deep storage. This type of storage design requires the use of mechanical pumping to fully evacuate storage areas.

Pumping stormwater from storage areas is less dependable and more costly than gravity drainage. Electrical service can suffer service interruptions, especially during thunderstorms. Maintenance of stormwater pumping facilities is a significant concern since these facilities require periodic inspection and maintenance. Where deep storage is required, or where there is not sufficient grade to provide adequate gravity drainage, pumped discharge is necessary.

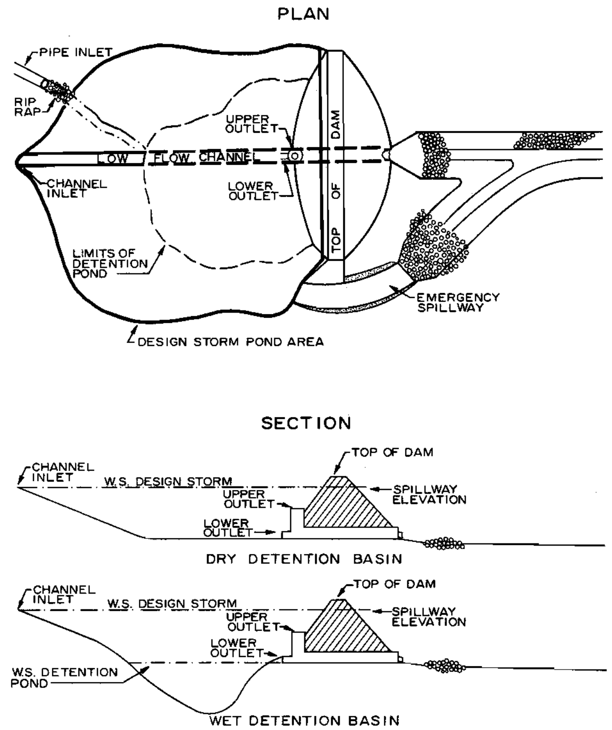
Storage

Stormwater storage can be defined as both the temporary detention and the long-term retention of stormwater within the system. The primary purpose of stormwater storage is to reduce the peak stormwater drainage rates both within the stormwater management system itself and in the receiving waterways. Stormwater storage also allows greater infiltration of stormwater, recharging the groundwater reservoir; reduces flow velocity and thus the potential for stream erosion; enhances the removal of sediment and other particulates suspended in stormwater; and usually reduces the cost of downstream stormwater conveyance and flood control facilities.

Stormwater storage may be either natural or man-made. In an undisturbed setting, natural stormwater storage areas normally exist. Stormwater is stored in natural surface depressions, in wetlands, on floodplains, and in soils. These natural storage areas dispersed throughout a drainage area serve to significantly reduce the volume and rate of stormwater runoff, and to increase the removal of stormwater from the surface water system by evaporation, transpiration, and infiltration.

Figure 6

TYPICAL STORMWATER DETENTION STORAGE STRUCTURES



Source: SEWRPC.

In an urban area, the storage capacity of the natural terrain is significantly reduced by grading to provide smooth, free-draining surfaces; by the filling of wetlands; and by the construction of impervious surfaces such as rooftops, driveways, and streets. These changes result in a significant reduction in stormwater storage capacity. In order to compensate for the loss of natural stormwater storage areas and to reduce the size and cost of conveyance facilities, it may be necessary or desirable to provide man-made storage in the stormwater management system. Such storage may be less costly than higher capacity conveyance facilities, and may reduce the impact of stormwater runoff on downstream areas.

Detention storage is the temporary storage of stormwater accompanied by controlled release. The purpose of detention storage is to hold back or delay stormwater runoff temporarily, thereby reducing the peak rate of stormwater runoff from the drainage area. A dry detention basin normally drains completely between spaced runoff events. A wet detention basin temporarily stores floodwaters on top of a permanent pool of water used for other purposes. Typical dry and wet detention basins are shown in Figure 6.

Retention storage is the long-term storage of stormwater without release to the surface water drainage system. The purpose of retention storage is not only to detain but to remove stormwater from the surface drainage system and allow stormwater to infiltrate or evaporate, reducing the overall volume of stormwater that reaches the outfall of the drainage basin. Stormwater retention basins are often relatively shallow basins, either natural or man-made, with substantial bottom area to allow infiltration into the groundwater reservoir.

Stormwater retention basins and wet detention basins with normal water levels at the water table elevation may serve as water supply and fire protection reservoirs, and may capture stormwater for industrial or municipal uses. Retention basins and wet detention basins can also serve as recreational facilities for nonbody contact uses and as aesthetic focal points in desirable "green" open spaces. Wet detention basins can be designed in series to include connecting open green areas that further enhance the overall stormwater management system effectiveness.

There are a wide variety of passive stormwater detention measures that can be used in an urban setting. These measures consist of grassed stormwater collection swales designed to flow at low velocities, thereby providing "in line" storage; stormwater conveyance swales designed to include check dams to reduce flow velocities, thereby providing storage; and berms, also used to provide increased storage volume. Stormwater storage can also be provided on flat rooftops, in parking lots, and in specially designed and constructed stormwater storage facilities. These storage measures generally detain stormwater for short periods of time, in some cases allowing increased infiltration, evaporation, and transpiration, and can significantly reduce downstream peak stormwater discharges.

The stormwater management planning effort included an evaluation of available sites for stormwater storage facility use. The evaluation of each site was based on site topography and specific storage volume-outlet discharge relationships.

It is important to note that the indiscriminate location and phasing of construction of detention facilities within a watershed can actually increase the magnitude and duration of downstream peak flows. Such a situation occurs when prolongation of peak, or near peak, outflows from a storage facility causes these flows to coincide with near peak flows from upstream or downstream areas. Therefore, it is imperative that such facilities be planned, designed, and evaluated on a watershedwide basis and within the context of a system plan by competent engineers experienced in this field, and not be ordinance requirements based upon broad "policy" plans.

It is not always desirable or feasible to provide storage in a stormwater management system. In most developed urban areas, suitable parcels of land are not readily available for the construction of stormwater retention or detention basins. Other methods of onsite storage and collection system storage may be feasible in such cases, but may cause objectionable disruption of urban activity.

Urban Nonpoint Source
Pollution Control Measures

Nonpoint source water pollution control is the management of urban and rural land uses to reduce the loadings of pollutants discharged to surface waters. For the purposes of this report, such control measures will be considered only with respect to urban nonpoint sources of pollution. A comprehensive discussion of the types and effects of both urban and rural nonpoint sources of water pollution is provided in SEWRPC Technical Report No. 21, Sources of Water Pollution in Southeastern Wisconsin: 1975 (1978), and a more in-depth discussion of urban nonpoint sources of pollution is set forth in Evaluation of Urban Nonpoint Source Pollution Management in Milwaukee County, Wisconsin, 1983, by the Wisconsin Department of Natural Resources, Southeastern Wisconsin Regional Planning Commission, and U. S. Department of the Interior, Geological Survey. Many of the various nonpoint source pollution control measures discussed below are described in detail in the Wisconsin Department of Natural Resources' Wisconsin Construction Site Best Management Practice Handbook (draft, August 1988) and Construction Site Erosion and Stormwater Management Plan and Model Ordinance (draft, 1985). In recent years, increased attention has been focused on nonpoint source pollution control through the Wisconsin Priority Watersheds Program and through stormwater discharge regulations being considered by the U. S. Environmental Protection Agency under the federal Clean Water Act.

There are two major categories of urban nonpoint sources of pollution. The first category is the erosion of soil from disturbed land areas, especially construction sites. The primary pollutants transported in this manner are suspended sediments and sediment-attached pollutants such as phosphorus and lead. Residential, commercial, industrial, highway, and public utility construction sites all have the potential to produce large amounts of sediment which will reach receiving streams if not controlled. Because of the transitory nature of construction projects, measures to control construction site erosion and runoff are inherently of a short-term nature. Such control measures include mulching and seeding of disturbed areas, construction of filter fabric and straw bale fences to intercept eroding soil prior to discharge to a receiving stream, channel stabilization, construction of sediment traps and wet detention basins, stabilization of stream banks through the provision of sod or riprap, and protection of stormwater inlets. It is feasible and desirable to deal with construction site erosion and sedimentation problems on a site-by-site basis through regulations. The proper control of erosion can be readily achieved under the provision of ordinances which govern construction practices, allowable soil loss, and the application of certain erosion control measures. It would be difficult and potentially unsound to attempt to deal with construction site erosion through stormwater management planning conducted for a particular drainage basin. Thus, this stormwater management plan does not specifically address construction site erosion control, other than to recommend that appropriate ordinances be developed and implemented to sufficiently regulate construction activities and the attendant erosion control measures.

The second major category of urban nonpoint sources of pollution is the stormwater runoff and associated pollutants contributed from developed urban areas. As land is converted from rural to urban uses, the impervious area is increased, different types of pollutants accumulate on the

Table 12

EFFECTIVENESS OF URBAN NONPOINT SOURCE WATER POLLUTION ABATEMENT MEASURES

Abatement Measure	Approximate Percent Reduction of Released Pollutants					
	Suspended Solids	Phosphorus	Nitrogen	Bio-Chemical Oxygen Demand	Metals	Bacteria
Wet Detention Basin	80-90	40-60	40-60	40-60	60-80	N/A
Percolation Basin	80-100	60-80	60-80	80-100	80-100	80-100
Infiltration Trench	80-100	60-80	60-80	80-100	80-100	80-100
Porous Pavement	80-100	60-80	60-80	80-100	80-100	80-100
Grass Swale	20-40	20-40	20-40	20-40	0-20	N/A
Grass Filter Strip	20-40	0-20	0-20	0-20	20-40	N/A
Stormwater Sedimentation-Flotation Basin	0-20	N/A	N/A	N/A	N/A	N/A

NOTE: N/A indicates data not available.

Source: Thomas R. Schueler, Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs, Metropolitan Washington Council of Governments, July 1987; and SEWRPC.

land surface, and the overall amount of pollutants is increased. The control of urban nonpoint source pollution requires long-term solutions which effectively reduce the loadings of those pollutants that are causing water quality problems, and which are flexible enough to be adapted to planned development patterns and densities. Owing to restrictions on available land and the constraints imposed by land use patterns in developed urban areas, the range of nonpoint source pollution control measures that are applicable in developed urban areas is more limited than in developing areas, where the necessary nonpoint control measures can be anticipated and planned. The control of nonpoint sources of pollution in developed urban areas requires the preparation on a basin-by-basin basis of detailed stormwater management plans. Thus, the control of urban stormwater runoff and associated pollutants is an important element of this stormwater management plan.

Nonpoint source pollution control measures appropriate for developed urban areas can be classified either as source area controls or as outfall controls. Source area controls are best management practices carried out in upland areas near the pollution source. Outfall controls are applied at or near the stormwater outlet prior to discharge to the receiving stream. Source area controls may include infiltration devices, decentralized storage facilities, street cleaning, increased leaf and clippings collection and disposal, and reduced use of road de-icing salt. Outfall controls may include centralized storage facilities and physical or chemical treatment processes. Table 12 summarizes the reductions in pollutant loadings that can be achieved by various nonpoint source pollution control measures.

Source area control measures and the types of land use for which such measures are most effective are listed in Table 13. Infiltration systems can achieve a high level of loading reduction in both dissolved and particulate pollutants from the drainage area served, with the pollutant loading reductions being proportional to the resulting reduction in stormwater volume. Some systems also filter additional pollutants from the remaining runoff—infiltration basins and trenches, grass filter strips,

Table 13

APPLICABILITY OF SOURCE AREA CONTROL MEASURES
TO ABATE URBAN NONPOINT SOURCES OF WATER POLLUTION

Control Measure	Applicability for Land Use				
	Residential	Industrial	Commercial	Institutional	Open Lands
Roof Drains to Lawns	X	X[a]	X	X	- -
Infiltration Basins and Trenches	X	X[a]	X	X	X
Porous Pavement	- -	- -	X	X	- -
Perforated Drainage Systems	X	- -	X	X	- -
Grass Swales	X	X[a]	X	X	X
Grass Filter Strips	X	X[a]	X	X	X
Wet Detention Basins	X	X	X	X	- -
Stormwater Sedimentation-Flotation Basins	- -	X	X	X	- -
Roof Storage	- -	X	X	X	- -
Street Cleaning	X	X	X	X	- -
Litter and Pet Waste Control Ordinances	X	- -	X	X	X
Leaf and Clippings Collection and Disposal	X	- -	- -	- -	- -
Reduced Use of Road De-icing Salt	X	X	X	X	X

NOTE: Source area control measures would be applicable to reduce pollutant loadings from those land uses marked with an "X."

[a]*These stormwater infiltration measures are not appropriate for manufacturing industrial areas, but may be considered on a site-specific basis for nonmanufacturing industrial areas.*

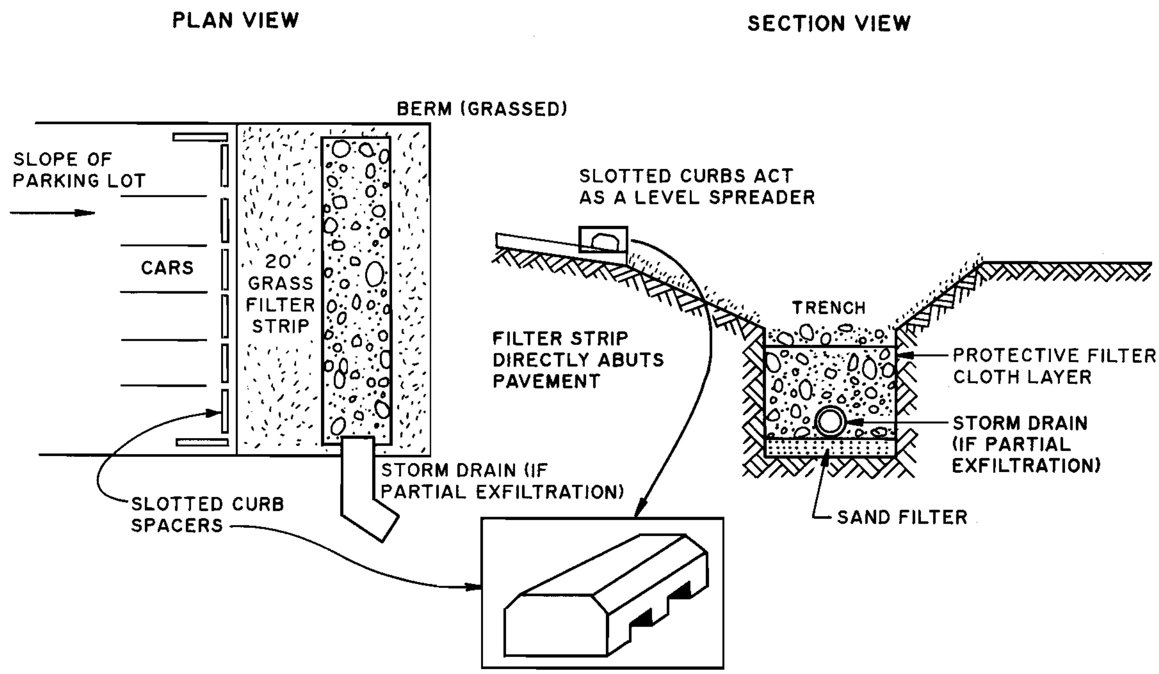
Source: SEWRPC.

porous pavements, grass swales and waterways, and perforated drainage systems. Grass-lined infiltration basins and gravel-filled infiltration trenches often collect the stormwater runoff from frequent storm events from small impervious areas such as parking lots or roofs. Typical infiltration trench installations for parking lots are shown in Figure 7. Infiltration trenches are generally lined with filter cloth. Trenches may be entirely below grade, or they may be adapted to the existing topography with one side being a low berm constructed of pervious material and covered with filter cloth and small riprap. Such an installation would collect and store runoff which would gradually be released by infiltration through the berm. Grass filter strips, which are generally placed between the pollution source and the collector system, remove pollutants in overland flow through both filtering and infiltration. Porous pavements are generally the

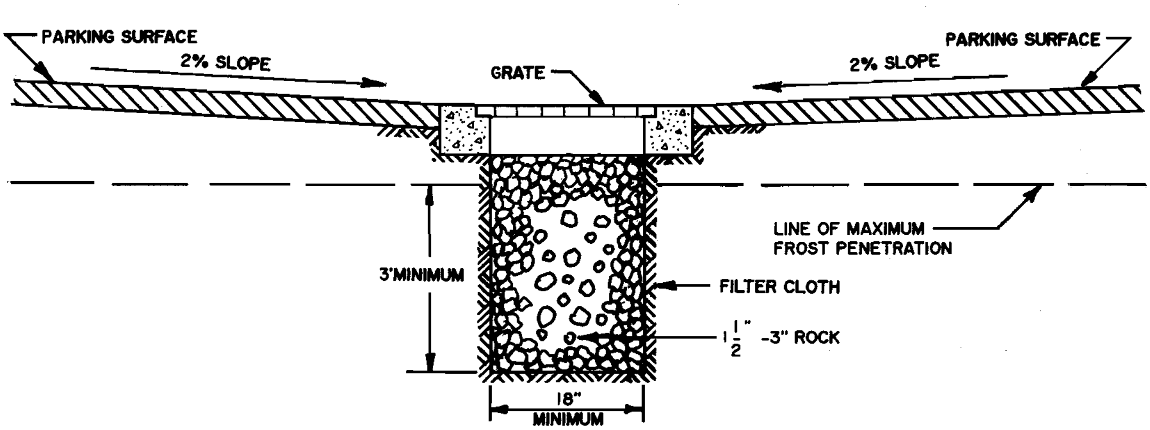
Figure 7

TYPICAL PARKING LOT INFILTRATION TRENCH INSTALLATIONS

PERIMETER TRENCH



INTERIOR TRENCH



Source: Metropolitan Washington Council of Governments and SEWRPC.

most applicable in parking areas which do not handle heavy traffic loads. Such pavements may consist of asphalt with predominantly large aggregate, or specially constructed concrete or paving-block grids with openings for the establishment of grass cover. Grass waterways and perforated drainage systems can be effectively incorporated into the conveyance system for transport of runoff to receiving waters. Grass swales, usually placed along roadways, also reduce pollutant loadings through both filtering and infiltration.

While properly located and sized infiltration devices can substantially reduce the loadings of pollutants from nonpoint sources to receiving waters, care must be taken to avoid contamination of the groundwater. Studies have shown that particulates are effectively filtered out in the top layers of soil surrounding infiltration devices. However, dissolved pollutants may reach the groundwater when infiltration devices are improperly located in areas with unsuitable topography and soils, or with a shallow depth to bedrock or to the groundwater table. Other potential adverse impacts of infiltration devices include wet basements, sump pump overloading, building and foundation failures, and excessive infiltration of clear water into sanitary sewers. Because of these potential problems, infiltration devices should be avoided in areas with a high potential for groundwater contamination, and in areas of intensive urban development. These measures are best used in areas of low-density development where problems with basements, foundations, and excessive sewer infiltration can be avoided.

Stormwater sedimentation-flotation basins, as shown in Figure 8, are designed to remove sediment and hydrocarbon loadings from parking lot runoff before they are conveyed to the storm drain network or to an infiltration device.[1] The effectiveness of such devices in removing pollutants has not been monitored in the field; however, because of their relatively small storage volumes and resultant brief retention times, they would not be expected to provide a high degree of pollutant removal. The basins require cleaning at least twice a year. Basins may be designed with or without weep holes in the sides and bottom. A basin with weep holes would theoretically provide greater pollutant removal than the standard three-chamber inlet due to exfiltration through the weep holes in the base of the sediment and oil chambers, but clogging of the weep holes with sediment may reduce the effectiveness of the basin.

Street cleaning can be an effective method of urban nonpoint source pollution control under certain circumstances. A modest increase in the sweeping of residential streets throughout the sweeping season produces only marginally higher pollutant reductions.[2] Data collected during the Milwaukee Nationwide Urban Runoff Program indicated that street cleaning in residential areas typically achieved less than a 10 percent reduction in pollutant loadings.[3] Approximately 20 to 70 percent reductions in pollutant loadings from industrial areas can be achieved if parking and storage areas are included in the cleaning operation. Street cleaning is the most effective early in spring, when the streets are laden with winter residue, and in fall, following leaf fall. Intensive street sweeping may reduce pollutant loadings during spring by up to 50 percent.[4]

Litter and pet waste control ordinances can be expected to produce pollutant reductions of only about 5 percent, as can increased leaf and clippings collection and disposal programs.

As discussed previously, man-made detention and retention storage facilities and natural deep depressions and wetlands can be utilized to reduce stormwater runoff rates and volumes.

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[1] *Thomas R. Schueler, Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs, Metropolitan Washington Council of Governments, July 1987.*

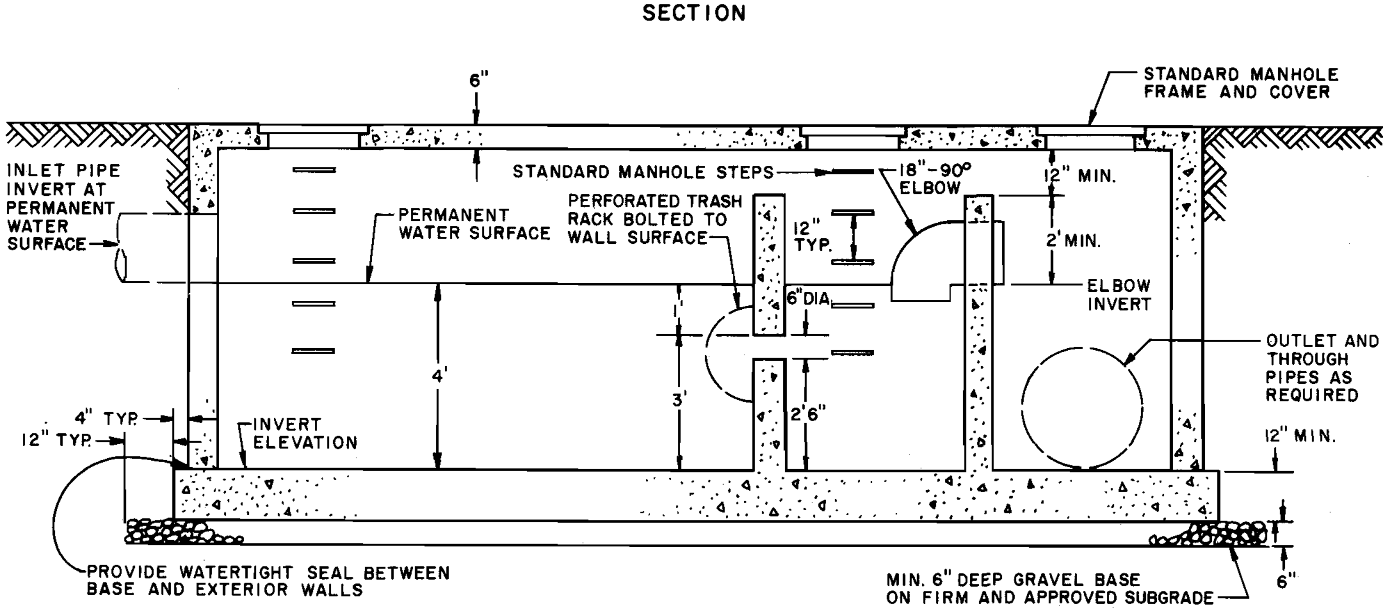
[2] *Robert Pitt, "The Incorporation of Urban Source Area Controls in Wisconsin's Priority Watershed Projects," Wisconsin Department of Natural Resources, 1986.*

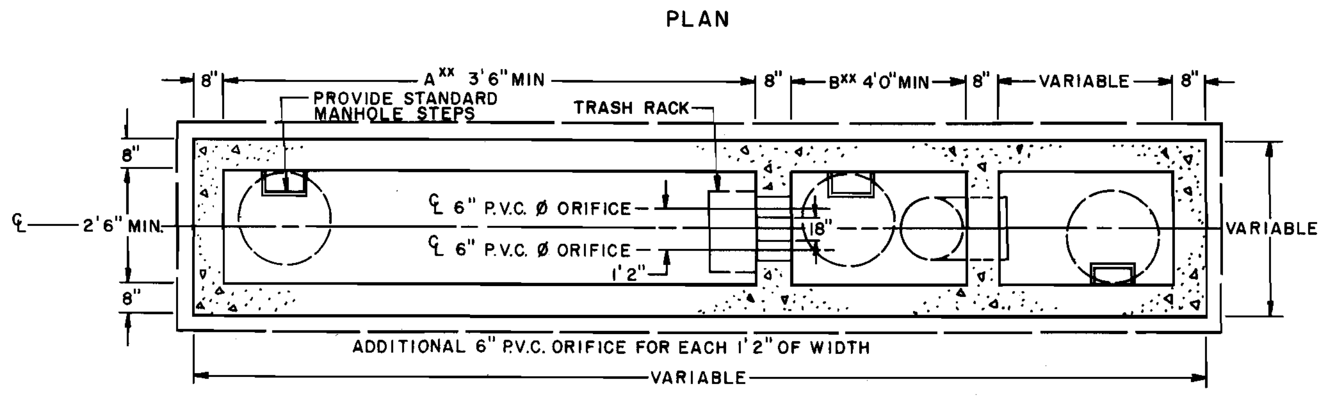
[3] *Robert Pitt, "Construction Site Erosion and Stormwater Management Plan and Model Ordinance," Draft Report, Wisconsin Department of Natural Resources, May 14, 1985, revised April 23, 1987.*

[4] *Wisconsin Department of Natural Resources, Evaluation of Urban Nonpoint Source Pollution Management in Milwaukee County, Wisconsin, Executive Summary, 1983.*

Figure 8

TYPICAL STORMWATER SEDIMENTATION-FLOTATION BASIN





[xx]WHEN COMBINED LENGTH OF OIL AND GRIT CHAMBERS EXCEEDS 12 FEET, A=2/3 TOTAL AND B=1/3 TOTAL.

Source: Montgomery County, Maryland; and SEWRPC.

Such storage areas can also produce significant reductions in nonpoint source pollutant loadings. Depending on their location within the overall stormwater management system, detention facilities may be classified as either source area or outfall control measures. Decentralized detention storage facilities intended to control runoff and pollutants from upland areas with relatively small contributing drainage areas are classified as source area control measures. Centralized detention facilities located near stormwater runoff outfalls or on receiving watercourses are classified as outfall control measures.

Along with retention, or percolation, basins and infiltration systems which are designed to completely store all tributary runoff, the wet detention basin is highly effective in reducing pollutant loadings. In wet detention basins, pollutants are removed through both sedimentation of particulates and biological assimilation of dissolved nutrients. Wet detention basins require considerable maintenance in order to function properly as nonpoint source control measures. Maintenance requirements for wet basins include mowing embankments, weed and algae control, inspection, litter removal, and periodic dredging of accumulated sediments. The cost of periodic dredging is the largest maintenance cost. That cost can be reduced by confining the accumulation of most of the inflowing sediment to a settling pond located at the inlet of a wet detention basin. Means of disposal of dredged sediment vary, depending on the level of contamination of the sediment. Sediments with high concentrations of toxic chemicals or metals must be disposed of in specially designed containment areas or landfills. Sediment to be dredged should be tested to determine the appropriate means of disposal.

Dry detention basins, which drain completely between flood events, are not as effective in reducing nonpoint source pollutant loadings as are wet basins. While some sediment accumulation will occur, much of it will be scoured from the bottom of the basin and discharged downstream by subsequent storm events. Dry detention basins can reduce downstream bank erosion by reducing flood flows and velocities.

Roof detention storage is a measure which is sometimes proposed to be applied in areas of existing urban development. Roof drains may be retrofitted with restrictors which permit ponding of stormwater on flat roofs, subject to the capacity of the roof to carry greater loads. The main benefit of roof storage of stormwater is that it reduces peak rates of runoff. Like dry detention basins, roof storage can reduce erosion in localized discharge areas by reducing outflows and velocities. There are several factors that make the use of roof storage impractical as an effective stormwater management measure in southeastern Wisconsin. These include leakage into buildings of water ponded on roofs, the inability of existing roofs to carry the additional loads owing to rooftop ponding without structural modifications, and problems associated with freezing of ponded water, and superimposed snow loads. Because of the limited applicability of roof storage, such storage should be considered for inclusion only in the design of a new structure where it could be demonstrated that it would be a cost-effective means for managing stormwater runoff within the context of the overall system and where the possibility of leakage and freezing problems could be addressed in the building design.

Wetlands can serve to remove pollutants from stormwater runoff by sedimentation, biological assimilation, and filtration. The long flow-through times and low flow velocities in wetlands allow suspended sediments and particulate pollutants to settle. Nutrients are assimilated by wetland plants, and metals and hydrocarbons are deposited in wetland sediments. The long-term effects of toxic pollutant accumulation on the water quality and biota of wetlands have not been extensively studied. While wetlands may be effective in controlling nonpoint source pollutant loadings to downstream waters under certain conditions, the accumulation of pollutants may be harmful to the wetland ecosystem. The effects of certain nonpoint pollutants on wetlands are known. An abundance of nutrients in a wetland can lead to dominance of less desirable, non-native plant species. Pesticides are taken up by certain plant species and are then released to the water column following plant decay. Due to the relatively long water retention times in wetlands, road de-icing salt concentrations may exceed acceptable levels, leading to density stratification, which may create dissolved oxygen deficiencies in the lower layers of the wetland water column. Depending on the hydrologic and hydraulic characteristics of a particular wetland, accumulated pollutants may be flushed to downstream waters during large storm events. The capacity of wetlands to remove pollutants and the long-term effects of such removal on wetlands have not been definitively established. In some cases, it may be desirable to provide facilities to reduce nonpoint source pollutant loadings prior to discharge to wetlands.

Physical/chemical outfall treatment control measures include microscreens, dissolved air flotation, swirl concentrators, high rate filtration, contact stabilization, and disinfection. Typically, a stormwater treatment facility would consist of a stormwater detention facility to provide a more constant flow rate followed by a physical/chemical treatment facility. The pollutant removal effectiveness of stormwater treatment facilities can range from 10 percent to more than 90 percent, depending on the treatment process and the type of pollutant removed.

Swirl concentrators are especially effective when applied to combined sanitary-stormwater sewerage systems. The process concentrates settleable solids which are then transmitted to a wastewater treatment plant. In the dissolved air flotation process, stormwater runoff is collected and air bubbles float solids to the surface where they are skimmed off. Microscreening is used to remove fine suspended particles. The filtration process removes a large range of particle sizes through straining, impingement, settling, and adhesion.[5] Contact stabilization is a process whereby the flow to be treated is mixed with activated sludge and the sludge is then aerated in a stabilization tank where organisms digest the organic material. Contact stabilization facilities are the most efficient when the organisms in the stabilization tank are kept alive between storms; therefore, such facilities are most the effectively operated in conjunction with a nearby wastewater treatment plant which will use the organisms in the treatment of dry-weather flows. Disinfection is accomplished through the application of chlorine or ozone to the stormwater effluent following treatment by other means.

Stormwater treatment methods are costly. Less costly urban nonpoint source control measures may be a more attractive alternative in many cases. For this reason, and because there have been few motivating legal requirements regarding the quality of stormwater discharged to the surface water system, municipalities have not normally pursued this component of the stormwater management system. Limited application of stormwater treatment has been effected for certain types of stormwater runoff from industrial areas.

Urban nonpoint pollutant sources in the West Bend stormwater management plan study area have been evaluated by the Wisconsin Department of Natural Resources under the Milwaukee River Priority Watersheds Program. A mathematical simulation model was applied to estimate pollutant loadings from urban nonpoint sources of pollution, and to predict the effectiveness of various urban nonpoint source control measures in reducing runoff flow volumes or pollutant loadings from urban areas. To the extent practicable, the results of those analyses were incorporated into the evaluation of alternative stormwater management plans and the selection of the recommended system plan for the City of West Bend.

SUMMARY

This chapter has described the characteristics and functions of five stormwater management system components. The three basic components of overland flow, collection, and conveyance have been traditionally considered in stormwater management system planning and, as such, were considered in the stormwater management planning effort for the City of West Bend.

With respect to overland flow, the system plan provides general guidelines and a description of practical techniques for minimizing the rate and volume of runoff. The plan assumes that these general guidelines will be followed to the extent practicable as community development and redevelopment proceed and the siting of buildings and the grading and improvement of surrounding sites take place. Specific measures for overland flow, however, must be designed on a site-specific basis as urban development or redevelopment takes place.

With respect to stormwater collection facilities, the system plan contains recommendations concerning the typical shape, general horizontal

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[5] *Robert Pitt, "Construction Site Erosion and Stormwater Management Plan and Model Ordinance," Draft Report, Wisconsin Department of Natural Resources, May 14, 1985, revised April 23, 1987.*

and vertical alignment, and type of roadside swales and of roadway gutters; and the type and general location of inlets and catch basins. In addition, the system plan provides general guidelines and criteria for the more detailed design of the collection facilities included in the plan. The plan recognizes that such details of the collection system as driveway culvert spacing and sizing; longitudinal gradients; provision of paved swale bottoms; gutter types, locations, and configurations; and inlet and catch basin types and locations must be determined on a site-specific basis in the design phase of system development preceding construction.

With respect to stormwater conveyance facilities, the system plan contains recommendations concerning the general horizontal and vertical alignment, shape, and type of open channel conveyance facilities; the general locations and sizes of culverts; and the general alignment, depth, size, slope, and type of storm sewer facilities. The system plan also indicates the general locations of manholes and junction chambers.

The two remaining system components—stormwater storage and nonpoint source water pollution control—were presented in this chapter as additional components that may be required within stormwater management systems to meet overall system development and performance objectives. The systems plan contains stormwater storage recommendations concerning the general location, area, and volume of storage facilities. Additional details of such storage facilities must be addressed on a site-specific basis in the detailed design phase preceding construction. Criteria for such design are provided in the plan.

Urban nonpoint source water pollution control measures available for use in both existing and newly developing urban settings were identified, along with an estimate of the reduction in pollutant loadings that can be achieved by each measure. To the extent practicable, the results of the Milwaukee River Priority Watersheds Study have been refined and integrated in the recommended plan for each of the subwatersheds in the study area.

The selection of street cross-sections, including appurtenant drainage details, is a decision which must be primarily based on the existing or proposed land use and density of development within an area of the City. In areas where the type and density of land use do not clearly dictate the use of either an urban or a rural street cross-section, an important consideration in the selection of the cross-section is the preferences of local residents and officials. Within residential and commercial areas of the City of West Bend, urban street cross-sections with gutters, inlets, and storm sewers have generally been constructed. Rural street cross-sections with roadside ditches were, however, utilized in the City's Industrial Park-South. In the preparation of the stormwater management plan, consideration was given to the use of both urban and rural street cross-sections. Rural cross-sections were considered only in areas of relatively low-density development where there would be adequate right-of-way for roadside swales and where the number of driveway culverts would be minimized.

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Chapter IV

STORMWATER MANAGEMENT OBJECTIVES, STANDARDS, AND DESIGN CRITERIA

INTRODUCTION

Planning may be defined as a rational process for formulating and meeting objectives. Consequently, the formulation of objectives is an essential task which must be undertaken before plans can be prepared. Accordingly, this chapter sets forth a set of stormwater management objectives and supporting standards for use in the design and evaluation of alternative stormwater management system plans for the City of West Bend and environs, and in the selection of a recommended plan from among those alternatives.

In addition, this chapter sets forth certain engineering design criteria and describes certain analytical procedures which were used in the preparation and evaluation of the alternative stormwater management system plans. These criteria and procedures include the engineering techniques used to design the alternative plan elements; to test the physical feasibility of those elements; and to make necessary economic comparisons between the plan elements. This chapter thus documents the degree of detail and level of sophistication employed in the preparation of the recommended stormwater management plan, and thereby is intended to provide a better understanding by all concerned of the plan and of the need for refinement of some aspects of the plan prior to and during implementation.

STORMWATER MANAGEMENT OBJECTIVES AND STANDARDS

The following five stormwater management objectives were formulated to guide the design, test, and evaluation of alternative stormwater management plans for the West Bend stormwater management planning area and the selection of a recommended plan from among the alternatives considered:

1. The development of an integrated system of stormwater drainage and flood control facilities which reduces the exposure of people to drainage-related inconvenience, flood damage, and health and safety hazards, and which reduces the exposure of real and personal property to damage through inadequate stormwater drainage and flood control.
2. The development of a stormwater management system which will effectively serve existing and proposed future land uses.
3. The development of a stormwater management system which will abate nonpoint source water pollution and help achieve the recommended water use objectives and supporting water quality standards for surface water bodies (see Map 9 and Table 14).
4. The development of a stormwater management system which will be flexible and readily adaptable to changing needs.
5. The development of a stormwater management system which will efficiently and effectively meet all of the other stated objectives at the lowest practicable cost.

Complementing each of the foregoing management system development objectives is a set of quantifiable standards which can be used to evaluate the relative or absolute ability of alternative stormwater management plan designs to meet each objective. These standards are set forth in Table 15. The planning standards fall into two groups—comparative and absolute. The comparative standards, by their very nature, can be applied only through a comparison of alternative plan proposals. The absolute standards can be applied individually to each alternative plan proposal since they are expressed in terms of maximum, minimum, or desirable values.

OVERRIDING CONSIDERATIONS

In the application of the stormwater management development objectives and standards to the preparation, test, and evaluation of stormwater management system plans, several overriding considerations must be recognized. First, it must be recognized that any proposed storm-

Table 14

RECOMMENDED WATER QUALITY STANDARDS FOR SURFACE WATERS IN THE CITY OF WEST BEND STUDY AREA: 2010

Water Quality Indicator	Coldwater Fish and Aquatic Life, Recreational Use, and Minimum Standards[a]	Warmwater Fish and Aquatic Life, Recreational Use, and Minimum Standards[a]	Limited Fish and Aquatic Life, Limited Recreational Use, and Minimum Standards[a]
Maximum Temperature (°F)	- -[b,c,d]	89[b,d]	89[b,d]
pH Range (standard units)	6.0-9.0[e]	6.0-9.0[e]	6.0-9.0[e]
Minimum Dissolved Oxygen (mg/l)[d]			
30-Day Mean	6.5	5.5	4.5
7-Day Mean	9.5[h]	6.0[f]	5.0[j]
1-Day Mean	5.0-8.0[i]	4.0-5.0[g]	3.0-4.0[k]
Absolute	3.0	2.5	1.5
Maximum Fecal Coliform (counts per 100 ml)	200-400[l]	200-400[l]	1,000-2,000-10,000[m]
Maximum Total Residual Chlorine (mg/l)			
4-Day Mean	0.011	0.011	0.011
1-Hour Mean	0.019	0.019	0.019
Maximum Un-ionized Ammonia Nitrogen (mg/l)	- -[o]	- -[o]	- -[o]
Maximum Total Phosphorus (mg/l):			
Streams	0.1	0.1	- -[o]
Inland Lakes[n]	0.02	0.02	- -

[a]*All waters shall meet the following minimum standards at all times and under all flow conditions: Substances that will cause objectionable deposits on the shore or in the bed of a body of water shall not be present in such amounts as to interfere with public rights in the waters of the State. Floating or submerged debris, oil, scum, or other material shall not be present in such amounts as to interfere with public rights in the waters of the State. Materials producing color, odor, taste, or unsightliness shall not be present in amounts found to be of public health significance. Unauthorized concentrations of substances are not permitted that alone or in combination with other substances present are chronically or acutely harmful or toxic to humans or to fish and aquatic life.*

[b]*There shall be no temperature changes that may adversely affect aquatic life. Natural daily and seasonal temperature fluctuations shall be maintained. The maximum temperature rise at the edge of a mixing zone above the existing natural temperature shall not exceed 5°F for streams and 3°F for lakes.*

[c]*There shall be no significant artificial increases in temperature where natural trout reproduction is to be protected. The maximum temperature shall not exceed 77°F.*

[d]*Dissolved oxygen and temperature standards apply to the entire water column within streams and to the epilimnion of stratified lakes and to the unstratified lakes; the dissolved oxygen standard does not apply to the hypolimnion of stratified inland lakes. Trends in the period of anaerobic conditions in the hypolimnion of stratified inland lakes should be considered important to the maintenance of water quality, however.*

[e]*The pH shall be within the range of 6.0 to 9.0 standard units, with no change greater than 0.5 unit outside the estimated natural seasonal maximum and minimum.*

[f]*A minimum dissolved oxygen standard of 6.0 milligrams per liter (mg/l) for a seven-day mean applies only between March 15 and July 31 for the support of embryonic, larval, and early juvenile stages of warmwater species.*

[g]*A minimum dissolved oxygen standard of 5.0 mg/l for a one-day mean applies only between March 15 and July 31 for the support of embryonic, larval, and early juvenile stages of warmwater species. For the remainder of the year, a minimum dissolved oxygen standard of 4.0 mg/l for a one-day mean applies.*

[h]*A minimum dissolved oxygen standard of 9.5 mg/l for a seven-day mean applies only between September 1 and April 30 for the support of embryonic and larval stages of coldwater species.*

Table 14 (continued)

[i] *A minimum dissolved oxygen standard of 8.0 mg/l for a one-day mean applies only between September 1 and April 30 for the support of embryonic and larval stages of coldwater species. For the remainder of the year, a minimum dissolved oxygen standard of 5.0 mg/l for a one-day mean applies.*

[j] *A minimum dissolved oxygen standard of 5.0 mg/l for a seven-day mean applies only between March 15 and July 31 for the support of embryonic, larval, and early juvenile stages of limited species.*

[k] *A minimum dissolved oxygen standard of 4.0 mg/l for a one-day mean applies only between March 15 and July 31 for the support of embryonic, larval, and early juvenile stages of limited species. For the remainder of the year, a minimum dissolved oxygen standard of 3.0 mg/l for a one-day mean applies.*

[l] *Shall not exceed a monthly geometric mean of 200 per 100 milliliters (ml) based on not fewer than five samples per month, nor a monthly geometric mean of 400 per 100 ml in more than 10 percent of all samples during any month.*

[m] *A monthly geometric mean fecal coliform level of 1,000 most probable number per 100 milliliters (MPN/100 ml) shall not be exceeded more than 5 percent of the time, or about once every two years. A fecal coliform level of 2,000 MPN/100 ml shall not be exceeded more than 10 percent of the time. A fecal coliform level of 10,000 MPN/100 ml shall not be exceeded more than 2 percent of the time, or about one week per year.*

[n] *The values presented for inland lakes are the critical total phosphorus concentrations which apply only during spring, when maximum mixing is underway.*

[o] *To protect fish and aquatic life, the following standards shall apply for un-ionized ammonia nitrogen (NH_3-N):*

1. *The one-hour mean concentration of un-ionized ammonia nitrogen shall not exceed, more often than once every three years on the average, the numerical value given by 0.427/FT/FPH/2, where:*

$$FT = 10^{0.03(20-TC)} \quad ; \; TC \leq T \leq 30$$

$$10^{0.03(20-T)} \quad ; \; 0 \leq \text{-}T \leq TC$$

$$FPH = 1 \quad ; \; 8 \leq pH \leq 9$$

$$\frac{1 + 10^{7.4-pH}}{1.25} \quad ; \; 6.5 \leq pH \leq 8$$

$$TC = 20°C \quad ; \; \text{Coldwater fish and aquatic life}$$

$$= 25°C \quad ; \; \text{Warmwater and limited fish and aquatic life.}$$

T = *Temperature of water body, in degrees C.*

pH = *pH of water body, in standard units.*

2. *The four-day mean concentration of un-ionized ammonia nitrogen shall not exceed, more often than once every three years on the average, the average numerical value given by 0.658/FT/FPH/R, where FT and FPH are as above, and:*

$$R = 16 \quad ; \; 7.7 \leq pH \leq 9$$

$$= 24 \left(\frac{10^{7.7-pH}}{1 + 10^{7.4-pH}} \right) \quad ; \; 6.5 \leq pH \leq 7.7$$

$$TC = 15°C \quad ; \; \text{Coldwater fish and aquatic life.}$$

$$= 20°C \quad ; \; \text{Warmwater and limited fish and aquatic life.}$$

The extremes for temperature (O°, 30°C) and pH (6.5 standard units, 9.0 standard units) are absolute, and these standards cannot be extrapolated beyond these limits. Because the formulas are nonlinear with respect to pH and temperature, the standards used for a particular water body should be based on separate calculations reflective of the fluctuations of pH and temperature during a study period. It is not appropriate to simply apply the formulas to average pH and temperature conditions over a study period.

Source: SEWRPC.

Table 15

WATER CONTROL FACILITY DEVELOPMENT OBJECTIVES, PRINCIPLES, AND STANDARDS FOR THE MILWAUKEE METROPOLITAN SEWERAGE DISTRICT

OBJECTIVE NO. 1

The development of an integrated system of stormwater drainage and flood control facilities which reduces the exposure of people to drainage-related inconvenience, flood damage, and health and safety hazards and which reduces the exposure of real and personal property to damage through inadequate stormwater drainage and flood control.

STANDARDS

1. In order to prevent significant property damage and safety hazards, the major components of the stormwater management system should be designed to accommodate runoff from a 100-year recurrence interval storm event.

2. In order to provide for an acceptable level of access to property and of traffic service, the minor components of the stormwater management system should be designed to accommodate runoff from a 10-year recurrence interval storm event.

3. In order to provide an acceptable level of access to property and of traffic service, the stormwater management system should be designed to provide two clear 10-foot lanes for moving traffic on existing arterial streets, and one clear 10-foot lane for moving traffic on existing collector and land access streets during storm events up to and including the 10-year recurrence interval event.

4. Flow of stormwater along and across the full pavement width of collector and land access streets shall be acceptable during storm events exceeding a 10-year recurrence interval when the streets are intended to constitute integral parts of the major stormwater drainage system.

5. Flood control facilities should be designed to alleviate flood damage to buildings during the 100-year recurrence interval flood under planned land use, drainage, and channel conditions.

OBJECTIVE NO. 2

The development of a stormwater management system which will effectively serve existing and proposed future land uses.

STANDARDS

1. Stormwater drainage systems should be designed assuming that the layout of collector and land access streets for proposed urban development and redevelopment will be carefully adjusted to the topography in order to minimize grading and drainage problems, to utilize to the fullest extent practicable the natural drainage and storage capabilities of the site, and to provide the most economical installation of a gravity flow drainage system. Generally, drainage systems should be designed to complement a street layout wherein collector streets follow valley lines and land access streets cross contour lines at right angles.

2. Stormwater drainage systems should be designed assuming that the layouts and grades of collector and land access streets can, during major storm events, serve as open runoff channels supplementary to the minor stormwater drainage system without flooding adjoining building sites. The stormwater drainage system design should avoid midblock sags in street grades, and street grades should generally parallel swale, channel, and storm sewer gradients.

3. Stormwater management systems shall utilize rural street cross-sections with roadside swales and culverts in all areas identified in the system plan for the use of such sections. Stormwater management systems in all other areas of the City shall utilize urban street cross-sections with curbs and gutters, inlets, and storm sewers.

4. The stormwater management system shall be designed to minimize the creation of new drainage or flooding problems, or the intensification of existing problems, at both upstream and downstream locations.

OBJECTIVE NO. 3

The development of a stormwater management system which will abate nonpoint source water pollution and help achieve the recommended water use objectives and supporting water quality standards for surface water bodies.

Table 15 (continued)

STANDARDS

1. Stormwater management and flood control facilities should not impede the achievement of existing water use objectives and supporting water quality standards for lakes, streams, and wetlands, nor degrade existing habitat conditions for fish and aquatic life. The applicable water use objectives for the lakes and streams concerned are shown on Map 9, and the water quality standards supporting these use objectives are presented in Table 14. The recommended objectives and standards are a revision of those set forth in the adopted areawide water quality management plan as documented in SEWRPC Planning Report No. 30, A Regional Water Quality Management Plan for Southeastern Wisconsin: 2000, Volume Two, Alternative Plans, February 1979. These objectives were revised based on the Wisconsin Department of Natural Resources' nonpoint source and stream appraisals set forth in the public review draft of the Nonpoint Source Control Plan for the East and West Branches of the Milwaukee River Priority Watershed, February 1989.

2. Stormwater management and flood control facilities should be designed to protect valuable and sensitive wetlands from the adverse impacts of stormwater runoff.

OBJECTIVE NO. 4

The development of a stormwater management system which will be flexible and readily adaptable to changing needs.

STANDARDS

1. The 100-year recurrence interval storm event should be used to design and size special structures, such as roadway underpasses, requiring pumping stations.

2. Street elevations and grades, and appurtenant site elevations and grades, shall be set to provide overland gravity drainage to natural watercourses so that positive drainage may be effected in the event of failure of piped stormwater drainage facilities.

OBJECTIVE NO. 5

The development of a stormwater management system which will efficiently and effectively meet all of the other stated objectives at the lowest practicable cost.

STANDARDS

1. The sum of stormwater management system capital investment and operation and maintenance costs should be minimized.

2. Maximum feasible use should be made of all existing stormwater management components, as well as the natural storm drainage system. The latter should be supplemented with engineered facilities only as necessary to serve the anticipated stormwater management needs generated by existing and proposed land use development and redevelopment.

3. Stormwater management facilities should be designed for staged, or phased, construction so as to limit the required investment in such facilities at any one time and to permit maximum flexibility to accommodate changes in urban development, in economic activity growth, in the objectives or standards, or in the technology of stormwater management.

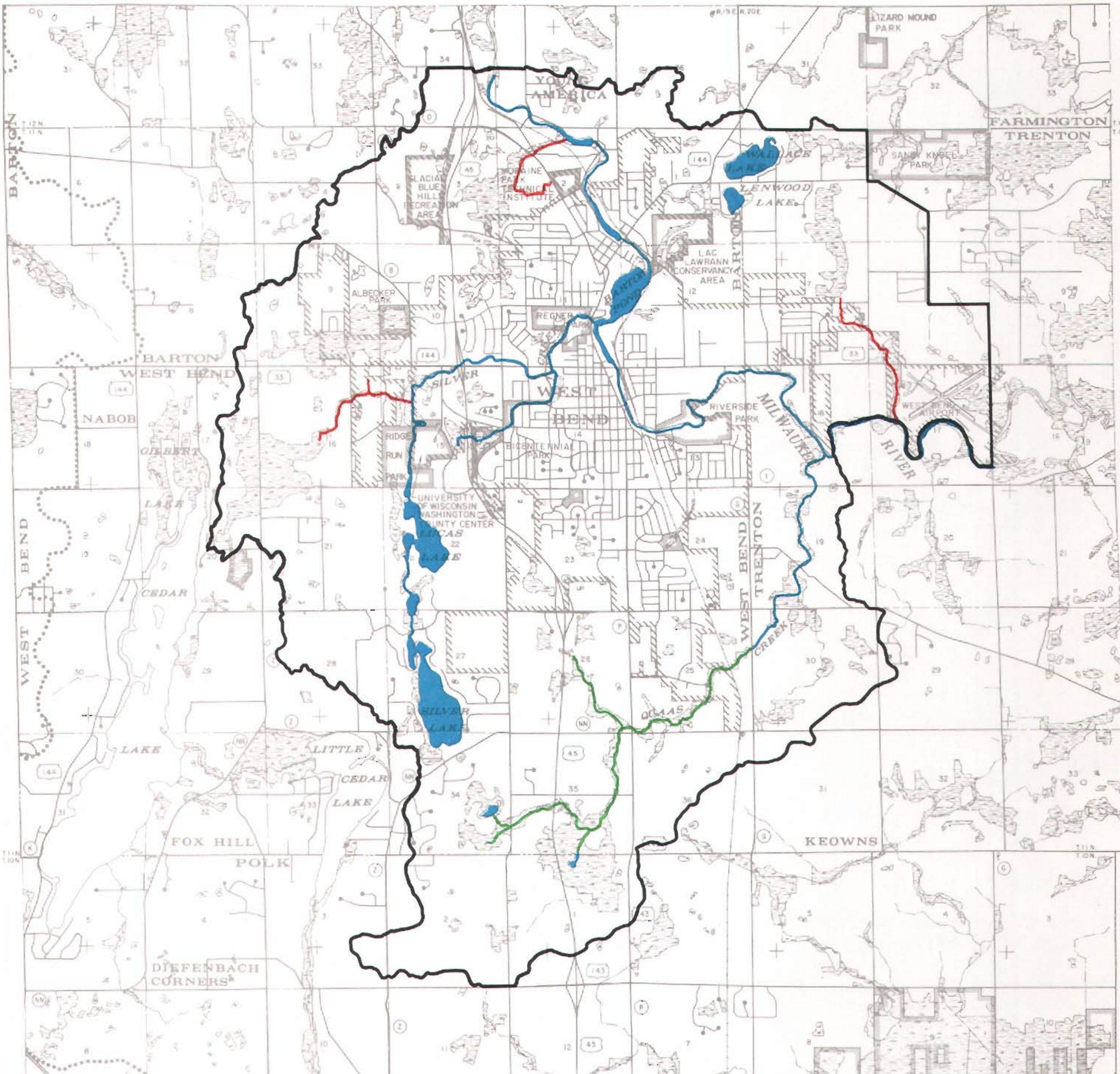
4. To the maximum extent practicable, the location and alignment of new storm sewers and engineered channels and storage facilities should coincide with existing public rights-of-way to minimize land acquisition or easement costs.

5. Stormwater storage facilities—consisting of retention facilities and of both centralized and onsite detention facilities—should, where hydraulically feasible and economically sound, be considered as a means of reducing the size and resultant costs of the required stormwater conveyance facilities downstream of the storage sites.

Source: SEWRPC.

Map 9

RECOMMENDED WATER USE OBJECTIVES FOR LAKES AND STREAMS IN THE WEST BEND STUDY AREA: 2010



LEGEND

- RECREATIONAL USE AND MAINTENANCE OF COLDWATER FISH AND AQUATIC LIFE (CLASS II TROUT FISHERY)
- RECREATIONAL USE AND MAINTENANCE OF WARMWATER FISH AND AQUATIC LIFE
- LIMITED RECREATIONAL USE AND MAINTENANCE OF LIMITED FISH AND AQUATIC LIFE

Source: SEWRPC.

water management facilities must constitute integral parts of a total system. It is not possible from an application of the standards alone, however, to assure such system integration, since the standards cannot be used to determine the effect of individual facilities on the system as a whole, nor on the environment within which the system must operate. This requires the application of planning and engineering techniques developed for this purpose which can be used to quantitatively test the potential performance of proposed facilities as part of a total system. The use of mathematical simulation models facilitates such quantitative tests. Furthermore, by using these models, the configuration and capacity of the system can be adjusted to the existing and future runoff loadings. Second, it must be recognized that it is unlikely that any one plan proposal will fully meet all of the standards; and the extent to which each standard is met, exceeded, or violated must serve as the measure of the ability of each alternative plan proposal to achieve the objective which the given standard complements. Third, it must be recognized that certain objectives and standards may be in conflict and require resolution through compromise, such compromise being an essential part of any design effort.

ANALYTICAL PROCEDURES AND ENGINEERING DESIGN CRITERIA

Certain engineering criteria and procedures were used in designing alternative stormwater management plan elements, and in making the economic evaluations of those alternatives. While these criteria and procedures are widely accepted and firmly based in current engineering practice, it is, nevertheless, useful to briefly document them here. The criteria and procedures provide the means for quantitatively sizing and analyzing the performance of both the minor and major components of the total stormwater management system components considered in this stormwater management plan. In addition, these criteria and procedures can serve as a basis for the more detailed design of stormwater management system components comprising the overall stormwater management system. These criteria and procedures thus constitute a reference for use in facility design, and as such are intended to be applied uniformly and consistently in all phases of the implementation of the recommended stormwater management plan.

Analytical Procedures

Rainfall Intensity-Duration-Frequency Data: Fundamental data for stormwater management planning and design are the rainfall intensity-duration-frequency relationships representative of the area. Such relationships facilitate determination of the average rainfall intensity—normally expressed in inches per hour—which may be expected to be reached or exceeded for a particular duration at a given recurrence interval. Under its comprehensive water resources planning program, the Southeastern Wisconsin Regional Planning Commission has developed a set of rainfall intensity-duration-frequency relationships using both a graphic procedure and a mathematical curve fitting method. The data for the 84-year rainfall record from 1903 through 1986 collected by the National Weather Service at the General Mitchell Field National Weather Service station in Milwaukee are summarized in tabular form in Table 16 and in graphic form in Figure 9. The intensity-duration-frequency equations resulting from the analysis of the Milwaukee data are presented in Table 17. Analyses conducted by the Commission staff indicate that these data are valid for use not only within the Milwaukee area, but anywhere in Southeastern Wisconsin. The curves in Figure 10, which relate total rainfall to duration and frequency, were developed using the curves in Figure 9.

Design Rainfall Frequency: To ensure that the stormwater system is able to effectively control the stormwater runoff in a cost-effective manner, storm events of specified recurrence intervals must be selected as a basis for the design and evaluation of both the minor and major drainage systems. The selection of these design storm events should be dictated by careful consideration of the frequency of inundation which can be accepted versus the cost of protection. This involves value judgments which should be made by the responsible local officials involved and applied consistently in both the public and private sectors.

The average frequency of rainfall used for design purposes determines the degree of protection afforded by the stormwater management system. This protection should be consistent with the damage to be prevented. In practice, however, the calculation of benefit-cost ratios is not deemed warranted for ordinary urban drainage facilities, and a design rainfall recurrence

Table 16

POINT RAINFALL INTENSITY-DURATION-FREQUENCY DATA FOR MILWAUKEE, WISCONSIN[a]

Recurrence Interval (years)	Duration and Intensity[b]						
	5 Minutes	10 Minutes	15 Minutes	30 Minutes	1 Hour	2 Hours	24 Hours
2	4.30	3.43	2.85	1.90	1.14	0.67	0.099
5	5.49	4.46	3.76	2.55	1.55	0.91	0.134
10	6.26	5.14	4.35	2.99	1.84	1.07	0.156
25	7.26	5.99	5.10	3.53	2.19	1.27	0.186
50	7.98	6.62	5.65	3.93	2.44	1.41	0.208
100	8.77	7.28	6.23	4.34	2.70	1.56	0.229

[a]*These data are based on a statistical analysis of Milwaukee rainfall data for the 84-year period 1903 through 1986.*

[b]*Intensity expressed in inches per hour.*

Source: SEWRPC.

interval is selected on the basis of experienced engineering judgment and experience with the performance of stormwater management facilities in similar areas.

In this respect, it should be noted that the cost of storm sewers and other drainage facilities is not directly proportional to either the design storm frequency or the flow rates. A 10-year recurrence interval storm produces approximately 16.5 percent greater rainfall intensities and 26 percent greater runoff intensities than a five-year recurrence interval storm. This higher runoff rate requires sewer pipe diameters to be on the order of 10 percent larger. However, drainage systems are limited to commercially available pipe sizes which, in the most frequently used range of 15- to 66-inch diameter, have incremental diameter increases of 10 to 20 percent, corresponding incremental capacity increases of 27 to 58 percent, and corresponding average in-place cost increases of 15 to 23 percent. The incremental cost increases on a systemwide basis may be expected to be on the order of 15 percent, because only portions of any given system will require modified sizes.

Another consideration in evaluating alternative design recurrence intervals for drainage facilities is the risk of exceeding capacity. Table 18 indicates that a five-year recurrence interval event, which may be expected to occur on the average of 20 times in 100 years, has a 50 percent chance of being exceeded in about 3.5 years, a period which may be unacceptable from a public relations point of view. In contrast, a 10-year recurrence interval event, which is expected to occur on the average of 10 times in 100 years, has a 50 percent chance of being exceeded in about seven years, and a 100-year recurrence interval event, which is expected to occur on the average of one time in 100 years, has a 50 percent chance of being exceeded in about 69 years.

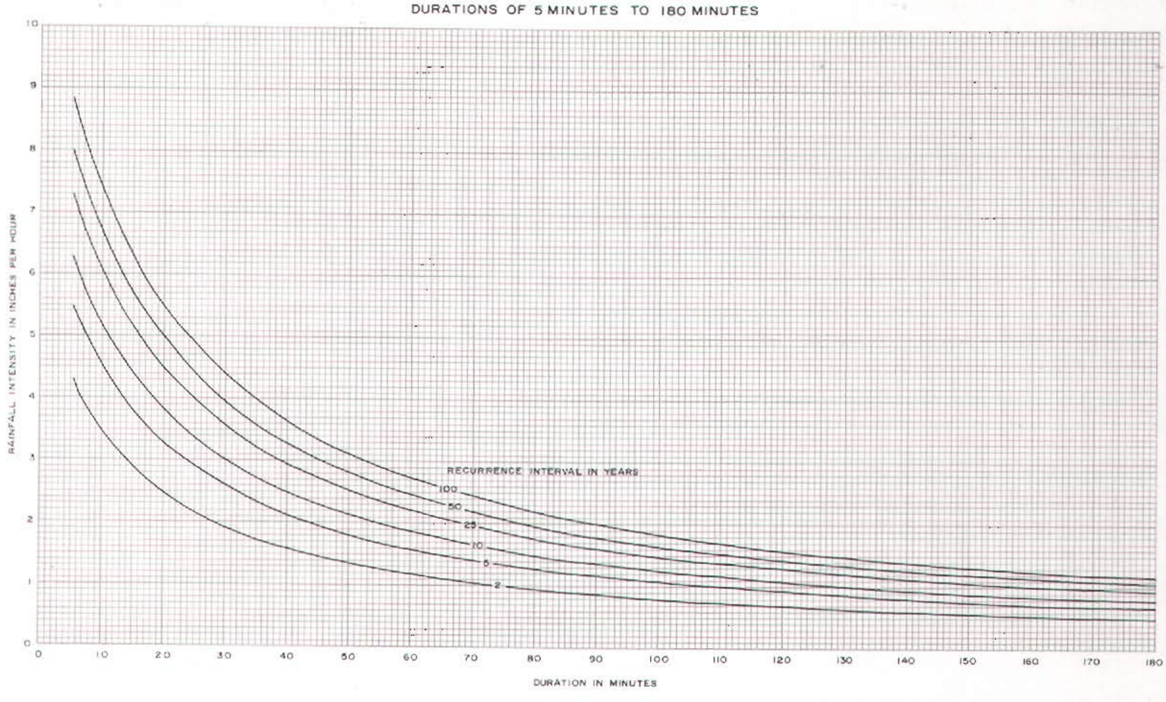
Based upon consideration of the costs and risks entailed, a 10-year recurrence interval storm was selected for use in the design of the minor elements of the stormwater management system for the City of West Bend stormwater management study area, including the design of most conveyance and storage facilities.

When designing the minor urban stormwater management system, the designer should be aware that exceeding capacity does not cause incipient catastrophe. On the contrary, it means only that the minor drainage system capacity has been completely utilized and the unaccommodated portion of the stormwater flow will begin to cause inconvenience and/or disruption of activities as it courses through the major system. In this respect, the minor system differs substantially from the major system.

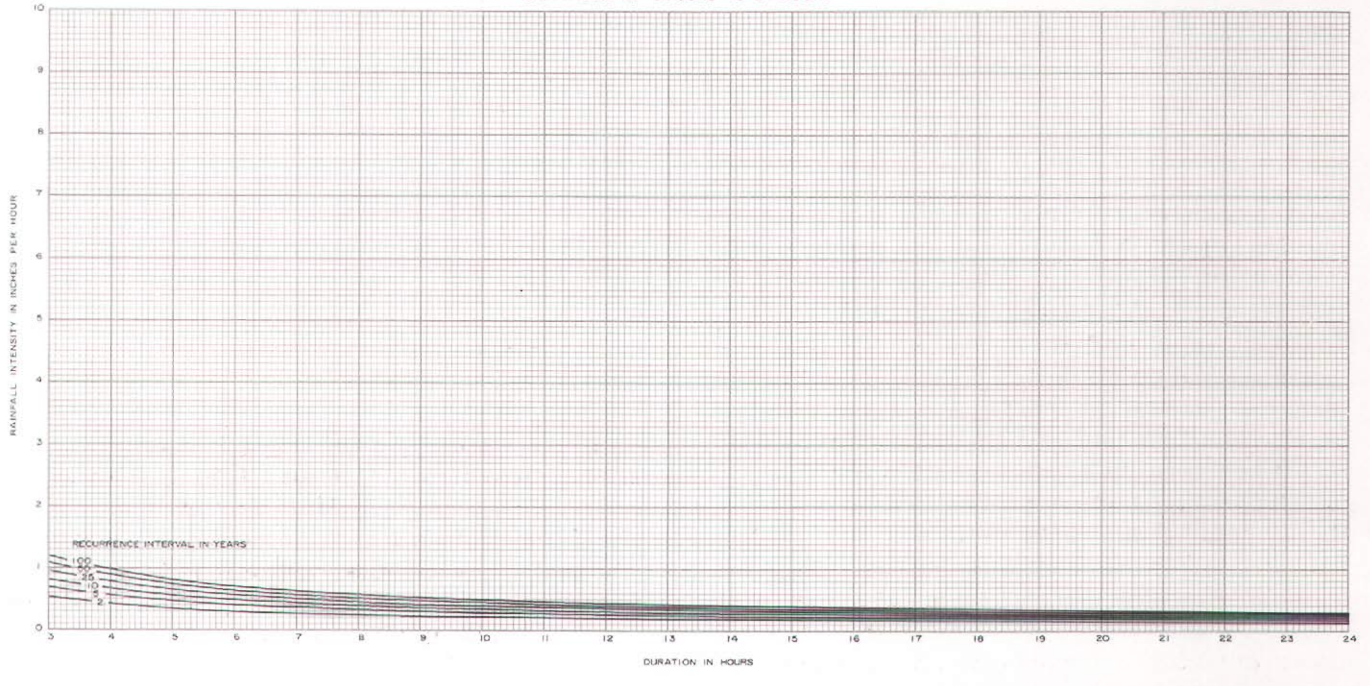
Figure 9

POINT RAINFALL INTENSITY-DURATION-FREQUENCY CURVES FOR MILWAUKEE, WISCONSIN[a]

DURATIONS OF 5 MINUTES TO 180 MINUTES



DURATIONS OF 3 HOURS TO 24 HOURS



[a]The curves are based on Milwaukee rainfall data for the 84-year period of 1903 to 1986. These curves are applicable within an accuracy of ± 10 percent to the entire Southeastern Wisconsin Planning Region.

Source: SEWRPC.

Table 17

POINT RAINFALL INTENSITY-DURATION-FREQUENCY EQUATIONS FOR THE WEST BEND STUDY AREA AND THE REGION[a]

Recurrence Interval (years)	Duration of Five Minutes or More But Less than 60 Minutes[b]	Duration of 60 Minutes or More Through 24 Hours[b]
2	$i = \frac{85.1}{14.8 + t}$	$i = 26.9\ t^{-0.771}$
5	$i = \frac{118.9}{16.7 + t}$	$i = 36.4\ t^{-0.771}$
10	$i = \frac{143.0}{17.8 + t}$	$i = 43.3\ t^{-0.773}$
25	$i = \frac{172.0}{18.7 + t}$	$i = 51.0\ t^{-0.772}$
50	$i = \frac{193.4}{19.2 + t}$	$i = 56.8\ t^{-0.771}$
100	$i = \frac{214.4}{19.4 + t}$	$i = 63.0\ t^{-0.773}$

[a] *The equations are based on Milwaukee rainfall data for the 84-year period 1903 to 1986. These equations are applicable, within an accuracy of $\pm$ 10 percent, to the entire Southeastern Wisconsin Planning Region.*

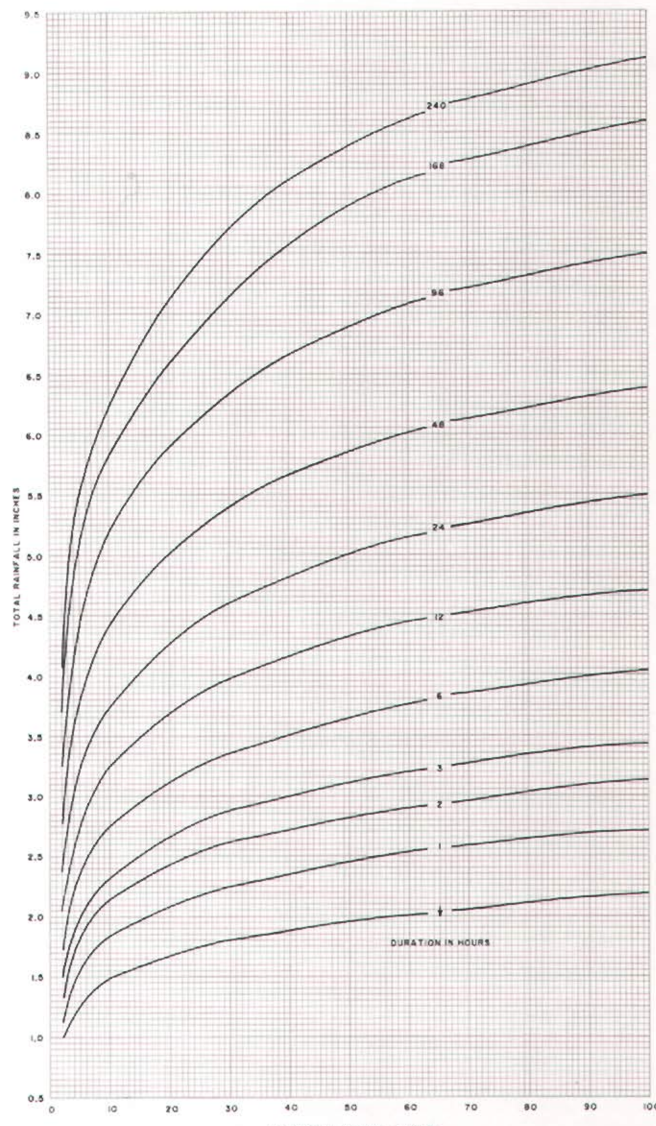
[b] *i = Rainfall intensity in inches per hour*
t = Duration in minutes

Source: SEWRPC.

A 100-year recurrence interval storm was selected for use in delineating areas of potential inundation along the stormwater drainage system, and to size some elements of the system. This recurrence interval is used by the Regional Planning Commission in its flood control planning efforts, and by federal and state agencies for floodland regulation. The 100-year recurrence interval event generally—with only certain unusual exceptions—approximates, in terms of the amount of land area inundated, the largest known flood levels that have actually occurred in the Region since its settlement by Europeans. Therefore, use of a 100-year recurrence interval event provides a conservatively safe level of protection against property damage and hazard to human health and safety from surcharge of the major, as opposed to the minor, stormwater management system.

Figure 10

POINT RAINFALL DEPTH-DURATION-FREQUENCY RELATIONSHIPS IN THE WEST BEND STUDY AREA AND THE REGION



Source: SEWRPC.

Time Distribution of Design Rainfall: The medial time distribution for a first quartile storm as developed by F. A. Huff was used to convert the design rainfall amount for a given duration and frequency to a design storm.[1] The Huff time distribution is shown in Figure 11 and the design storm patterns, or hyetographs, for 10-

[1] *F. A. Huff, "Time Distribution of Rainfall in Heavy Storms," Water Resources Research, Vol. 3, No. 4, 1967, pp. 1007-1019.*

Table 18

THEORETICAL RISK OF DESIGN STORM OCCURRENCE

Average Recurrence Interval (Tr) Years	Probability that Interval Between Events Will Not Be Exceeded in Period of N Years						
	5 Percent	10 Percent	25 Percent	50 Percent	75 Percent	90 Percent	95 Percent
100	299.573 yr	230.259 yr	138.629 yr	69.315 yr	28.768 yr	10.536 yr	5.129 yr
10	29.957	23.026	13.863	6.931	2.877	1.054	0.513
5	14.979	11.513	6.931	3.466	1.438	0.575	0.256
2	5.991	4.605	2.773	1.386	0.575	0.211	0.103
1	2.996	2.303	1.386	0.693	0.288	0.105	0.051
0.5	1.498	1.151	0.693	0.347	0.144	0.053	0.026
0.25	0.749	0.576	0.347	0.173	0.072	0.026	0.013

NOTE: Based on:

$$Pn = e^{-N/Tr}$$

$$N = Tr \times LOG_e \frac{1}{Pn}$$

$$Tr = \frac{N}{LOG_e \frac{1}{Pn}}$$

Where:

Pn = Probability of nonoccurrence
N = Number of years of interest
Tr = Recurrence Interval, years

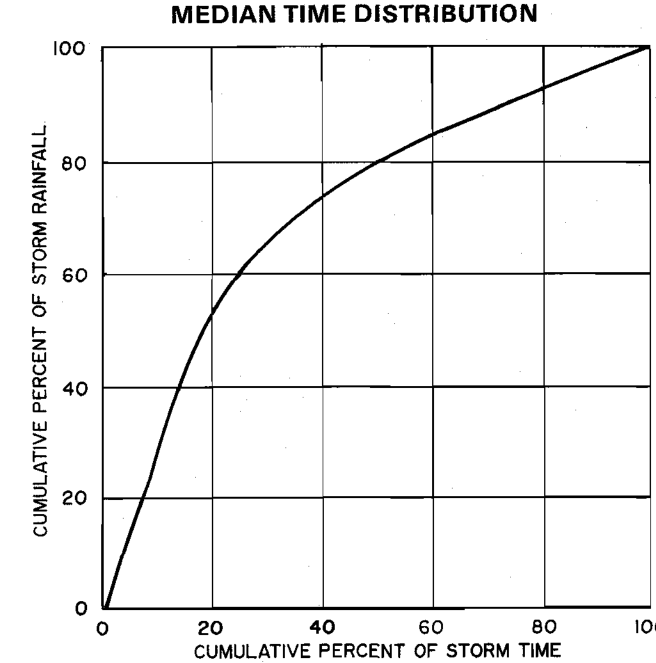
Source: SEWRPC.

and 100-year recurrence interval storms of one-hour duration are given in Figures 12 and 13. Figures 12 and 13 were developed by distributing the 10- and 100-year recurrence interval, one-hour rainfall amounts given in Figure 10 according to the curve in Figure 11.

Additional Hydrologic and Hydraulic Data: Data on the hydrologic and hydraulic characteristics of the study area were also available from the files of the Commission, including data on soils; topography; the drainage patterns of the natural streams and watercourses; the waterway openings of related bridges and culverts, and related flood hazard areas; wetlands; and areas with existing flood problems. Used in the analyses were topographic maps prepared by the City and the Commission to Commission specifications at scales of 1 inch equals 100 feet and of 1 inch equals 200 feet with contours at two-foot intervals, and Commission ratioed and rectified aerial photographs at a scale of 1 inch equals 400 feet. In portions of the study area outside the planned urban service area where large-scale topographic maps were not available, U. S. Geological Survey topographic maps prepared at

Figure 11

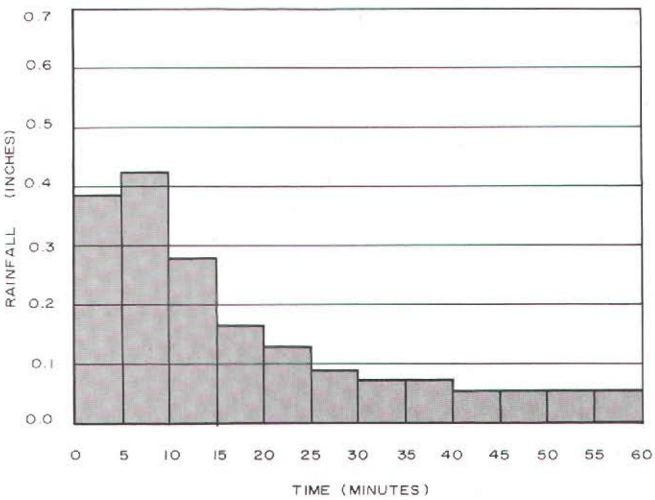
FIRST QUARTILE STORM MEDIAN TIME DISTRIBUTION



Source: F. A. Huff, "Time Distribution of Rainfall in Heavy Storms," Water Resources Research, Vol. 3, No. 4, 1967, pp. 1007-1019.

Figure 12

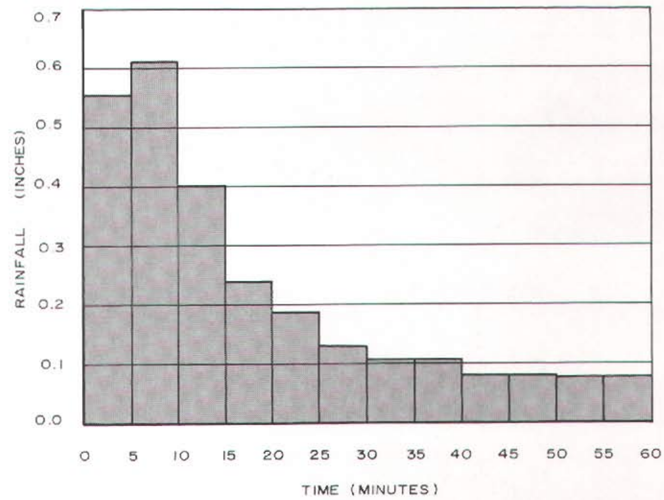
DESIGN STORM PATTERN FOR 10-YEAR RECURRENCE INTERVAL, ONE-HOUR STORM



Source: SEWRPC.

Figure 13

DESIGN STORM PATTERN FOR 100-YEAR RECURRENCE INTERVAL, ONE-HOUR STORM



Source: SEWRPC.

a scale of 1 inch equals 2,000 feet, with contours at 10-foot intervals, were used. Stormwater drainage system maps, construction plans and as-built plans, land use and utility development plans, and other pertinent information were obtained from the files of the City and from a number of other governmental agencies operating in the study area. These materials were evaluated and included in the body of resource materials drawn upon in the analytic and design phases of the work.

Simulation of Hydrologic, Hydraulic, and Nonpoint Source Pollutant Delivery Processes: Quantification of the stormwater flow rates and volumes and of nonpoint source pollutant loading rates under both existing and probable future land use conditions allows sound, rational decisions to be made concerning stormwater management. Such quantification aids in determining the type, location, and configuration of stormwater management facilities, and is essential to sizing facilities such as storm sewers, open channels, culverts and bridges, storage and pumping facilities, and nonpoint source pollution abatement measures. Rainfall-runoff modeling techniques were used under the study to quantify stormwater flow rate and volume in both the minor and major drainage systems.

1. The U. S. Army Corps of Engineers HEC-1 "Flood Hydrograph Package" model was utilized to provide the framework for development, combination, and routing of the flood hydrographs generated for each subbasin of a given subwatershed. That process of combining and routing hydrographs yielded total flood hydrographs at critical points along the natural watercourses in each subwatershed. Flood hydrographs for subbasins with predominately rural land uses under existing and probable future conditions were developed using the U. S. Soil Conservation Service (SCS) dimensionless unit hydrograph option of HEC-1. Under this procedure, rainfall runoff is determined by subtracting interception, infiltration, and surface storage losses from the design storm amounts. Such losses are determined using a runoff curve number calculated from the land use and hydrologic soil group distributions in a given subbasin.

   A unit hydrograph, representing one inch of runoff from a given subbasin for a given duration of rainfall excess, was developed for each subbasin by applying timing parameters characteristic of the subbasin to the SCS standard dimensionless unit hydrograph. The subbasin flood hydrograph was generated by applying each time increment of rainfall excess to the unit hydrograph and then summing the individual hydrographs for each storm time increment, according to the principle of superposition.

Future condition flood hydrographs for some subbasins currently in urban land uses with engineered stormwater management facilities, and for subbasins that are planned to undergo conversion of land from rural to urban uses, were developed using the kinematic wave hydrograph development and routing option of HEC-1. To apply the kinematic wave procedure, the existing or planned stormwater drainage system for a given catchment area is idealized as several elements representing the overland flow, collection, and conveyance characteristics of the system. The kinematic wave forms of the Saint Venant equations for one-dimensional, gradually varied unsteady flow are then solved to generate and route flood hydrographs through the drainage system. Rainfall excess amounts are determined by the SCS method already noted.

The HEC-1 model also has options for hydrograph combination and routing through stream channels and storage facilities. Those options were used to combine and route hydrographs from rural and urban areas and to size storage facilities. The HEC-1 model enables the evaluation of a complex hydrologic network, accounting for the effects of natural and man-made storage reservoirs on downstream peak flow rates.

2. The ILUDRAIN mathematical simulation model was used to develop runoff hydrographs for certain existing and planned areas of urban development with engineered stormwater management systems. The ILUDRAIN model is a desk top computer version of the Illinois Urban Drainage Area Simulator (ILLUDAS) model. The outfall hydrographs generated with ILUDRAIN were input to the HEC-1 model for combining with the hydrographs from rural areas and routing of all hydrographs through the network of streams, wetlands, ponds, and lakes in each subwatershed. In the application of ILUDRAIN, each storm sewer system is treated as a subbasin and is further divided into catchment areas. Hydrographs are produced for the pervious and impervious portions of each catchment area by applying the design storm hyetograph to the contributing areas. These hydrographs are combined and routed downstream from one critical location in the system to the next to provide system loadings in the form of peak flow rates and total flow volumes. This model was used in both of its two operational modes, the evaluation mode and the design mode. In the evaluation mode, the model routes hydrographs through a specified drainage system and is used to calculate needed hydraulic capacity at each critical location in the system. In that mode of operation, undersized components can be identified, and the effects of detention storage on peak flow rates, and therefore on required hydraulic capacities, can be analyzed. In the design mode the model may be used to calculate channel or sewer capacities needed to carry the hydraulic loadings at specified slopes. The simulation model application results are presented in Volumes, Two, Three, and Four of this report.

3. The U. S. Army Corps of Engineers HEC-2 "Water Surface Profiles" model for gradually varied steady flow was used to determine flood stages and flood hazard areas along the streams which are part of the major drainage system. Flood profiles were developed using the 100-year recurrence interval flood flow for year 2010 land use conditions, with both existing and planned stormwater drainage and channel conditions. Where those profiles indicated the existence of flooding problem areas during the 100-year recurrence interval flood under future land use conditions, HEC-2 was used to evaluate alternative modifications to the channel and/or hydraulic structures for the purpose of alleviating flooding problems.

The results of the hydrologic simulations were checked by comparison and contrast with previous analyses made for the federal flood insurance studies, and by application of the U. S. Geological Survey flood frequency equations for urban and rural areas of Wisconsin.[2,3] For the future design of specific minor system conveyance components with relatively small drainage areas, it is recommended that the Rational Method or U. S. Soil Conservation Service TR-55 methods be used to estimate flows.[4,5] If detention storage is to be provided, it is recommended that the TR-55 method for sizing detention basins be used. Experience indicates the Rational Method and the TR-55 methods should provide good results in the design of the components of relatively small, less complex drainage systems, and the results obtained with those methods should be consistent with this system plan. For major system components and minor system components involving complex systems with relatively large drainage areas, it is recommended that design flows be computed using the hydrologic models developed for this stormwater management system plan by the Regional Planning Commission.

An additional mathematical simulation model was used to determine nonpoint source pollutant loadings. The Source Loading and Management Model (SLAMM) was applied by the Wisconsin Department of Natural Resources in the urban nonpoint source pollution control studies conducted for the Milwaukee River Priority Watersheds Program. The results of those studies were integrated into this system plan where practicable. SLAMM was used to estimate existing pollutant contributions from various land use areas. The model was also used to estimate pollutant contributions under planned land use conditions and to evaluate the effects of various pollution abatement measures. Analyses with the SLAMM model were made using historical precipitation data from 1981. A considerable amount of urban nonpoint source pollutant loading data was collected in that year under the Nationwide Urban Runoff Program. Those data were used to calibrate the SLAMM model.

Criteria and Assumptions

Street Cross-Sections, Site Grading, Inlets, and Parallel Roadside Culverts: An important secondary function of all streets and highways is the collection and conveyance of stormwater runoff. The planning of stormwater drainage systems should therefore be done simultaneously with the planning of the location, configuration, and gradients of the street system. At the systems planning level, recommendations concerning the approximate centerline elevations and gradients of existing and proposed streets are provided. Pertinent details of the curbs and gutters, roadside swales, and street crowns are assumed based upon typical cross-sections and must be further addressed in subsequent project development engineering.

The location and size of inlets and culverts, as a part of the minor stormwater drainage system, are dictated by the allowable stormwater spread and depth of flow in streets, and attendant interference with the safe movement of pedestrian and vehicular traffic.

Given the standards formulated under the study, only two assumptions concerning site grading, and one assumption concerning culverts and inlets, were required for the systems planning. It was assumed that all new urban development and redevelopment would be designed to facilitate good drainage, with slopes away from all sides of buildings of at least one-quarter inch per foot to provide positive gravity drainage to streets or to interior drainage swales. It was assumed that interior drainage swales along side lot or back lot lines or site boundaries would have a minimum gradient of 0.01 foot per foot, and would provide positive gravity drainage to streets.

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[2]*Duane H. Conger, Estimating Magnitude and Frequency of Floods for Wisconsin Urban Streams, U. S. Geological Survey, Water-Resources Investigations Report 86-4005, prepared in cooperation with the Wisconsin Department of Transportation, SEWRPC, and Milwaukee Metropolitan Sewerage District, December 1986.*

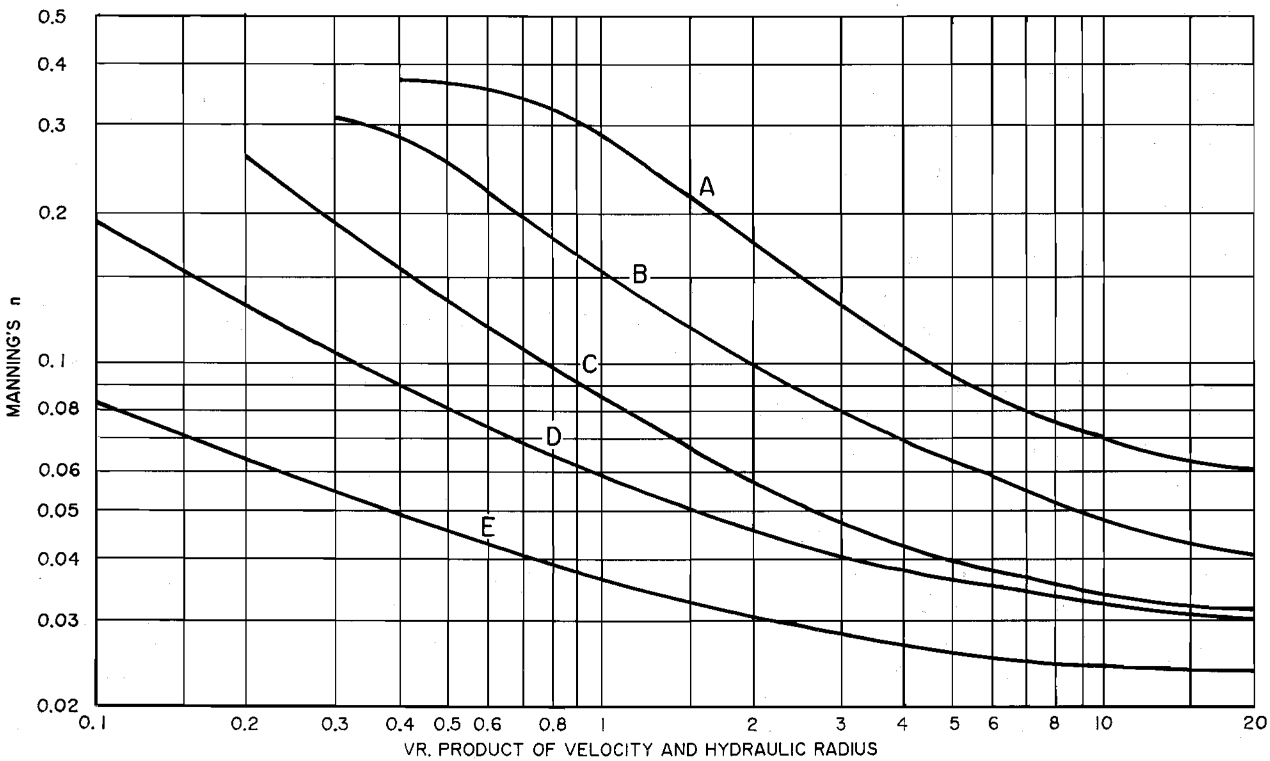
[3]*Duane H. Conger, Techniques for Estimating Magnitude and Frequency of Floods for Wisconsin Streams, U. S. Geological Survey, Water-Resources Investigations Open-File Report 80-1214, prepared in cooperation with the Wisconsin Department of Transportation.*

[4]*SEWRPC Technical Record, Vol. 2, No. 4, April-May 1965.*

[5]*U. S. Soil Conservation Service, Urban Hydrology for Small Watersheds, 2nd Edition, Technical Release 55, June 1986.*

Figure 14

MANNING'S "n" FOR VEGETAL-LINED CHANNELS FOR VARIOUS RETARDANCE LEVELS



Source: U. S. Soil Conservation Service.

With regard to inlets and parallel roadside culverts, it was assumed that these system components would be designed to provide sufficient capacity to intake and pass all flow in the tributary gutters or swales from storms up to and including the 10-year recurrence interval event. In the systems planning, critical locations were selected at which to check the specified overland and swale flow depths.

Roadside Swales: At the systems planning level, only recommendations relating to the general configuration, size, approximate depth, slope, and type of roadside swales are provided. More detailed engineering at the project development level will be needed to determine precise depth, location, and horizontal and vertical alignment of the swales, and the best response to constraints posed by structures and utilities.

In the systems planning, the Manning equation was used together with the cross-sectional area of flow to determine the required hydraulic capacity of swales. A Manning's "n" value corresponding to retardance level "D" in Figure 14 was assumed for well-constructed, properly maintained, frequently mowed, grass-lined roadside drainage swales, such as may be expected to exist adjacent to front yards in residential areas. A Manning's "n" value corresponding to retardance level "C" in Figure 14 was assumed for properly constructed, less frequently maintained (one- to two-month mowing cycle), grass-lined roadside drainage swales commonly found in rural areas.

The following criteria and assumptions relating to the details of the grass-lined storm drainage swales and channels in and along street rights-of-way were used in the development of the stormwater management plan:

1. Swales were assumed generally to be located in public street rights-of-way and to follow the street alignments and gradients.

2. Swale cross-sections were assumed to conform to the City of West Bend standard cross-section shown in Figure 2 in Chapter III of this volume.

3. All swales were designed to accommodate the peak runoff expected from a minor—that is, a 10-year recurrence interval—storm when flowing full and without freeboard.

4. All swales were designed to provide a maximum flow velocity of five feet per second during the design storm event.

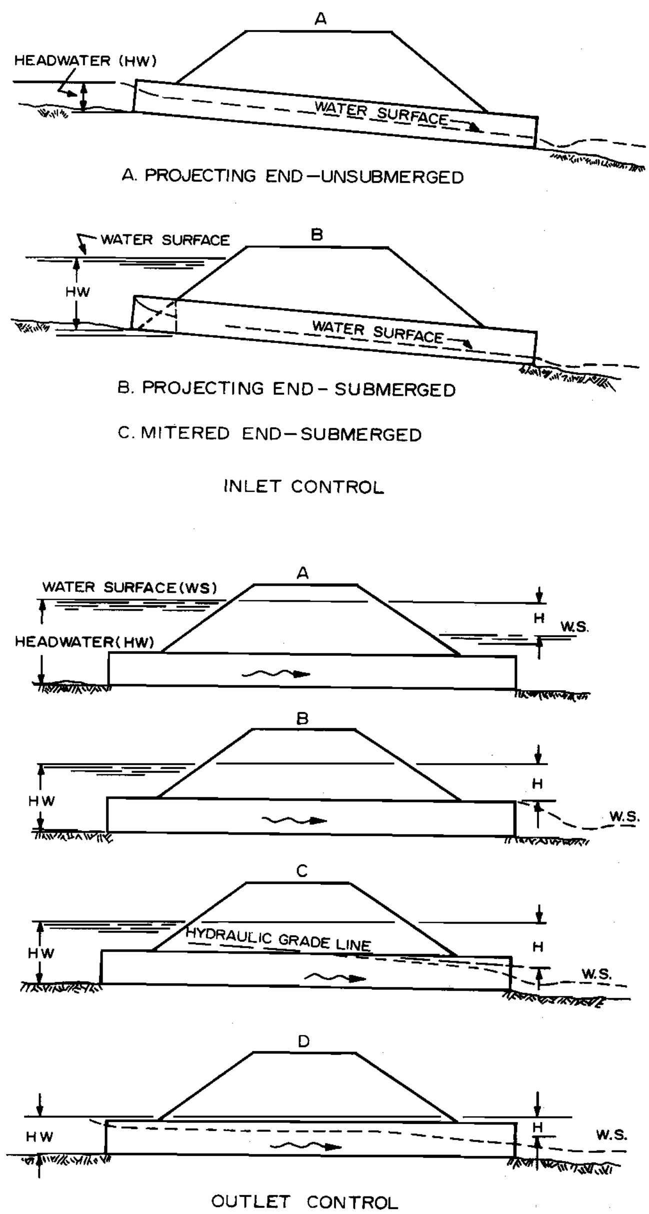
5. The minimum depth of swales below the street shoulder was one and one-half feet, while the maximum depth did not exceed three feet.

Cross Culverts: Cross culverts, which are a common feature of open drainage systems, are used to convey stormwater under a street, highway, railroad, or embankment. At the systems planning level, recommendations concerning the location and size of cross culverts are provided. More detailed engineering at the project development level will be needed to determine the precise depth, location, and horizontal and vertical alignment of the culverts; the type of material to be used; and the best response to constraints posed by structures and utilities.

The hydraulic capacity of any culvert is affected by its cross-sectional area, shape, entrance geometry, length, slope, construction material, and depth of ponding at the inlet and outlet, details which must be addressed at the project development level. Culvert flows are classified as having either inlet or outlet control—that is, according to whether the discharge capacity is controlled by the inlet or outlet characteristics. Typical inlet control and outlet control culvert conditions are shown in Figure 15. Under inlet control conditions, the discharge capacity of a culvert is controlled at its entrance by the depth of headwater, the entrance shape and cross-sectional area, and the type of entrance edge. Under outlet control conditions, the discharge capacity of a culvert is influenced by the headwater depth, tailwater depth, entrance shape and cross-sectional area, and type of entrance edge; by the cross-sectional area, shape, slope, and length; and by the roughness of the culvert barrel.

Figure 15

CULVERT HYDRAULIC CONDITIONS

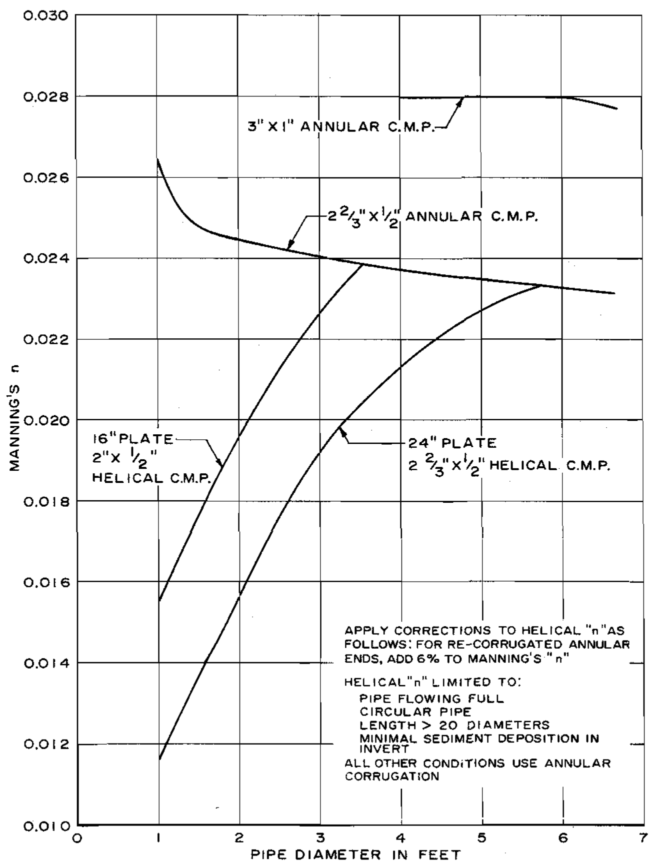


Source: American Iron & Steel Institute.

In planning the system, required culvert sizes were determined by evaluating multiple constraints and selecting an appropriate size which appeared to best meet all requirements. Nomographs and capacity charts are available in the literature for varying pipe shapes, sizes, materials of construction, and entrance conditions.

Figure 16

MANNING'S "n" VERSUS DIAMETER FOR CORRUGATED METAL PIPE CULVERTS FLOWING FULL



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

Manning's "n" values, as shown in Figure 16, were assumed for properly installed and maintained corrugated metal pipe and pipe arch culverts. A Manning's "n" value of 0.012 was assumed for well-constructed, precast, concrete pipe culverts flowing full. Where analyses indicated that pipes would flow less than full at design loading, the hydraulic element charts set forth in Figures 17 and 18 were used in the solution of Manning's equation, or were computed directly in the simulation model. Hydraulic conditions for major system components under major storm event conditions were evaluated on a case-by-case basis.

The following criteria and assumptions were used in the development of culvert sizes for the stormwater management system plan:

1. The culvert location should provide a direct exit, avoiding an abrupt change in direction at the outlet end and, preferably, at the inlet end.
2. The minimum culvert size should be 12 inches in diameter.
3. The culverts should be laid on a constant gradient.
4. New culverts located on private property were assumed to be circular pipes or pipe arches, constructed of corrugated metal. New culverts located on public property and in public rights-of-way were assumed to be circular pipes, pipe arches, or elliptical pipes constructed of concrete.
5. Culvert inlets were assumed to be unblocked.
6. Culverts were assumed to have an unsubmerged outlet during a minor—that is, a 10-year recurrence interval—storm event.

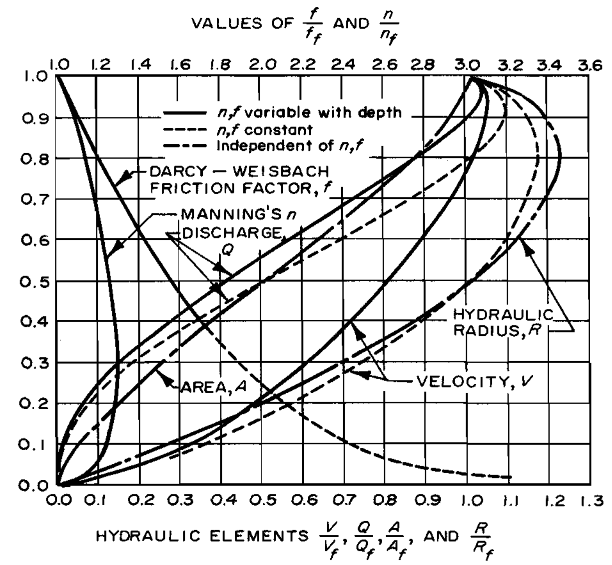
During the facility design phase subsequent to the adoption of the system plan, the following additional criteria should be considered:

1. Appropriate energy dissipation and/or erosion protection should be provided at culvert inlets and outlets. The type of protection will be dictated by site-specific hydraulic considerations.
2. In streams with an existing or potential valuable fishery, the bottoms of culverts should be designed to allow for the free passage of aquatic organisms for a variety of flow extremes. Typical culvert installations to permit fish passage are shown in Figure 19.

Open Drainage Channels: Open drainage channels in and along exclusive rights-of-way are a necessary and appropriate component of the total stormwater drainage system of the City and environs. Such channels may, in certain areas, serve as part of the minor drainage system, as, for example, in parks and cemeteries, in some commercial and industrial areas, and in some low-density residential areas. Such channels form part of the major stormwater drainage system as well. In some areas of the stormwater management study area, open drainage channels, together with roadside swales, may serve

Figure 17

HYDRAULIC ELEMENTS
GRAPH FOR CIRCULAR SEWERS

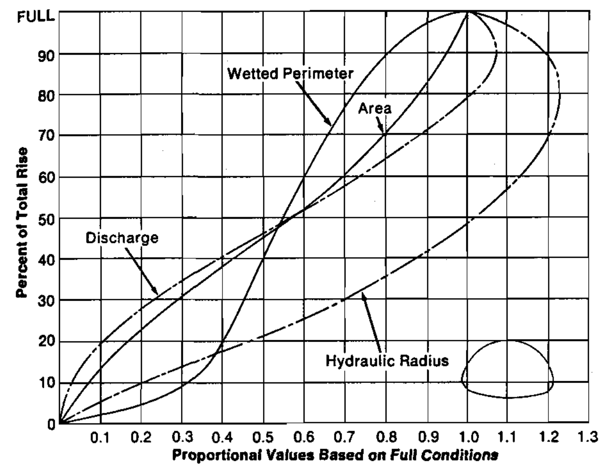


NOTE: n, V, Q, AND R REPRESENT PARTIAL FLOW CONDITIONS. n_f, V_f, Q_f, AND R_f REPRESENT FULL FLOW CONDITIONS.

Source: American Society of Civil Engineers.

Figure 18

HYDRAULIC PROPERTIES OF CORRUGATED STEEL
AND STRUCTURAL PLATE PIPE-ARCHES



Source: American Iron & Steel Institute.

as the sole component of the engineered stormwater drainage system which conveys surface runoff to the receiving natural stream system.

At the systems planning level, recommendations are provided with respect to the general location, cross-section bottom width and approximate bottom elevation, side slopes, gradient, and type of open drainage channels. More detailed engineering at the project development level will be needed to determine the precise location and horizontal and vertical alignment of the channels, the need for and type of channel lining, and the best response to constraints posed by structures, other utilities, and street layout.

In the systems planning, the Manning's equation was used to determine the hydraulic capacity of open channels. Careful consideration was given to allowable grades and depths of flow to prevent unacceptable velocities and damage to the facilities and adjacent land uses. Where flood hazard areas were delineated, the HEC-2 step backwater simulation model was used.

The following criteria relating to the details of the open drainage channels were used in the development of the stormwater management plan and can serve as guidelines in the facility design:

1. All open drainage channels should be designed to accommodate the peak runoff from a 100-year recurrence interval storm under planned land use and channel conditions.

2. Where feasible, it is desirable for modified channels to have a two-foot freeboard above the design flood elevation.

3. Features to mitigate adverse impacts on fish and wildlife habitat should be considered in the design of channel modifications and enclosures.[6]

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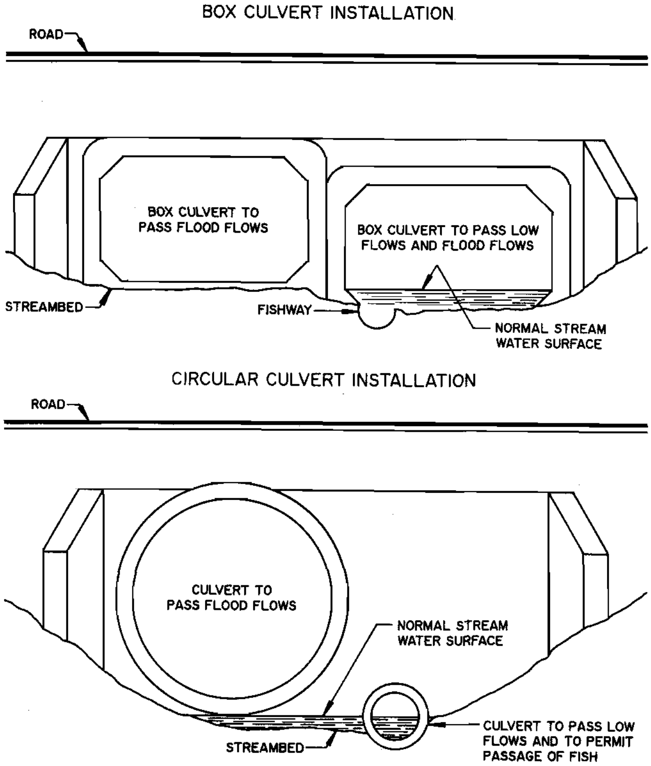
[6]*A work group to develop mitigative procedures for channelized streams in Wisconsin has been formed by the Wisconsin Department of Natural Resources, and includes representatives of the Milwaukee Metropolitan Sewerage District, the Southeastern Wisconsin Regional Planning Commission, local public works officials, the U. S. Army Corps of Engineers, the U. S. Fish and Wildlife Service, the University of Wisconsin, the Wisconsin Society of Civil Engineers, and the Wisconsin Society of Professional Engineers.*

Figure 19

TYPICAL CULVERT INSTALLATIONS TO PERMIT FISH PASSAGE



Source: SEWRPC.

4. Channel modifications shall not increase the height of the 100-year recurrence interval flood by 0.01 foot or more in any unprotected upstream or downstream stream reaches. Increases in flood stages that are equal to or greater than 0.01 foot resulting from any channel construction shall be contained within the upstream or downstream extent of the channel, except where topographic or land use conditions could accommodate the increased stage without creating additional flood damage potential.

5. Alternative cross-sections for modified channels using turf or riprap lining are shown in Figure 20. Selected design criteria for the various alternative channel types are summarized in Figure 20 and Table 19.

   a. Turf-lined, or Type A, channels should be used wherever practicable. Where there is adequate right-of-way, such channels should have maximum side slopes of one vertical on four horizontal. In no instance should the side slopes be steeper than one vertical on two horizontal. A Manning's "n" value of 0.030 should be used, and the maximum velocity during the 100-year recurrence interval flood should not exceed six feet per second. A maintenance access road should be located along the top of the bank, or along a 12-foot-wide maintenance bench as shown in Figure 20. Where deemed important for environmental reasons, as discussed under wetland vegetation channels below, base flow should be conveyed in either a trickle channel or a low-flow channel.

   b. Riprap-lined, or Type B, channels should be provided if erosive velocities are to be expected in turf-lined channels. A typical channel section for this situation is shown as Type B in Figure 20. Where feasible, riprap-lined channel side slopes should be one vertical on three horizontal, but they should not be steeper than one vertical on two horizontal. A Manning's "n" value of 0.035 should be used, and the maximum velocity should be no more than 10 feet per second.

6. Where right-of-way restrictions or hydraulic considerations prevent use of turf-lined channels, fully or partially lined concrete channels may be used, as shown in Figure 20, Types C through F. A Manning's "n" value of 0.015 should be used for concrete channels. Composite turf- and concrete-lined channels should be designed using the appropriate "n" for each segment of the channel cross-section.

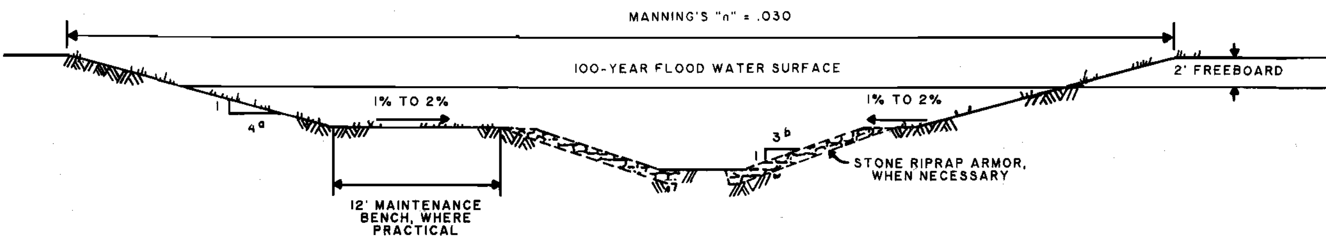
   a. Partially turf-lined, or Type C, channels with concrete invert may be used in residential areas. Where practicable, the turf-lined side slopes should be one vertical on four horizontal, but in no instance should they be steeper than one vertical on two horizontal. During the 100-year recurrence interval flood, the maximum velocity should be six feet per second.

   b. Partially concrete-lined, or Type D, channels may be used in residential areas and in some industrial and com-

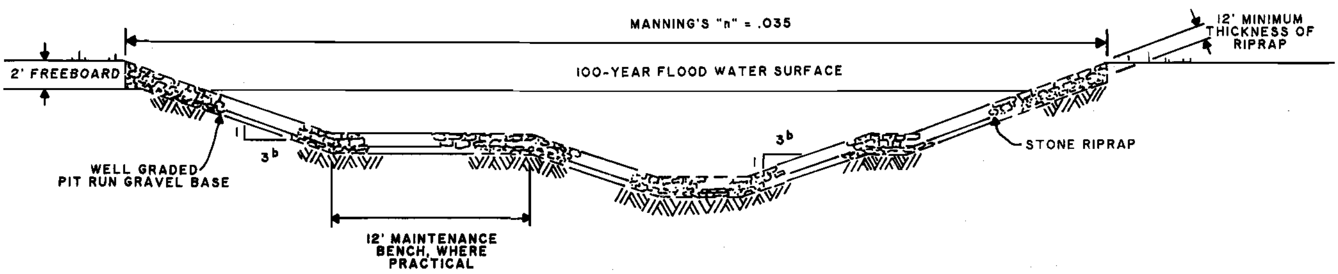
Figure 20

TYPICAL MODIFIED CHANNEL CROSS-SECTIONS

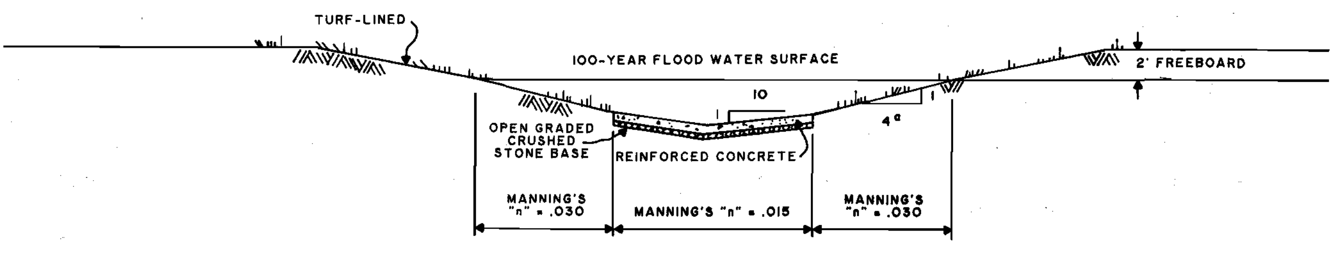
TYPE A
TURF-LINED CHANNEL



TYPE B
RIPRAP-LINED CHANNEL



TYPE C
PARTIALLY TURF-LINED WITH CONCRETE INVERT CHANNEL



TYPE D
PARTIALLY CONCRETE-LINED CHANNEL

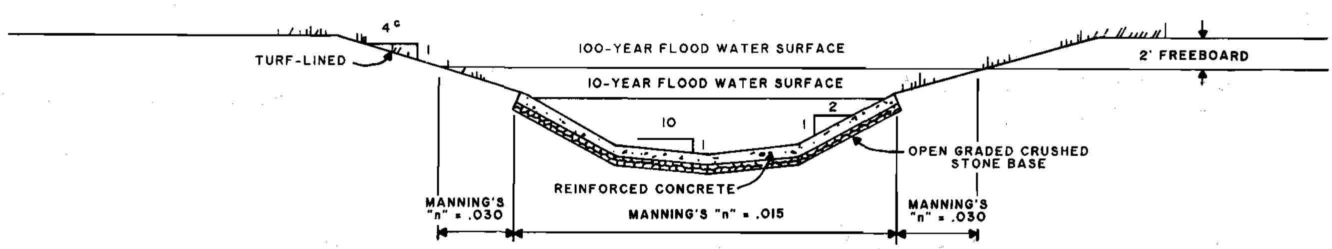
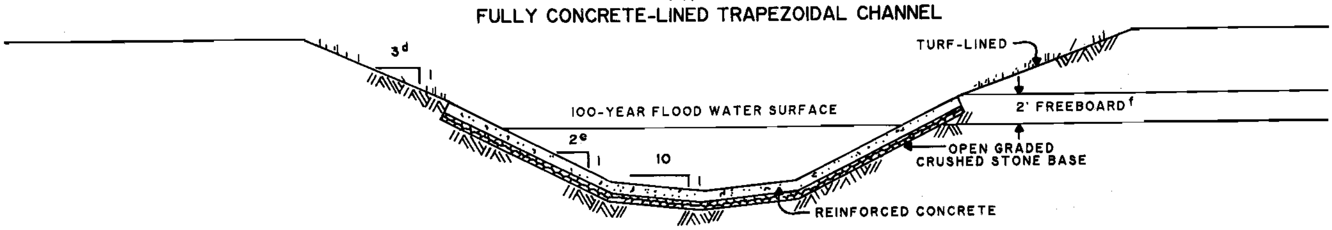
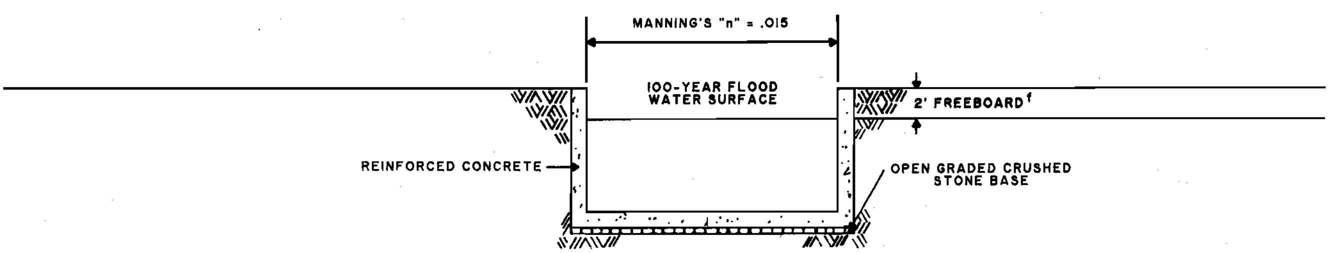


Figure 20 (continued)

TYPE E
FULLY CONCRETE-LINED TRAPEZOIDAL CHANNEL



TYPE F
CONCRETE-LINED RECTANGULAR CHANNEL



[a]*Desirable side slope is one vertical on four horizontal. Steepest allowable side slope is one vertical on two horizontal.*

[b]*Desirable side slope is one vertical on three horizontal. Steepest allowable side slope is one vertical on two horizontal.*

[c]*Desirable side slope is one vertical on four horizontal. Steepest allowable side slope is one vertical on two and one-half horizontal.*

[d]*Desirable side slope is one vertical on three horizontal. Steepest allowable side slope is one vertical on two horizontal.*

[e]*Desirable side slope is one vertical on two horizontal. Steepest allowable side slope is one vertical on one horizontal.*

[f]*A freeboard of two feet is desirable. The minimum permissible freeboard is one foot.*

Source: SEWRPC.

Table 19

CHANNEL MODIFICATION DESIGN CRITERIA

Modification Type	Turf- or Riprap-Lined Side Slopes	Concrete-Lined Side Slope	Maximum Allowable Velocity (feet/second)
A	1V:2H to 1V:4H	- -	6
B	1V:2H to 1V:3H	- -	10
C	1V:2H to 1V:4H	- -[a]	6
D	1V:2.5H to 1V:4H	1V:2H	9[b], 11[c]
E	1V:2H to 1V:3H	1V:1H to 1V:2H	12
F	- -	Vertical	12

[a]*Only the channel bottom is concrete.*

[b]*For the 10-year recurrence interval flood.*

[c]*For the 100-year recurrence interval flood.*

Source: SEWRPC.

mercial areas where there are right-of-way limitations. The slope of the concrete-lined portions should be no steeper than one vertical on two horizontal. Turf-lined slopes should be one vertical on four horizontal if practicable, but should be no steeper than one vertical on two and one-half horizontal. The 10-year recurrence interval flood should be conveyed within the concrete channel. The maximum velocity should be nine feet per second for the 10-year recurrence interval flood and 11 feet per second for the 100-year recurrence interval flood.

c. Fully concrete-lined, or Type E, trapezoidal channels may be used in industrial and commercial areas with restricted right-of-way. This type channel is designed to carry the 100-year recurrence interval flood flow within the concrete channel. It is desirable to have two feet of freeboard to the top of the concrete, but a minimum of one foot is permissible. The slope of the concrete-lined portions can range from one vertical on two horizontal to one vertical on one horizontal. It is desirable for turf-lined side slopes to be one vertical on three horizontal, but slopes of one vertical on two horizontal are permissible where right-of-way is restricted. The maximum allowable average velocity during the 100-year recurrence interval flood is 12 feet per second.

d. Concrete-lined rectangular, or Type F, channels may be used in commercial and industrial areas with restricted rights-of-way. The freeboard requirements are the same as for Type F channels. The maximum velocity during the 100-year recurrence interval flood should not exceed 12 feet per second.

7. The Manning's "n" value criteria for modified channels may be adjusted somewhat in cases where site-specific conditions, such as anticipated vegetative growth and frequency of maintenance, dictate such adjustment.

8. The maximum allowable velocities for modified channels may be increased in localized reaches where site-specific conditions create higher velocities. Adequate erosion protection should be provided in those reaches.

9. Where practicable, grade control structures should be provided as necessary to reduce the channel gradient and obtain flow velocities within the accepted limits. Channel bottom drop structures should not be used in streams with existing or potential valuable fisheries.

10. Appropriate energy dissipation and erosion protection should be provided at any grade control structures. The type of protection will be dictated by site-specific hydraulic considerations.

11. Channel bends should have a minimum radius equal to twice the design flow top width, or 100 feet, whichever is greater.

12. Where modified channels are to be located in an existing wetland area, turf-lined channels should be constructed with wetland vegetation in the bottoms, as shown in Figure 21. The choice between using a trickle channel or a low-flow channel should be based on the overall size of the modified channel relative to the size of the trickle or low-flow channel required to pass the design flow. The trickle channel or the low-flow channel should have a design capacity of about 3 percent of the 100-year recurrence interval flood. Trickle channel depths should be about 1.5 feet. The maximum low-flow channel depth should be about five feet. These design flow and depth criteria are intended to be used as guidelines that may be adjusted to meet site-specific conditions. The design criteria for turf-lined channels apply to wetland bottom channels with the following modifications and additions.

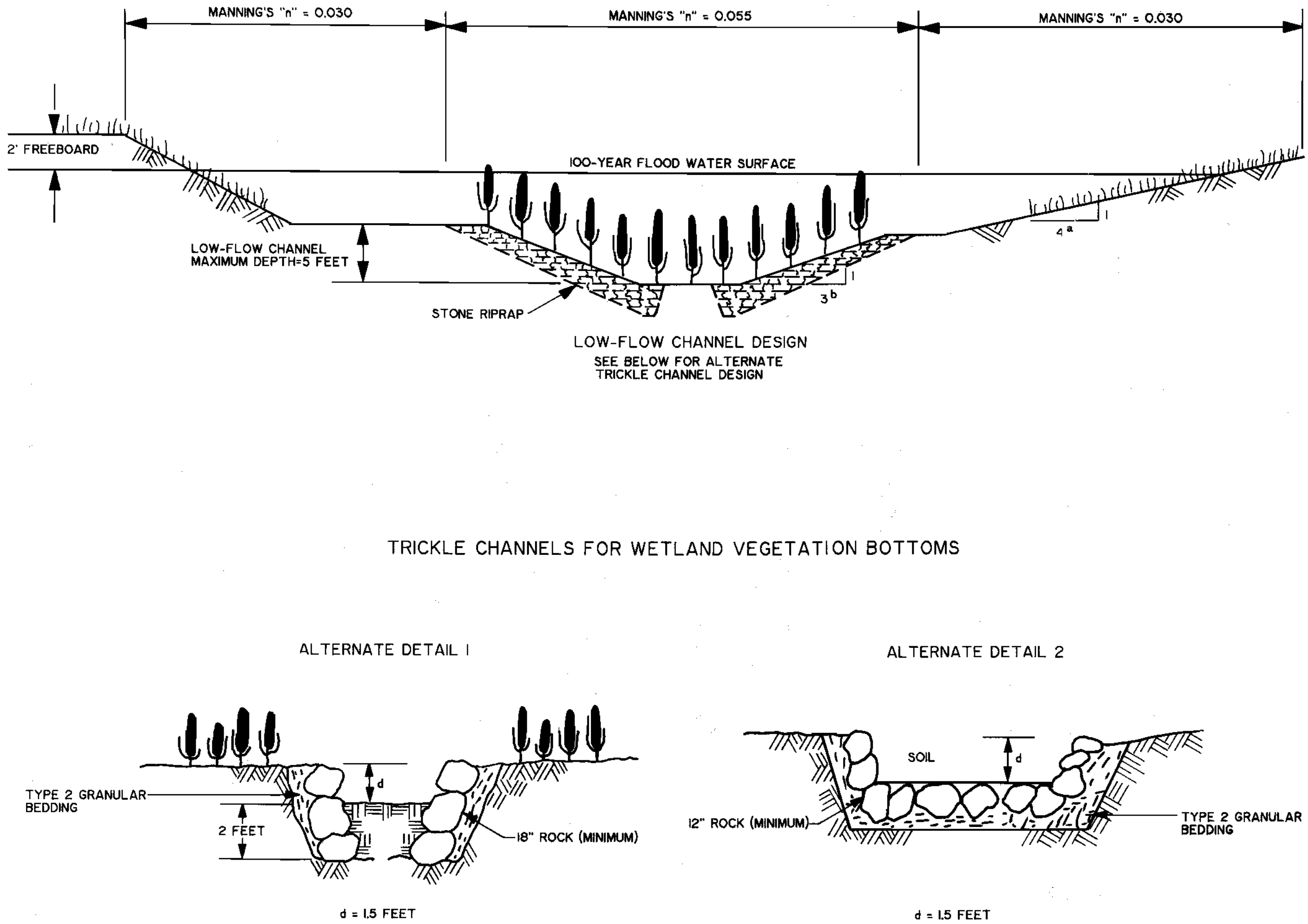
    a. The longitudinal channel slope and the initial channel shape, which are selected to meet the design velocity criteria, should be determined using Manning's "n" values characteristic of newly constructed channels. The Manning's "n" values given above for turf- and riprap-lined channels should be used.

    b. The design water surface profile should be determined using Manning's "n" values characteristic of mature wetland channels. Wetland channels with trickle channels should be designed using Manning's "n" values determined from Figure 22. The turf-lined portions of wetland channels with low-flow channels should be designed using a Manning's "n" value of 0.030, and the low-flow channels should be designed using a Manning's "n" value of 0.055.

<u>Storm Sewers</u>: At the systems planning level, only recommendations for the general configuration, size, approximate invert elevation, slope, and type of storm sewer facilities are provided. More detailed engineering at the facility design level will be needed to determine the precise invert elevation, location, and horizontal and vertical alignment of the sewer, the type of material used for the sewer, and the best response to constraints posed by structures and other utilities. It is recommended that, to the

Figure 21

WETLAND BOTTOM CHANNEL CROSS-SECTIONS



[a] *Desirable side slope is one vertical on four horizontal. Steepest allowable side slope is one vertical on two horizontal.*

[b] *Desirable side slope is one vertical on three horizontal. Steepest allowable side slope is one vertical on two horizontal*

Source: Denver Urban Drainage and Flood Control District, and SEWRPC.

extent practicable, stormwater management facilities be located generally as shown in Figure 23.

In the systems planning, Manning's equation was used together with the cross-sectional area of flow to determine the hydraulic capacity of sewers. Values for the Manning's roughness coefficient "n" vary with the type and conditions of the sewer, the depth of flow in the sewer, and the diameter of the sewer. A Manning's "n" value of 0.012 was assumed typical of well-constructed, precast, concrete pipe sewer lines. Manning's "n" values for existing corrugated metal storm sewer lines were determined using Figure 16.

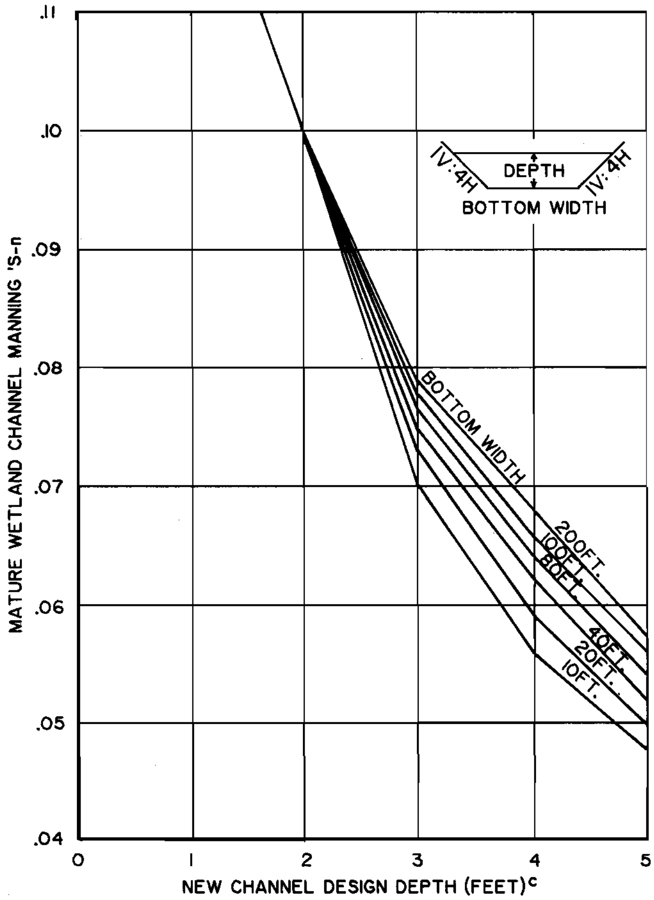
Where the analyses indicated the sewers would flow less than full at design loading, the hydraulic element chart set forth in Figure 17 was used to determine the critical characteristics, or those characteristics were computed directly into the simulation model.

The following criteria and assumption relating to the details of the storm sewers were used in the development of the stormwater management plan:

1. Storm sewers were assumed generally to be located in public street rights-of-way and to follow the street alignments and gradients.

Figure 22

MANNING'S "n" FOR WETLAND BOTTOM CHANNELS WITH TRICKLE CHANNELS[a,b]



[a]FOR DESIGN, USE MANNING'S $n = 0.030$ FOR A NEW (IMMATURE) CHANNEL TO SET THE CHANNEL'S LONGITUDINAL SLOPE. USING THIS LONGITUDINAL SLOPE, ADJUST THE DEPTH OR WIDTH FOR THE WETLAND MANNING'S n IN THIS CHART.

[b]FOR CHANNEL DESIGN DEPTH GREATER THAN FIVE FEET, USE THE DEPTH OF FIVE FEET IN THE ABOVE CHART.

[c]DEPTH OF CHANNEL BEFORE WETLAND VEGETATION MATURES.

Source: Denver Urban Drainage and Flood Control District, and SEWRPC.

2. All storm sewers should be designed to accommodate the peak runoff expected from a minor—that is, a 10-year recurrence interval—storm when flowing full.

3. The minimum pipe size should be 12 inches in diameter.

4. The minimum desirable velocity during the design storm event should be 2.5 feet per second.

5. Planned storm sewer outlet invert elevations should be above the channel bottom elevations of the receiving watercourses. This criterion assumes that there is periodic cleaning and maintenance of stream channels.

6. The minimum depth of cover over the top of the sewer should be three feet.

Stormwater Storage Facilities: Natural storage of stormwater is provided during overland flow in surface depressions, vegetated areas, and pervious soils. Natural storage can be enhanced by preserving open areas, woodlands, wetlands, ponds, and areas with large infiltration capacities. These attributes can usually be incorporated into a stormwater management system at less cost than would be required for the incorporation of artificial storage facilities. Artificial storage facilities include constructed onsite swales, roadside swales, temporary storage facilities on parking lots and other open areas, and retention and detention basins.

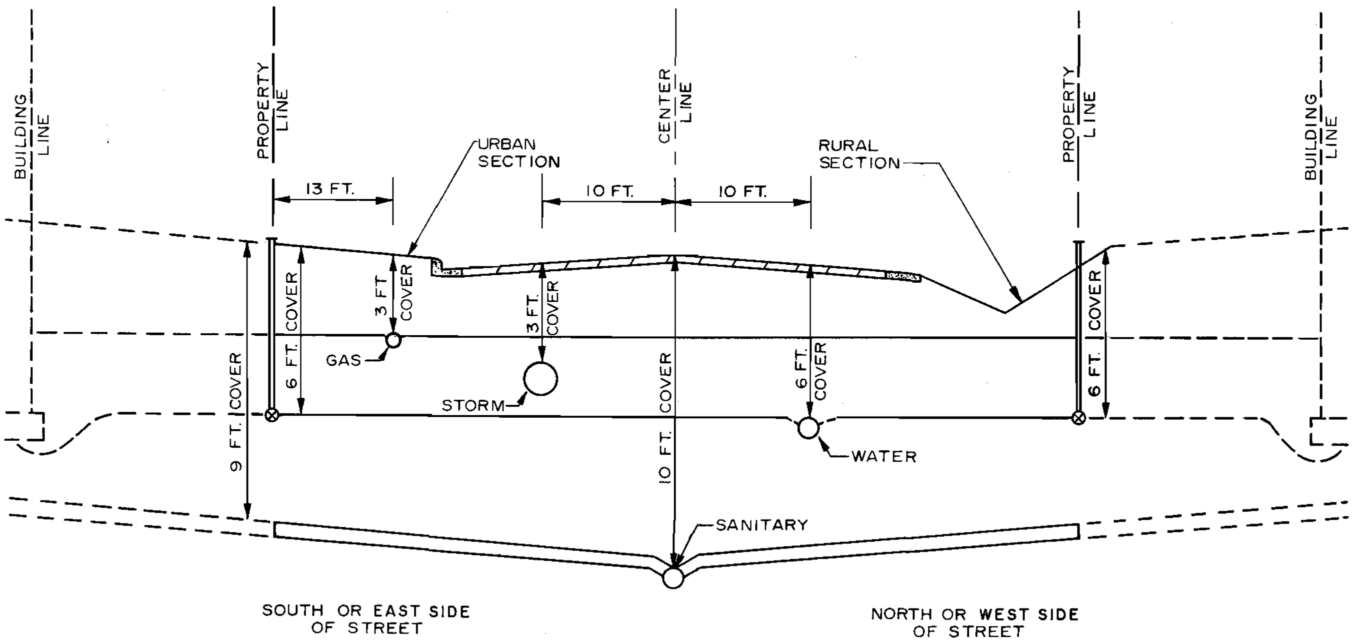
At the systems planning level, recommendations concerning only the location, type, approximate size, and capacity of storage facilities and outlet flow constraints are provided. More detailed engineering at the project development level will be needed to precisely locate, configure, and size storage facilities and to specify such details as the inlet and outlet control facilities. In planning the system, required storage volumes were calculated using the HEC-1 or ILUDRAIN simulation models. The following criteria relating to storage facilities were used in the development of the stormwater management system plan:

1. Storage facilities should be sized to accommodate a minor—that is, a 10-year recurrence interval—storm event under planned land use and channel system conditions. This criterion does not apply to storage facilities designed as components of the downstream floodland management system, which should be sized considering a major—that is, a 100-year recurrence interval—storm event. Storage systems planned for water quality improvement should be designed considering more frequent storms than those used for minor system design.

2. Where practical, storage facilities should be designed to limit the design outflow to no more than the capacity of the existing

Figure 23

SUGGESTED UTILITY LOCATIONS IN THE CITY OF WEST BEND



Source: City of West Bend and SEWRPC.

downstream conveyance and storage systems.

3. Where modification to, or replacement of, the existing downstream conveyance and storage system is necessary, any proposed upland storage facilities that are required should be sized to minimize the costs of the combined storage and conveyance system.

4. The effects of storage facilities on the frequency, duration, and magnitude of downstream flooding under future conditions as compared to existing conditions should be carefully examined. Owing to routing through a storage facility, the outflow hydrograph should be significantly flattened in comparison to the inflow hydrograph, peak flows should be reduced, and the duration of peak, or near-peak, flows increased. When prolongation of near-peak flows causes those flows to coincide with near-peak flows of upstream or downstream tributaries, storage facilities should be designed so as not to increase combined future downstream flood peaks above the existing peaks. In cases where the increased duration and magnitude of downstream flood peaks creates an unacceptable level of damages, even though the individual storage facility outflow flood peaks were limited to the existing condition peak, the storage facilities should be sized to reduce the peak outflows and the duration of downstream flooding to a more acceptable level. In some instances meeting the above criteria for reducing the effects of a prolonged peak may require reducing the peak storage facility outflow to an amount less than the existing subbasin outflow.

5. Storage depths on parking lots, truck stopping areas, and similar open spaces should not exceed six inches during the design flood event.

6. Storage facilities that include dams or earth embankments to detain floodwaters should include an emergency spillway to pass flows in excess of the 100-year design flood and should satisfy the applicable criteria of Chapter NR 333 of the Wisconsin Administrative Code relating to dam safety.

Stormwater Pumping Facilities: At the systems planning level, only recommendations concerning the location, type, and capacity of the pumping facility are provided. More detailed engineering at the project development level will be needed to determine the type of pumps, type of drives and motor requirements, type of electrical controls, and size and configuration of intake facilities.

The following criteria and assumption relating to stormwater pumping facilities were used in the development of the stormwater management system plan:

1. An evaluation should be made of the ability of the pumping station to provide protected areas with relief from flooding during storms ranging up to and including the 100-year recurrence interval storm.

2. The pumping station should be designed with a gravity overflow to the major drainage system.

3. For systems planning purposes, it was assumed that the pumps would be high-capacity, low-head centrifugal pumps with constant-speed motors designed for intermittent service.

Stormwater Management Facility Safety Design Criteria: Because of the detailed nature of the design of most safety measures for stormwater management facilities, such design is most appropriately accomplished at the final design stage rather than at the systems planning stage. Therefore, this systems plan does not include criteria relating to specific safety measures. Potential safety hazards were considered as intangible elements in the comparison of alternative plans.

Urban Nonpoint Source Pollution Control Measures: At the systems planning level, only the type, location, and general water quality benefits expected from urban nonpoint source pollution abatement measures are provided. The detailed design of a nonpoint source pollution abatement program will require a site-specific inventory of nonpoint pollution problems, the determination of the exact sizing and extent of application of measures, an identification of which measures are publicly acceptable and can be incorporated into the existing public works programs of the City, and the physical detailed design of any structural measures.

Detailed criteria for construction site pollutant control are given in the Wisconsin Department of Natural Resources, "Wisconsin Construction Site Best Management Practice Handbook" (draft, October 1988). Also, the Construction Site Erosion and Stormwater Management Plan and Model Ordinance (draft, 1985) prepared by the Department of Natural Resources contains detailed design procedures for nonpoint source pollution control measures. Additional design considerations and criteria are given in Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs, Metropolitan Washington Council of Governments, 1987. The following general criteria for other nonpoint source control measures were considered in the development of this stormwater management plan and can serve as guidelines in the facilities design phase.

1. Pretreatment of storm runoff to infiltration devices should be considered to minimize clogging and reduce maintenance. Such pretreatment would typically consist of a sedimentation box. The addition of a sedimentation-flotation basin to trap oil and grease may be necessary when the device is constructed in a commercial area.

2. Where compatible with the goal of efficiently transporting stormwater runoff, infiltration through grass swales should be maximized by designing for lower flow velocities within the allowable range for grass swales. Accordingly, the maximum longitudinal slope on swales intended to infiltrate runoff should be less than 5 percent.

3. To maximize stormwater infiltration potential, perforated drainage pipes should be used only where longitudinal slopes of less than 3 percent can be attained.

4. Where the use of wet detention basins is warranted for water quality management purposes, consideration should be given to selecting a pond area-outflow rate relationship which will increase particle settling efficiencies without compromising the flood control objectives for the basin.

5. Where feasible, to avoid short circuiting of flow and to maximize the detention efficiency of wet detention basins, the mini-

mum basin length-to-width ratio should be three, or baffles should be provided to increase the flow length.

6. The average depths of wet detention basins should range between three and eight feet. A three-foot minimum depth is needed to minimize scour and resuspension of deposited sediments, and an eight-foot maximum depth will aid in reducing aquatic plant growth and will increase winter survival of fish.

7. The design of retention basins and other infiltration systems at the facilities level requires site-specific investigations to establish design parameters and to avoid groundwater contamination. Important considerations related to the assessment of the potential for groundwater contamination are the soil permeability, the depth to the water table, the depth to bedrock, and the existing and potential uses of the receiving groundwater. For this systems plan, infiltration systems are limited to areas that are covered by relatively permeable Hydrologic Soil Group A or B soils, where the depth to the seasonally high water table is greater than five feet, and where the tributary land slopes do not exceed 5 percent.

8. The maximum area draining to a single infiltration trench should be less than five acres.

ECONOMIC EVALUATION

It is customary to evaluate plans for water resource development projects on the basis of benefits and costs. This is particularly appropriate if the prospective development represents opportunities for investments to provide economic return to the public and if a comparison of alternative investments is desirable. In the case of stormwater management systems, however, it is assumed that such systems must be provided to fulfill a fundamental need of the community, and consequently, they do not compete with alternatives of investment in other economic sectors. Accordingly, it is assumed that the least costly alternative system that meets the stormwater management objectives set forth in this chapter will be the most desirable alternative economically.

The economic evaluations conducted under this stormwater management planning program include capital cost estimates and annual operation and maintenance cost estimates. Capital costs include construction contract costs plus engineering, inspection, and contract administration costs. Cost data for stormwater drainage and flood control measures are presented in Appendix A. Cost data for urban nonpoint source pollution control measures were obtained from Commission files, the City of West Bend, and private consultants.

Where feasible, construction cost curves for entire components are presented. Such curves are given for surface storage facilities, storm sewers, dikes, floodwalls, circular culverts, and pumping stations. For other structural drainage and flood control measures, unit construction costs for each element of the particular measure are tabulated. Unit cost tabulations are provided for bridge alteration or replacement, channel modifications, and channel enclosures. Where site-specific conditions were expected to result in unit costs that would vary from the generalized data of Appendix A, unit costs were adjusted appropriately.

Figures A-1 through A-8 and Tables A-1 through A-8 in Appendix A represent 1986 construction or operation and maintenance costs based on an Engineering News-Record, Construction Cost Index (CCI) of 4520. When estimating total project costs, the costs obtained from those figures and tables should be adjusted using the CCI for the year of the estimate and increased by 35 percent to account for engineering, administration, and contingencies. Where applicable, the cost of land acquisition or easements should be added.

The cost data presented in Appendix A were obtained from bid tabulations for other recent flood control and drainage projects within the Region, from past Regional Planning Commission studies, from studies conducted by the U. S. Army Corps of Engineers, and from the 1982 Dodge Guide to Public Works and Heavy Construction Costs.[7] Where pre-1986 data were used

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[7] *Leonard A. McMahon, 1982 Dodge Guide to Public Works and Heavy Construction Costs, ed. Percival E. Pereira, Annual Edition No. 14, McGraw Hill, Princeton, New Jersey, 1981.*

in the development of cost curves or unit costs, the CCI was used to adjust the costs to 1986. Cost data for the structural measures considered were adopted after comparison and evaluation of data from these sources. The validity of the adopted unit cost data for the typical elements of a channel modification project was verified by using the data to estimate the costs of several constructed flood control projects within the Region for which total costs were available.

Cost estimating data and procedures for nonstructural flood control methods are given in Tables A-9 through A-11. The data were developed from past studies by the Regional Planning Commission and from studies conducted within the Region by the Corps of Engineers. These data represent total 1986 costs and they should not be increased for engineering, administration, and contingencies.

For both structural and nonstructural flood control measures and urban nonpoint source pollution control measures, the adopted base cost data are those that are considered the most applicable to the types of projects considered for the West Bend stormwater management plan. The cost data presented in Appendix A were used in the economic evaluation of alternative systems plans, and are not intended to be used for project estimating purposes. Actual costs will vary from these estimates, reflecting site-specific conditions, local availability and supply of materials, and labor costs. Any necessary land acquisition costs were estimated utilizing real estate cost estimates provided by the City of West Bend.

SUMMARY

The process of formulating objectives and standards for stormwater management is an essential part of the planning process. To reflect the basic needs and values of the community, it is necessary that these stormwater management objectives and standards be prepared within the context of, and be fully consistent with, proposed land use conditions and broad community development objectives.

The following five stormwater management objectives were established to guide the design and evaluation of alternative stormwater management plans:

1. The development of an integrated system of stormwater drainage and flood control facilities which reduces the exposure of people to drainage-related inconvenience, flood damage, and health and safety hazards, and which reduces the exposure of real and personal property to damage through inadequate stormwater drainage and flood control.

2. The development of a stormwater management system which will effectively serve existing and proposed future land uses.

3. The development of a stormwater management system which will abate nonpoint source water pollution and help achieve the recommended water use objectives and supporting water quality standards for surface water bodies.

4. The development of a stormwater management system which will be flexible and readily adaptable to changing needs.

5. The development of a stormwater management system which will efficiently and effectively meet all of the other stated objectives at the lowest practicable cost.

Complementing each of the foregoing stormwater management development objectives is a set of quantifiable standards which can be used to evaluate the relative or absolute ability of alternative stormwater management plan designs to meet the objective.

In addition to presenting and discussing the objectives and standards established for the West Bend stormwater management plan, this chapter has presented the engineering design criteria and analytic procedures that were used to design and size the alternative plan elements and which will serve as a basis for the more detailed design of stormwater management system components. Criteria and procedures were developed for estimating stormwater flow rate and volume and for designing street cross-sections, swales, culverts, storm sewer inlets, storm sewers, open channels, storage facilities, pumping facilities, and water quality management measures.

APPENDICES

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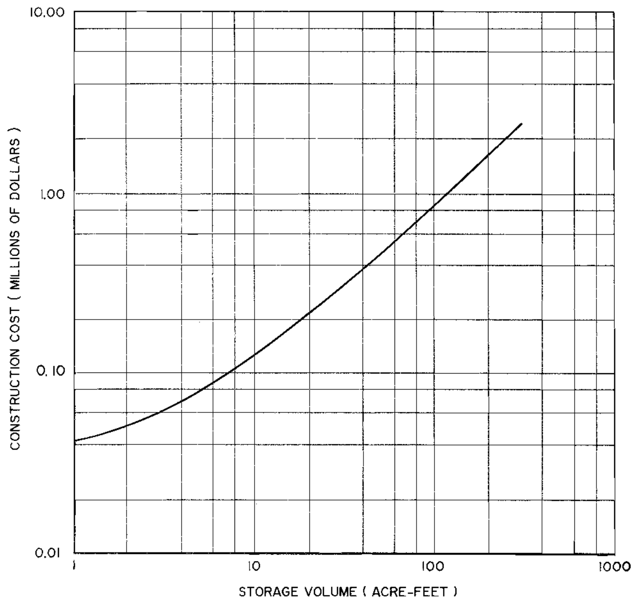
Appendix A

COST DATA FOR STORMWATER MANAGEMENT AND FLOOD CONTROL FACILITIES

Figure A-1

SURFACE STORAGE FACILITY COST CURVE[a]

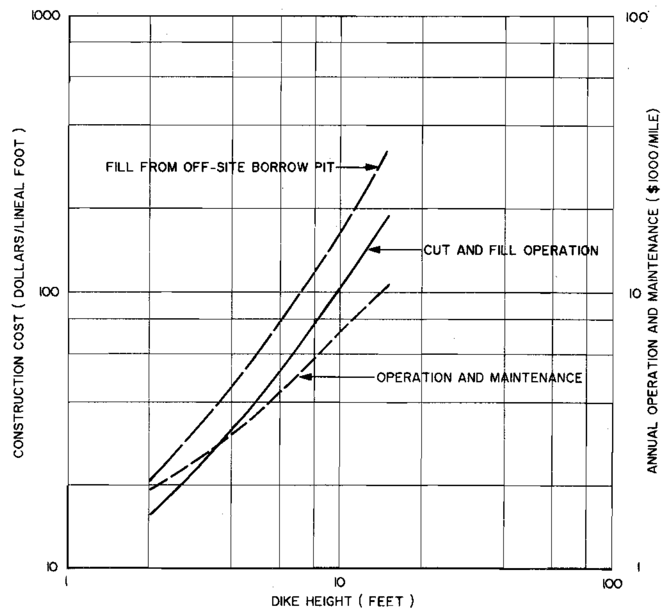


[a]ENR CCI = 4,520 (1986). Does not include land acquisition, engineering, administration, and contingencies. Operation and maintenance costs given in Table A-8.

Source: SEWRPC.

Figure A-2

DIKE COST CURVES[a]

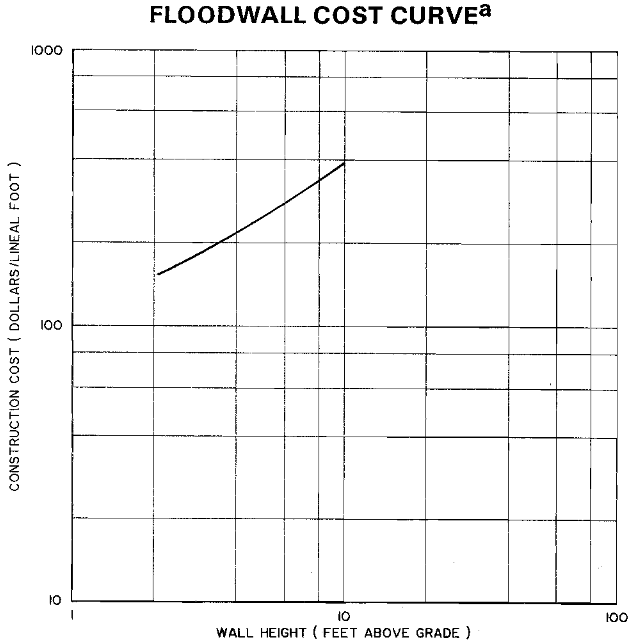


[a]ENR CCI = 4,520 (1986). Does not include land acquisition, engineering, administration, and contingencies.

Source: SEWRPC.

Figure A-3

FLOODWALL COST CURVE[a]

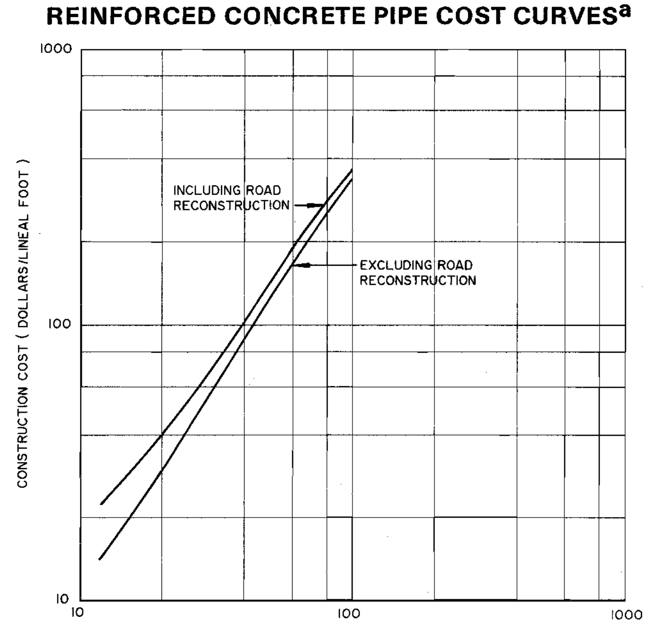


[a]ENR CCI = 4,520 (1986). Does not include land acquisition, engineering, administration, and contingencies. Annual operation and maintenance costs = $3,000/mile.

Source: SEWRPC.

Figure A-4

REINFORCED CONCRETE PIPE COST CURVES[a]

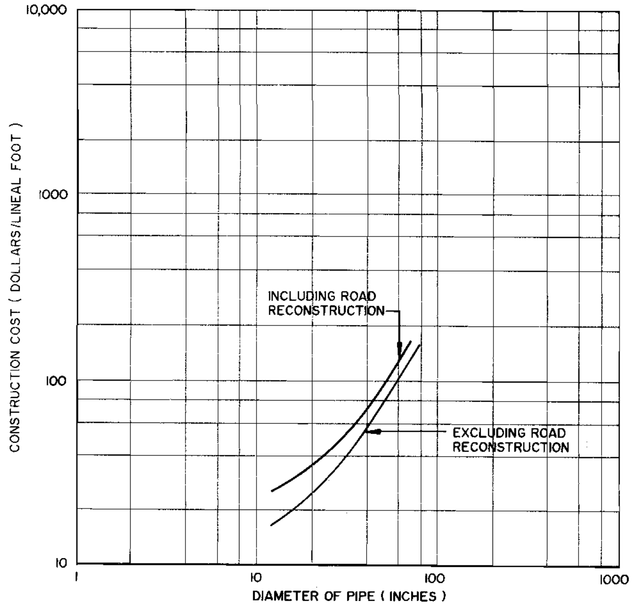


[a]ENR CCI = 4,520 (1986). Does not include easements, engineering, administration, and contingencies.

Source: SEWRPC.

Figure A-5

CORRUGATED METAL PIPE COST CURVES[a]

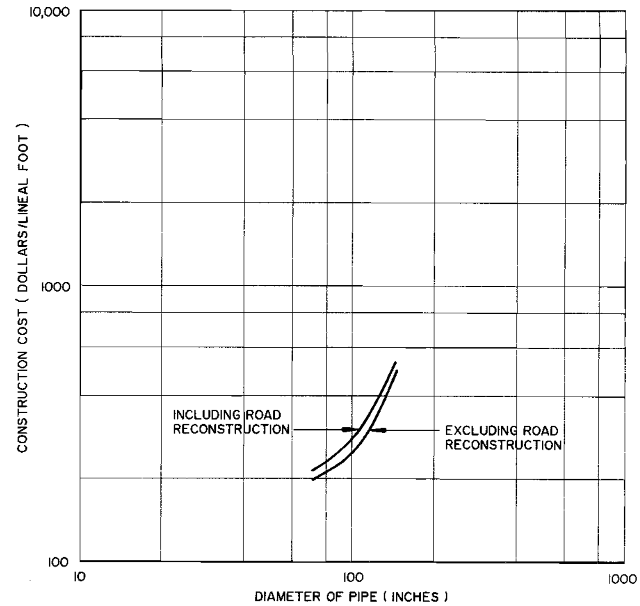


[a]ENR CCI = 4,520 (1986). Does not include easements, engineering, administration, and contingencies.

Source: Dodge Guide and SEWRPC.

Figure A-6

STRUCTURAL PLATE PIPE COST CURVES[a]

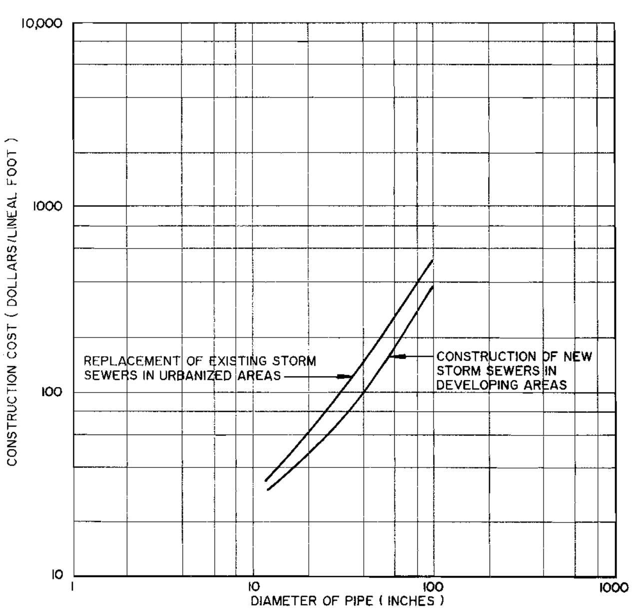


[a]ENR CCI = 4,520 (1986). Does not include easements, engineering, administration, and contingencies.

Source: SEWRPC.

Figure A-7

REINFORCED CONCRETE PIPE STORM SEWER COST CURVE[a,b]



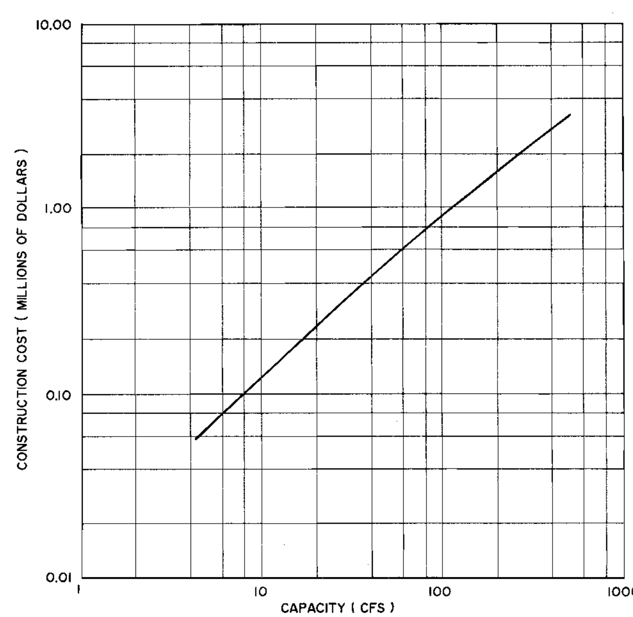
[a]ENR CCI = 4,520 (1986). Does not include easements, engineering, administration, and contingencies. Annual operation and maintenance costs = \$1,000/mile for diameter ≥ 36 inches and \$2,000/mile for diameter < 36 inches.

[b]This curve is applicable for pipe invert depths of up to 12 feet. For depths greater than 12 feet, site-specific cost adjustments should be made.

Source: SEWRPC.

Figure A-8

PUMPING STATION COST CURVE[a]



[a]ENR CCI = 4,520 (1986). Does not include land acquisition, engineering, administration, and contingencies. Annual operation and maintenance costs = \$6,000/year.

Source: U. S. Army Corps of Engineers and SEWRPC.

Table A-1

UNIT COSTS FOR CHANNEL MODIFICATION COMPONENTS

Component	Unit Cost[a]
Clearing and Grubbing	$3,500 per acre
Excavation	$3 to $20 per cubic yard[b]
Concrete	$160 per cubic yard
Riprap	$40 per cubic yard
Gabions	$100 per cubic yard
Landscaping	$3,400 per acre

[a]*ENR CCI = 4,520 (1986). Annual channel maintenance cost = $2,000 per mile.*

[b]*Cost dependent on haul distance to disposal site, disposal site tipping fees, and whether excavated material includes toxic substances requiring special disposal methods.*

Source: SEWRPC.

Table A-2

UNIT COSTS FOR BRIDGE REMOVAL AND REPLACEMENT

Type of Bridge	Unit Cost[a,b] ($ per square foot)
Street	60
Pedestrian	70

[a]*ENR CCI = 4,520 (1986).*

[b]*Based on bridge deck area including street, curbs, sidewalks, and parapets.*

Source: SEWRPC.

Table A-3

UNIT COSTS FOR RAILWAY BRIDGE REMOVAL AND REPLACEMENT

Number of Tracks	Unit Cost[a] ($ per lineal foot of span)
1	4,900
2	8,700
3	12,500

[a]*ENR CCI = 4,520 (1986).*

Source: SEWRPC.

Table A-4

UNIT COSTS FOR CONCRETE BOX CULVERTS

Culvert Size (feet)	Unit Cost[a,b] ($ per lineal foot)
4 x 2	125
5 x 3	180
8 x 4	370
8 x 6	400
8 x 8	460
10 x 3	350
10 x 4	440
10 x 6	490
10 x 8	580
10 x 10	660
12 x 6	640
12 x 8	670
12 x 10	820
12 x 12	900
16 x 6	600

[a]*ENR CCI = 4,520 (1986).*

[b]*Add $30 per lineal foot of pipe to account for road reconstruction.*

Source: SEWRPC.

Table A-5

UNIT COSTS FOR CORRUGATED METAL PIPE ARCHES

Pipe Size, Span x Rise (inches)	Unit Cost[a] ($ per lineal foot)	
	Excluding Road Reconstruction	Including Road Reconstruction
36 x 22	70	80
43 x 27	100	110
50 x 31	110	120
58 x 36	130	140
65 x 40	180	200
72 x 44	190	210

[a]*ENR CCI = 4,520 (1986).*

Source: Dodge Guide and SEWRPC.

Table A-6

UNIT COSTS FOR STRUCTURAL PLATE PIPE ARCHES

Pipe Size, Span x Rise (inches)	Unit Cost[a] ($ per lineal foot)	
	Excluding Road Reconstruction	Including Road Reconstruction
73 x 55	280	290
84 x 61	300	320
98 x 69	340	360
114 x 77	410	430
131 x 85	500	520
148 x 93	540	570
161 x 101	600	630
178 x 109	640	670
190 x 118	700	740
199 x 121	720	760

[a]*ENR CCI = 4,520 (1986).*

Source: Dodge Guide and SEWRPC.

Table A-7

UNIT COSTS FOR REINFORCED CONCRETE PIPE ARCH (RCPA) AND HORIZONTAL ELLIPTICAL (HE) STORM SEWERS

Pipe Size, Span x Rise (inches)		Unit Cost[a] ($ per lineal foot)	
		Replacement of Existing Storm Sewers in Urbanized Areas	Construction of New Storm Sewers in Developing Areas
22 x 14	23 x 14	56	44
29 x 18	30 x 19	83	63
36 x 23	38 x 24	113	83
44 x 27	45 x 29	139	99
51 x 31	53 x 34	174	124
58 x 36	60 x 38	210	150
65 x 40	68 x 43	242	172
73 x 45	76 x 48	290	205

[a]*ENR CCI = 4,520 (1986).*

Source: SEWRPC.

Table A-8

ANNUAL OPERATION AND MAINTENANCE COSTS FOR SURFACE STORAGE FACILITIES

Storage Volume (acre-feet)	Annual Operation and Maintenance as a Percent of Construction Cost[a]
Volume $\leq$ 5	6
5 $<$ Volume $\leq$ 20	4
Volume $>$ 20	3

[a]*Includes periodic sediment removal.*

Source: SEWRPC.

Table A-9

STRUCTURE FLOODPROOFING COSTS[a]

Structure Type	Cost per Structure
Single-Family Home	$4,600
Two-Family Residence	6,800
Industrial/Commercial Building	Market Value x (0.07 + 0.05 x height, in feet, of floodproofing above first floor)

[a]*ENR CCI = 4,520 (1986). Costs include administration and contingencies.*

Source: SEWRPC.

Table A-10

SINGLE-FAMILY HOME ELEVATION COST[a]

Cost = $22,800 + $3,400 x Number of Feet Raised

[a]*ENR CCI = 4,520 (1986). Costs include administration and contingencies.*

Source: SEWRPC.

Table A-11

SINGLE-FAMILY HOME REMOVAL[a]

Cost = $14,000 + Structure and Site Acquisition Cost

[a]*ENR CCI = 4,520 (1986).*

Source: SEWRPC.