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Inside Region $1.00
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REFINING THE DELINEATION OF ENVIRONMENTAL CORRIDORS IN SOUTHEASTERN WISCONSIN

by **Bruce P. Rubin, Chief Land Use Planner, SEWRPC, and**
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INTRODUCTION

In SEWRPC Planning Report No. 27, A Regional Park and Open Space Plan for Southeastern Wisconsin: 2000, published in 1977, it was noted:

> The natural resource base of an area is a primary determinant of its development potential and its ability to provide a pleasant and habitable environment for all forms of life. Thus, the preservation, protection, and wise use of the natural resource base is of vital importance to sound social and economical development, as well as to the preservation of environmental quality in that area.

In southeastern Wisconsin the preservation, protection, and wise use of the natural resource base is particularly important because increasing numbers of urban residents are becoming year-round residents of outlying areas of southeastern Wisconsin, seeking both the varied outdoor recreational opportunities offered by the natural resource amenities present in these outlying areas and the open space that these areas provide for residential development. The need to protect valuable natural resource amenities, therefore, has become increasingly important to the maintenance of the general well being and environmental quality of the Southeastern Wisconsin Region.

In an effort to identify those natural resources that should be protected and preserved in southeastern Wisconsin, the Southeastern Wisconsin Regional Planning Commission (SEWRPC) has identified environmental corridors, which are linear areas in the landscape containing concentrations of natural resource amenities, as well as scenic, recreational, and historic resource amenities. These corridors generally lie along the major stream valleys, around major lakes, and in the Kettle Moraine area of southeastern Wisconsin. Almost all of the remaining high-value woodlands, wetlands, wildlife habitat areas, major bodies of surface water, and delineated floodlands and shorelands are contained within these corridors. In addition, significant groundwater recharge and discharge areas, many of the important recreational and scenic areas, and the best remaining potential park sites are located within the environmental corridors. Such environmental corridors are, in effect, a composite of the most important individual elements of the natural resource base in southeastern Wisconsin and have immeasurable environmental and recreational value.

Recognizing the importance and value of environmental corridors, the Commission, in its initial comprehensive land use plan and in succeeding planning programs, has recommended the protection and preservation of environmental corridors in essentially natural open uses. This recommendation is based on the conviction that failure to provide for the protection and preservation of the natural resources found in southeastern Wisconsin, and primarily within the environmental corridors, could result in serious environmental degradation and the creation of difficult and costly problems, such as flooding and water pollution.

In recommending that environmental corridors be preserved and protected in their natural state, the Commission has recognized that, because of the many interlocking and interacting relationships existing between living organisms and their environment, the destruction or deterioration of one natural resource element of the total environment may lead to a chain reaction of deterioration and destruction. For example, the drainage of wetlands could have far-reaching effects since such drainage can destroy fish spawning grounds, wildlife habitat, groundwater recharge areas, and natural filtration and floodwater storage areas of interconnecting lake and stream systems. The resulting deterioration of surface water quality may, in turn, lead to the deterioration of the quality of the groundwater which serves as a source of domestic, municipal, and industrial water supply and on which low flows of rivers and streams may depend. Such drainage may also cause increased flood flows and stages with attendant damages. As another example, destruction of woodland cover, which may have taken a century or more to develop, may result in soil erosion, stream siltation, more rapid runoff, and increased flooding, as well as the destruction of wildlife habitat. Although the effects of any one of these environmental changes may not in and of itself be overwhelming, the combined effects must eventually lead to the serious deterioration of the underlying natural resource base and the overall ability of the environment to support life. The need to maintain the integrity of the remaining environmental corridors thus becomes apparent.

In its application of the environmental corridor concept to various regional planning programs, the Commission has refined and detailed the environmental corridor delineations to meet specific planning and plan implementation needs. The Commission has initiated an environmental corridor refinement process designed to provide for a precise and detailed delineation of environmental corridor lands. The purpose of this article is to describe this environmental corridor refinement process. The balance of this article is divided into sections on four central topics: 1) the evolution of the environmental corridor concept in southeastern Wisconsin, 2) the need to refine the delineation of environmental corridors, 3) the corridor refinement methodology, and 4) a case study comparing the location and size of primary environmental corridors derived from the refinement process described herein with the location and size of primary environmental corridors as identified in the Commission's initial regional land use plan.

THE ENVIRONMENTAL CORRIDOR CONCEPT IN SOUTHEASTERN WISCONSIN

The Regional Planning Commission's emphasis in recent years on the delineation and preservation of environmental corridors should not obscure the fact that an urban version of the concept was originated and implemented in Milwaukee County almost 75 years ago by Charles B. Whitnall and other members of the Milwaukee County Park Commission. The urban version of the environmental corridor, the parkway, was a factor in Whitnall's thinking as early as 1906, although the first plans for a Milwaukee County parkway system did not appear until 1924.

Essentially conceived by Whitnall, the concept of the environmental corridor was re-articulated in Wisconsin in 1962 in a State Department of Resource Development report entitled, Recreation in Wisconsin. The concept was adopted and applied by the Southeastern Wisconsin Regional Planning Commission, which incorporated it into its regional land use plan as documented in SEWRPC Planning Report No. 7, The Regional Land Use-Transportation Study. This plan was adopted by the Commission in November 1966. Environmental corridors, as conceived by the SEWRPC under the initial regional land use plan, normally include one or more of the following seven elements of the natural resource base: 1) lakes, rivers, and streams and their associated undeveloped shorelands and floodlands, 2) wetlands, 3) woodlands, 4) wildlife habitat areas, 5) rugged terrain and high-relief topography, 6) significant geological formations and physiographic features, and 7) wet, poorly drained, and organic soils. In addition, there are certain other elements which, although not part of the natural resource base per se, are closely related to that base and important to the identification of environmental corridors. These elements are: 1) existing outdoor recreation sites, 2) potential outdoor recreation and related open space sites, 3) historic sites and structures, and 4) significant scenic areas and vistas. Primary environmental corridors, as conceived by the Commission, are those linear areas in the landscape encompassing at least three of the above-mentioned 11 resource or resource-related elements. Secondary corridors are linear features in the landscape encompassing only one or two of these resource elements. In recognition of the ability of primary environmental corridor lands to contribute to the maintenance of the ecological balance, natural beauty, and economic well being of the Region, the Commission has, since 1966, recommended that the designated primary environmental corridors in southeastern Wisconsin be preserved for essentially natural, open uses.

NEED FOR REFINEMENT OF ENVIRONMENTAL CORRIDORS

Regional plans prepared by the Commission are not envisioned as static documents, but rather are continuously updated, revised, and refined to reflect changing conditions and needs. The same is true for the various components of plans prepared by the Commission, including the primary environmental corridor component of the original regional land use plan. Since its adoption of the regional land use plan in 1966, the Commission has made several refinements to the primary environmental corridors as originally delineated. These refinements have resulted primarily from the Commission watershed studies, which have provided more detailed information upon which to base delineations of the corridors, as well as from the Commission's regional park and open space planning program. While certain refinements of the environmental corridor delineations have been made as a result of major planning programs undertaken by the Commission, such refinements have all been made at the systems level of planning. Consequently, the resulting environmental corridor delineations are relatively general. A more detailed delineation of environmental corridors designed to implement the recommendations of the adopted regional land use plan, park and open space plan, and watershed plans concerning environmental corridors is needed. This need stems from: 1) increased involvement by the Commission in the preparation of local plans and plan implementation devices; 2) increased requests from private landowners and developers, and from land surveyors, engineers, and planners associated with owners and developers, for detailed natural resource-related information, and 3) changes in state and federal government policies regarding sanitary sewer service extensions and wetland preservation.

Increased Involvement by the Commission in the Preparation of Local Plans

The Commission has always maintained a community assistance planning function of assisting local units of government in the Region in local planning efforts. It thereby promotes coordination of local and regional plans and plan implementation actions, as well as sound community development. Since the adoption of the initial regional land use plan in 1966, the Commission has completed other regional or subregional plan elements related to transportation, sanitary sewerage, parks and open space, housing, and air and water resource management. The preparation of such regional plans has generated numerous requests from local units of government for more detailed local plans designed to implement the recommendations contained in the regional plans. As these requests to the Commission staff have increased, so also has the need for more precise planning data—data that can be used in local project-level planning—including the need for more precise data on the natural resource base and the location and extent of the environmental corridors.

Increased Requests from Local Units of Government and the Private Sector for More Detailed Information Concerning the Natural Resource Base and Environmental Corridors

The natural resource base is subject to great misuse through improper land use development. Such misuse may lead to severe environmental and developmental problems, which are difficult and costly to correct, and to deterioration and destruction of the natural resource base itself. Local decision-makers, whether officials of local units of government or private concerns, must have detailed information on the resource base in order to make sound decisions that will serve to preserve the best remaining elements of the resource base while promoting a more efficient, economical, healthful, and attractive urban environment. The Commission is increasingly called upon to provide this detailed data on the natural resource base and on the location and extent of the environmental corridors. For example, in response to requests for detailed data, the Commission in the past year has: 1) provided information on natural resource base elements and environmental corridor delineations in the vicinity of the Retzer Nature Center in Waukesha County, Wisconsin, to the Waukesha County Park and Planning Commission to enable that agency to define project boundaries for a potential expansion of that park site; 2) assisted a land developer in the redesign of a preliminary plat for a residential subdivision in the Village of Williams Bay, Walworth County, to preserve the significant woodlands, wetlands, and wildlife habitat within the identified environmental corridor on the parcel in question while accommodating the number of housing units proposed in the preliminary plat; and 3) provided detailed delineations of environmental corridors to the City of Hartford, Washington County, to be used by the community in the making of day-to-day decisions on local plat reviews, subdivision regulations, and zoning changes. Requests such as these are received almost daily by the Commission. Therefore, it is imperative that the detailed information required to adequately respond to such requests in a timely manner be readily available in the Commission's data files.

Changes in State and Federal Government Policies Governing Sanitary Sewer Service Extensions and Wetland Preservation

Under rules adopted by the Wisconsin Natural Resources Board in 1979, the Wisconsin Department of Natural Resources (DNR) may approve only those sanitary sewer extensions that are found to be in conformance with the adopted regional water quality management plan, as documented in SEWRPC Planning

Report No. 30, A Regional Water Quality Management Plan for Southeastern Wisconsin: 2000. Prior to the adoption of these rules, DNR review and approval of sanitary sewers was limited primarily to engineering considerations. The broadened scope of the DNR review now requires that water quality-related considerations be taken into account in the review and approval of proposed sanitary sewer extensions. The areawide water quality management plan provides the basis for such review and approval. The water quality plan contains explicit recommendations with respect to the preservation of environmental corridors within the Region. Thus, in order for proposed sanitary sewer extensions to be reviewed properly, detailed information concerning the location and extent of the environmental corridors is required to ensure that the proposed sewer service areas do not promote the development of incompatible urban land use in the corridors and thereby destroy the corridors.

Recent changes in federal law have important implications for the development of wetlands, whether located inside or outside environmental corridors. The U. S. Army Corps of Engineers, jointly with the U. S. Environmental Protection Agency, is responsible for implementing Section 404 of the federal Water Pollution Control Act as it pertains to the protection and preservation of the nation's water resources, including wetlands. Under Section 404, these agencies may restrict or prohibit the filling and development of wetlands if such filling and development would have a deleterious effect on water supplies, fish spawning and water fowl breeding areas, wildlife habitat, natural plant communities, or recreational areas. The identification of high-value wetlands, whether located inside or outside environmental corridors, is thus important to local decision-makers. Such information will enable better development decisions to be made at the local level and will minimize problems that can occur through violations of Section 404 of the federal Water Pollution Control Act.

THE ENVIRONMENTAL CORRIDOR REFINEMENT PROCESS

It should be emphasized that the concept of the environmental corridors espoused by the Commission for almost 20 years, namely that environmental corridors are linear features in the landscape which represent a composite of the best remaining elements of the natural resource base, has not changed. The environmental corridor refinement process proposed herein is simply a technique to be used in applying the environmental corridor concept to local project-level planning or, more specifically, a technique to enable environmental corridors heretofore delineated only on relatively small-scale maps to be delineated in greater detail for use in detailed project planning and development-related decision-making at the local level.

Natural Resource Base and Natural Resource Base-Related Elements

Under the refinement process, certain elements of the natural resource base that were utilized in identifying environmental corridors under the original regional land use planning program are redelineated in a more precise manner. These elements include: lakes, rivers, streams and their associated shorelands and floodlands; wetlands; areas covered by wet, poorly drained, and organic soils; woodlands; wildlife habitat areas; and areas of steep slopes. In addition, prairies, although not included as a separate element in the original corridor delineation program, are considered to be an important element of the natural resource base in the environmental corridor refinement process. Additional elements closely related to or centered on the natural resource base are considered important both in the original identification and in the corridor refinement program. These are: existing park and open space sites, potential park and open space sites, historic sites, and scenic viewpoints. In addition, areas with scientific, natural, or educational value, although not separately identified in the original corridor delineation process, are considered important in the refinement process.

Inventory data on the natural resource base and natural resource base-related elements considered necessary to the environmental corridor refinement process were compiled from a variety of sources, and were subsequently delineated and mapped on ratioed and rectified aerial photographs at a common scale of 1" = 400' using a color code. Such mapping at a common scale permitted analysis of the relationship among the various elements. The colors used to map the natural resource base and natural resource base-related elements on aerial photographs are given in Table 1. A sample compilation for a four-square-mile area—U. S. Public Land Survey sections 1, 2, 11, and 12, Township 2 North, Range 22 East, Town of Somers, Kenosha County—showing the identified natural resource and related elements in that area is presented in Figure 1. The natural resources mapped are discussed below.

Table 1

NATURAL RESOURCE BASE ELEMENTS AND NATURAL RESOURCE BASE-RELATED ELEMENTS DELINEATED ON 1" = 400' AERIAL PHOTOGRAPHS

Element	Pencil Type[a] and Color
Natural Resource Base	
Lake	
Major (50 acres or larger)	C2125 (medium blue)
Minor (5-49 acres)	C2125 (medium blue)
River or Stream (perennial)	C2125 (medium blue)
Shoreland	
Perennial (lake, river, or stream)	C2125 (medium blue)
Intermittent Stream	C2198 (light green)
100-Year Floodland	P915 (lemon yellow)
Wetland	P909 (grass green)
Wet, Poorly Drained, and Organic Soils	(Not delineated)[b]
Woodland	C2123 (dark brown)
Wildlife Habitat	
High Value	P918 (orange)
Medium Value	P918 (orange)
Low Value	P918 (orange)
Steep Slope	
20 Percent or Greater	P929 (pink)
12 Percent to 19 Percent	P929 (pink)
Prairie	C2126 (medium red)
Natural Resource Base-Related	
Existing Park or Other Open Space Site	
Rural Open Space Site	P942 (yellow ochre)
Other Park or Recreation Site	P942 (yellow ochre)
Potential Park Site	
High Value	BV750 (vermillion)
Medium Value	BV750 (vermillion)
Low Value	BV750 (vermillion)
Historic Site	
Structural	P931 (purple)
Other Cultural	P931 (purple)
Archeological	P931 (purple)
Scenic Viewpoint (combine with area of steep slope)	BV761½ (nonphoto blue)
Natural and Scientific Area	
State Scientific Area	P931 (purple)
Natural Area of Statewide or Greater Significance	P931 (purple)
Natural Area of Countywide or Regional Significance	P931 (purple)
Natural Area of Local Significance	P931 (purple)

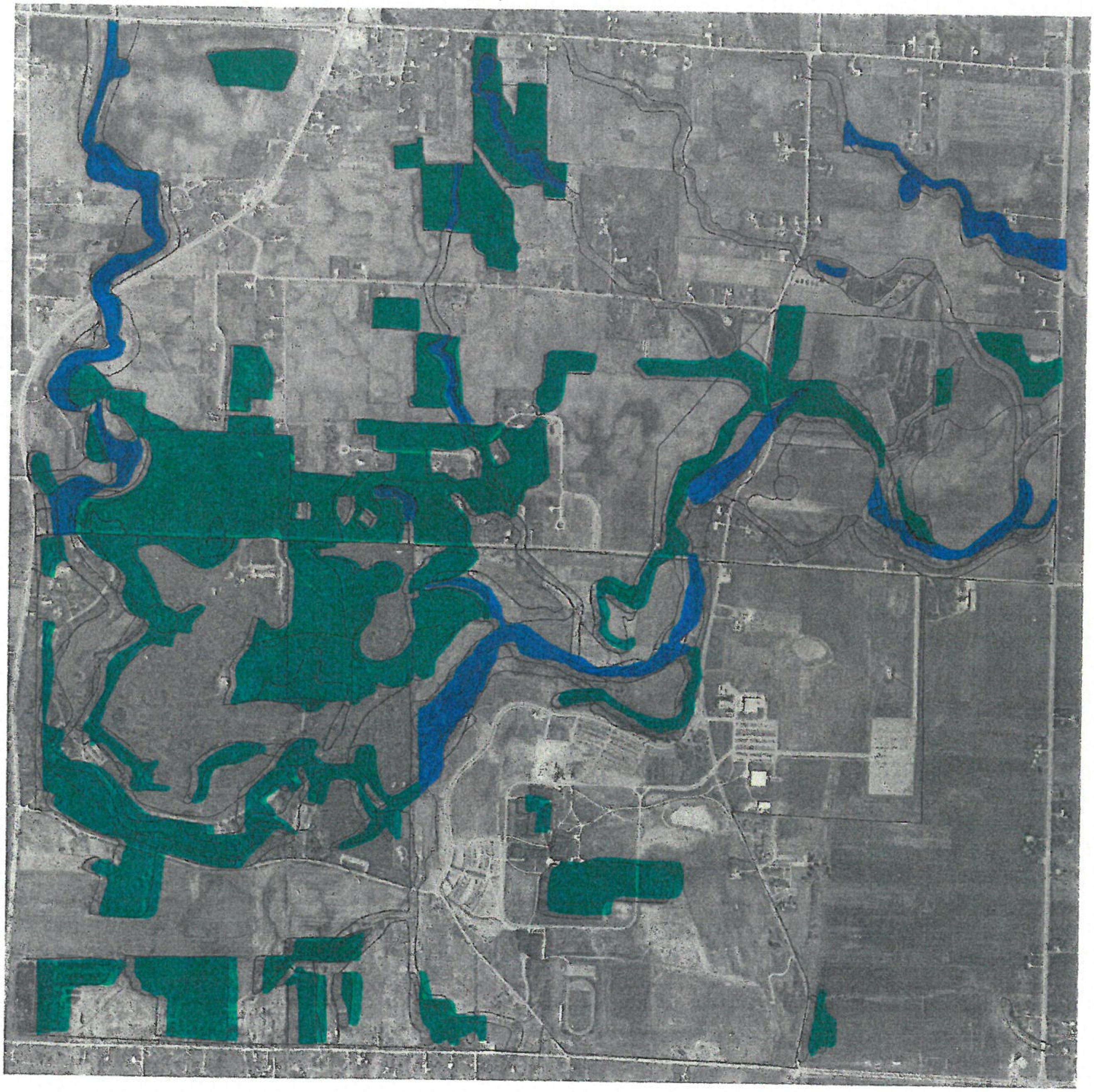
[a] *C = Colorbrite; P = Prismacolor; BV = Berol Verithin.*

[b] *Wet, poorly drained, or organic soils were identified on 1" = 1000' scale soils maps.*

Source: SEWRPC.

Figure 1

SAMPLE DELINEATION OF NATURAL RESOURCE BASE ELEMENTS AND NATURAL RESOURCE BASE-RELATED ELEMENTS ON AN AERIAL PHOTOGRAPH: SECTIONS 1, 2, 11, AND 12, TOWNSHIP 2 NORTH, RANGE 22 EAST, TOWN OF SOMERS, KENOSHA COUNTY



LEGEND

NATURAL RESOURCE BASE ELEMENTS

LAKES, RIVERS, STREAMS, AND FLOODLANDS AND SHORELANDS

NONE MAJOR LAKE

NONE MINOR LAKE

NONE RIVER OR STREAM (50 FEET OR MORE IN WIDTH)

NONE LAKE OR RIVER SHORELAND

PERENNIAL STREAM SHORELAND (LESS THAN 50 FEET IN WIDTH)

INTERMITTENT STREAM SHORELAND

100-YEAR RECURRENCE INTERVAL FLOODLAND

WETLAND

WOODLAND

PRAIRIE

NONE

WILDLIFE HABITAT

NONE HIGH VALUE

NONE MEDIUM VALUE

LOW VALUE

AREA OF STEEP SLOPE

20 PERCENT OR GREATER

12-19 PERCENT

NATURAL RESOURCE BASE RELATED ELEMENTS

EXISTING PARK OR OPEN SPACE SITE

NONE RURAL OPEN SPACE

PARK OR RECREATION AREA

POTENTIAL PARK SITE

NONE HIGH VALUE

MEDIUM VALUE

NONE LOW VALUE

NATURAL AND SCIENTIFIC AREA

NONE STATE SCIENTIFIC AREA

STATEWIDE SIGNIFICANCE

NONE COUNTY OR REGIONAL SIGNIFICANCE

NONE LOCAL SIGNIFICANCE

HISTORIC SITE

NONE STRUCTURAL

CULTURAL

ARCHEOLOGICAL

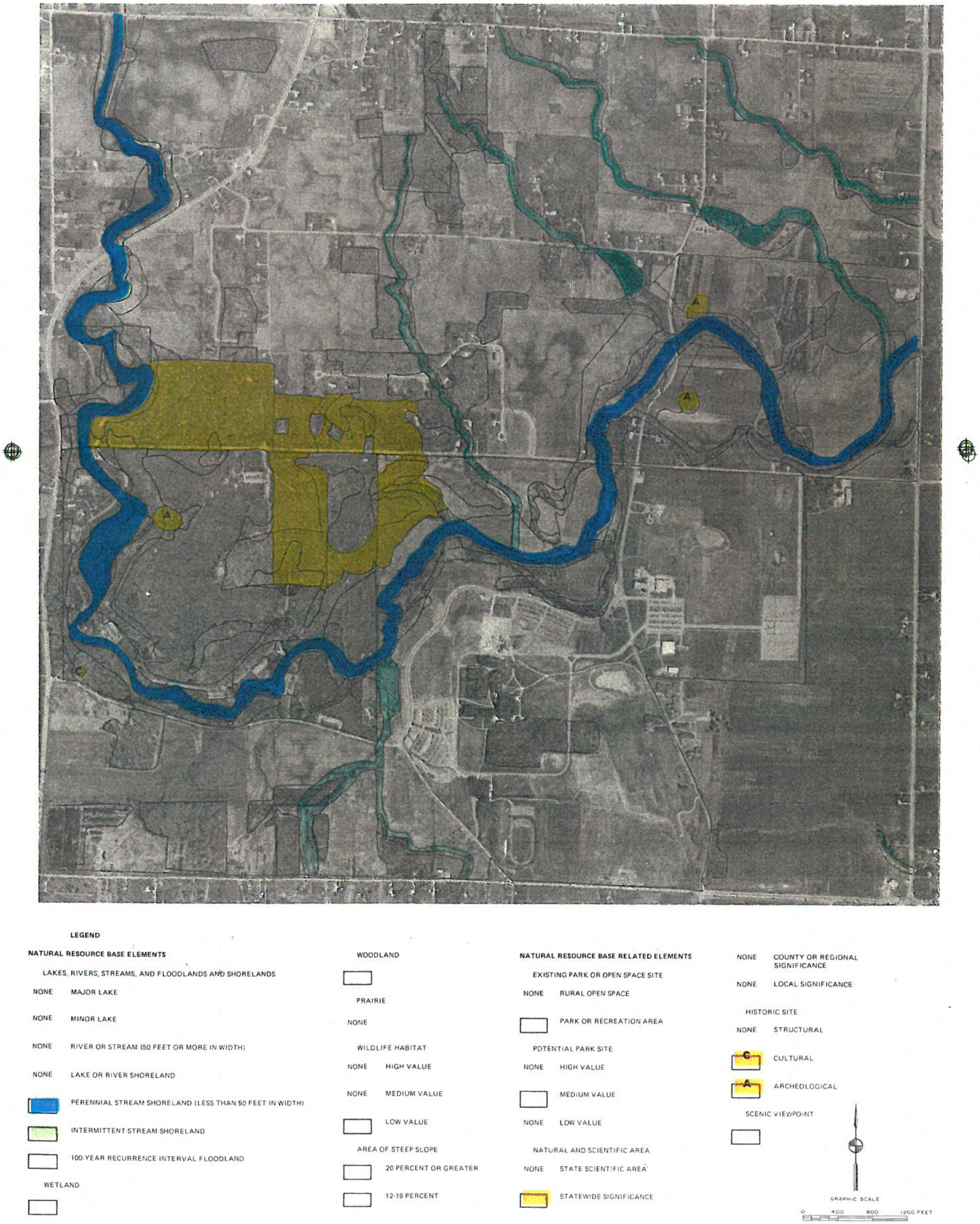
SCENIC VIEWPOINT

GRAPHIC SCALE

0 400 800 1200 FEET

Source: SEWRPC.

SAMPLE DELINEATION OF NATURAL RESOURCE BASE ELEMENTS AND NATURAL RESOURCE BASE-RELATED ELEMENTS ON AN AERIAL PHOTOGRAPH: SECTIONS 1, 2, 11, AND 12, TOWNSHIP 2 NORTH, RANGE 22 EAST, TOWN OF SOMERS, KENOSHA COUNTY



Source: SEWRPC.

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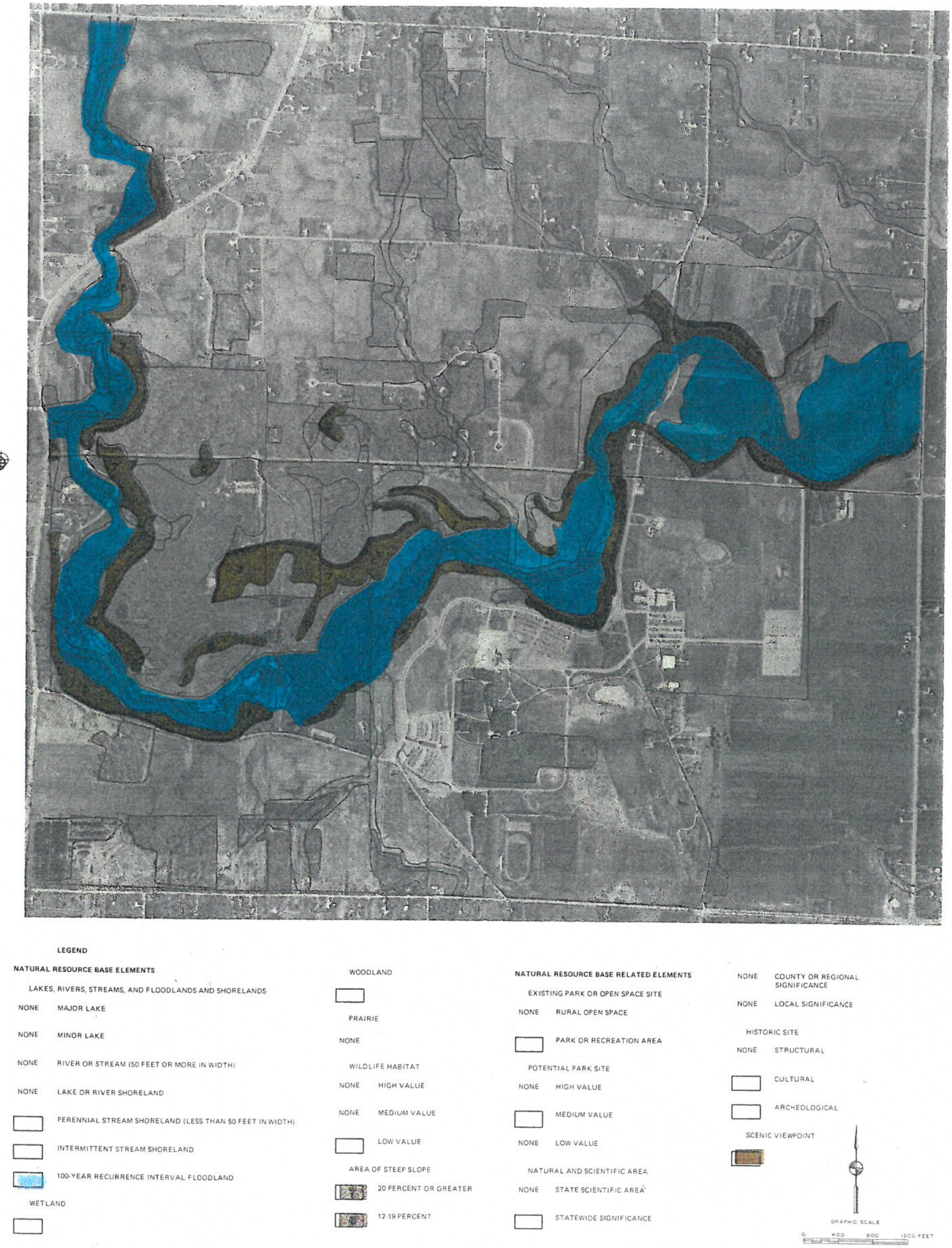
SAMPLE DELINEATION OF NATURAL RESOURCE BASE ELEMENTS AND NATURAL RESOURCE BASE-RELATED ELEMENTS ON AN AERIAL PHOTOGRAPH: SECTIONS 1, 2, 11, AND 12, TOWNSHIP 2 NORTH, RANGE 22 EAST, TOWN OF SOMERS, KENOSHA COUNTY



Source: SEWRPC.

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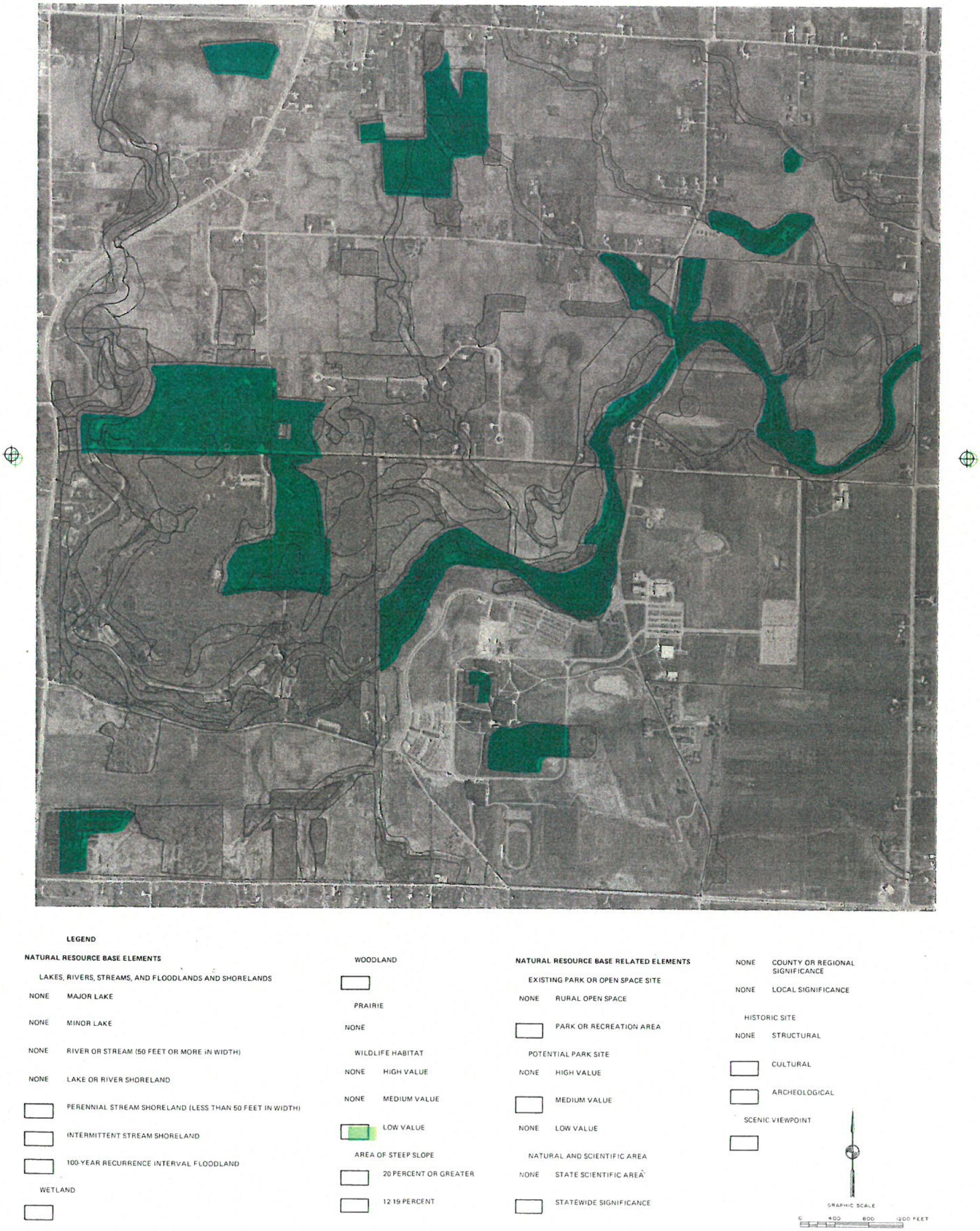

Source: SEWRPC.

Figure 1

SAMPLE DELINEATION OF NATURAL RESOURCE BASE ELEMENTS AND NATURAL RESOURCE BASE-RELATED ELEMENTS ON AN AERIAL PHOTOGRAPH: SECTIONS 1, 2, 11, AND 12, TOWNSHIP 2 NORTH, RANGE 22 EAST, TOWN OF SOMERS, KENOSHA COUNTY

LEGEND

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NONE MAJOR LAKE

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PERENNIAL STREAM SHORELAND (LESS THAN 50 FEET IN WIDTH)

INTERMITTENT STREAM SHORELAND

100-YEAR RECURRENCE INTERVAL FLOODLAND

WETLAND

WOODLAND

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NONE

WILDLIFE HABITAT

NONE HIGH VALUE

NONE MEDIUM VALUE

LOW VALUE

AREA OF STEEP SLOPE

20 PERCENT OR GREATER

12-19 PERCENT

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PARK OR RECREATION AREA

POTENTIAL PARK SITE

NONE HIGH VALUE

MEDIUM VALUE

NONE LOW VALUE

NATURAL AND SCIENTIFIC AREA

NONE STATE SCIENTIFIC AREA

STATEWIDE SIGNIFICANCE

NONE COUNTY OR REGIONAL SIGNIFICANCE

NONE LOCAL SIGNIFICANCE

HISTORIC SITE

NONE STRUCTURAL

CULTURAL

ARCHEOLOGICAL

SCENIC VIEWPOINT

GRAPHIC SCALE

0 400 800 1200 FEET

Source: SEWRPC.

Lakes: Lakes have been classified by the Commission as either major or minor. Major lakes have 50 acres or more of surface water area, while minor lakes have less than 50 acres of surface water area. All major lakes in southeastern Wisconsin are listed in Appendix C of SEWRPC Planning Guide No. 5, Floodland and Shoreland Development Guide. The surface area of each of these lakes is documented in a staff memorandum of April 15, 1977.

Minor lakes were identified under the corridor refinement process using aerial photographs. Only those minor lakes with a surface area in excess of five acres were identified. Minor lakes less than five acres in size were generally located within another natural resource base element, primarily wetlands, and were included within the delineation of such a related natural resource base element. It is also important to note that certain small surface water bodies such as sewage treatment lagoons and water-filled quarries were not identified as minor lakes.

Rivers and Streams: Rivers and streams have been classified by the Commission as perennial and intermittent. The identification of perennial and intermittent rivers and streams was made on the basis of the classifications shown on 7.5-minute quadrange topographic maps published by the U. S. Geological Survey. Only rivers and streams having a width of 50 feet or more were delineated as separate natural resource base elements on the 1" = 400' scale aerial photographs. Rivers and streams less than 50 feet in width were included within the delineation of shorelands described below.

Shorelands: Shorelands associated with the identified major and minor lakes and with the identified perennial and intermittent rivers and streams were located and delineated. Because it is often difficult to identify the precise lateral extent of a shoreland area, a band of 50 feet in depth lying along both sides of and including all intermittent streams was delineated as the shoreland area; while a band 75 feet in depth lying along both sides of and including all perennial streams less than 50 feet in width was delineated as the shoreland area. For those perennial streams and rivers having a width of 50 feet or greater and for all major and minor lake shorelines, a band 75 feet in depth was delineated as the shoreland area. The shoreland area associated with Lake Michigan was delineated as a band 200 feet from the inland edge of the bluff when that bluff is within 200 feet of the lake itself. If the bluff is at a distance greater than 200 feet from the lake, as in the Town of Belgium in Ozaukee County, the shoreland area was delineated as a band 200 feet in depth from the inland edge of the beach.

Floodlands: The floodlands of a river or stream are the wide, gently sloping areas contiguous with, and usually lying on both sides of, a river or stream channel that are subject to inundation during a flood. For purposes of the environmental corridor refinement process, the areas inundated by the 100-year recurrence interval flood event were considered to comprise the floodlands of the Region. It is important to note that the limits of the 100-year recurrence interval flood can only be delineated on large-scale topographic maps based upon the hydrologic and hydraulic studies that together identify the stage—or elevation—of the design flood and the attendant extent of the floodlands. For purposes of delineation on the 1" = 400' scale aerial photographs, only those floodlands that were identified on large-scale—1" = 200' scale, 2' contour interval—topographic maps meeting National Map Accuracy Standards were mapped.

Wetlands: Wetlands are defined by the Commission as areas in which the water table is at, near, or above the land surface, and which are characterized by both hydric soils, such as peats or mucks or other organic soils, and by the growth of hydrophytes, such as sedges, cattails, red osier dogwood, and tamarack. A special inventory of wetlands conducted by the Commission in 1979 served as the basis for the identification of wetlands. In this special inventory, wetlands were identified on 1" = 400' scale ratioed and rectified aerial photographs. Supplementary data utilized in such identification included historic wetland information collected by the Game Management Division of the Wisconsin Conservation Department and documented in the Wisconsin Wetland Inventory dated 1956 through 1960; the SEWRPC land use inventories; U. S. Geological Survey 7.5-minute quadrangle topographic maps; other large-scale topographic mapping; and soils information as documented in SEWRPC Planning Report No. 8, Soils of Southeastern Wisconsin. It is important to note that a field examination was conducted to determine wetland boundaries where they could not be determined through analyses of the aforementioned data.

Wet, Poorly Drained, and Organic Soils: Certain soils tend to be well suited for supporting certain plant communities and wildlife habitat. These soils are generally wet, poorly drained, and organic, and when devoted to natural open space uses contribute significantly to the ecology of an area. Those soils which have been classified as wet, poorly drained, and organic in the detailed operational soil survey completed in the Region in 1965, as documented in SEWRPC Planning Report No. 8, were identified on 1" = 1000' scale aerial photographs. Use of these soils data in the refinement process is discussed later in this article in the section discussing the identification and delineation of environmental corridors and other resource areas.

Woodlands: Woodlands are defined by the Commission as those upland areas one acre or more in size having 17 or more deciduous trees per acre each measuring at least four inches in diameter at breast height and having at least a 50 percent canopy cover. In addition, coniferous tree plantations and reforestation projects were identified as woodlands by the Commission. Woodlands so defined were delineated on 1" = 400' scale ratioed and rectified aerial photographs. It is important to note that all lowland wooded areas, such as tamarack swamps, were classified as wetlands because the water table in such areas is located at, near, or above the land surface and because such areas are generally characterized by hydric soils which support hydrophitic trees and shrubs.

Wildlife Habitat: Wildlife habitat is defined by the Commission as an area devoted to natural open uses of a size and with a vegetative cover capable of supporting a high and balanced diversity of wildlife. Such areas generally have vegetation that provides nesting opportunities, travel routes, concealment, and weather impact modification for a variety of wildlife species. Wildlife habitat areas within the Region were inventoried for the Commission in 1963 and again in 1970 by the Wisconsin Department of Natural Resources using as field work sheets 1" = 400' scale ratioed and rectified aerial photographs. Some adjustments were made to these wildlife habitat areas based upon a review of 1975 aerial photographs, particularly in areas where urban development and agricultural uses had encroached upon the habitat as identified on the 1963 and 1970 photographs. The wildlife habitat areas were rated in the inventories as being of high, medium, or low value.

High-value wildlife habitat areas contain a wide diversity of wildlife; are adequate in size to meet all of the habitat requirements of the species concerned—including territorial and vegetative composition requirements; and are generally located in proximity to other wildlife habitat areas. Medium-value wildlife habitat areas generally lack one of the three aforementioned criteria for a high-value wildlife habitat; however, such habitat areas do retain a good plant and animal diversity. Low-value wildlife habitats are remnant in nature in that they generally lack two or more of the three aforementioned criteria for a high-value wildlife habitat but may, nevertheless, be important if they are located close to medium- or high-value wildlife habitat areas, if they provide corridors linking higher value wildlife habitat areas, or if they provide the only available range in the area.

Steep Slopes: Under Commission standards, a slope of 12 percent or greater is considered unsuitable for all types of urban development as well as for most types of agricultural uses. Steep slopes are divided by the Commission into two categories: slopes 12 to 19 percent and slopes 20 percent or greater. Slope information was derived from the detailed operational soil survey information documented in SEWRPC Planning Report No. 8, Soils of Southeastern Wisconsin. Under the regional soil survey, percent of slope, in addition to soil type and erosion factor, was identified and delineated on 1" = 1000' aerial photographs. These aerial photographs, along with the U. S. Geological Survey 7.5-minute quadrangle topographic maps, serve as the basis for the delineation of areas of steep slopes on 1" = 400' scale ratioed and rectified aerial photographs.

Prairies: Prairies are defined by the Commission as open, generally treeless areas which are dominated by native grasses. There are three general types of prairies within the Region—wet prairies, mesic prairies, and dry prairies. The types correspond to soil moisture conditions. In addition, it is important to note that oak openings, which are savannahs—that is, park-like areas dominated by dry prairie grasses and forbs but having between one and 17 oak trees, usually burr oaks, per acre—are included in prairie inventories. Only those prairies and oak openings identified by the Wisconsin Scientific Areas Preservation Council and those known to local naturalists were included in the refinement process and delineated on the 1" = 400' ratioed and rectified aerial photographs.

Existing Park and Open Space Sites: A detailed classification of park and open space sites may be found in SEWRPC Planning Report No. 27, A Regional Park and Open Space Plan for Southeastern Wisconsin: 2000. For purposes of the corridor refinement process, park and open space sites were classified into one of two groups—the first group consisting of general-use outdoor recreation sites, special-use outdoor recreation sites, and urban open space sites, and the second group consisting of rural open space sites. The first group of sites generally provides developed outdoor recreation facilities for relatively intensive use, while the second group consists primarily of natural areas that are generally used only for extensive outdoor recreation and natural resource preservation purposes. All park and open space sites within the Region were identified, delineated, and categorized under the Commission's 1973 regional park and open space site inventory. This inventory information was transferred to the 1" = 400' scale ratioed and rectified aerial photographs for use in the corridor refinement process.

Potential Parks: A potential park site is a site which has been identified by the Commission as having the potential to provide opportunities for a variety of resource-oriented outdoor recreation activities. The sites evaluated for their recreation potential were assigned a high, medium, or low value rating. Sites rated as high value are those which possess the most favorable development potential for resource-oriented outdoor recreation facilities and which appear to have no serious development limitations. Sites rated as medium value possess certain minor development limitations, while sites rated as low value possess some major development limitations and, therefore, have relatively poor potential for development without major modification. A potential park site inventory was conducted by the Commission in 1963 and updated in 1968 and 1975. The potential park sites identified in the 1975 potential park inventory update were transferred to the 1" = 400' scale ratioed and rectified aerial photographs.

Historic Sites: Historic sites have been classified by the Commission into one of three categories—structures, archaeological features, and other cultural features. In general, historic structures include architecturally or historically significant homes, churches, inns, government buildings, mills, schools, and museums. Archaeological sites consist of areas occupied or utilized by man for a sufficient length of time to be marked by certain features—such as mounds—or to contain a number of artifacts. Such sites are generally associated with early American Indian settlements. Other cultural features include sites of early European settlements or are closely related to such settlements and include, for example, old plank roads and cemeteries. An inventory of historic sites within the Region was conducted by the Commission in 1973 under the regional park and open space planning program. This inventory served as the basis for the delineation of historic sites in the Region under the corridor refinement process. The Commission inventory was supplemented by inventory information gathered by the State Historical Society of Wisconsin in 1979. The locations of the historic sites identified in those two inventories were transferred to 1" = 400' scale ratioed and rectified aerial photographs.

Scenic Viewpoints: A scenic viewpoint is defined by the Commission as a vantage point from which a diversity of natural features can be observed. A special inventory of scenic viewpoints was conducted by the Commission in 1979 and 1980 for use in the identification and delineation of natural resource base and related elements. Three basic criteria were applied in identifying such viewpoints: 1) the variety of features viewed should exist harmoniously in a natural or rural landscape, 2) there should be one dominant or interesting feature, such as a river or lake, which serves as a focal point of the scenic area, and 3) the viewpoint should permit an observation area from which the variety of natural features can be seen. With the aid of the 1" = 2000' scale U. S. Geological Survey 7.5-minute quadrangle maps, areas with a relief greater than 30 feet and a slope of 12 percent or more were identified. Those areas of steep slopes so identified having a ridge of at least 200 feet in length and a view of at least three natural resource features—including surface waters, wetlands, woodlands, agricultural lands, or other significant geological features—within approximately one-half mile of the ridge were identified as scenic viewpoints. Areas so identified were then transferred to 1" = 400' scale ratioed and rectified aerial photographs.

Natural and Scientific Areas: Natural areas, as defined by the Wisconsin Scientific Areas Preservation Council, are tracts of land or water so little modified by man's activity or sufficiently recovered from the effects of such activity that they contain intact native plant and animal communities believed to be representative of the presettlement landscape. State Scientific Areas are those natural areas, geological sites, or archaeological sites identified as being of at least statewide significance and which have been so designated by the Wisconsin Department of Natural Resources, Scientific Areas Preservation Council. Natural areas which have not been designated as State Scientific Areas by the Scientific Areas Preservation Council have been divided into three basic categories. They are:

1. Natural Areas of Statewide or Greater Significance—Natural areas of statewide or greater significance are those natural areas which have not been significantly modified by man's activity, or have sufficiently recovered from the effects of such activity so as to contain nearly intact native plant and animal communities which are believed to be representative of the presettlement landscape. These are areas which have not as yet been classified as State Scientific Areas.

2. Natural Areas of Countywide or Regional Significance—Natural areas of countywide or regional significance are defined as those natural areas which have been slightly modified by man's activities or which have insufficiently recovered from the effects of such activity, but which still contain good examples of native plant and animal communities representative of the presettlement landscape. These natural areas are of lesser significance because their quality is less than ecologically ideal, and because there is evidence of past or present disturbances such as logging, grazing, water level changes as a result of ditching or filling, or pollution. These areas may contain plant or animal community types common to the Region, in which case only the best examples would qualify for State Scientific Area recognition. These natural areas may also be of insufficient size to be of statewide significance. Such areas could serve local communities as educational sites, passive recreational areas, and ecological zones. In addition, such areas, if protected in an undisturbed condition, may be expected to increase in value over time. Therefore, some of these areas may eventually become natural or scientific areas of statewide significance.

3. Natural Areas of Local Significance—Natural areas of local significance are defined as those natural areas which have been significantly modified by man's activities but have, nevertheless, retained a modest amount of natural cover. Such natural areas are suitable for local educational use and should not be excluded from a natural area survey. Natural areas of local significance may reflect patterns of former vegetation or serve as examples of the influence of human settlement on vegetation. These natural areas may also be expected to increase in value if protected.

Classification of an area into one of the foregoing categories is based upon consideration of the diversity of plant and animal species and community types present; the structure and integrity of the native plant or animal community; the extent of disturbance from man's activities such as logging, grazing, water level changes, and pollution; the commonness of the plant and animal communities present; any unique natural features within the area; the size of the area; and the area's educational value. Those natural areas identified by the Wisconsin Scientific Areas Preservation Council, the Wisconsin Department of Natural Resources, and SEWRPC were delineated on 1" = 400' scale ratioed and rectified aerial photographs.

Assignment of Numerical Point Values to Each Natural Resource Base and Resource Base-Related Element

In order to facilitate the identification of those areas having the most significant concentrations of natural resource values, each natural resource base and natural resource base-related element was assigned a numeric value rating. The numeric value rating assigned was intended to reflect the "natural" characteristic of each resource component. Although this assignment process admittedly involved subjective judgments on the part of the Commission staff, it greatly facilitated the identification and delineation of environmental corridors as described in the following section of this article.

The value rating ultimately assigned to each resource element was based upon a consensus among Commission staff members having education and experience in a variety of disciplines, including biology, landscape architecture, water resource management, and land use planning. The interdisciplinary, consensus approach provided a broad base for the value-rating process and minimized the potential for rating one resource component excessively high or low as a result of the personal interest or concern of any one staff member. Those features of the landscape having "inherent natural resource values" were assigned a higher point value than features having "implied natural resource values." Thus, features such as surface water, woodlands, wetlands, high-value wildlife habitat, prairies, and scientific areas were assigned high point value ratings, while features like existing park sites, potential park sites, historic sites, and scenic viewpoints were assigned relatively low point value ratings. It should be noted in this respect that floodlands, although a critical consideration in areawide and local planning, were assigned relatively low point value ratings. This was done for two reasons. First, significant portions of floodlands within the Region are not in a natural state, with some floodlands in urban areas being developed for urban uses and some floodlands in rural areas being utilized almost entirely for agricultural production. Such conditions were deemed to be inconsistent with the concept of environmental corridors as primarily natural areas. Second, those portions of floodlands that are not in intensive urban or agricultural uses and, thus, exist in a natural state are likely to be a part of an area having a relatively high composite point value rating and thereby ultimately included within a delineated environmental corridor by virtue of the fact that such floodlands probably are located within identified wetland, wildlife habitat, prairie, or other scientific or natural areas of the Region.

In order to identify concentrations of high-value natural resource features, the delineations of the individual natural resource base and resource base-related elements, as mapped on the 1" = 400' scale ratioed and rectified aerial photographs—an example of which is presented in Figure 1—were transferred to a single mylar transparency overlay drafted at the same 1" = 400' scale. All natural resource base and related elements were delineated in pencil on the composite, and a cumulative point total for each delineated area was calculated. Within each area delineated on the mylar, the total composite point value was recorded and the natural resource base and related elements within that area were identified through the use of code letters. The code letters, together with the point values assigned to each of the natural resource base and resource base-related elements, are presented in Table 2, while the mylar transparency covering the same area as that shown in Figure 1, indicating the cumulative point values of all resource components, is shown in Figure 2.

Identification and Delineation of Environmental Corridors and Other High-Value Resource Areas

The delineation of the detailed natural resource base and resource base-related inventory data on 1" = 400' scale ratioed and rectified aerial photographs, and the assignment of point values to each of the resource base and related elements facilitated the final step in the corridor refinement process—namely, the identification and delineation of environmental corridor and other high-value resource areas. As previously noted, an effort was made to ensure that the concept of environmental corridors as set forth in regional level system plans was carried through in the refinement process. Thus, a hierarchy of natural resource areas was identified—namely, primary environmental corridors, secondary environmental corridors, isolated high-value resource areas, and other natural resource or resource-related areas. These areas were identified through the application of criteria related to the point values assigned to the individual resource components, as well as of criteria established with respect to the acreage, width, and length of the resource components. These criteria are listed in Table 3.

A point value of 10 or more established an area as having "significant" natural resource value. As further shown in Table 3, areas with "significant" natural resource values include primary environmental corridors, secondary environmental corridors, and isolated high-value natural areas. Primary environmental corridors occupy an area of at least 400 acres and have a minimum length of two miles and a minimum width of 200 feet. Such corridors generally include a wide variety of natural resource base and related elements.

Secondary environmental corridors occupy an area of at least 100 acres and have a minimum length of one mile. Such corridors also include a variety of natural resource base and related elements, but are generally less diverse and are smaller in size, length, and width than primary environmental corridors.

Isolated high-value natural areas are at least five acres in size. Such areas generally consist of those natural resource base elements that have "inherent natural" value such as wetlands, woodlands, wildlife habitat areas, and surface water areas but that are separated physically from the environmental corridors by intensive urban and agricultural land uses. Other natural resource and related features have no minimum area, length, or width requirements. These features generally include those natural resource base-related elements that have "implied natural" value, such as an existing park, a potential park site, or an historic site.

In the classification and delineation of natural resource features, areas with significant natural resource values—areas with a point value of 10 or more points—that were located in proximity to other areas with significant natural resource values were often linked with such areas as a single natural resource feature,

Table 2

CODE LETTERS AND POINT VALUES FOR NATURAL RESOURCE BASE AND NATURAL RESOURCE BASE-RELATED ELEMENTS

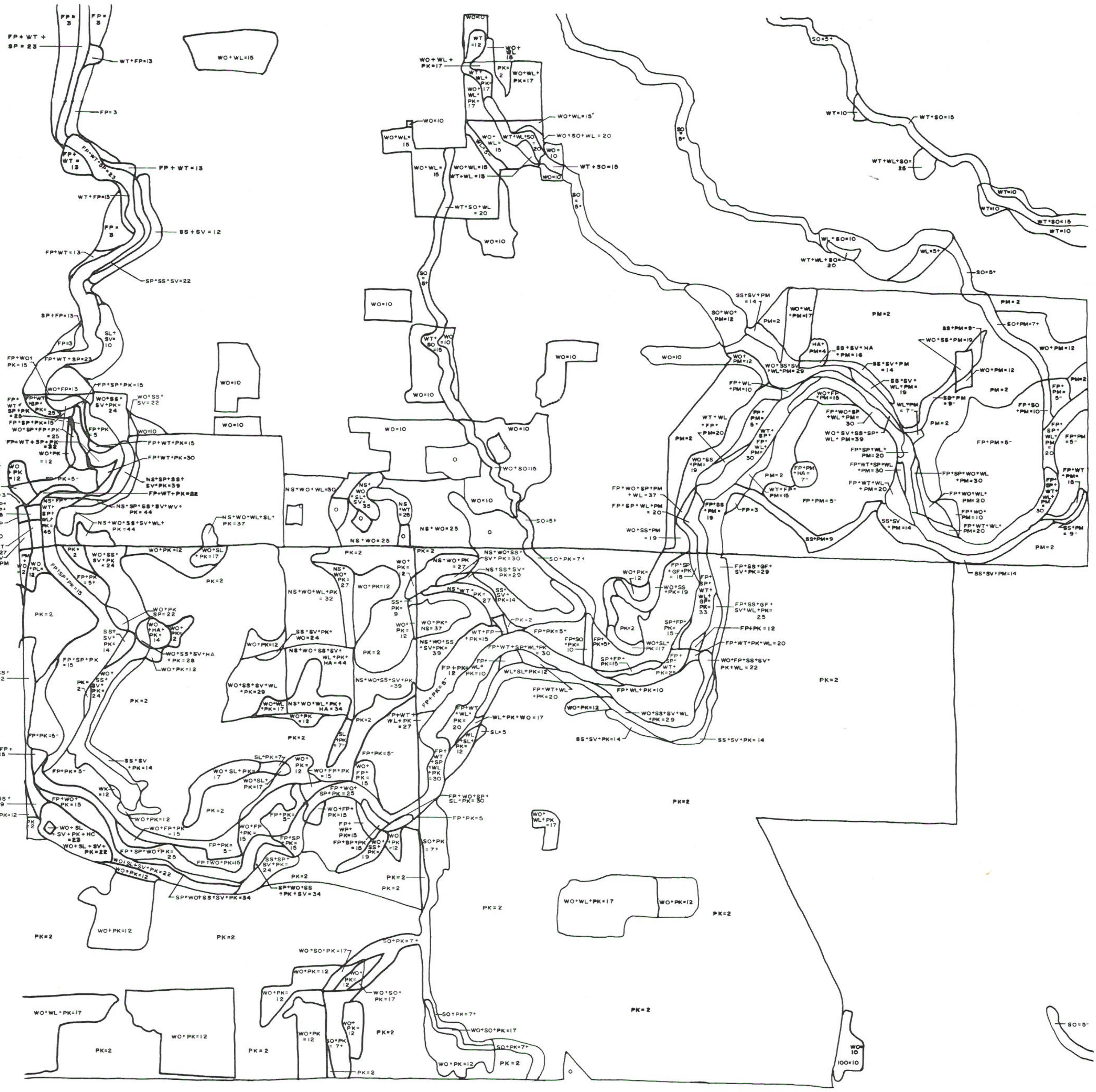
Element	Code	Point Value
Natural Resource Base		
Lake		
Major (50 acres or larger)	LA	20
Minor (5-49 acres)	LM	20
River or Stream (perennial)	PS	10
Shoreland		
Perennial (lake, river, or stream)	SP	10
Intermittent Stream	SO	5
100-Year Floodland	FP	3
Wetland	WT	10
Wet, Poorly Drained, and Organic Soils	--[a]	--[a]
Woodland	WO	10
Wildlife Habitat		
High Value	WH	10
Medium Value	WM	7
Low Value	WL	5
Steep Slope		
20 Percent or Greater	SS	7
12 Percent to 19 Percent	SL	5
Prairie	PR	10
Natural Resource Base-Related		
Existing Park or Other Open Space Site		
Rural Open Space Site	OS	5
Other Park or Recreation Site	PK	2
Potential Park		
High Value	PH	3
Medium Value	PM	2
Low Value	PL	1
Historic Site		
Structural	HS	1
Other Cultural	HC	1
Archeological	HA	2
Scenic Viewpoint (combined with area of steep slope)	SV	5
Natural and Scientific Area		
State Scientific Area	SA	15
Natural Area of Statewide or Greater Significance	NS	15
Natural Area of Countywide or Regional Significance	NC	10
Natural Area of Local Significance	NL	5

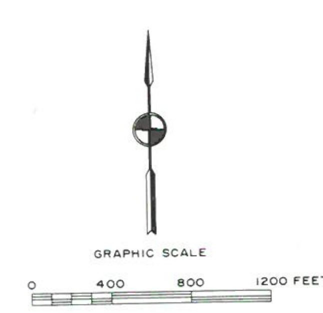
[a] *Code letters and point values for wet, poorly drained, and organic soils were not assigned. The consideration of wet, poorly drained, and organic soils in the determination of environmental corridors is discussed in the section of this article on the identification and delineation of environmental corridors and other high-value resource areas.*

Source: SEWRPC.

Figure 2

SAMPLE DELINEATION OF NATURAL RESOURCE BASE AND NATURAL RESOURCE BASE-RELATED ELEMENTS, ALONG WITH CORRESPONDING CODES AND CUMULATIVE POINT VALUES, ON A MYLAR TRANSPARENCY: SECTIONS 1, 2, 11, AND 12, TOWNSHIP 2 NORTH, RANGE 22 EAST, TOWN OF SOMERS, KENOSHA COUNTY





LEGEND

NATURAL RESOURCE AREA BOUNDARY

WO+WL=15 NATURAL RESOURCE IDENTIFICATION CODE (SEE TABLE 2)

Source: SEWRPC.

Table 3

CRITERIA UTILIZED IN THE CLASSIFICATION OF NATURAL RESOURCE FEATURES

Natural Resource Feature	Minimum Point Value	Minimum Area (acres)	Minimum Length (miles)	Minimum Width (feet)
Primary Environmental Corridor	10	400	2	200
Secondary Environmental Corridor.	10	100	1	- -
Isolated High-Value Natural Area	10	5	- -	200
Other Natural Resource or Related Feature.	1	- -	- -	- -

Source: SEWRPC.

thereby establishing continuity between adjacent areas with significant natural resource values. The distance across which such continuity could be provided was related to the acreage of the smaller of the two areas under consideration. The guidelines used for linking natural resource features are presented in Table 4. It is important to note that the continuity distance guideline was applied only to areas with significant natural resource values, namely areas with 10 or more assigned points.

As shown in Table 4, in order to establish continuity between a small area ranging from five to 19 acres in size and a larger area, the small area must be located within 220 feet of an adjacent area of equal or greater size. Similarly, a large area 640 acres in size may be linked to another area of equal or greater size up to a distance of one-half mile.

These distances are based upon consideration of such features as the dispersal of seed by animals and wind as well as the normal travel ranges of animal species common to southeastern Wisconsin, such as deer, rabbit, skunk, raccoon, muskrat, mink, songbirds, and waterfowl. Typically, animals occupying a smaller area, such as a habitat between five and 19 acres in size, will travel shorter distances to reach an area of similar size. For example, a population of between 50 and 100 Franklin ground squirrels occupying an area that ranges from eight to 10 acres in size will travel a distance of about 175 feet to an area of similar habitat to forage for food. On the other hand, some animals occupying larger areas typically have greater travel ranges and forage requirements. For example, mammals such as the raccoon, red fox, and skunk, whose home range includes areas 640 acres in size or greater, normally travel up to one-half mile in search of food or to seek a new habitat.

Having determined that two areas should be linked, the most suitable linking segment was identified. The most appropriate linking segment was determined by applying the following criteria:

1. When applicable, an area less than 200 feet wide with significant natural resource value should be widened to 200 feet;

2. Other areas possessing natural resource features—that is, areas with a value rating of less than 10 points—should be utilized; and

3. Open areas—agricultural or unused lands—should be utilized.

In addition, four rules were followed in special situations in the identification and delineation of environmental corridors and natural resource features:

1. In the identification and delineation of secondary environmental corridors, there were no minimum width considerations. However, the termination points of such corridors must contain a natural resource area at least five acres in size and 200 feet in width. A primary environmental corridor may serve as the termination point of a secondary environmental corridor.

2. Elongated, narrow—less than 200 feet wide—areas that had significant natural resource values and that "connected" two segments of primary environmental corridor lands were identified and delineated as secondary environmental corridors. This is the only situation where the minimum length and area requirements for secondary environmental corridors were not strictly applied. It should also be noted that such areas were generally located along intermittent or perennial streams that flowed from one primary environmental corridor to another.

Table 4

DISTANCE GUIDELINES FOR LINKING NATURAL RESOURCE FEATURES

Acreage of Smaller Area with Significant Resource Value	Maximum Continuity Distance	
	Feet	Miles
640 or More	2,640	1/2
320-639.	1,760	1/3
160-319.	1,320	1/4
80-159	880	1/6
40-79	660	1/8
20-39	440	1/12
5-19	220	1/24

Source: SEWRPC.

3. Areas less than five acres in size—regardless of the resource point values assigned to them—that were surrounded by significant natural resource features—namely, primary environmental corridors, secondary environmental corridors, or isolated natural areas—were included in the delineation of those corridors or isolated natural resource features. Areas greater than five acres in size and surrounded by significant natural resource features but having less than 10 points were not included in the delineation of the primary or secondary environmental corridors or isolated natural areas.

4. As previously noted, areas covered by wet, poorly drained, and organic soils were not delineated on the 1" = 400' scale ratioed and rectified aerial photographs. In order to account for such soils as an element of the natural resource base in the environmental corridor refinement process, the soil characteristics of those areas having a point value between five and nine points inclusive were examined. If the soils in such an area were "wet, poorly drained, or organic," the area was assigned a value equivalent to 10 points by affixing, on the mylar transparency, a plus (+) sign to the cumulative total point value of the other natural resource base and related elements. That area was thereby qualified for inclusion as a significant natural resource feature. If the soils in such an area were not "wet, poorly drained, or organic," the area retained the cumulative total point value of the other natural resource and related elements, and a minus (-) sign was affixed to this total point value. Thus, while "wet, poorly drained, and organic" soils were not directly assigned a point value, such areas were given an effective point value of five.

As previously noted, natural resource base and related elements were identified and delineated on 1" = 400' scale ratioed and rectified aerial photographs (see Figure 1). These delineations were then composited on a mylar transparency overlay drafted at a scale of 1" = 400', on which were indicated the cumulative point value for all resource areas (see Figure 2). In order to complete the final step in the corridor refinement process—the identification and delineation of environmental corridors and high-value resource areas—a print of the mylar overlay was made and all of the areas with a value of 10 or more points were shaded in light green. This was followed by the application of the area, length, width, and continuity distance guidelines, as well as of the four aforelisted rules. Primary environmental corridors were then identified and delineated on this paper print by outlining in a continuous red line; secondary environmental corridors were identified and delineated by outlining in a continuous black line; and isolated natural features were identified and delineated by outlining in a broken black line. Those areas that were identified as continuity segments were outlined in the appropriate natural resource feature color and shaded (see Figure 3). Finally, these delineations were transferred back to the original 1" = 400' scale mylar transparency overlay to allow duplicate copies of the corridor information to be obtained for local project level planning purposes (see Figure 4).

Thus, as a result of the environmental corridor refinement process, there are three display maps on file in the Commission offices for each of the 692 four-square-mile aerial photographs covering the Region: 1) a 1" = 400' scale 1975 ratioed and rectified aerial photograph showing the natural resource base and natural resource base-related elements; 2) a 1" = 400' scale mylar overlay which a) summarizes the delineation of natural resource base and related elements, b) identifies the cumulative point total for each area with natural resource values, and c) shows the delineation of primary and secondary environmental corridors and other high-value resource areas; and 3) a 1" = 400' scale print of the mylar transparency which was utilized as a work map showing the application of criteria necessary to identify and delineate the corridor and other high-value resource areas.

A CASE STUDY: PRIMARY ENVIRONMENTAL CORRIDORS IN SALEM TOWNSHIP, KENOSHA COUNTY

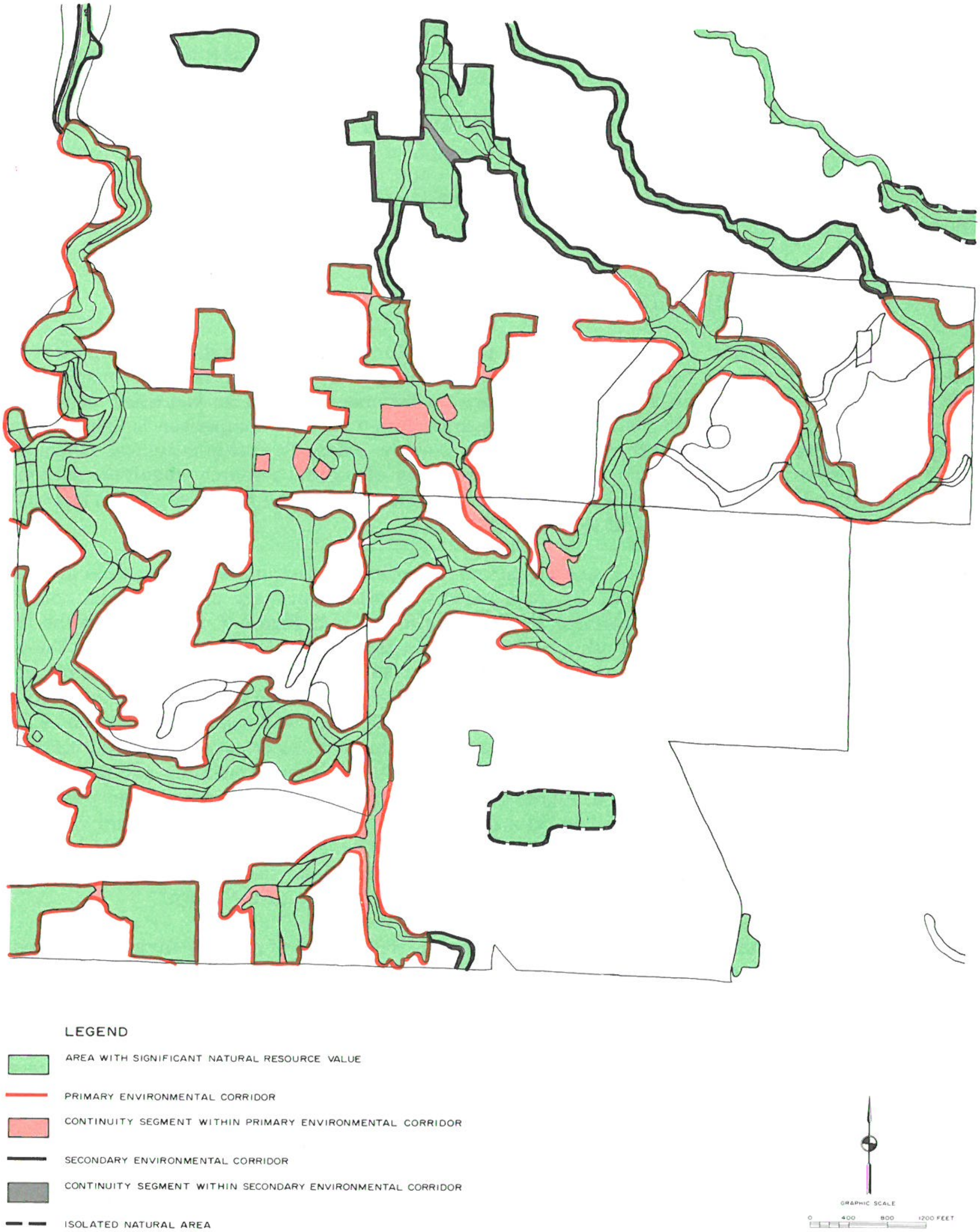
The purpose of this portion of the article is to provide—for a sample township—a comparison of the location and size of primary environmental corridors identified in the corridor refinement process herein described to the location and size of primary environmental corridors identified in the original regional land use plan prepared in 1966. The sample area chosen for this comparison is Salem Township, a 36-square-mile area located in south-central Kenosha County. Salem Township is typical of many townships in southeastern Wisconsin which possess a large variety of natural resource amenities. A number of major and minor lakes are located in Salem Township and a major river, the Fox River, flows in a southerly direction through the western portion of the Township.

The simplest way to compare the two spatial patterns of primary environmental corridors identified in Salem Township is through a review of Figure 5, which shows the primary environmental corridors in Salem Township as identified in the corridor refinement process, and Figure 6, which shows the primary environmental corridors in Salem Township as identified in the original land use plan. While the acreage of primary environmental corridors is virtually the same—7,360 acres as identified through the corridor refinement process versus 7,480 acres as identified in the original land use plan—the location and extent of the individual corridors vary significantly. Figure 6, for example, shows a large concentration of primary environmental corridor lands between the Camp Lake and the Fox River, south of Silver Lake to the Wisconsin-Illinois border, and only small amounts of primary environmental corridor land in the far northwest and northeast portions of the Town. Figure 5, prepared under the corridor refinement process, shows significantly fewer primary environmental corridor lands in the area between Camp Lake and the Fox River south of Silver Lake but significantly more corridor lands in the Paddock, Hooker, and Montgomery Lakes environmental corridor located in the northeast portion of the Town and in the Rock, Voltz, Cross, Shangrila, and Benet Lakes corridor area located in the southeast portion of the Town.

This case study clearly indicates the differences between the delineation of primary environmental corridor lands under regional system level plans and the delineation of such lands under the refinement process described herein. In addition, this case study indicates the importance of corridor refinement if the corridor concept is to be meaningfully integrated into local project level plans. For example, the series of detailed natural resource inventory maps and mylar transparency overlays developed in the environmental corridor refinement process could be utilized as a basis for the identification and application of appropriate zoning districts to preserve the natural resource features delineated. These natural resources and the primary environmental corridor lands which encompass them cannot be precisely delineated in regional system level planning.

Figure 3

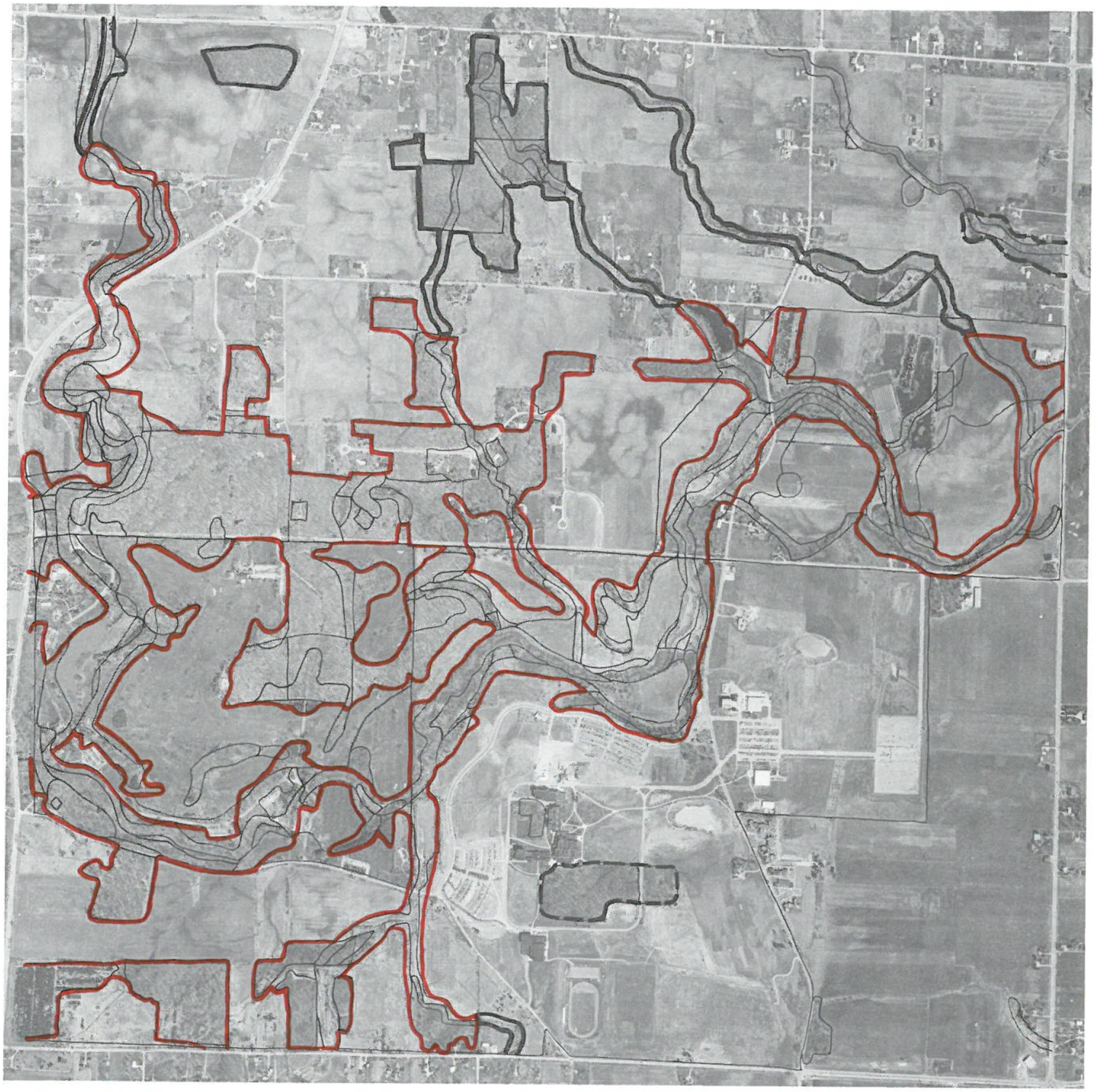
WORK MAP DISPLAYING APPLICATION OF CRITERIA UTILIZED IN THE IDENTIFICATION OF ENVIRONMENTAL CORRIDORS AND ISOLATED NATURAL FEATURES: SECTIONS 1, 2, 11, AND 12, TOWNSHIP 2 NORTH, RANGE 22 EAST, TOWN OF SOMERS, KENOSHA COUNTY



Source: SEWRPC.

Figure 4

DELINEATION OF ENVIRONMENTAL CORRIDORS AND ISOLATED FEATURES: SECTIONS 1, 2, 11, AND 12, TOWNSHIP 2 NORTH, RANGE 22 EAST, TOWN OF SOMERS, KENOSHA COUNTY

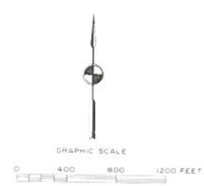


LEGEND

PRIMARY ENVIRONMENTAL CORRIDOR

SECONDARY ENVIRONMENTAL CORRIDOR

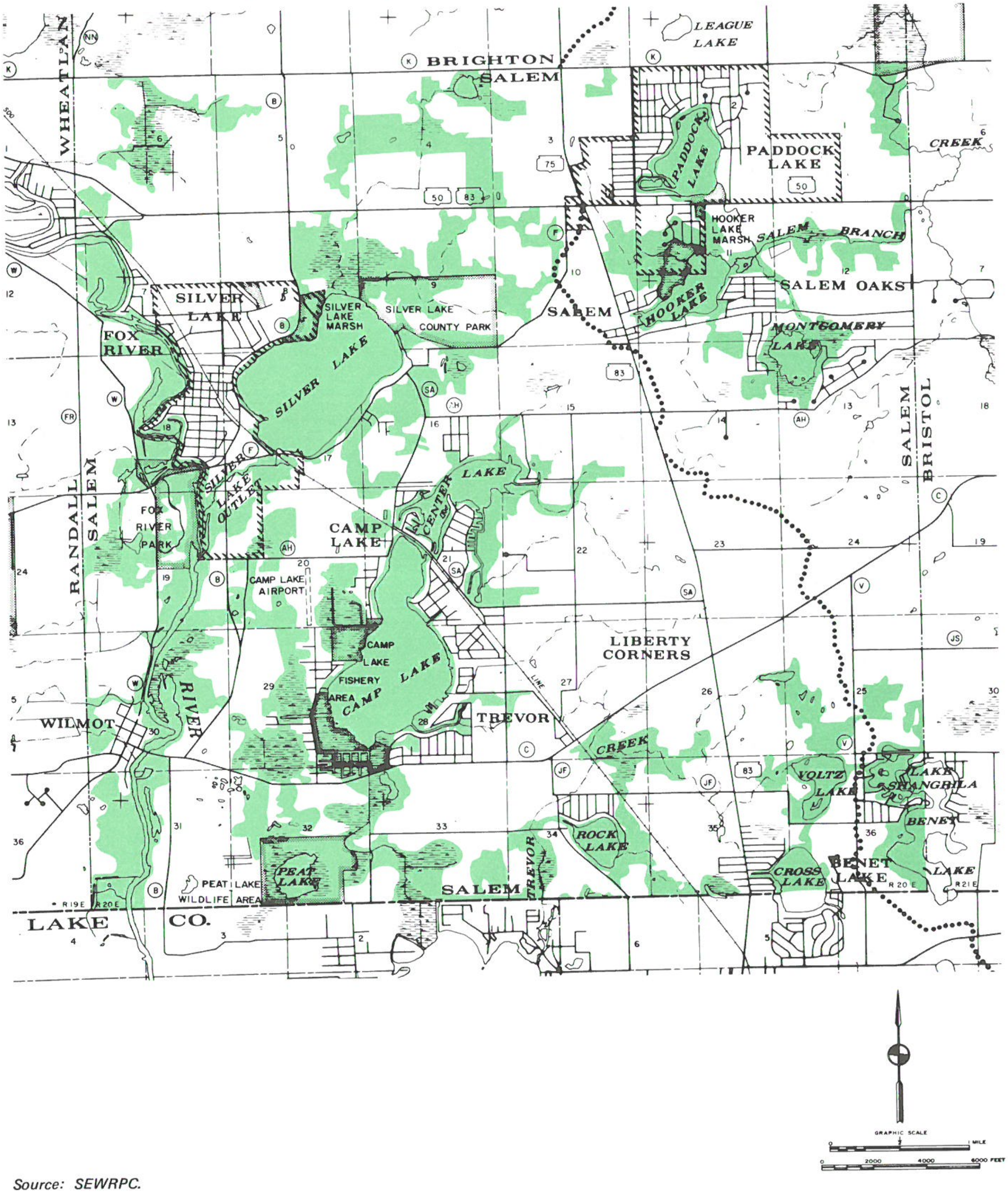
ISOLATED NATURAL AREA



Source: SEWRPC.

Figure 5

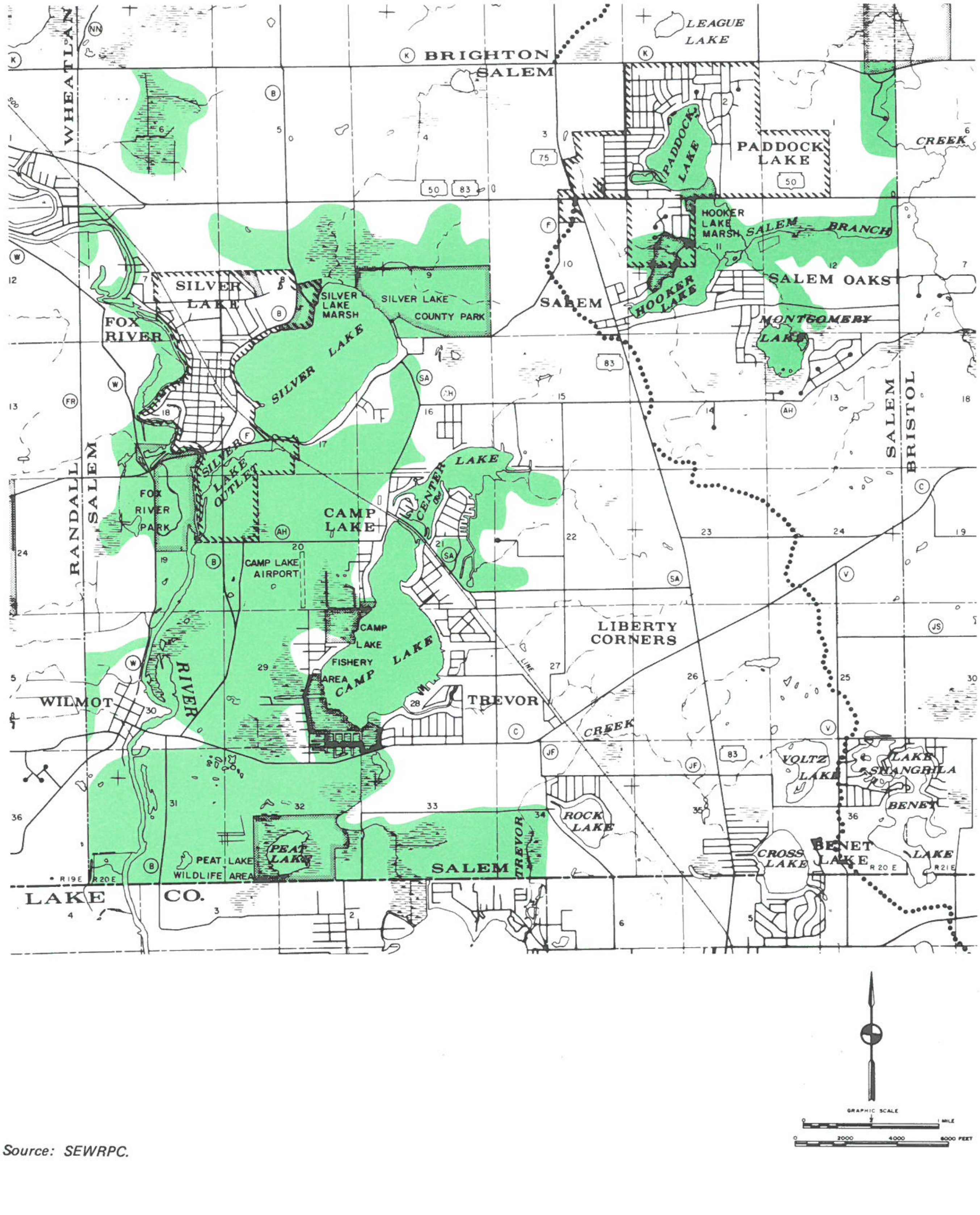
PRIMARY ENVIRONMENTAL CORRIDORS IN SALEM TOWNSHIP
AS IDENTIFIED IN THE CORRIDOR REFINEMENT PROCESS



Source: SEWRPC.

Figure 6

PRIMARY ENVIRONMENTAL CORRIDORS IN SALEM TOWNSHIP AS IDENTIFIED IN THE ORIGINAL LAND USE PLAN



Source: SEWRPC.

WATER QUALITY AND QUANTITY SIMULATION MODELING FOR THE AREAWIDE WATER QUALITY MANAGEMENT PLANNING PROGRAM FOR SOUTHEASTERN WISCONSIN: 1976

by Thomas R. Sear, P.E., Senior Water Resources Engineer, SEWRPC

INTRODUCTION

A quantitative analysis of surface water quality conditions in the Southeastern Wisconsin Region is fundamental to the assessment of the existing water quality problems, the testing and evaluation of alternative water quality management plans, and the selection of a recommended plan for the areawide water quality management planning program for southeastern Wisconsin. Of particular interest to the areawide water quality management planning program are those measurable and predictable aspects of the hydrology and hydraulics of the Region which affect the quality of the surface waters, such as periods of critically low streamflows or periods of diffuse source washoff, which have a direct impact on water quality management planning.

Water quantity and quality at any point in time within the Region's surface water system are a function of three factors. First are the meteorological events which determine the amount of runoff and, therefore, not only the amount of water that the stream system must carry in times of high flow, but the magnitude of the base flow and hence the amounts of water available for various instream uses including such water quality-related uses as the maintenance of warm and cold water fisheries, recreation, waste assimilation, and industrial uses. The second factor is the nature and use of the land, with emphasis on those features that affect the quantity, quality, and temporal distribution of runoff. The third factor involves those stream characteristics that determine the manner in which runoff from the land moves through the stream system and, therefore, significantly influences the rates at which pollutants are either assimilated within or transported from the watershed.

Recently developed water resources engineering techniques make it possible to perform the necessary quantitative analysis of the water quality conditions in the Region for existing and alternative future conditions as influenced by the above three factors. These techniques involve the formulation and application of complex mathematical relationships that simulate the interrelated and dynamic behavior of the specific aspects of the hydrologic-hydraulic water quality phenomena of the Region's surface water system. At the outset, it should be emphasized that a hydrologic-hydraulic water quality simulation model is only one of several tools that are used to assist the water quality manager and/or planner in the difficult task of comparing and evaluating the alternative water quality management plans. The model can neither answer all the questions nor solve all the problems related to water quality management. The important value of the model is its capability to provide, quickly and efficiently, quantified information on the effects of alternative water quality management plans on instream water quality.

The purpose of this article is to describe the water quality simulation model used in the areawide water quality management planning program for southeastern Wisconsin. More specifically, this article discusses the need for and the nature of modeling in areawide water quality management planning, the criteria and methods of model selection, the submodels incorporated within the model, the input data requirements, the data base development, the model calibration process, and the application of the model to alternatives analysis.

This article is intended only as a summary of the hydrologic-hydraulic water quality analysis procedures used in the areawide water quality management planning program. Complete documentation of the analysis and modeling is contained in the files of the Southeastern Wisconsin Regional Plannning Commission. The complete documentation involves the 42 study volumes and supporting exhibits that are described in Table 1 and outlined in Table 2. Documentation of the modeling of the Menomonee River watershed is summarized in SEWRPC Planning Report No. 26, A Comprehensive Plan for the Menomonee River Watershed, Volume One, Inventory Findings and Forecasts. The modeling of the Kinnickinnic River watershed is summarized in SEWRPC Planning Report No. 32, A Comprehensive Plan for the Kinnickinnic River Watershed. Supporting documents similar to those outlined in Table 2 are available in the SEWRPC offices for the Menomonee and Kinnickinnic Rivers. Readers requiring a more detailed description of the modeling process than that contained in this article are referred to the SEWRPC files described above.

OVERVIEW OF WATER QUALITY SIMULATION MODELING

Need for Modeling

Water quality management planning on a watershed scale requires an understanding of how the system behaves under existing and alternative future conditions in order to comprehend the severity and causes of water quality problems and to evaluate the likely effects of alternative solutions to those problems. The ideal way to investigate the behavior of the hydrologic-hydraulic water quality system of the Region would be to make direct measurements or observation of the phenomena involved. Such a direct approach is generally not feasible, primarily for three reasons. First, the costs of installing, operating, and maintaining the necessary network of precipitation gages, streamflow gages, and water quality monitoring stations needed to achieve the extensive data required for areawide water quality management planning are prohibitive. Secondly, even if an ideal data collection system could be established in the Region, it is highly improbable that the sampling or observation period available within the time frame of the areawide

Table 1

SEWRPC STUDY VOLUMES DESCRIBING THE HYDROLOGIC-HYDRAULIC WATER QUALITY SIMULATION MODELING CONDUCTED FOR THE INITIAL AREAWIDE WATER QUALITY MANAGEMENT PLANNING PROGRAM

Watershed	Study Volumes Identification Numbers[a]		
	Hydrologic-Hydraulic Modeling	Existing Water Quality Modeling	Year 2000 and Alternative Modeling
Areawide Summary	6200	6300	6400
Pike River	6205	6305	6405
Root River	6210	6310	6410
Des Plaines River	6215	6315	6415
Fox River	6225	6325	6425
Lower Rock River	6230	6330	6430
Middle Rock River	6235	6335	6435
Upper Rock River	6240	6340	6440
Oak Creek	6245	6345	6445
Milwaukee River	6250	6350	6450
Sauk Creek	6255	6355	6455
Sheboygan River	6260	6360	6460
Barnes, Pike, and Sucker Creeks	6265	6465	6465
Inland Lakes	6270	6370	6470

[a] *It should be noted that water quality planning is envisioned as a continuing work activity of the Commission. Therefore, subsequent simulation work and documentation thereof may be obtained through communications with the Commission staff.*

Source: SEWRPC.

program would include such critical natural events as extreme low flow periods or washoff events that are required for the assessment of water quality. Finally, with respect to evaluating the Region's hydrologic-hydraulic water quality relationships under alternative future land use and stream conditions, it is apparent that a regional monitoring network would be of only limited value since its measurements and observations would reflect only existing land use and stream conditions.

It follows, therefore, that a detailed understanding of the spatial and temporal fluctuations in the quantity and quality of the surface water resources of the Region under both existing and alternative future conditions requires the application of some engineering and planning techniques that can supplement and build upon a limited base of measured water resources data. The techniques must be capable of quantifying the hydrologic-hydraulic water quality impact of existing and alternative future conditions with a degree of accuracy sufficient to permit sound engineering and planning decisions to be made concerning both the location, type, and size of costly pollution abatement structures and facilities and the nature and the extent of water quality-related land management measures.

Hydrologic-hydraulic water quality simulation, accomplished with digital computer programs, has proven to be an effective water resources planning-water quality management technique. Although systems may be simulated by means of programs executed on digital computers, on analog computers, or on actual physical models, digital computer simulation has been utilized most extensively in water resources planning by private consulting firms and by governmental agencies, including the Commission, since the early 1960's, when private as well as public engineering and planning organizations began to gain access to digital computers and the mathematical programs required to apply the computers to water resources engineering and planning.

Nature of Modeling

A variety of digital computer models are available for use in water resources planning. These models range from a relatively simple set of mathematical expressions, or equations, that generate pollutant concentrations for discrete-flow events to large and complex models that continuously simulate watershed hydrology, hydraulics, and water quality in response to changing meteorological conditions.

Discrete Event Versus Continuous Process Simulation: The difference between discrete event and continuous process simulation, particularly in hydrologic-hydraulic water quality modeling, is an important distinction since there is a marked difference in the capabilities and costs of these two fundamentally different approaches. Discrete event hydrologic-hydraulic models, for example, are designed to simulate the response of a watershed or a portion of a watershed to a major rainfall or rainfall-snowmelt event by converting the rainfall or rainfall-snowmelt that occurs on the land into a hydrograph that can then be routed through the stream system. Such models are not intended for use in simulating the runoff attributable to small rainfall or rainfall-snowmelt events and do not simulate base flow conditions that occur in the streams before and after runoff events.

The principal advantages of discrete event hydrologic-hydraulic water quality models relative to continuous process models is that they require relatively little meteorological data, and they can be operated on smaller computers with shorter run times. The principal disadvantages of discrete event models are that they require the specification of design storm and antecedent conditions, thereby assuming equivalence between the recurrence interval of a flood flow or pollutant washoff event and the recurrence interval of the hydrologic event that caused it. Discrete event models cannot simulate long-term transport of potential pollutants and are able to utilize only a small part of the available historic hydro-meteorologic and water quality data during calibration and testing.

Continuous process hydrologic-hydraulic water quality models continuously and sequentially simulate processes such as precipitation, interception, and depression storage; snow accumulation and melt; evapotranspiration; direct runoff; infiltration and interflow; release from groundwater storage as base flow;

Table 2

OUTLINE FOR WATERSHED MODELING STUDY VOLUMES

I. STUDY VOLUMES NUMBERED 6200-6270 "QUANTITY MODELING"

A. Data Set Management

1. Meteorological data sets used for watershed simulation
2. Data set organization
3. Status of meteorological data set

B. Lands Data

1. Subbasins and subbasin areas
2. Hydrologic soils
3. Slopes analysis
4. Land use
5. Watershed Thiessen polygon network
6. Land segment types and land segment determination
7. Review of previously used Lands parameters
8. Development of initial Lands parameters

C. Channel Data

1. River Mile stationing
2. Channel profiles
3. Watershed schematic representation
4. Development of reach parameters
   a. Typical reach cross-sections
   b. Manning's N coefficient values and field survey
   c. Structure data inventory, field survey, and field data
   d. Reach length and elevations
5. Historic channel network

D. Streamflow Data

1. Inventory of streamflow gages, both continuous and partial record gages
2. Inventory of historic streamflow data
3. Statistical analysis of historic streamflow data
4. Determination of calibration events
5. Calibration hydrographs
6. Hyetographs of calibration hydrographs

E. Calibration

1. Calibration time periods and representation of land use and channel changes during calibration
2. Log and changes in Lands parameters
3. Display of final calibration results

F. Production Runs

1. Establishment of production run Land Surface Runoff Files
2. Actual run description, including network and land segment type assignment
3. Output files

G. Analyses of Production Results

1. Statistical analyses of production run results
2. Display of production results

II. STUDY VOLUMES NUMBERED 6300-7370 - "QUALITY MODELING"

A. Data Set Management

1. Data Set organization
2. Meteorological data sets used
3. Status of Data Set input

B. Quality Data

1. Selection of initial watershedwide parameters
2. Selection of initial reach parameters
3. Initial instream water quality conditions

C. Instream Water Quality Data

1. Inventory of instream water quality data for use in water quality calibration
2. Management of water quality data to be used for calibration
3. Display of instream water quality data

D. Nonpoint Loads

1. Water Quality land segment type determination
2. Determination of relationship between hydrologic and water quality land segment types
3. Selection of initial nonpoint source parameters for each water quality land segment type

E. Point Loads

1. Inventory of point load data: municipal, private, and industrial

Table 2 (continued)

2. Analysis of point load data for calibration purposes

F. Calibration

1. Calibration time periods, representation of changing land use, channel, point load, and nonpoint source conditions during calibration
2. Changes in all quality, biota, bottom, nonpoint source, and watershedwide parameters
3. Display of calibrated results

G. Production Run (base line water quality conditions)

1. Assumptions used for production run of existing conditions
2. Point load descriptions
3. Output locations and output files

H. Analysis of Production Run Results

1. Statistical analyses
2. Mass loadings analyses
3. Display of results

I. $Q_{7,10}$ Simulation (low flow analysis)

1. Assumptions for the $Q_{7,10}$ simulation
2. $Q_{7,10}$ flow analyses
3. Point loads assumptions
4. Nonpoint (base flow) loadings
5. $Q_{7,10}$ simulation run
6. Display of results

III. STUDY VOLUMES NUMBERED 6400-6470 - "ALTERNATIVE MODELING"

A. 2000 Land Use

1. 2000 land use map
2. 2000 land use segments
3. Schematic representation

B. 2000 Point Sources

1. Point source changes
2. Adjustments to point source files

C. 2000 Simulation

1. Output
2. Mass analysis
3. Statistics
4. Constituent-frequency relationships

D. Alternatives

1. Alternative description
2. Output
3. Mass analysis
4. Statistics
5. Constituent-frequency relationships

Source: SEWRPC.

channel and reservoir routing; pollutant washoff; and instream water quality processes. Such models typically operate on a time interval ranging from a day to a fraction of an hour and continuously maintain a water balance, or accounting, among the various hydrologic-hydraulic processes. Thus the entire spectrum of streamflow conditions is simulated, ranging from flood flows and pollutant washoff occurring during and immediately after major runoff-producing events to extreme low flow events typical of drought periods.

Continuous process models have two principal advantages relative to discrete event models. First, such models permit the transformation of long, historic meteorological records—which are normally available and may extend over many decades—into a correspondingly long record of synthetic hydrologic-hydraulic water quality data, thus encompassing a wide spectrum of possible occurrences. Statistical analysis of the simulated hydrologic-hydraulic water quality data series then permits conclusions to be drawn concerning the exceedance frequency of particular discharge, stage, or water quality levels. Second, continuous process models permit the maximum utilization of most historic hydrologic-hydraulic water quality information, an important factor in the study of small urban watersheds that typically lack extensive data bases and therefore require the maximum utilization of all the data that are available or are obtained specifically for a study. A principal disadvantage of continuous process models is that they require large amounts of input data—particularly daily and hourly meteorological information. Such voluminous data require costly collation and coding. Another significant disadvantage of continuous process models is the extensive computer system storage and run time required with correspondingly high computer use costs.

The development and use of discrete event models generally preceded that of continuous process models, primarily because of the relative simplicity and more modest computer system requirements of the discrete event models. As a result, there are more discrete event models available and in use than there are continuous process models. A recent state-of-the-art survey[1] of urban-area models revealed the existence of 18 models that simulate the dynamics—the time-varying characteristics—of urban-area hydrology, with some of the models also having the capability to simulate the dynamics of urban-area hydraulics and water quality. Four of the 18 models were continuous simulation models, and the remaining 14 were discrete event models.

Algorithms: In order to simulate the hydrologic-hydraulic water quality system of the Region by the application of a digital computer model, it is necessary to construct a mathematical algorithm of each system unit and concomitant processes and to then interconnect these algorithms so as to, in effect, represent the linked as well as the individual behavior of the system components. For example, most hydrologic-hydraulic models include a determination of the storage effect of a stream reach on the shape of a hydrograph that passes through the reach. Simulation of this element of the system is accomplished by mathematically expressing the alteration in hydrograph shape as a function of reach geometry and hydraulic conditions. Similarly, the hydrograph that enters the reach is a function of all watershed hydrologic and hydraulic characteristics upstream of the reach.

It is important to emphasize that the model used in the Commission's areawide water quality management planning program, or, more specifically, the mathematical computations and logic decisions executed during the operation of the water quality model, is neither more nor less sophisticated or valid than the operations which could, with virtually unlimited personnel and time, be accomplished manually by technical personnel. The only advantage of digital computer simulation over manual computations is the rapidity of the computer computations. The application of mathematical simulation models to water resources engineering and planning is dependent on the development of a computational device, the digital computer, which is capable of rapidly making, without error, voluminous repetitive calculations and logic operations at a reasonable cost, and is not dependent on an increased understanding of hydrologic and hydraulic phenomena. In fact, most of the hydrologic and hydraulic phenomena included in the most sophisticated existing water resource simulation models were known and formulated many years prior to the advent of simulation, some as early as the eighteenth century, although some of the water quality algorithms are based on recent research. Because of the staff and time requirements and their associated monetary costs, it would have been impractical to manually execute the computations necessitated in a single application of the model used in the areawide water quality management planning program.

Simulation and Decision-Making: Hydrologic-hydraulic water quality simulation, in the context of the areawide water quality management planning program, was not used to design alternative solutions to the water quality problems of southeastern Wisconsin. The simulation modeling only provided the quantitative analysis necessary to evaluate the effect of various alternative water quality management plans upon the Region's water quality.

SIMULATION MODEL USED IN THE AREAWIDE WATER QUALITY PLANNING PROGRAM

Model Selection Criteria

Prior to selection of a hydrologic-hydraulic water quality simulation model for use in the areawide water quality management planning program, the proposed planning program as well as the water quality prob-

[1] *A. Brandstetter, Comparative Analysis of Urban Storm-Water Models, Battelle Memorial Institute, Richland, Washington, August 1974.*

lems of the Region were examined in order to determine the applicability of simulation modeling. Based on that examination, it was determined that the "ideal" model should have the following three features:

1. The ability to simulate the hydrology, hydraulics, and water quality conditions of streams and watercourses in both rural and urban areas.

2. The ability to accurately incorporate the hydrologic-hydraulic water quality effects of land use changes—particularly the effects of the conversion of land from rural to urban uses within an entire tributary watershed.

3. The ability to assess the impact on surface water quality of discharges from point sources of pollution, such as municipal and industrial discharges, and the impact on surface water quality of nonpoint sources of pollution, such as organic materials and plant nutrients washed from the land surface or leached out of soil profiles.

In addition to the above criteria, which pertain directly to the needs of the areawide water quality planning program, the model selection process included consideration of two factors related to the overall work program of the Commission. First, because the installation of a new model, or a portion of a new model, requires considerable staff time and expense, maximum use should be made of existing in-house models. Second, the model selected for use in the areawide water quality planning program should have the potential to substantially fill the water resource simulation modeling needs of other ongoing or scheduled Commission water resources planning programs. During the time period in which the hydrologic-hydraulic water quality model was being selected and initially implemented on the Commission's computer system—approximately June 1974 to April 1975—the Commission was either participating in or planning to undertake the following major water resource studies: the Menomonee River watershed planning program,[2] the International Joint Commission Menomonee River pilot watershed study,[3] the Kinnickinnic River watershed planning program,[4] the Pewaukee floodland information project,[5] the Sussex floodland information project,[6] and the Pewaukee floodland management project.[7] Since it was anticipated that the model or portions of it would be extensively used in these and other Commission water resources planning programs over a period of several years, it was deemed desirable to select a flexible model and one for which some formal model maintenance, refinement, and extension services were available.

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[2] *See SEWRPC Planning Report No. 26, A Comprehensive Plan for the Menomonee River Watershed, Volume One, Inventory Findings and Forecasts, October 1976, and Volume Two, Alternative Plans and Recommended Plan, October 1976.*

[3] *Wisconsin Department of Natural Resources, University of Wisconsin System—Water Resources Center, and SEWRPC, Menomonee River Pilot Watershed Study Work Plan, September 1974.*

[4] *See SEWRPC's Kinnickinnic River Watershed Planning Program Prospectus, November 1974.*

[5] *See SEWRPC Community Assistance Planning Report No. 9, Floodland Information Report for the Pewaukee River, October 1976.*

[6] *See SEWRPC Community Assistance Planning Report No. 11, Floodland Information Report for Sussex Creek and Willow Creek, Village of Sussex, December 1976.*

[7] *See SEWRPC Community Assistance Planning Report No. 14, Floodland Management Plan for the Village of Pewaukee, February 1978.*

Model Selection

Based upon the above-listed considerations, the Commission staff selected a specific, well-documented continuous process hydrologic-hydraulic water quality model contained within a program "package" called Hydrocomp Simulation Programming.[8] This package of digital computer simulation programs is available on a proprietary basis through the consulting firm of Hydrocomp International, Inc., of Palo Alto, California, and has been under development since the early 1960's, when pioneer work in hydrology and hydraulic modeling was initiated at Stanford University.[9] In 1972, Hydrocomp International, Inc., added the water quality simulation capability to the hydrologic-hydraulic simulation capability of its continuous process model. The Hydrocomp simulation program (HSP) was installed on the SEWRPC computing system early in 1975. The program is currently being maintained by Hydrocomp International, Inc., on a proprietary basis, with updated versions of the programs implemented by the Commission during 1976, 1977, and 1978.

Each of the three submodels contained in the model is discussed below. These separate discussions emphasize the function of each submodel within the overall modeling scheme, the types of algorithms that are contained within each submodel, data needs, and the kinds of output that each submodel provides. The reader is referred to the above-referenced reports or manuals for detailed descriptions of each submodel.

Hydrologic Submodel

The principal function of the Hydrologic Submodel is to determine the volume and temporal distribution of flow from the land to the stream system. As used here, the concept of runoff from the land is broadly interpreted to include overland flow, direct surface runoff, interflow, and groundwater flow to the streams. The amount and rate of runoff from the land to the watershed stream system is largely a function of two factors. The first is the meteorologic events that determine the quality of water available on or beneath the land surface and the second is the nature and use of the land.

The smallest drainage unit considered in the hydrologic inventory is the "hydrologic subbasin," defined as a relatively small area of generally less than two square miles in areal extent and tributary to a common drainage point. These were delineated so as to be of a generally homogeneous nature with respect to soil, slope, and land cover whenever possible. The Commission's delineated 2,176 hydrologic subbasins are within, tributary to, or downstream from southeastern Wisconsin, and range from 0.02 square mile to 6.32 square miles in areal extent, with an average of about 1.35 square miles. Delineations prepared in Commission work programs preceding the areawide water quality management planning program were used where available, but were rechecked, refined, and confirmed before incorporation into the final mapping. Revised and new delineations alike were recorded on U.S. Geological Survey (USGS) 7.5-minute quadrangle topographic maps, after being identified on and transferred from any large-scale topographic mapping available. Such mapping included 2'-4'contour mapping prepared at a scale of 1" = 200',[10] 5' contour topographic mapping of Waukesha County prepared at a scale of 1" = 200', and any special cross sections or survey data available in the Commission files. The Commission's 1975 aerial photography prepared at a scale of 1" = 400' was also used as a reference.

The delineations were field-checked whenever necessary, and were transferred to polyester film Commission base maps at a scale of 1" = 2000' for general reference. The subbasin areas were then delineated and measured, and their traced boundaries recorded on computer tape, by use of the Commission interactive analog-to-digital data conversion system (digitizing system).

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[8] *Hydrocomp, Inc., Hydrocomp Simulation Programming Operations Manual, Fourth Edition, January 1976, and Hydrocomp Simulation Programming-Mathematical Model of Water Quality Indices in Rivers and Impoundments, 1972.*

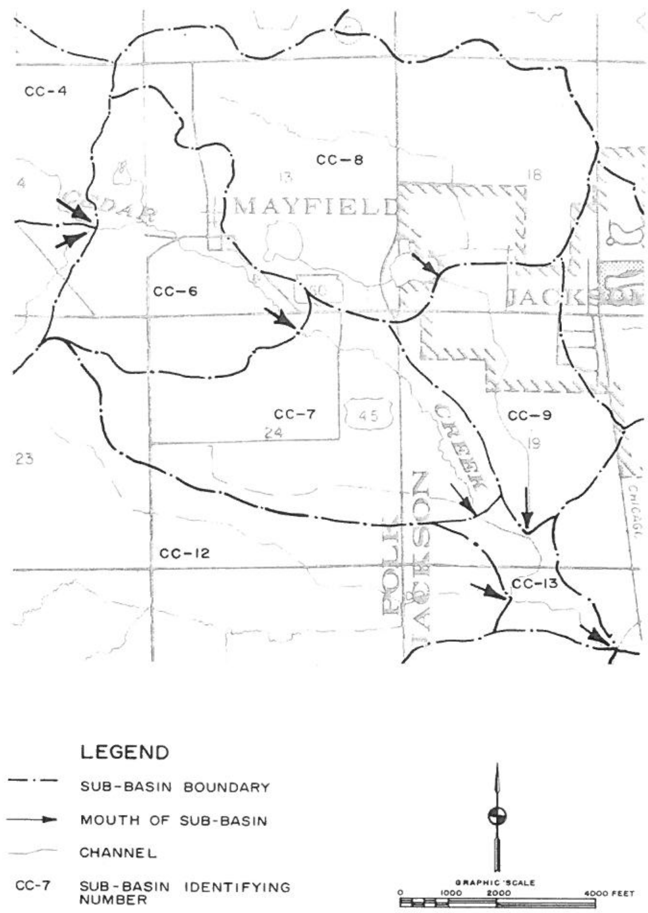
[9] *N. H. Crawford and R. K. Linsley, Digital Simulation in Hydrology: Stanford Watershed Model IV, Technical Report No. 39, Department of Civil Engineering, Stanford University, July 1966.*

[10] *See SEWRPC 1975 Annual Report for the then-current availability of large-scale mapping.*

The subbasins were then aggregated to subwatershed units of workable size and were combined to compose the 12 major watersheds in the Region. An example of the 1" = 2000' base map for a portion of the Cedar Creek subwatershed of the Milwaukee River watershed is depicted on Map 1. Map 2 illustrates the subbasin and watershed delineations for the Region as a whole. As noted elsewhere in this article, the subbasins served as a base unit for the land cover inventory. Based upon the inventories and analyses, such hydrologic subbasins also may be aggregated to "hydrologic land segments" representing one or more subbasins that have similar characteristics as discussed below. This aggregation was a particularly important step for minimizing the data processing costs of simulation.

Map 1

SAMPLE HYDROLOGIC SUBBASIN MAP— PORTION OF CEDAR CREEK SUBWATERSHED MILWAUKEE RIVER WATERSHED



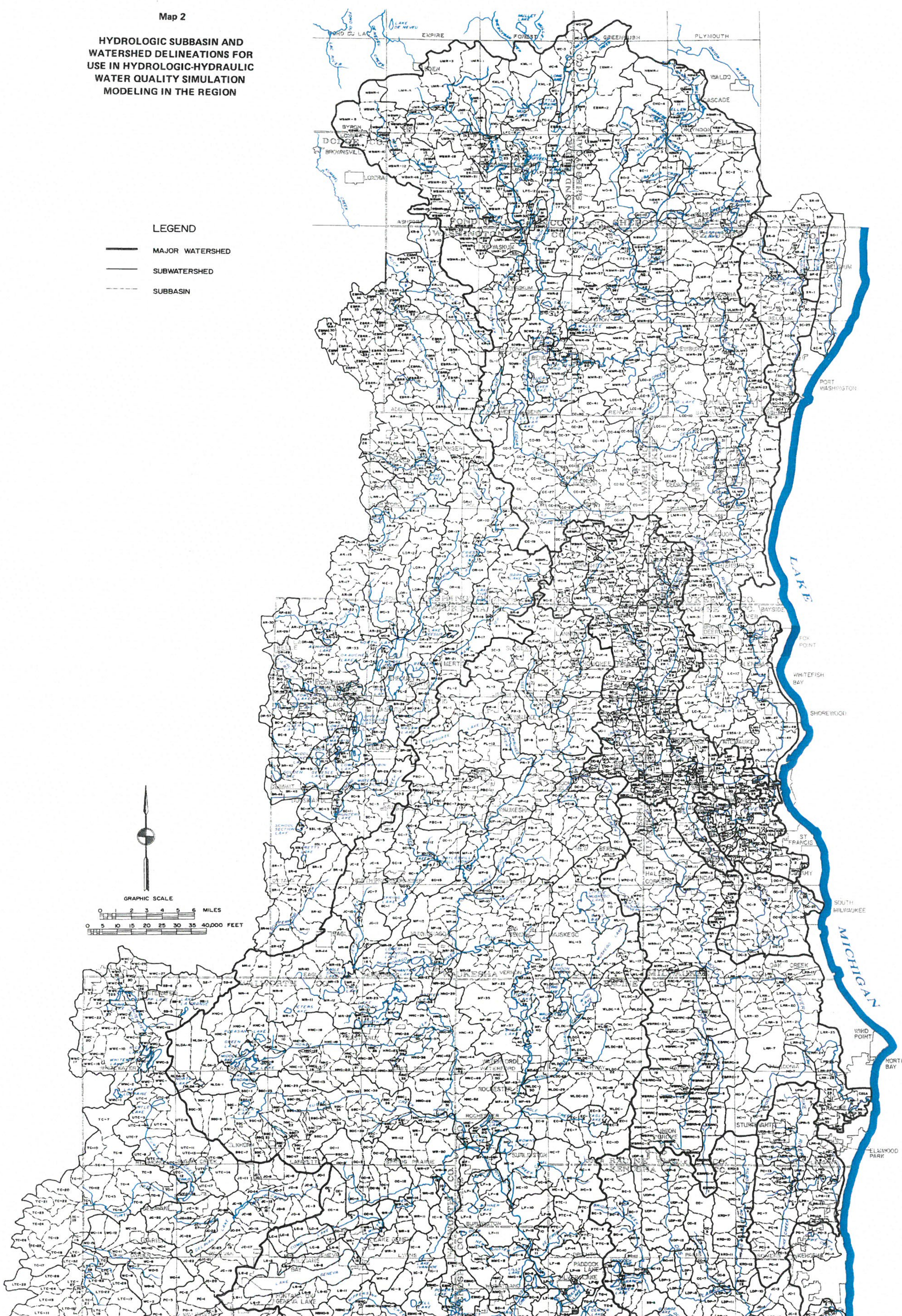
Source: SEWRPC.

The basic conceptual unit on which the Hydrologic Submodel operates is called the hydrologic land segment type. A hydrologic land segment type is defined as a unique combination of meteorological characteristics, such as precipitation and temperature, land characteristics, such as the proportion of land surface covered by impervious surfaces, and soil type. A strict interpretation of this definition results in a virtually infinite number of unique hydrologic land segment types within even a small watershed because of the large number of possible combinations of meteorological characteristics, land characteristics, and soils which exhibit a continuous, as opposed to discrete, spatial variation throughout the watershed. To apply the concept, the study area is divided into hydrologic land segments. A hydrologic land segment is defined as a surface drainage unit which exhibits a runoff pattern characteristic of a specific hydrologic land segment type. Thus the practical, operational definition of a hydrologic land segment is a surface drainage unit consisting of a subbasin, or a combination of subbasins, that is represented by a particular hydrologic land segment type. The hydrologic land segments were defined so as to provide a travel time of approximately one hour for flow through the segment, and so that simulated output data could be obtained at sites where historic water quality sampling data are already available or at points located upstream or downstream of known sources of pollution.

To identify the hydrologic land segments within the Region, a Thiessen polygon network—see Map 3—was first constructed to determine the geographical area to be represented by each meteorological station located in the Region or adjacent to it. Soil type, as represented by hydrologic soil groups as defined by the U. S. Soil Conservation Service, and land use, as delineated in the Commission land use inventory and then classified into one of five land cover categories, were then superimposed on the Thiessen polygons. This resulted in the identification of the hydrologic land segment types, and subsequently of the hydrologic land segments, as illustrated in Figure 1. As described later in this article, approximately 1,200 hydrologic land segments were identified within the Region.

Map 2

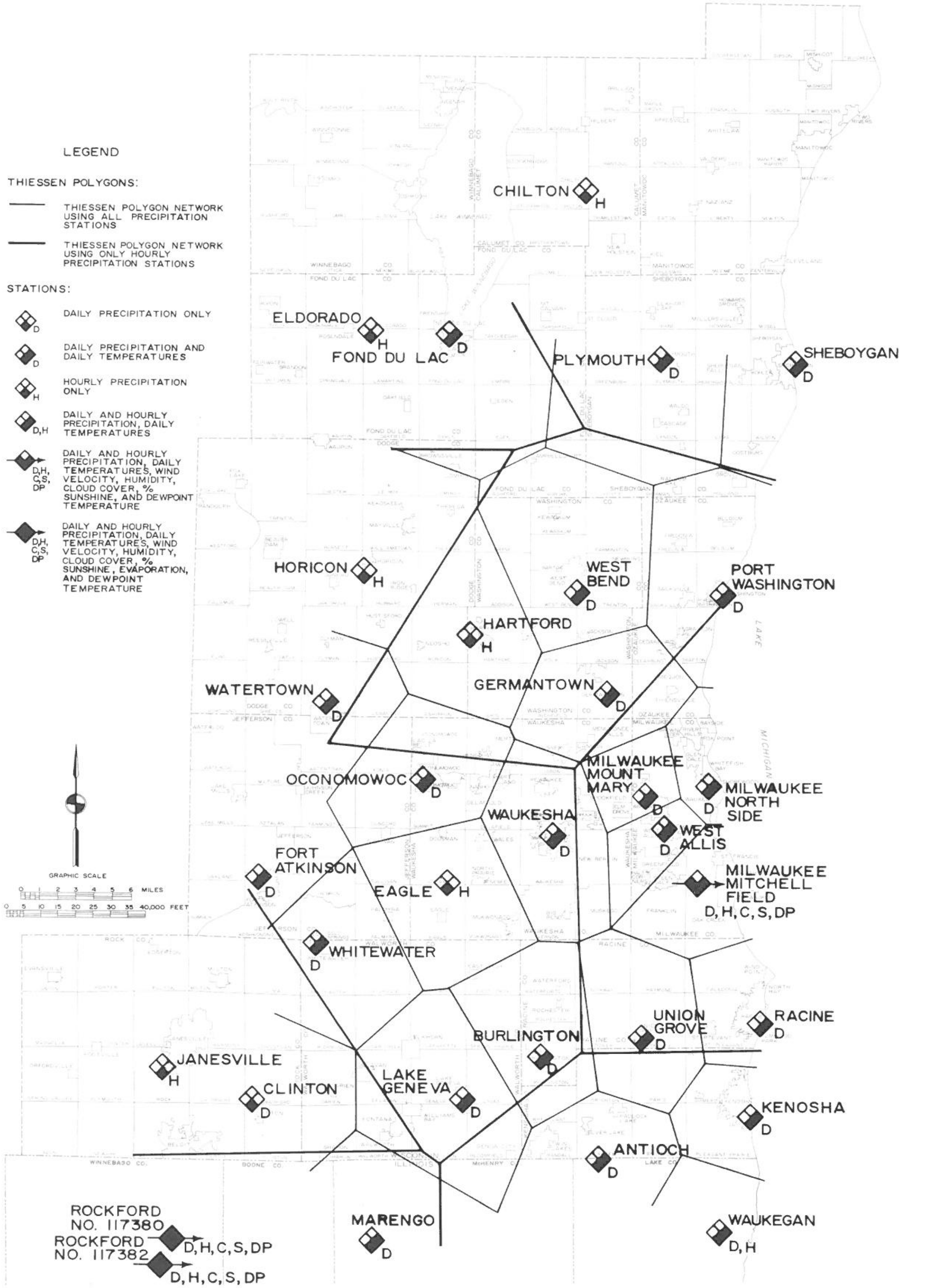
HYDROLOGIC SUBBASIN AND WATERSHED DELINEATIONS FOR USE IN HYDROLOGIC-HYDRAULIC WATER QUALITY SIMULATION MODELING IN THE REGION



Source: SEWRPC.

Map 3

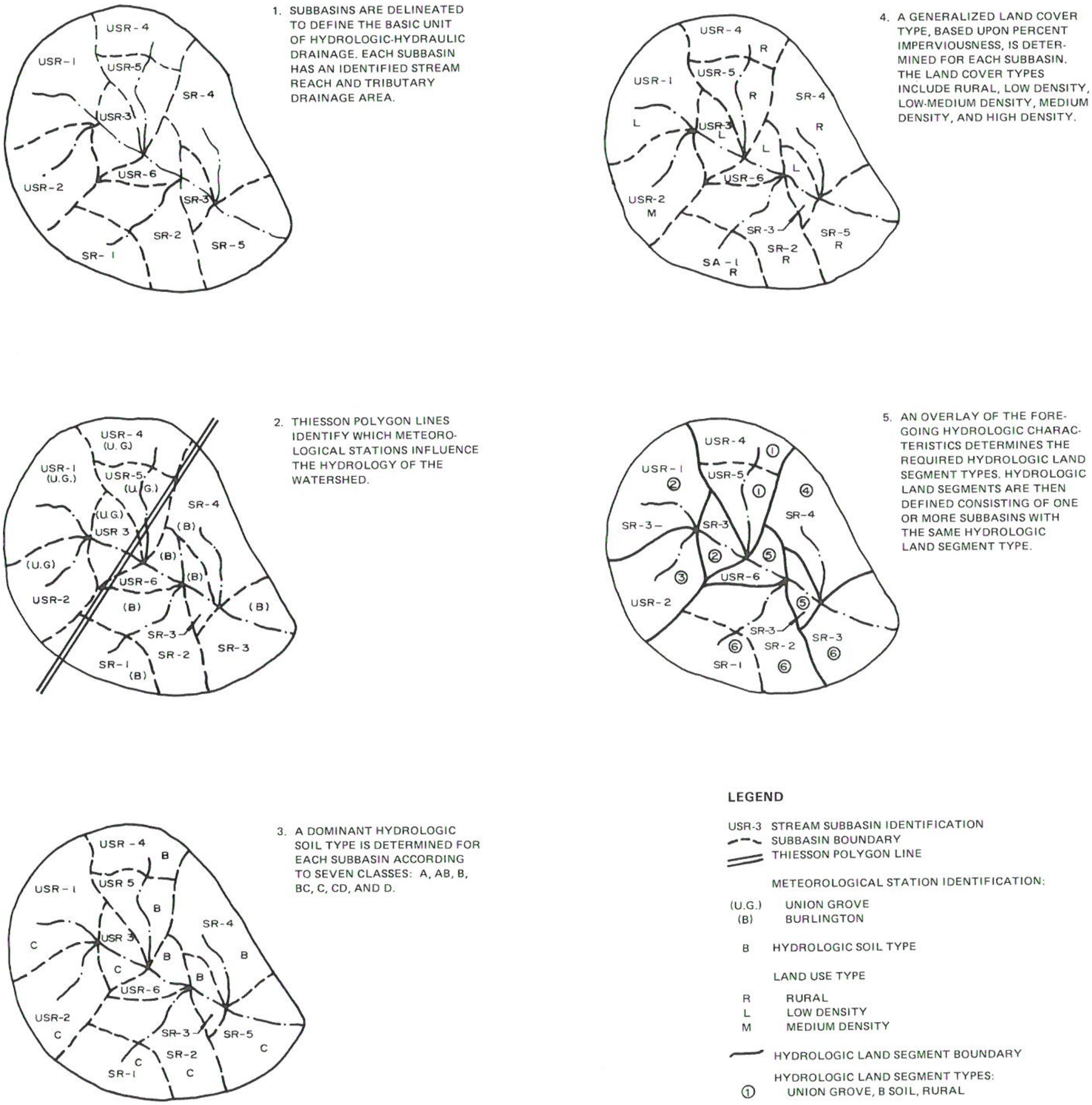
NATIONAL WEATHER SERVICE METEOROLOGIC OBSERVATION STATIONS ON THIESSEN POLYGON NETWORK FOR USE IN SEWRPC HYDROLOGIC-HYDRAULIC WATER QUALITY SIMULATION MODELING



Source: SEWRPC.

Figure 1

GRAPHIC REPRESENTATION OF THE PROCESS OF HYDROLOGIC LAND SEGMENT DETERMINATION



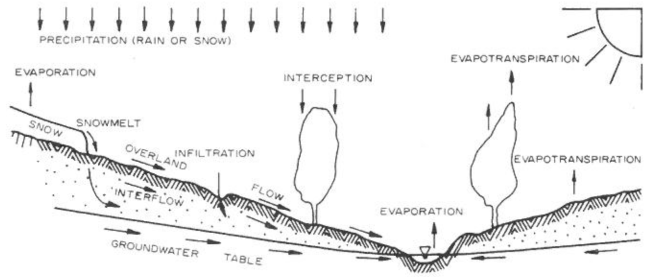
Source: SEWRPC.

The hydrologic processes explicitly simulated within the Hydrologic Submodel are shown in Figure 2. The submodel, simulating the system conditions on a time interval of one hour, constantly and sequentially maintains a water balance within and between the various hydrologic processes. The water balance accounting procedure is based on the interdependency between the various hydrologic processes, shown schematically in Figure 3. The Hydrologic Submodel maintains a running account of the quantity of water that enters, leaves, and remains within each phase of the hydrologic cycle during each successive time interval.

As already noted, the volume and rate of runoff from the land are determined by meteorological phenomena and the character and use of the land. Therefore, meteorological data and land data constitute the two principal types of input data for each hydrologic land segment in the Hydrologic Submodel. Table 3 identifies the eight categories of historic meteorologic data sets that are used as input, either directly or indirectly, to the Hydrologic Submodel for each land segment and notes the use of each data set in the submodel. The procedures used to acquire, code, and develop the eight types of meteorologic data sets are described later in this article.

Figure 2

HYDROLOGIC PROCESSES SIMULATED WITH THE HYDROLOGIC SUBMODEL



Source: Hydrocomp, Inc., and SEWRPC.

Table 4 identifies the 16 land and 12 snow parameters that are used as input to the Hydrologic Submodel for each hydrologic land segment, and indicates the source of numerical values for each parameter. Numerical values assigned to each of these parameters for a given hydrologic land segment have the effect of adapting the Hydrologic Submodel to the hydrologic land segment. The procedures used to assign values to the land parameters for each hydrologic land segment are described later in this article.

Hydraulic Submodel

The primary function of the Hydraulic Submodel is to accept as input the aggregated simulated runoff from the land surface and the simulated discharge of groundwater as produced by the Hydrologic Submodel, to route it through the stream system, and to thereby produce a series of hourly discharge values at predetermined locations along the rivers and streams of the Region. Computations proceed at a simulated time interval of one hour, and statistical analysis performed on the resulting continuous series of hourly discharges can provide discharge-frequency relationships.

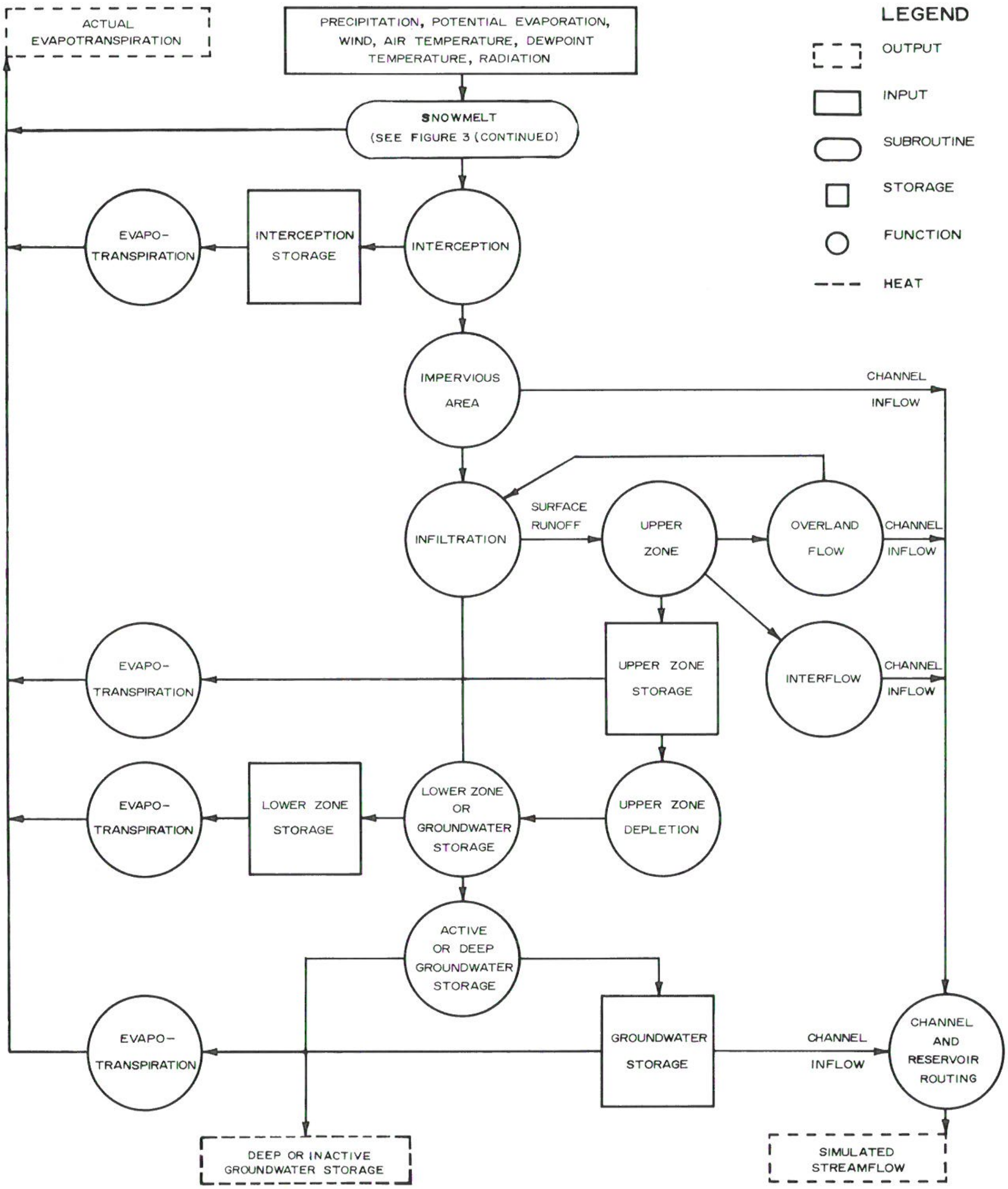
In addition to maintaining a continuous accounting of inflow to the stream system, the Hydraulic Submodel performs two types of routing calculations: one for channel reaches and another for impoundments; that is, for lakes and reservoirs. These two routing procedures are similar in concept in that both employ the principle of conservation of mass. The two routing procedures differ significantly with respect to input data needs and in the manner in which the computations are executed. For the purpose of applying these two routing techniques, the channel system is divided into reaches and impoundment sites.

Reach routing is accomplished on a continuous basis using the kinematic wave technique. Application of this technique requires that the following information be provided for each reach of the stream: length, upstream and downstream channel invert elevations, a channel floodplain cross section, Manning's roughness coefficients for the channel and its floodplains, and the size and characteristics of the tributary drainage area. Table 5 identifies the 15 channel-related parameters that are input to the Hydraulic Submodel for each reach and indicates the primary source of numerical values of each parameter. Numerical values assigned to each of these channel parameters for a given reach have the effect of adapting the Hydraulic Submodel to each reach. The principal means of establishing channel parameters is direct observation or measurement. Additional information on the procedures used to assign values to the channel parameters for each channel reach is presented later in this article.

As simulated in the kinematic wave routing algorithm, an incremental volume of flow enters a reach during a given time interval from the reach immediately upstream and from the land area contiguous to the reach. The incremental volume of flow is added to that volume of water already in the reach at the beginning of the time interval, and the Manning equation is then used to estimate the discharge from the reach during the time interval. The volume of water in the reach at the end of the time interval is then calculated as the initial volume plus the inflow volumes, minus the outfall volume. The above computational process is then

Figure 3

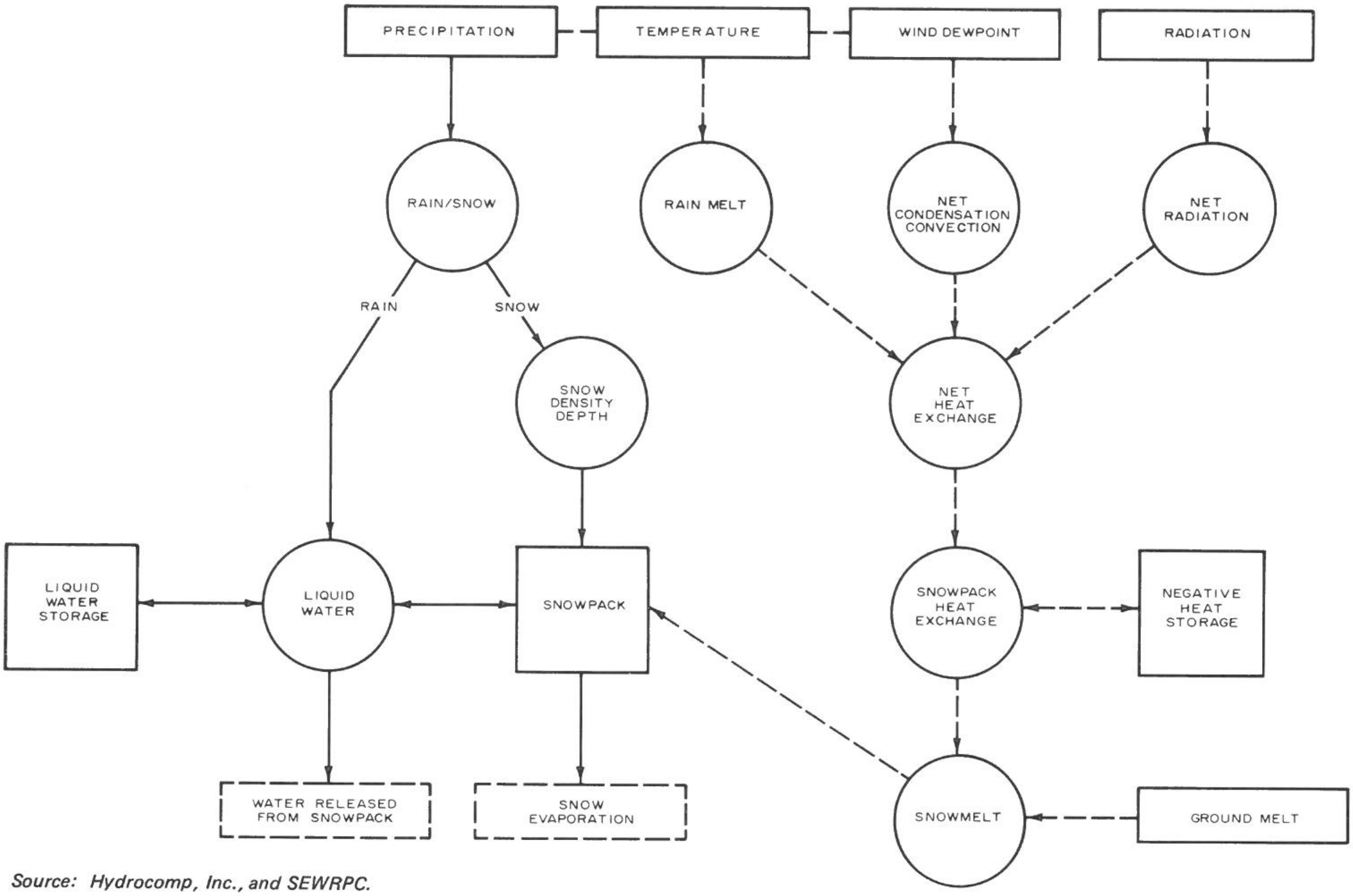
INTERDEPENDENCE BETWEEN PROCESSES IN THE HYDROLOGIC SUBMODEL



Source: Hydrocomp, Inc., and SEWRPC.

Figure 3 (continued)

FLOWCHART FOR SNOWMELT SUBROUTINE



Source: Hydrocomp, Inc., and SEWRPC.

repeated for the next time interval and, as in the case of the first time interval, the discharge from the reach is obtained. The channel routing computations proceed in a similar manner for subsequent time intervals for the reach in question and for all other reaches, thus effectively simulating the passage of water through the channel system.

Impoundment routing through lakes or reservoirs is accomplished on a continuous basis using the technique known as reservoir routing. Use of this analytic procedure requires that a stage-discharge-cumulative storage relationship be established for each impoundment, with the values selected so as to encompass the entire range of physically possible impoundment water surface elevations. As simulated by the reservoir routing algorithm, a volume of flow enters the impoundment during a particular time interval, with the origin of the flow being the discharge from a reach or impoundment immediately upstream, the discharge from the land area contiguous to the impoundment, and precipitation falling directly on the reservoir surface. The incremental volume of flow is then added to the volume of water already in the impoundment at the beginning of the time interval, and the stage-discharge-cumulative volume relationship is then used to estimate the discharge from the impoundment during the time interval. The volume of water stored in the impoundment at the end of the time interval is calculated as the initial volume plus the inflow volume, minus the outfall volume and the volume of water evaporated directly from the impoundment surface. This computational process is repeated through subsequent time intervals, with the result of each computation providing the stage and discharge of the impoundment at the end of each time interval.

Table 3

METEOROLOGICAL DATA SETS AND THEIR USE IN THE HYDROLOGIC AND WATER QUALITY SUBMODELS APPLIED IN THE AREAWIDE WATER QUALITY MANAGEMENT PLANNING PROGRAM

Data Set	Units	Frequency		Origin of Data		Use in Hydrologic Submodel	Use in Water Quality Submodel	Use in Synthesizing Other Meteorological Input Data for the Submodels
		Desirable	Allowable	Historic	Computed			
Precipitation	10^{-2} inches	Hourly or more frequent	Daily	X	--	Rain or snowfall applied to the land Data from hourly stations used to disaggregate data from daily stations	--	--
Radiation	Langleys/ Day[a]	Daily	Semimonthly	–	X	Snowmelt	Water temperature-heat flux to water by short wave solar radiation	Compute potential evaporation
Potential Evaporation	10^{-3} inches	Daily	Semimonthly	–	X	Evaporation from lakes, reservoirs, wetlands, depression storage, and interception storage Evapo-transpiration from upper zone storage, lower zone storage, and groundwater storage Evaporation from snow	--	--
Temperature	^{o}F	Daily (maximum and minimum)	–	X	--	Snowmelt Density of new snow Occurrence of precipitation as snow	Water temperature-heat flux to water surface by long wave solar radiation Water temperature-Heat flux from water by conduction-convection	Average daily temperature used to compute evaporation
Wind Movement	Miles/Day	Daily	--	X	--	Snowmelt by condensation-convection Evaporation from snow	Water temperature-heat loss from water surface by evaporation Lake reaeration	Compute evaporation
Dewpoint-Temperature[b]	^{o}F	Daily	Semimonthly	X	--	Snowmelt by condensation-convection Evaporation from snow	Water temperature-heat loss from water surface by evaporation	Compute evaporation
Cloud Cover	Decimal fraction	Daily	Semimonthly	X	--	–	Water temperature-heat flux to water surface by long wave solar radiation.	--
Sunshine	Percent possible	Daily	--	X	--	--	--	Compute solar radiation which was in turn used to compute evaporation.

[a] Solar energy flux—that is, the rate at which solar energy is delivered to a surface, such as the earth's surface—is expressed in terms of energy per unit area per unit time. The langley expresses energy per unit area and is equivalent to 1.0 calories/cm^2 or 3.97 x 10^{-3} BTU/cm^2. Therefore, a langley/day, which expresses solar energy flux in terms of energy per unit area per unit time, is equivalent to 1.0 calories/cm^2/day or 3.97 x 10^{-3} BTU/cm^2/day. The solar energy flux above the earth's atmosphere and normal to the radiation path is about 2,880 langleys/day.

[b] Dewpoint temperature is the temperature at which air becomes saturated when cooled under conditions of constant pressure and constant water vapor content.

Source: Hydrocomp, Inc., and SEWRPC.

Table 4

PARAMETERS REQUIRED FOR EACH HYDROLOGIC LAND SEGMENT SIMULATED WITH THE HYDROLOGIC SUBMODEL

Parameter		Definition or Meaning	Unit	Primary Source of Numerical Value[a]
Number	Symbol			
1	K1	Ratio of average annual segment precipitation to average annual precipitation at measuring station	None	Isohyetal map of annual precipitation
2	A	Impervious area factor related to directly connected impervious area in segment as a percent of total area	None	Aerial photographs
3	EPXM	Maximum interception storage	Inches	Extent and type of vegetation as determined from aerial photographs and field examination
4	UZSN	Nominal transient groundwater storage in the upper soil zones	Inches	A function of LZSN and therefore determined primarily by calibration
5	LZSN	Nominal transient groundwater storage in the lower soil zones	Inches	Related to annual precipitation but determined primarily by calibration
6	K3	Evaporation loss index: percent of segment area covered by deep-rooted vegetation	None	Extent and type of vegetation as determined from aerial photographs and field examination
7	K24L	Decimal fraction of the groundwater recharge that percolates to deep or inactive groundwater storage	None	[b]
8	K24EL	Decimal fraction of land segment with shallow groundwater subject to direct evapotranspiration	None	Soils and topographic data
9	INFILTRATION	Nominal infiltration rate	None	Calibration
10	INTERFLOW	Index of Interflow	None	Calibration
11	L	Average length of overland flow	Feet	Topographic maps
12	SS	Average slope of overland flow	None	Topographic maps
13	NN	Manning roughness coefficient for overland flow	None	Field reconnaissance
14	IRC	Interflow recession rate	None	Hydrograph analysis
15	KK24	Groundwater recession rate	None	Hydrograph analysis
16	KV	Variable to permit the KK24 to vary with the groundwater slope	None	--[b]
17	RADCON	Adjust theoretical snowmelt equations to field conditions	None	--[b]
18	CONDS-CONV	Adjust theoretical snowmelt equations to field conditions	None	--[b]
19	SCF	Adjust snowfall measurements to account for typical catch deficiency	None	--[c]
20	ELDIF	Elevation of segment above mean elevation of temperature station	10^3 feet	Topographic maps
21	IDNS	Density of new snow at 0^oF	None	--[b]
22	F	Decimal fraction of land segment with forest cover	None	Aerial photographs
23	DGM	Groundmelt rate attributable to conduction of heat from underlying soil to snow	Inches/day	--[b]
24	WC	Maximum water content of the snowpack, expressed as a fraction of the water equivalent of the pack, that is, the maximum amount of liquid water that can be accumulated in the snowpack	None	--[c]
25	MPACK	Water equivalent of snowpack when segment is completely covered by snow	Inches	--[b]
26	EVAPSNOW	Adjust theoretical snow evaporation equations to field conditions	None	--[b]
27	MELEV	Mean elevation of segment	Feet Sea Level Datum	Topographic map
28	TSNOW	Air temperature below which precipitation occurs as snow	^oF	--[b]

[a] *Regardless of the primary source of parameter values, all land parameters were subject to adjustment during the calibration process.*

[b] *Initial values were assigned based on experience with the Hydrologic Submodel on watersheds having similar geographic or climatological characteristics. For example, refer to "Simulation of Discharge and Stage Frequency for Flood Plain Mapping in the North Branch of the Chicago River" by Hydrocomp, Inc., for the Northeastern Illinois Planning Commission, February 1971, 75 pp.*

[c] *Initial values were assigned based on information and data reported in hydrology textbooks. For example, refer to R. K. Linsley, M. A. Kohler, and J. L. H. Paulhus, Hydrology for Engineers, Second Edition, McGraw-Hill, N. Y. 1975.*

Source: Hydrocomp, Inc., and SEWRPC.

Table 5

HYDRAULIC CHANNEL PARAMETERS REQUIRED FOR EACH REACH

DISCHARGE-RELATED PARAMETERS FOR STREAMS

Parameter		Definition of Meaning	Unit	Primary Source of Numerical Value
Number	Symbol			
1	REACH	Reach identification number	None	Assigned so as to increase in the downstream direction
2	LIKE	Permits repeating W1, W2, H, S-FP, N-CH, and N-FP of a preceding reach by entering the number of that reach	None	- -
3	TYPE	Indicates the type of channel or the presence of an impoundment. PHBE indicates a stream reach. RESR indicates an impoundment	None	Observed condition of existing stream system or hypothetical future condition of stream system
4	TRIB	Identification number of the reach that the reach in question is tributary to	None	Stream system configuration and assigned identification numbers
5	SEGMT[a]	Index number of land segment type tributary to reach	None	Map of watershed subbasins and stream system
6	TRIB-AREA[a]	Watershed area directly tributary to reach	Square Miles	- -

CROSS SECTION-RELATED PARAMETERS

Parameter		Definition of Meaning	Unit	Primary Source of Numerical Value
Number	Symbol			
7	LENGTH	Length of reach	Miles	Map of watershed subbasins and stream system
8	EL-UP	Channel bottom elevation at upstream end of reach	Feet	Channel bottom profile
9	EL-DOWN	Channel bottom elevation at downstream end of reach	Feet	- -
10	W1	Channel bottom width	Feet	Generalized, representative reach floodland cross-section constructed from detailed cross-sections prepared for Hydraulic Submodel 2
11	W2	Channel bank-to-bank width	Feet	
12	H	Channel depth	Feet	
13	S-FP	Lateral slope of the floodplains	None	

Table 5 (continued)

ROUGHNESS COEFFICIENTS

Parameter		Definition of Meaning	Unit	Primary Source of Numerical Value
Number	Symbol			
14	N-CH	Manning roughness coefficient for the channel	None	Coefficients established for Hydraulic Submodel 2 revised as needed during calibration
15	N-FP	Manning roughness coefficient for both floodplains	None	
16	KC	Storage constant when lake is below bankfull	Cubic Feet per Second per Acre-Foot	Storage-discharge curves derived from hydrographic and structure surveys
17	HEXC	Storage exponent when lake is below bankfull	None	
18	KF	Storage constant when lake is above bankfull	Cubic Feet per Second per Acre-Foot	
19	HEXF	Storage exponent when lake is above bankfull	None	
20	VB	Lake volume at bankfull	Acre-Foot	
21	VL	Lake volume at spillway crest[b]	Acre-Foot	

[a]*Specifies the three dominant segment types and associated areas tributary to each stream reach.*

[b]*Also specifies volume and depth of lower layers for stratified lakes.*

Source: Hydrocomp, Inc., and SEWRPC.

Water Quality Submodel

The principal function of the Water Quality Submodel as used in the areawide water quality management planning program is to simulate the time-varying concentrations or loadings of some or all of the following water quality indicators at selected points throughout the surface water system of the Region: temperature, dissolved oxygen, fecal coliform organisms, phosphate-phosphorus, total dissolved solids, carbonaceous biochemical oxygen demand, ammonia-nitrogen, nitrate-nitrogen, nitrite-nitrogen, algae, zooplankton, and chlorides, as well as other conservative constituents. These water quality indicators were selected because they are directly related to the water quality standards that support the adopted water use objectives for the Region.[11] The analysis of the simulated concentrations of the various water quality indicators provides an estimate of the effect on water quality of alternative measures to control both point and nonpoint (diffuse) sources of pollutants.

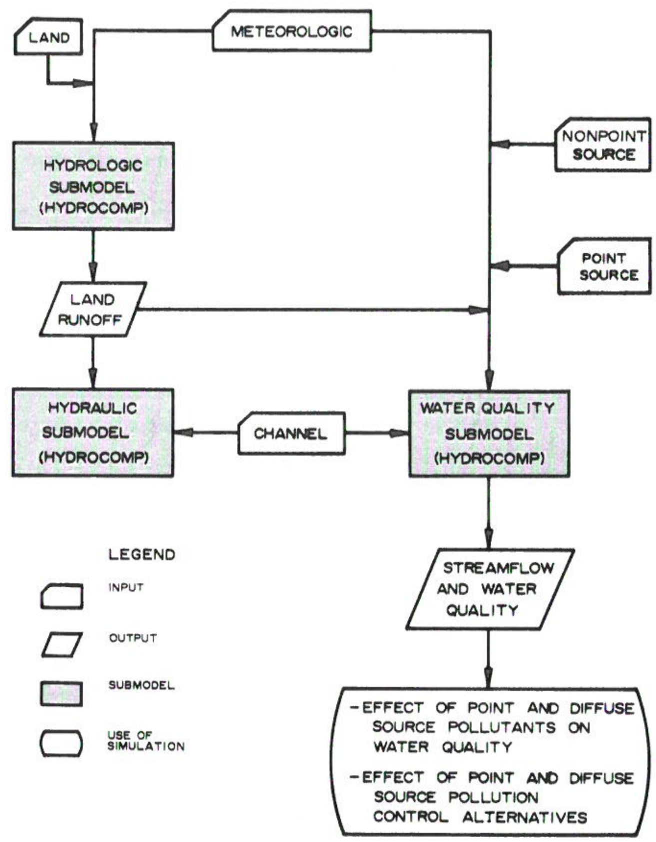
The concentration or loading of a particular water quality constituent in the surface waters of the Region at a particular point in time is the function of three factors. The first factor is the temporal and spatial distribution of runoff, which determines the volume of water available to transport a potential pollutant to

[11] *See Chapter IV of SEWRPC Planning Report No. 30, A Regional Water Quality Management Plan for Southeastern Wisconsin: 2000, Volume Two, Alternative Plans.*

and through the surface water system. The second factor is the nature and use of the land, with emphasis on those features that affect both the quantity and quality of point and nonpoint sources of pollutants. The third factor includes those characteristics of the stream system that determine the rate and manner in which a water quality constituent is either assimilated or transported from the watershed.

Figure 4

SCHEMATIC PRESENTATION OF HYDROLOGIC-HYDRAULIC WATER QUALITY SIMULATION MODEL



Source: SEWRPC.

The simulation of these three factors requires a large and diverse data base. As shown in Figure 4, the operation of the Water Quality Submodel requires the input of five data sets—meteorologic, land, channel, nonpoint source, and point source—as well as output from the Hydrologic Submodel. The historic meteorologic data that are used as input, either directly or indirectly, to the Water Quality Submodel are described in Table 3. The channel data required for the hydraulic portions of the Water Quality Submodel are similar to those that are required for the Hydraulic Submodel, discussed earlier in this article and set forth in Table 5. In addition, a considerable amount of nonhydraulic channel data must be provided. These data consist primarily of reach-dependent water quality parameters and coefficients, such as the maximum benthic algae concentration, deoxygenation coefficient, and nutrient loading rates from benthic deposits for each reach. These nonhydraulic channel data are listed and described in Table 6.

The basic conceptual unit upon which the Water Quality Submodel operates is called the water quality land segment type. A water quality land segment type is defined as a unique combination of meteorological characteristics, such as precipitation and temperature; land characteristics, such as the proportion of land surface covered by impervious surfaces; soil type; vegetative cover; and land management practices, such as contour plowing on agricultural land and street sweeping in urban areas. A strict interpretation of this definition results in a virtually infinite number of unique water quality land segment types within even a small watershed because of the large number of possible combinations of the above-mentioned characteristics within a watershed that exhibit continuous, as opposed to discrete, spatial variations throughout the watershed. To apply the concept, the study area is divided into water quality land segments. A water quality land segment is defined as a surface drainage unit which exhibits the pollutant runoff characteristic of a specific water quality land segment type. Thus, the practical, operational definition of a water quality land segment is a surface drainage unit consisting of a subbasin, or a combination of subbasins, which can be considered to be represented by a particular water quality land segment type.

Water quality land segment types and water quality land segments are refinements of hydrologic land segment types and hydrologic land segments in that they incorporate the pollutant runoff characteristics of the land. For a given hydrologic land segment, the different types of land management practices that affect pollutant runoff will produce different water quality response although the same hydrologic response. Thus, several water quality land segments may have to be identified within a single hydrologic land segment.

Table 6

STREAM REACTION WATER QUALITY PARAMETERS[a]

Parameter	Definition
Quality	
RCH	Reach number
LIKE	Reach number of reach with identical reaction rates
KBOD	Biochemical oxygen demand decay coefficient per hour at $20^{\circ}C$
KSET	Biochemical oxygen demand settling rate in feet per hour
KDO	Re-aeration correction factor
KEXP	Exposure factor
KSA	Surface area factor
KSD	Fecal coliform die-away coefficient
BASEXT	Base extinction coefficient per foot
KNH320	Ammonia oxidation rate per hour at $20^{\circ}C$
ABENT20	Benthal oxygen demand in milligrams oxygen per square meter per hour at $20^{\circ}C$
Bottom	
RELE1B	Biochemical oxygen demand aerobic release rate in milligrams biochemical oxygen demand per square meter per hour
RELE2B	Biochemical oxygen demand release rate in milligrams biochemical oxygen demand per square meter per hour
RELE1P	Phosphate aerobic release rate in milligrams phosphorus per square meter per hour
RELE2P	Phosphate anaerobic release rate in milligrams nitrogen per square meter per hour
RELE1N	Ammonia aerobic release rate in milligrams nitrogen per square meter per hour
RELE2N	Ammonia anaerobic release rate in milligrams nitrogen per square meter per hour
Lands	
KEVAP	Evaporation coefficient
KCOND	Conduction coefficient
KATRAD	Atmospheric long-wave radiation coefficient
Watershed	
ALPHAZ	Advection averaging coefficient
ALRAT	Ratio of chlorophyll-a to phosphorus in algae
RIMP	Impervious surface washoff coefficient
RSUR	Pervious surface washoff coefficient
SRAB	Fraction of solar radiation absorbed in first meter of water
VELB	River velocity above which scouring occurs
NONREF	Degradable fraction of algae
ALRES	Algal respiration rate
VMAXL	Maximum light limited algal growth rate
VMAXP	Maximum phosphorus limited algal growth rate
VMAXN	Maximum nitrogen limited algal growth rate
SUPSAT	Maximum degree of super saturation permitted
OQ	Photosynthetic oxygen coefficient
SINK	Algal sinking rate in reservoirs
SINKC	Algal sinking rate in rivers
TETNIF	Nitrification temperature correction factor
THETBOD	Biochemical oxygen demand oxidation temperature correction factor
GRAZ20	Zooplankton filtering rate at $20^{\circ}C$ in liters per milligram zooplankton per hour

[a] *The primary sources of water quality coefficient data are limited to previous studies and experienced judgment. The state-of-the-art regarding water quality systems analysis prohibits direct measurement of most water quality reaction coefficients.*

Source: Hydrocomp, Inc., and SEWRPC.

A nonpoint source pollutant data set is required for each water quality indicator that is to be modeled for each water quality land segment. Each data set contains the daily land surface loading rates for both the pervious and impervious portions of the water quality land segment, expressed as a weight per unit area, and a loading limit for the pervious and impervious areas, expressed as a multiple of the daily loading rate. This loading limit, which is approached asymptotically if no washoff occurs over a period of time, reflects such phenomena as the frequency and efficiency of street cleaning, the natural decay processes of the various water quality constituents, and the removal of material by wind action. The nonpoint source data sets for each water quality land segment also contain the concentration of each constituent in the groundwater flow to the stream system. The nonpoint source loading parameters are summarized in Table 7.

Table 7

NONPOINT SOURCE POLLUTANT LOADING PARAMETERS

Parameter	Definition
SEG	Water quality land segment type identification number
CM	Calendar month for which loading rates apply
YI	Loading rate of given pollutant on impervious area in pounds per acre per day
LLI	Maximum load of given pollutant on impervious area in days
YP	Loading rate of given pollutant on pervious area in pounds per acre per day
LLP	Maximum load of given pollutant on pervious area in days
CONC	Concentration of given pollutant in subsurface waters entering the stream

Source: Hydrocomp, Inc., and SEWRPC.

Each point source of pollution similarly requires a data set, consisting of the identification of the river reach to which the point source discharges, the volumetric rate of discharge of the point source, and a series of corresponding concentrations for each of the water quality constituents to be modeled present in the discharge from the point source. The input characterization of both point and nonpoint pollution sources may be varied by the use of seasonal loading rates. The final category of input to the Water Quality Submodel is the output from the Hydrologic Submodel, which consists of hourly runoff volumes from the pervious and impervious portion of each hydrologic land segment, as well as hourly groundwater discharges to the stream system.

For the purpose of describing the operation of the Water Quality Submodel, the water quality simulation process may be viewed as being composed of a land phase and a channel phase, each of which is simulated on an hourly basis. In the land phase, the quantity of a given constituent that is available for washoff from the land at the beginning of a time interval is equal to the amount of pollutant material on the land surface plus the net amount of material that accumulates on the land surface during the time interval, subject to the limiting value of the maximum land surface loadings. The hourly quantity of washoff from the land to the stream system of a pollutant material during a runoff event is proportional to the amount of material on the land surface at the beginning of the interval and is also dependent on the hourly runoff rate. The above process is used to simulate all water quality constituents except temperature and dissolved oxygen in the land surface runoff. The Water Quality Submodel assumes that the temperature of the runoff is equal to the atmospheric temperature at the time of the runoff, and that the runoff is saturated with dissolved oxygen. Runoff from pervious surfaces and runoff from impervious surfaces during and immediately after a rainfall or rainfall-snowmelt event comprise the two mechanisms whereby accumulated nonpoint source pollutant materials are transported from the land surface to the stream system. Groundwater flow is the mechanism for continuously transporting pollutants to the stream system from the subsurface waters of the Region.

Operating on a reach-by-reach basis, the channel phase of the Water Quality Submodel uses kinematic routing to determine the inflow to, outflow from, and net flow within each reach on an hourly basis. This is followed by a summation over the hourly interval of all mass inflows and outflows of each water quality constituent so as to determine an average concentration throughout the reach at the beginning of the one-hour interval based on the assumption of complete, instantaneous mixing. The biochemical processes are then simulated for a one-hour period so as to determine an average reach concentration for each constituent at the end of the hourly interval. The above channel phase computations are then repeated within the reach for each subsequent time interval and for all other reaches.

DATA BASE DEVELOPMENT

The singularly most time-consuming work required in the application of the hydrologic-hydraulic water quality simulation model to the Region was data base development. This consisted of the acquisition, verification, and coding of the data needed to operate, calibrate, validate, and apply the model. As shown schematically in Figure 4, application of the model requires the development of the following five categories of data: meteorologic, land, channel, nonpoint source, and point source. Each of the five categories provides input to at least one of the three submodels. Of the five data types, the acquisition, verification, and coding of the meteorologic data involved the greatest work effort. That data was comprised of 37 years of hourly and daily information on seven meteorologic variables. The meteorologic data were also the most critical to the proper operation of the model in that experience with the model indicated that simulated discharges, stages, and water quality levels are very sensitive to how well the meteorologic data, in particular the hourly precipitation data, represent actual historic meteorologic conditions.

With respect to origin, the data contained in the data base are largely secondary in that they are collations of existing records of past observations and measurements. For example, the bulk of the meteorologic data are secondary in that they were assembled, in large part, from National Weather Service records. Some of the data are primary in that they were obtained from field measurements made during the areawide water quality management planning program. Portions of the physical channel data, for example, were obtained through field surveys conducted during the course of the study. A small fraction of the data are synthetic in that they were calculated from other readily available historic data. Calculated data were prepared by the Commission for model use if historic data were not directly available. For instance, the solar radiation data used are synthetic in that it was necessary to compute solar radiation data from historic percent sunshine measurements because of the absence of long-term historic solar radiation observations in or near the Region, coupled with the impracticality of developing long-term original solar radiation data. The five categories of data identified above constitute the input data needed to operate the simulation model. Calibration data, which are discussed in a subsequent section of this article, are not required to operate the model, but are vital to the calibration of the model. The principal types of calibration data are streamflow and water quality data.

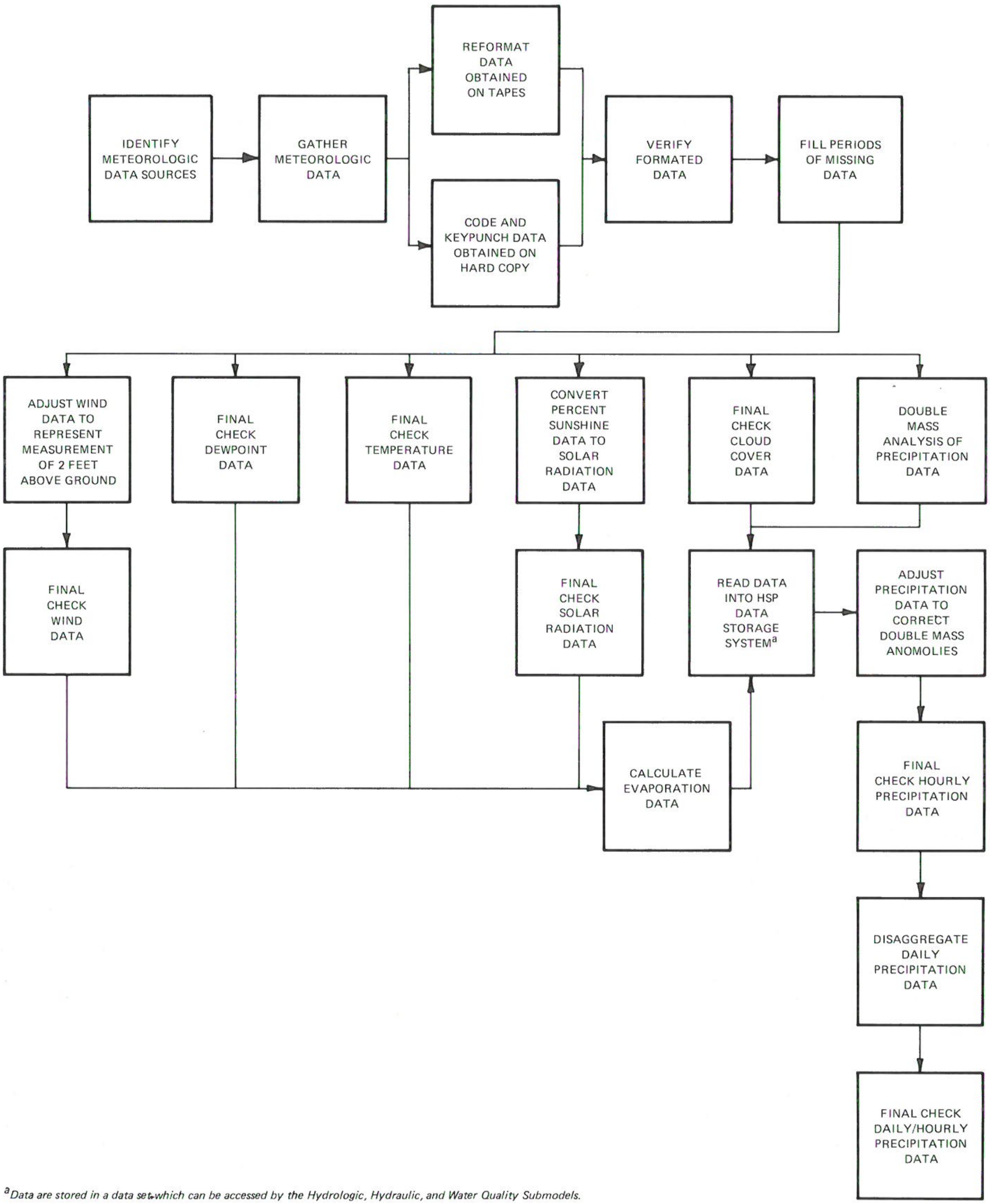
Meteorologic Data

The following seven types of meteorologic data are required as direct input to the Hydrologic and/or Water Quality Submodels: hourly precipitation, daily maximum-minimum temperature, daily wind movement, daily solar radiation, daily dewpoint temperature, daily potential evaporation, and daily cloud cover. Map 3 shows the 32 National Weather Service meteorological observation stations used in or near the Region and the Thiessen polygon network that was constructed to delineate the geographic area to be represented by each station. Daily precipitation and maximum-minimum temperature data were available for all 32 stations. Hourly precipitation data were available only for 8 stations: Milwaukee, Hartford, Eagle, Horicon, El Dorado, and Chilton in Wisconsin, and Rockford and Waukegan in Illinois. Data from these 8 stations were used to disaggregate the daily precipitation data for the other 24 stations. Other meteorologic data sets, such as wind movement and dewpoint temperature, are available only for the Milwaukee and Rockford first order National Weather Service meteorological stations.

The process used to assemble the meteorologic data base is schematically depicted in Figure 5. Selected information about each of the meteorologic data sets is presented in Table 8. Meteorologic data sets were developed for the 37-year period from 1940 through 1976. January 1, 1940, was selected as the beginning date for the meteorologic data sets since it marks the earliest date for which observations of all of the parameters were carried out at the Milwaukee and Rockford National Weather Service stations. Other meteorologic data sets, such as wind movement and dewpoint temperature, which were available only for the Milwaukee and Rockford National Weather Service stations, were applied to the entire Region.

Figure 5

SCHEMATIC REPRESENTATION OF METEOROLOGIC DATA ASSEMBLY



[a] *Data are stored in a data set which can be accessed by the Hydrologic, Hydraulic, and Water Quality Submodels.*

Source: SEWRPC.

Table 8

METEOROLOGIC DATA STATION SUMMARY

Station	Data Set	Data Source(s)[a]	Period of Available Record	Corrections or Adjustments Made[b]
Antioch	Daily Precipitation	NCC, SC, OP	April 1, 1941 - March 31, 1977	- -
Beaver Dam	- -	- -	- -	Not used
Beloit	- -	- -	- -	Not used
Burlington	Daily Precipitation	NCC, SC	August 1, 1948 - March 31, 1977	- -
	Temperature	NCC, SC, OP	October 18, 1951 - March 31, 1977	
Burnett	Hourly Precipitation	NCC, ACOE	January 1, 1940 - November 1970	Not Used
Chilton	Hourly Precipitation	NCC, ACOE	April 1, 1940 - December 31, 1974	May and July of 1940 estimated
Clinton	Daily Precipitation	NCC, SC	January 1948 - March 1977	13 scattered months estimated
Eagle	Hourly Precipitation	NCC, ACOE	April 1, 1940 - December 31, 1972	8 scattered months estimated
El Dorado	Hourly Precipitation	NCC, ACOE	April 1, 1948 - December 1974	- -
Fond du Lac	Daily Precipitation	NCC, SC, OP	January 1, 1940 - March 31, 1977	- -
	Temperature		June 1, 1948 - March 31, 1977	
Fort Atkinson	Daily Precipitation	NCC, SC, OP	January 1, 1945 - March 31, 1977	6 months estimated
	Temperature	NCC, SC, OP	June 1, 1948 - March 31, 1977	6 months estimated
Germantown	Hourly Precipitation	NCC	January 1, 1940 - March 31, 1977	- -
	Temperature	NCC	January 1, 1940 - March 31, 1977	
	Daily Precipitation	NCC	January 1, 1940 - March 31, 1977	
Hartford	Daily Precipitation	NCC, OP, SC	August 22, 1948 - March 31, 1977	16 months estimated
	Temperature		June 1, 1953 - March 31, 1977	1 month estimated
Horicon	Hourly Precipitation	NCC	- -	Data lack required precision
Janesville	Daily Precipitation	NCC	January 1, 1945 - September 30, 1975	- -
	Temperature	NCC	June 1, 1947 - September 30, 1975	- -
	Hourly Precipitation	NCC, SC, OP	January 5, 1941 - December 31, 1974	2 months estimated
Kenosha	Daily Precipitation	NCC	January 1, 1945 - March 31, 1977	5 months estimated
	Temperature	NCC	June 1, 1948 - March 31, 1977	11 months estimated
Lake Geneva	Daily Precipitation	NCC, OP, SC	April 1, 1945 - March 31, 1977	3 months estimated
	Temperature	NCC, OP, SC	April 10, 1945 - March 31, 1977	3 months estimated
Lake Mills	- -	- -	- -	Not used
Marengo	Daily Precipitation	NCC, SC, OP	January 1, 1940 - March 31, 1977	12 months estimated
	Temperature	NCC, SC, OP	March 31, 1977	9 months estimated
Milwaukee-WBAP	Hourly Precipitation	NCC	January 1, 1940 - March 31, 1977	- -
	Cloud Cover	NCC	January 1, 1940 - March 31, 1977	
	Percent Possible Sunshine	NCC	January 1, 1940 - March 31, 1977	
	Temperature	NCC	January 1, 1940 - March 31, 1977	
	Wind	NCC	January 1, 1940 - March 31, 1977	
	Dewpoint	NCC	January 1, 1940 - March 31, 1977	
	Solar Radiation	NCC	January 1, 1940 - March 31, 1977	Calculated from percent possible sunshine
	Potential Evaporation	NCC	January 1, 1940 - March 31, 1977	Calculated from solar radiation, dewpoint, temperature, and wind movement
Milwaukee-Mount Mary	Hourly Precipitation	NCC	January 1, 1940 - March 31, 1977	- -
	Temperature	NCC	January 1, 1940 - March 31, 1977	
	Daily Precipitation	NCC	January 1, 1940 - March 31, 1977	
Milwaukee-North Side	Daily Precipitation	NCC	October 1949 - December 1959 and January 1966 - September 1976	31 months missing
	Temperature	NCC	October 1949 - December 1959 and January 1966 - September 1976	31 months missing
Oconomowoc	Daily Precipitation	NCC, SC, OP	January 1, 1945 - March 31, 1977	5 months estimated
	Temperature	NCC, SC, OP	June 1, 1948 - March 31, 1977	5 months estimated
Plymouth	Daily Precipitation	NCC	January 1, 1940 - March 31, 1977	2 months estimated
	Temperature	NCC, OP, SC	January 1, 1940 - March 31, 1977	3 months estimated
Port Washington	Daily Precipitation	NCC, SC, OP	January 1, 1940 - March 31, 1977	2 months estimated
	Temperature	NCC, SC, OP	August 20, 1959 - March 31, 1977	

Table 8 (continued)

Station	Data Set	Data Source(s)[a]	Period of Available Record	Corrections or Adjustments Made[b]
Racine	Daily Precipitation	NCC, SC, OP, Racine Journal Times	January 1, 1940 - March 31, 1977	- -
	Temperature	NCC, SC, OP, Racine Journal Times	January 1, 1940 - March 31, 1977	
Rockford I	Daily Precipitation	NCC	January 1, 1940 - December 31, 1950	- -
	Temperature	NCC	January 1, 1940 - December 31, 1950	
	Hourly Precipitation	NCC	July 1, 1948 - December 31, 1950	- -
Rockford II	Daily Precipitation	NCC, SC, OP	January 1, 1951- March 31, 1977	- -
	Temperature	NCC, SC, OP	January 1, 1951 - March 31, 1977	
	Hourly Precipitation	NCC, SC, OP	January 1, 1951 - April 31, 1977	
Sheboygan	Daily Precipitation	NCC, SC, OP	January 1, 1940 - March 31, 1977	- -
	Temperature		January 1, 1940 - March 31, 1977	
Union Grove	Daily Precipitation	NCC, SC, OP	January 1, 1945 - March 31, 1977	5 months estimated
	Temperature	NCC, SC, OP	January 1, 1964 - March 31, 1977	
Watertown	Daily Precipitation	NCC, SC	January 1, 1940 - September 30, 1975	1 month estimated
	Temperature	NCC, SC	January 1, 1940 - September 30, 1975	1 month estimated
Waukegan	Daily Precipitation	NCC, SC, OP, Lake County Public Works Department	January 1, 1940 - March 31, 1977	1 month estimated
	Temperature	NCC, SC, OP, Lake County Public Works Department	January 1, 1940 - March 31, 1977	1 month estimated
	Hourly Precipitation	NCC, SC, OP, Lake County Public Works Department	January 1, 1940 - September 30, 1968	1 month estimated
Waukesha	Daily Precipitation	NCC, SC, OP	January 1, 1940 - March 31, 1977	- -
	Temperature	NCC, SC, OP	January 1, 1940 - March 31, 1977	
West Allis	Daily Precipitation	NCC, SC, OP	January 1, 1940 - March 31, 1977	- -
	Temperature	NCC, SC, OP	January 1, 1940 - March 31, 1977	
West Bend	Daily Precipitation	NCC, SC, OP	January 1, 1940 - September 30, 1975	- -
	Temperature	NCC, SC, OP	January 1, 1940 - September 30, 1975	
Whitewater	Daily Precipitation	NCC, SC, OP	June 1, 1948 - March 31, 1977	- -
	Temperature	NCC, SC, OP	October 13, 1949 - March 31, 1977	

[a] *NCC: National Climatic Center and Weather Bureau publications.*
SC: State Climatologist.
OP: Operator.
ACOE: Army Corps of Engineers.

[b] *Minor adjustments were made to all records to fill in short periods of missing data.*

Source: SEWRPC.

Most of the meteorologic data used to construct the data base were obtained by the Commission directly from the National Climatic Service, located in Asheville, North Carolina—the official repository for all National Weather Service data. Meteorologic data were also obtained from other sources when necessary, including the Office of the State Climatologist in the Wisconsin State Geological Survey, the Chicago District Office of the U. S. Army Corps of Engineers, historic newspaper records, selected public work departments, and weather station operators themselves.

Land Data

As shown in Figure 4, land data are needed to operate the Hydrologic Submodel, the outputs of which are in turn needed by the Hydraulic and Water Quality Submodels. Table 4 identifies the 28 land or land-related parameters required for each land segment type defined earlier in this report. A land segment type is represented by a unique combination of meteorological conditions, and two key land characteristics: soil type and land use or cover. These three factors are considered to be the major determinants of the magnitude and timing of surface runoff, interflow, and groundwater contribution to the watershed stream system. Therefore, these factors provide the basis for defining the hydrologic and water quality land segment types. Other land characteristics may influence the hydrologic response of the land surface—for example, slope, depth to bedrock, type of vegetation, and the density of the storm water drainage system—but soil type and land use and cover were selected as the most basic and most representative characteristics.

Identification of Hydrologic Subbasins: The process used to identify hydrologic land segments in the Region began with the subdivision of the watersheds of the Region into subbasins, as discussed above. A total of 2,176 subbasins were delineated in the 12 watersheds, and ranged in size from 0.02 square mile to 6.32 square miles. These subbasins form the basic "building blocks" for identifying hydrologic land segments and subsequently the water quality land segments in a watershed.

Influence of Meteorological Stations: As noted earlier in this report, and as shown on Map 3, a Thiessen polygon network was constructed for the Region and surrounding areas in order to facilitate the subdivision of the Region into areas related to the 32 meteorological stations used in the water quality modeling. The polygon boundaries were approximated by subbasin boundaries, and each subbasin was accordingly assigned to one of the meteorological stations. Thus, each subbasin in the Region was associated with the closest meteorological station, and thereby to representative meteorological conditions.

Hydrologic Soil Groups: The soils of the Region have been classified into four hydrologic soil groups, designated A, B, C, and D, based upon those soil properties affecting runoff. This soil classification system was developed by the Soil Conservation Service of the U. S. Department of Agriculture specifically for use in hydrologic work. In terms of runoff characteristics, these four soil groups range from the Group "A" soils—which exhibit relatively low runoff because of high infiltration capacity, high permeability, and good drainage—to group "D" soils—which exhibit relatively high runoff because of low infiltration capacity, low permeability, and poor drainage. Each subbasin was identified with a specific dominant hydrologic soil group. In some cases, no one soil group was dominant, and classifications of AB, BC, and CD soil groups were used.

Slope: A slope analysis was conducted by determining the ground slope at the centers of the U. S. Public Land Survey quarter sections within the Region. Topographic information required to estimate the ground slope was taken from U. S. Geological Survey quadrangle maps. Although more accurate slope values could have been obtained for some areas of the Region from large-scale topographic maps, or for almost all of the Region from the Commission's soil maps, these sources of information were not used because the resulting accuracy would have exceeded that required by the model. Slope values were found to vary up to 20 percent. The slope range representative of each subbasin was noted and assigned. A characteristic slope was then computed and assigned for each meteorological station within each watershed.

Land Use and Cover: Land use and cover are the characteristics that most reliably reflect man's influence on the hydrology and related water quality conditions in a watershed. Table 9 lists the five land use and cover types identified for use in delineating hydrologic land segments. Table 10 lists the 21 land use and cover types identified for use in delineating water quality land segments. These 21 land use and cover types encompass the spectrum of probable future, as well as existing, conditions in the Region and its watersheds.

The three land use and cover types most representative of each of the subbasins were determined and assigned to the subbasins. Information used to determine the land use and cover included current 1" = 400' scale aerial photographs—prepared as part of the Commission's ongoing land use and transportation planning program—and plan design year 2000 land use conditions.

Table 9

LAND USE AND COVER CLASSIFICATIONS USED IN DEFINING HYDROLOGIC LAND SEGMENT TYPES

Land Use and Cover Classification	Characteristic Percent Impervious
Rural	1.5-3
Low-Density Development.	11
Medium-Density Development	30
High-Density Development	50
Very High-Density Development . . .	60

Source: SEWRPC.

Table 10

LAND USE AND COVER CLASSIFICATIONS USED IN DEFINING WATER QUALITY LAND SEGMENT TYPES

Water Quality Land Use and Cover Classification	Corresponding Hydrologic Land Use and Cover
Golf Course	Rural
Other Recreation	Rural
Row Crop	Rural
Grain	Rural
Vegetables and Other Agriculture	Rural
Hay	Rural
Orchard and Nursery	Rural
Sod Farm	Rural
Woodland	Rural
Other Open Land	Rural
Commercial	High density
Industrial	High density
Landfill	High density
Extractive	High density
Highway	High density
Railroad	High density
Airfield	High density
Low Residential	Low density
Medium Residential	Medium density
High Residential	High density
Very High Residential	Very high density

Source: SEWRPC.

The delineated hydrologic subbasins were translated from USGS 7.5-minute quadrangle maps to sepia overlays uniquely prepared for each individual aerial photograph. These overlays were prepared on the Commission computer-driven Calcomp table plotter, using data tapes of the subbasin delineations developed on the Commission's digitizing system, with the tapes processed for scale conversion on the SEWRPC IBM 370-Model 165 digital computer. The overlays were used to delineate the land cover categories described elsewhere in this article, and to quantify the extent of the land cover within the subbasins through measurement by dot counting. The dot-counted areas were adjusted to the acreage control totals for the aerial photographs. The extent of land cover within the various subbasins was then totaled by computer processing operations, and printouts were prepared for use by the Commission staff. Subsequently, the printouts served as the basis for the assignment of runoff factors to characterize the three dominant land covers for existing and planned future land cover conditions in each water quality land segment in the Region. A Commission check indicated that this procedure resulted in land cover assignments with an accuracy roughly equivalent to that achieved by quarter-section approximation of land cover in the watersheds. Moreover, the rates and amounts of storm water runoff and snowmelt—and their routing through the watersheds—could be expected to be better represented by this method than by rectilinear approximation of subbasins or subwatersheds.

Resulting Hydrologic and Water Quality Land Segment Types: Each hydrologic land segment type represents a unique combination of watershed, meteorological station, soil type, and land use and cover classifications, as illustrated in Figure 1. There are 12 x 32 x 7 x 5 possible combinations of these characteristics, hence a total of 13,440 unique hydrologic land segment types are possible within the Region. Not all meteorological stations, soil types, or land uses, however, are represented in all of the watersheds of the Region. Thus, the actual number of hydrologic land segment types defined is smaller. There are 12 x 32 x 7 x 21 possible combinations of characteristics determining water quality land segment types, hence a total of 56,448 water quality land segment types are possible within the Region. Again, the actual number defined is much lower.

The hydrologic characteristics of each hydrologic land segment were described for input to the mathematical model by a unique set of values assigned to the parameters listed in Table 4. Each water quality land segment was described for input to the model by reference to the representative hydrologic land segment and to a value for the parameters listed in Table 7.

Channel Data

The flow and pollutant assimilative capacity of streams and the flushing and stratification characteristics of lakes are largely a function of stream and lake geometry. Detailed information on lake geometry was available for most major lakes through the Wisconsin Department of Natural Resources hydrographic surveys. Stream channel geometry measurements, including stream bottom elevations, channel bottom and channel top widths, channel depths, and floodland slope, were available for some stream reaches within the Region from the U. S. Army Corps of Engineers and the U. S. Department of Agriculture, Soil Conservation Service, and from previous Commission studies. These sources were supplemented by additional data collected in field surveys conducted as a part of the areawide water quality management planning program. From inventories and field surveys, 1,862 hydraulic structures were documented. For the significant structures on the stream reaches selected for simulation, further surveys were conducted that included taking photographs of waterway conditions for use in the estimation of Manning's "n" roughness coefficients for streams and floodplains. These structure surveys were conducted for 424 bridges, culverts, and dams. In addition, channel and floodplain cross sections were measured at 390 locations in the Region. The resulting elevations and sketches were used in characterizing the stream reaches analyzed. The locations of the structures and reaches for which cross sections were measured are set forth on Map 4. Data were already available in the Commission files for more than 923 structures and for cross sections for more than 635 stream miles as a result of earlier studies conducted in the Region.

Each stream in the Region was segmented into homogeneous reaches, ranging from about 0.5 mile to about 3.0 miles in length. Each reach was described for use in the model by a unique set of numerical values assigned to the hydraulic parameters described in Table 5 and by the water quality parameters described in Table 6. Representative values of water quality coefficients used in modeling southeastern Wisconsin streams are presented in Table 11.

Nonpoint Source Data

Figure 4 illustrates that nonpoint source pollution data are required as input to the Water Quality Submodel, along with meteorologic, land, channel, and point source data. The nonpoint source data must describe the accumulation of pollutants on the land surface and the variation in these accumulations from one land use or cover to another so that model washoff algorithms may properly calculate the accumulated pollutant available for washoff. Table 7 presents the pertinent nonpoint source parameters.

The choice of initial numerical values for the nonpoint source pollution parameters was based primarily on values reported in literature on areas similar to southeastern Wisconsin. Values calibrated in the water quality modeling of the Menomonee River provided useful initial values for many urban land uses.[12] Some of the initial values assigned to nonpoint source pollution parameters were adjusted during the calibration process to improve the correlation between measured and simulated water quality.

A unique set of numerical values describing the nonpoint source parameters was assigned to each water quality land segment type. Typical values assigned to the various dominant land use and cover types are listed in Table 12. The nonpoint source parameters used incorporated seasonal variations intended to reflect changes in vegetal cover and fertilizer application rates.

Point Source Data

Point sources discharge pollutants that can significantly affect surface water quality, particularly during low flow conditions. It is necessary to define the temporal and spatial variation in point source discharges in order to understand their effects on the surface water system. Point source data requirements and the data sources generally used are presented in Table 13.

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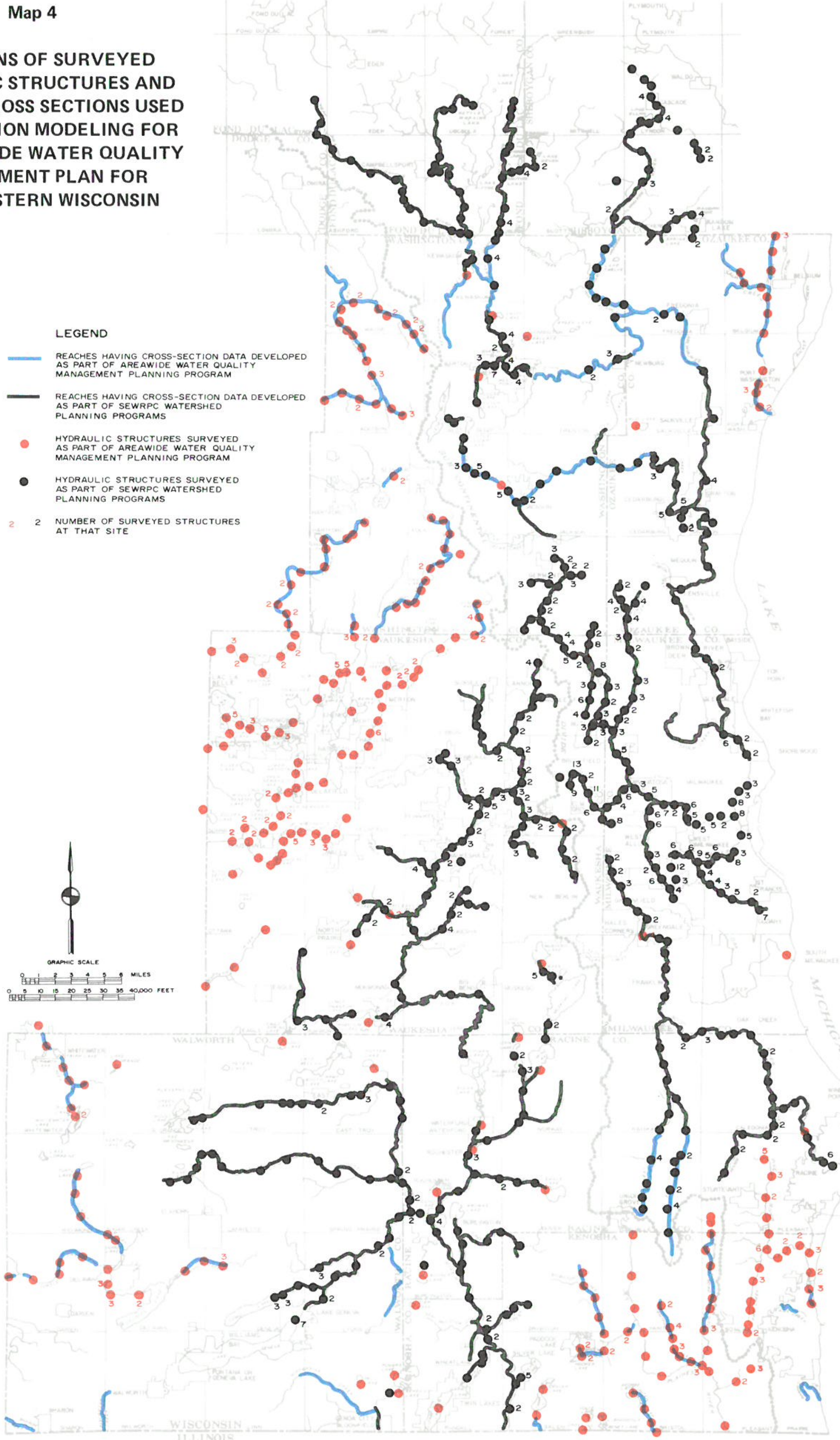
[12] *See SEWRPC Planning Report No. 26, A Comprehensive Plan for the Menomonee River Watershed, October 1976.*

Map 4

LOCATIONS OF SURVEYED HYDRAULIC STRUCTURES AND CHANNEL CROSS SECTIONS USED IN SIMULATION MODELING FOR THE AREAWIDE WATER QUALITY MANAGEMENT PLAN FOR SOUTHEASTERN WISCONSIN



Source: SEWRPC.

Table 11

TYPICAL VALUES ASSIGNED TO STREAM REACTION WATER QUALITY PARAMETERS

Parameter	Typical Value Assigned
Quality	
KBOD	0.01
KSET	0.01
KDO	1.00
KEXP	0.70
KSA	1.00
KFD	0.20
BASEXT	0.30
KNH320	0.05
ABENT20	50.00
Bottom	
RELE1B	0.10
RELE2B	0.20
RELE1P	0.00
RELE2P	0.00
RELE1N	0.00
RELE2N	0.00
Lands	
KEVAP	2.24
KCOND	6.12
KATRAD	9.37-12.0
Watershed	
ALPHA	0.70
ALRAT	0.60
RIMP	0.50
RSUR	1.64
SRAB	0.35
VELB	10.00
NONREF	0.50
ACRES	0.002
VMAXL	0.30
VMAXP	0.30
VMAXN	0.30
SUPSAT	1.15
OQ	1.63
SINK	0.01
SINKC	0.01
TETNIF	1.10
THETBOD	1.05
GRAZ20	0.005

Source: SEWRPC.

It must be understood that the historic data available from the various sources provide a basis for only a limited understanding of the nature of the point discharges. Data describing adequately the hourly variations in the quality, as well as quantity, of discharge from sewage treatment plants were generally lacking, although such variations are important to an understanding of effluent flows affected by excessive inflow or by variations in industrial loadings. The daily and monthly monitoring data, although considered adequate to provide a general understanding of the nature of the discharges involved, were considered subject to question and modification during model calibration. In some cases, proper calibration required a further inventory of effluent characteristics or a further analysis of the likely effect of the known unit processes applied for wastewater treatment. As necessary, the Commission staff contacted the operator or the operating agency responsible for a pollution source in order to check for any special circumstances that may have affected the effluent character during the period used for model calibration.

Calibration Data

The five categories of data discussed above—meteorologic, land, channel, nonpoint source pollution sources, and point source pollution sources—constitute the total input data for operation of the hydrologic-hydraulic water quality simulation model. Of equal importance are calibration data which—although not needed to operate the model—are necessary for adjustment of the model parameters to reflect local conditions. The calibration data are derived strictly from field measurements and include actual recorded streamflow and water quality data. Since calibration data represent the actual historic response of the watershed to a variety of hydrologic-meteorologic events and conditions, such data may be compared to the simulated response to the same conditions. By iterative testing and adjustment, the model may thus be calibrated.

Streamflow Data: Continuous streamflow data are available from 15 streamflow gaging station locations within the Region, and are maintained cooperatively by the U. S. Geological Survey, local units of government, and the Commission. In addition, four sites maintained by other agencies in cooperation with the USGS were used, two of these sites being outside the Region. The locations and period of record of available data for these 19 streamflow gages are summarized in Table 14. The daily streamflow records for these gages are published by the U. S. Geological Survey in the annual report, Water Resources Data for Wisconsin.

Table 12

TYPICAL VALUES ASSIGNED TO NONPOINT SOURCE PARAMETERS

Pollutant	Loading Limits: Impervious	Loading Limits: Pervious	Parameter[a]	Land Use: Golf Course	Other Recreation	Row Crop	Grain	Vegetables and Other Agriculture	Hay	Orchard and Nursery	Sod Farm	Woodland
Biochemical Oxygen Demand	15	15	YI	0.03	0.06	0.06	0.06	0.06	0.06	0.17	0.22	0.17
			YP	0.06	0.12	1.64	1.03	1.64	0.08	0.01	6.56	0.01
			CONC	2	2	2	2	2	2	2	2	2
Ammonia-Nitrogen	15	15	YI	0.02	0.01	0.002	0.004	0.004	0.002	0.01	0.005	0.01
			YP	0.01	0.001	0.005	0.005	0.005	0.0005	0.001	0.014	0.001
			CONC	0.06	0.05	0.15	0.15	0.10	0.15	0.10	0.15	0.10
Nitrate-Nitrogen	20	20	YI	0.0008	0.02	0.006	0.006	0.02	0.006	0.02	0.02	0.02
			YP	0.003	0.003	0.008	0.002	0.008	0.0003	0.0006	0.02	0.0006
			CONC	6	6	6	6	6	6	6	2	6
Phosphate-Phosphorus	15	15	YI	0.003	0.002	0.001	0.002	0.002	0.001	0.002	0.003	0.002
			YP	0.004	0.001	0.0006	0.0002	0.0006	0.0001	0.001	0.002	0.001
			CONC	0.02	0.015	0.0002	0.0002	0.0002	0.0002	0.015	0	0.015
Fecal Coliform	20	20	YI	100	250	100	250	250	100	100	100	100
			YP	10	10	0.13	0.13	0.13	50	10	0.13	10
			CONC	300	300	600	300	300	600	350	600	350
Organic Nitrogen	20	20	YI	0.0001	0.007	0.002	0.007	0.007	0.002	0.007	0.005	0.007
			YP	0.002	0.002	0.002	0.003	0.002	0.001	0.001	0.005	0.001
			CONC	2	2	2	2	2	2	2	2	2

Pollutant	Loading Limits: Impervious	Loading Limits: Pervious	Parameter[a]	Land Use: Open Land	Commercial	Industrial	Landfill	Extractive	Highway	Railroad
Biochemical Oxygen Demand	15	15	YI	0.08	0.14	0.14	0.14	0.22	0.28	0.28
			YP	0.01	0.46	0.39	0.39	0.20	0.39	0.39
			CONC	2	2	2	2	2	2	2
Ammonia-Nitrogen	15	15	YI	0.002	0.005	0.005	0.005	0.005	0.005	0.005
			YP	0.001	0.2	0.2	0.2	0.002	0.2	0.2
			CONC	0.15	0.15	0.15	0.15	0.06	0.15	0.15
Nitrate-Nitrogen	20	20	YI	0.006	0.015	0.015	0.015	0.015	0.018	0.018
			YP	0.006	0.002	0.002	0.002	0.002	0.002	0.002
			CONC	6	6	6	6	4	6	6
Phosphate-Phosphorus	15	15	YI	0.002	0.003	0.003	0.003	0.004	0.003	0.003
			YP	0.001	0.04	0.03	0.03	0.01	0.03	0.03
			CONC	0.015	0.15	0.15	0.15	0.015	0.15	0.15
Fecal Coliform	20	20	YI	100	100	100	100	100	400	400
			YP	10	100	170	170	95	170	170
			CONC	600	600	600	600	600	500	500
Organic Nitrogen	20	20	YI	0.002	0.004	0.004	0.004	0.005	0.004	0.004
			YP	0.001	0.01	0.007	0.007	0.10	0.007	0.007
			CONC	2	2	2	2	2	2	2

Table 12 (continued)

Pollutant	Loading Limits: Impervious	Loading Limits: Pervious	Parameter[a]	Land Use: Airfield	Low Residential	Medium Residential	High Residential	Very High Residential
Biochemical Oxygen Demand	15	15	YI YP CONC	0.28 0.04 0.1	0.08 0.02 2	0.08 0.04 2	0.08 0.05 2	0.08 0.08 2
Ammonia-Nitrogen	15	15	YI YP CONC	0.15 0.026 0.05	0.002 0.008 0.06	0.002 0.01 0.06	0.002 0.01 0.06	0.002 0.01 0.06
Nitrate-Nitrogen	20	20	YI YP CONC	0.03 0.002 6	0.006 0.003 1.5	0.006 0.004 4	0.006 0.006 6	0.006 0.006 6
Phosphate-Phosphorus	15	15	YI YP CONC	0.005 0.005 0.015	0.002 0.002 0.015	0.002 0.004 0.015	0.002 0.008 0.015	0.002 0.008 0.015
Fecal Coliform	20	20	YI YP CONC	800 800 1000	100 36 500	100 46 500	100 95 500	100 95 500
Organic Nitrogen	20	20	YI YP CONC	0.04 0.04 1	0.002 0.002 2	0.002 0.003 2	0.002 0.004 2	0.002 0.005 2

[a] *YI = Loading rate of given pollutant on impervious area in pounds per acre per day.*
YP = Loading rate of given pollutant on pervious area in pounds per acre per day.
CONC = Concentration of given pollutant in subsurface waters entering the stream.

Source: SEWRPC.

Table 13

POINT SOURCE DATA REQUIREMENTS AND SOURCES[a]

Parameter for Which Time Series Data Required	Most Typical Data Source	Typical Frequency of Sample Analysis
Flow	Operating Records	Daily
Temperature	Operating Records	Daily
Biochemical Oxygen Demand	Operating Records	Daily
Dissolved Oxygen	DNR River Basin Surveys	Quarterly or less frequent
Ammonia-Nitrogen	DNR River Basin Surveys	Quarterly or less frequent
Nitrate-Nitrogen	DNR River Basin Surveys	Quarterly or less frequent
Organic Nitrogen	DNR River Basin Surveys	Quarterly or less frequent
Phosphate-Phosphorus	DNR River Basin Surveys	Quarterly or less frequent (also estimated from operating records for total phosphorus and from SEWRPC Technical Report No. 18, Volume One)
Fecal Coliform	Operating Records	Daily for large plants, weekly for smaller plants

[a] *This summary applies primarily to municipal point sources. Data for private and other point sources are generally available only for lower sampling frequencies.*

Source: SEWRPC.

The data were coded from this source and from the more detailed hourly data in the USGS files, were keypunched, and were input to the computer data management system. The Hydrologic and Hydraulic Submodels were then calibrated against these data.

Water Quality Data: The principal sources of water quality data used in calibrating the Water Quality Submodel were collected during the Commission's water quality index site sampling program, undertaken by the Wisconsin Department of Natural Resources under contract to the Commission, and during the lake studies conducted by the Commission. The 36 water quality index sampling sites and seven study lakes where calibration data were collected are listed in Tables 15 and 16 and shown on Map 5.

Thirty samples were collected at each of the 36 sites and analyzed for 15 water quality indicators; periphyton, phytoplankton, zooplankton, temperature, dissolved oxygen, specific conduc-

Table 14

STREAMFLOW DATA STATIONS USED IN MODEL CALIBRATION

Station Location	Gage Number	Drainage Area (square miles)	Period of Record
Milwaukee River at New Fane.	4086200	54.1	April 1968 - March 1977
Milwaukee River at Kewaskum	4086150	138.0	April 1968 - March 1977
Milwaukee River at Fillmore.	4086340	148.0	April 1968 - March 1977
Milwaukee River at Waubeka	4086360	432.0	March 1968 - March 1977
Cedar Creek at Cedarburg	4086500	120.0	August 1930 - September 1970 and July 1973 - March 1977
Milwaukee River at Milwaukee	4087000	686.0	April 1914 - March 1977
Fox River at Waukesha.	5543830	127.0	January 1963 - March 1977
Mukwonago River at Mukwonago. . . .	5544200	76.2	July 1973 - March 1977
White River at Burlington	5545300	97.5	April 1973 - March 1977
Fox River at Wilmot	5546500	868.0	October 1939 - March 1977
Oak Creek at South Milwaukee	4087204	25.0	October 1963 - March 1977
Root River at Franklin.	4087220	49.3	October 1963 - March 1977
Root River Canal at Franklin	4087233	57.2	October 1963 - March 1977
Root River at Racine.	4087240	187.0	August 1963 - March 1977
Pike River at UW-Parkside	4087257	38.7	October 1971 - March 1977
Menomonee River at Wauwatosa	4087120	123.0	October 1961 - September 1975
Des Plaines River at Russell Road. . . .	5527800	123.0	June 1967 - March 1977
Turtle Creek at Clinton.	5431500	202.0	September 1939 - March 1977
Kinnickinnic River at Milwaukee	4087160	20.4	September 1976 - March 1977

Source: SEWRPC.

tivity, nitrate-nitrogen, nitrite-nitrogen, ammonia-nitrogen, organic nitrogen, phosphate, total phosphorus, ultimate carbonaceous biochemical oxygen demand, fecal coliform, and chlorides. Spring samples were also analyzed for hydrogen ion concentration (pH) and total suspended solids. Four samples were collected during the first day of sampling at each site, and each site was sampled once daily thereafter until a storm event. During storm runoff periods, samples were collected more frequently as appropriate for the event. Dates during which samples were collected are indicated in Table 15. As shown in the table, continuing dry weather conditions during October 1976 caused the Commission to suspend water quality sampling efforts until March 1977, at which time field work was reactivated during a significant rainfall event. In all cases, sampling was conducted so as to characterize the low flow conditions prior to the storm runoff events. This was coordinated jointly by the Wisconsin Department of Natural Resources and the Commission through the cooperation of the U. S. Weather Service at General Mitchell Field in Milwaukee.

For a complete description of the lake calibration data, refer to Commission publications documenting the lake studies, and to the publications listed in Table 16. The parameters, locations, and frequencies of sampling are far more complex to describe than are the water quality index sampling procedures for the streams.

MODEL CALIBRATION

Need for and Nature of Model Calibration

Many of the algorithms contained in the model are mathematical approximations of complex natural phenomena. Therefore, before the model could be used to reliably simulate streamflow behavior and water quality conditions under alternative hypothetical water quality conditions, it was necessary to calibrate the model; that is, to compare simulation model results with factual historic data and, if a significant difference was found, to make parameter adjustments so as to adjust—or calibrate—the model to the specific natural and man-made features of the Region. While the model is general in that it is applicable to a wide range of geographic and climatic conditions, its successful application to any given water resource system—such as

Table 15

WATER QUALITY INDEX SITE SAMPLING LOCATIONS AND DATES

Site Identification	Location	Sampling Dates
	Milwaukee River Watershed	
MI-D	Milwaukee River at Kewaskum Dam	November 3, 1976 - November 19, 1976 and March 27, 1977 - April 1, 1977
MI-4	North Branch Milwaukee River at Fillmore	November 3, 1976 - November 19, 1976 and March 27, 1977 - April 1, 1977
MI-8	Cedar Creek at Cedarburg (STH 60)	November 3, 1976 - November 19, 1976 March 27, 1977 - April 1, 1977
MI-11	Milwaukee River at Estabrook Park	November 3, 1976 - November 19, 1976 and March 27, 1977 - April 1, 1977
MI-C	East Branch Milwaukee River at New Fane	November 3, 1976 - November 19, 1976 and March 27, 1977 - April 1, 1977
MI-A	Milwaukee River at Waubeka	November 3, 1976 - November 19, 1976 and March 27, 1977 - April 1, 1977
MI-B	Lincoln Creek at Cameron Avenue	November 3, 1976 - November 19, 1976 and March 27, 1977 - April 1, 1977
MI-3	Milwaukee River at STH 33 near West Bend	November 3, 1976 - November 19, 1976 and March 27, 1977 - April 1, 1977
MI-9	Milwaukee River at CTH C near Grafton	November 3, 1976 - November 19, 1976 and March 27, 1977 - April 1, 1977
	Sauk Creek Watershed	
Sk-2	Sauk Creek at STH 33	November 3, 1976 - November 19, 1976 and March 27, 1977 - March 31, 1977
	Kinnickinnic River Watershed	
Kk-A	Kinnickinnic River at 7th Street	September 7, 1976 - October 5, 1976 and February 10, 1977
Kk-B	Kinnickinnic River at Jackson Park Bridge	September 7, 1976 - October 5, 1976
	Oak Creek Watershed	
Ok-A	Oak Creek downstream from 15th Avenue bridge	September 7, 1976 - October 5, 1976
	Root River Watershed	
Rt-2	Root River near Franklin upstream from STH 100	September 7, 1976 - October 6, 1976
Rt-3	Root River Canal near Franklin at 6 Mile Road	September 7, 1976 - October 6, 1976
Rt-6	Root River at Racine downstream from STH 38 bridge	September 7, 1976 - October 6, 1976
	Pike River Watershed	
Pk-1	Pike River at STH 31	September 7, 1976 - October 6, 1976
Pk-A	Pike River at CTH A	September 7, 1976 - October 6, 1976
Dp-A	Des Plaines River at Russell Road downstream from Russell, Illinois	September 7, 1976 - October 6, 1976
Dp-2	Des Plaines River at STH 50	September 7, 1976 - October 6, 1976
	Fox River Watershed	
Fx-27	Fox River at Wilmot downstream from CTH C	September 7, 1976 - October 6, 1976 and March 27, 1977 - March 31, 1977
Fx-7	Fox River at Waukesha downstream from Prairie Street bridge	October 11, 1976 - November 2, 1976 and March 27, 1977 - March 31, 1977
Fx-12	Mukwonago River at Mukwonago upstream from STH 83 bridge	October 11, 1976 - November 2, 1976 and March 27, 1977 - March 31, 1977
Fx-20	White River southwest of Burlington downstream from STH 36 bridge	September 7, 1976 - October 6, 1976
Fx-21	Honey Creek at Carver Road	October 11, 1976 - November 2, 1976 and March 27, 1977 - March 31, 1977
Fx-A	Sugar Creek at Potter Road in Section 14	October 11, 1976 - November 2, 1976 and March 27, 1977 - March 31, 1977
Fx-17	Fox River at CTH W	September 15, 1976 - November 2, 1976 and March 27, 1977 - March 31, 1977
Fx-B	Poplar Creek at Bluemound Road	October 11, 1976 - November 2, 1976

Table 15 (continued)

	Rock River Watershed	
Rk-B	Turtle Creek at STH 140, Rock County near Clinton	October 11, 1976 - November 2, 1976 and March 27, 1977 - March 31, 1977
Rk-10	Whitewater Creek at N. Fremont Street	October 11, 1976 - November 2, 1976 and March 27, 1977 - March 31, 1977
Rk-A	Scuppernong River at County Line, CTH Z	October 11, 1976 - November 2, 1976 and March 27, 1977 - March 31, 1977
Rk-9	Bark River at USH 18	October 11, 1967 - November 2, 1976 and March 27, 1977 - March 31, 1977
Rk-8	Oconomowoc River at CTH BB	October 11, 1976 - November 2, 1976 and March 27, 1977 - March 31, 1977
Rk-5	Ashippun River at CTH CW	October 11, 1976 - November 2, 1976 and March 27, 1977 - March 31, 1977
Rk-4	Rubicon River at Goodland Road	November 3, 1976 - November 19, 1976 and March 27, 1977 - March 31, 1977
Rk-6	Oconomowoc River at STH 83	October 11, 1976 - November 1, 1976 and March 27, 1977 - March 31, 1977

Source: SEWRPC.

the Region's watersheds—very much depends on the calibration process in which pertinent data on the natural resource and man-made features of the watershed are used to adapt the model to local conditions. A schematic representation of the model calibration process as used in the areawide water quality management planning program is shown in Figure 6.

The basic premise of the simulation process is that, once the simulation model is calibrated for a particular water resource system, the model will respond accurately to a variety of model inputs representing hypothetical watershed conditions—such as land use changes and point source modifications—and thereby provide a powerful analytic tool in the watershed planning process.

Of the two types of calibration data available for southeastern Wisconsin—streamflow data and water quality data—streamflow data are the most available. There is a considerable and generally adequate data base available, therefore, for calibration of the Hydrologic and Hydraulic Submodels of the overall model. A less adequate data base is available for the calibration of the Water Quality Submodel.

In some simulation model applications, parameter adjustments are not sufficient and it is necessary to improve the algorithms in the model. This problem did not arise in the application of the model to southeastern Wisconsin.

Hydrologic Submodel and Hydraulic Submodel Calibration

Meteorologic data sets, land data sets for land segment types, and channel data sets for stream reaches were prepared using the procedures described earlier in this chapter. The choice of numerical values for the 28 parameters in each of the land data sets was strongly influenced by the parameter values previously established for the Menomonee River watershed[13] and whichever other watersheds had previously been calibrated.[14]

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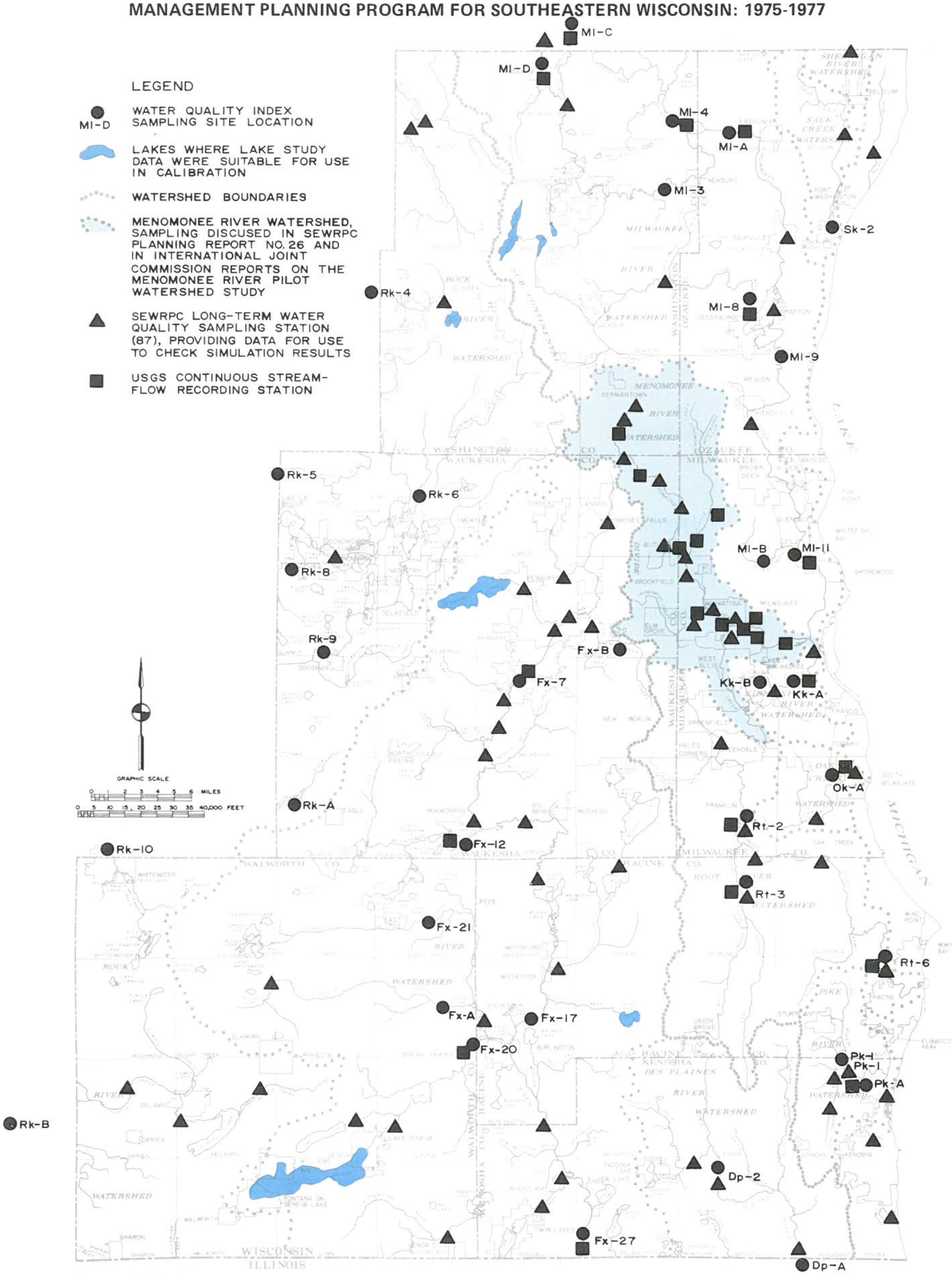
[13] *Ibid.*

[14] *The Region's watersheds were calibrated in the following order: Menomonee River, Oak Creek, Pike River, Root River, Des Plaines River, Kinnickinnic River, Fox River, Milwaukee River, Rock River, minor streams tributary to Lake Michigan, Sauk Creek, and Sheboygan River.*

Map 5

WATER QUALITY INDEX SAMPLING SITE LOCATIONS FOR AREAWIDE WATER QUALITY MANAGEMENT PLANNING PROGRAM FOR SOUTHEASTERN WISCONSIN: 1975-1977



Source: *SEWRPC.*

Table 16

MAJOR INLAND LAKE STUDY REPORTS PROVIDING CALIBRATION DATA FOR WATER QUALITY MODELING

Lake	County	Source Report
Pewaukee	Waukesha	Wisconsin Department of Natural Resources, Bureau of Research, April 1978 draft to be published as SEWRPC Community Assistance Planning Report, Water Quality Management for Pewaukee Lake, Waukesha County
Eagle	Racine	Wisconsin Department of Natural Resources, Bureau of Research, April 1978 draft to be published as SEWRPC Community Assistance Planning Report, Water Quality Management for Eagle Lake, Racine County
Geneva	Walworth	Geneva Lake Watershed Environmental Agency, April 1978 draft to be published as SEWRPC Community Assistance Planning Report, Water Quality Management for Geneva Lake, Walworth County
Little Cedar	Washington	Camp Dresser & McKee Limnetics, March 1977, An Environmental Study of Little Cedar Lake and the Hydrologic and Water Quality Characteristics of its Associated Watershed
Big Cedar	Washington	Camp Dresser & McKee Limnetics, March 1977, An Environmental Study of Big Cedar Lake and the Hydrologic and Water Quality Characteristics of its Associated Watershed
Silver	Washington	Camp Dresser & McKee Limnetics, March 1977, An Environmental Study of Silver Lake and the Hydrologic and Water Quality Characteristics of its Associated Watershed
Pike	Washington	Wisconsin Department of Natural Resources, Bureau of Research, April 1978 draft to be published as SEWRPC Community Assistance Planning Report, Water Quality Management for Pike Lake, Washington County

Source: SEWRPC.

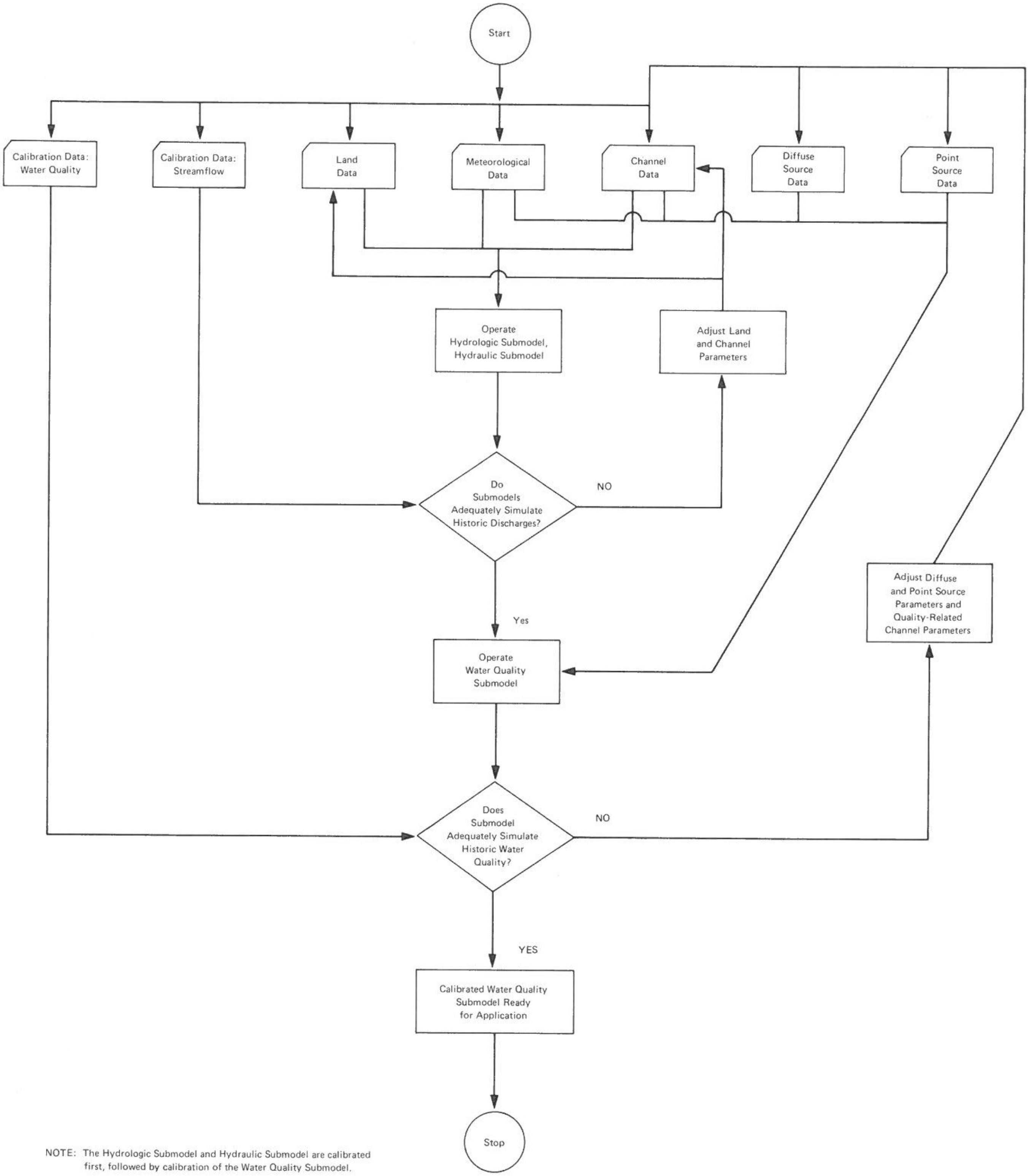
Hydrologic and hydraulic calibration of each watershed involved operating the Hydrologic Submodel from October 1963 through September 1975 over each watershed, comparing the quantity of runoff simulated on a monthly basis with that recorded, adjusting Land parameters as necessary, then operating the Hydrologic Submodel over the same period again. This process was repeated from 5 to 10 times for each watershed until simulated and recorded monthly runoff were in agreement. The Hydraulic Submodel was then operated through the same period, results compared with daily and hourly hydrographs, channel parameters adjusted, and the submodel rerun until the Hydraulic Submodel properly reflected the observed flow timing. An example of the results obtained with the Hydrologic and Hydraulic Submodels is presented in SEWRPC Planning Report No. 26, A Comprehensive Plan for the Menomonee River Watershed. Similar results were obtained for all watersheds simulated, and results are documented in the Commission files.

Water Quality Submodel Calibration

After completing calibration of the Hydrologic and Hydraulic Submodels, the Water Quality Submodel calibration process was initiated. A sequential approach was used since successful water quality simulation is contingent upon effective hydrologic-hydraulic modeling, because runoff from the land surface and flow

Figure 6

THE HYDROLOGIC-HYDRAULIC WATER QUALITY SIMULATION MODEL CALIBRATION PROCESS



NOTE: The Hydrologic Submodel and Hydraulic Submodel are calibrated first, followed by calibration of the Water Quality Submodel.

Source: SEWRPC.

in the streams provide the transport mechanism for water quality constituents. Meteorologic, channel, nonpoint source, and point source input data sets were prepared using the procedures described earlier in this article. With respect to calibration data, the Water Quality Submodel was calibrated to the stream data collected under the previously discussed index site sampling program.

For each watershed, the calibration process was initiated by concentrating on the most upstream stations in the watershed and achieving an acceptable correlation between the observed water quality at those locations and the results obtained with the Water Quality Submodel. After achieving a successful calibration with emphasis on six parameters—temperature, dissolved oxygen, phosphate-phosphorus, nitrogen forms, fecal coliform, and carbonaceous biochemical oxygen demand—the calibration effort then moved to the next downstream station. This process of calibration at successive stations down through the watershed was continued, with some necessary iteration to upstream stations, until the calibration for the full watershed was achieved with the data from the first sampling period. Where spring data were available, the submodel was operated continuously through the spring sampling period, with calibration completed for both periods with a minimum of additional iterations.

An example of the results obtained with the Water Quality Submodel calibration is presented in SEWRPC Planning Report No. 26. Similar results were obtained for all watersheds simulated and are documented in the Commission files.

MODEL VERIFICATION

Ideally, another full data series would be available to verify the calibration. Such data would be of detail and frequency equivalent to that of the data used for model calibration. Simulation of the actual time period of the second set of sampling data would then be used to verify the validity of the simulation model used to characterize the water quality of the surface water system. Unfortunately, such data are expensive, yet would be highly valuable in further refining the model calibration.

Fortunately, the Commission has maintained a continuing water quality sampling program at 87 sampling stations since 1964. The results of this sampling are documented in SEWRPC Technical Report No. 4, Water Quality and Flow of Streams in Southeastern Wisconsin, and in SEWRPC Technical Report No. 17, Water Quality of Lakes and Streams in Southeastern Wisconsin: 1964-1975. Data were compiled under both wet weather and dry weather conditions, as well as under seasonal and diurnal variations. Because the data were not obtained in a detailed time series of the sort used for model calibration, the verification process could not rely on the same highly specific and graphical comparison of plots of the observed and simulated variation in water quality conditions. However, the output of existing conditions was used to confirm that the water quality simulation results were realistic and that they characterized conditions that were consistent with the observed long-term conditions.

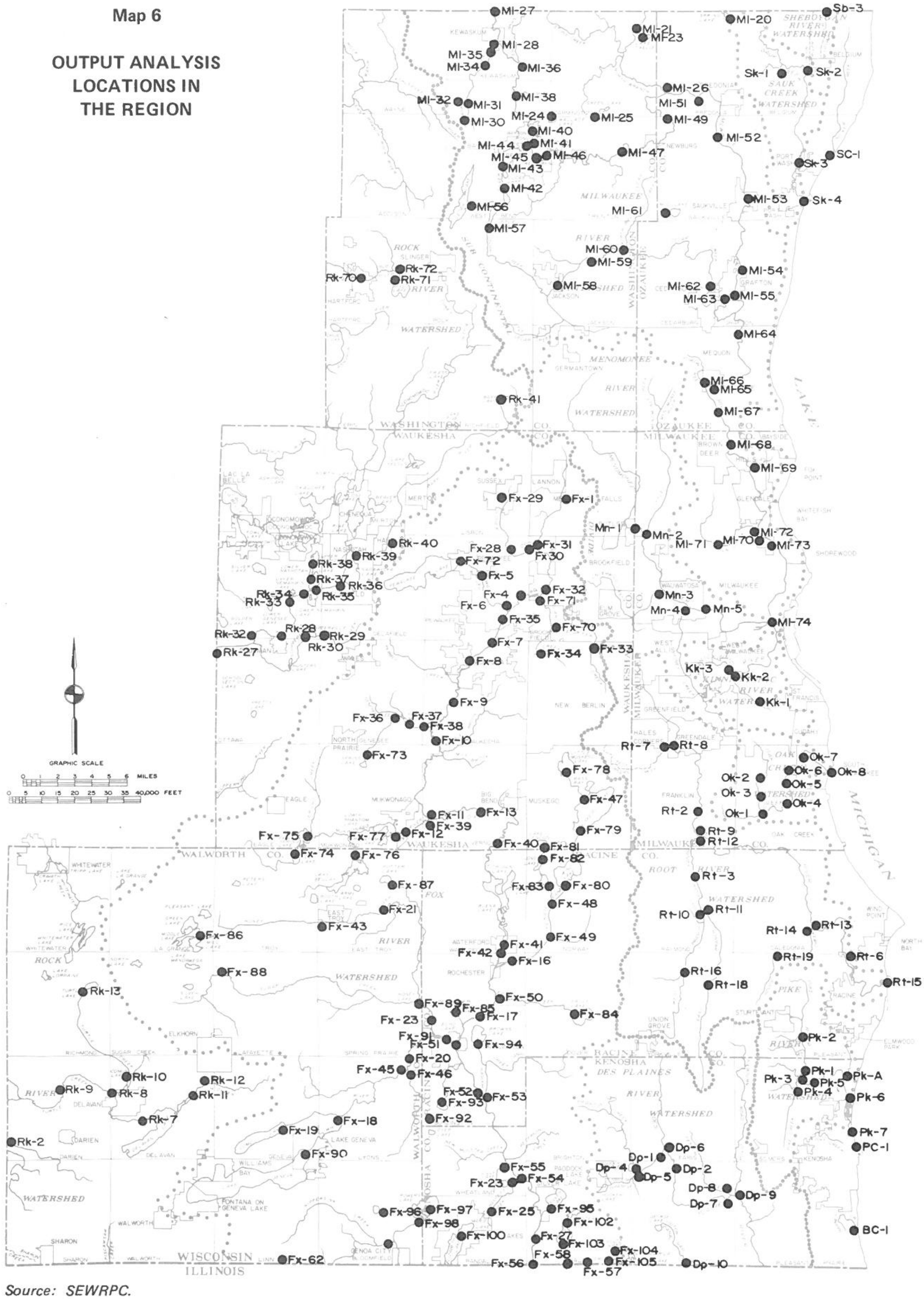
ANALYSIS OF ALTERNATIVE WATER QUALITY MANAGEMENT CONDITIONS

Several alternative water quality management conditions were simulated in each watershed within the Region over a simulated three-year period of representative meteorologic conditions. The three-year period was selected during the conduct of the Menomonee River watershed study after comparing the simulated water quality conditions for a 10-year period to the simulated conditions for selected shorter periods. The three-year period chosen was found to replicate the statistical distribution of water quality conditions produced by the 10-year simulation, but at a 70 percent reduction in machine cost. Simulated stream water quality was output at the 232 locations indicated on Map 6. Water quality was simulated in all reaches within the defined hydrologic subbasins, but the output was analyzed at only the 232 indicated reaches in order to limit the data generated to a manageable quantity. The water quality output was statistically analyzed, and two major summaries were prepared:

1. Concentration-Frequency Curves—These curves display various levels of dissolved oxygen, ammonia-nitrogen, nitrate-nitrogen, phosphate-phosphorus, and temperature against the percent of time each level of pollutant was exceeded over the three-year simulation period. Since the three-year simula-

Map 6

OUTPUT ANALYSIS LOCATIONS IN THE REGION



Source: SEWRPC.

tion period was selected so as to be representative of long-term meteorologic conditions in the Region, the curve also indicates the percent of time a level of pollutant may be expected to be exceeded under long-term conditions. From these curves, the frequency with which a given pollutant standard may be expected to be violated can be readily discerned. Figure 7 provides an example of a typical concentration-frequency curve. For publication, these curves were simplified as "Water Quality Achievement Charts" (see Figure 7) reflecting the percentage of time that a specified pollutant concentration standard may be expected to be achieved.

2. Mass Tables—These tables summarize the mass, expressed as pounds per year, of ammonia-nitrogen, nitrate-nitrogen, biochemical oxygen demand, phosphate-phosphorus, and organic nitrogen flowing through the output reach under each of the conditions analyzed. Mass tables are useful in determining which water quality management actions may be expected to most significantly reduce pollutant loads at a given point. Table 17 is an example of a typical mass table.

Table 18 summarizes the water quality management conditions that were simulated in developing the plan recommendations for each watershed. The following paragraphs further describe the alternative conditions referred to in Table 18.

Existing Conditions

The first condition simulated in each watershed represented 1975 land use and channel conditions and the known point sources in existence and operating as of 1975. Data from the simulation of existing conditions were used, together with the extensive inventory data collected under the study, to help identify existing water quality problems. Importantly, the data served as a base against which conditions under alternative water quality management proposals could be evaluated. The point sources considered were as reported in SEWRPC Technical Report No. 21, Sources of Water Pollution in Southeastern Wisconsin: 1975.

Projected Design Year 2000 Conditions

Projected design year 2000 conditions—i.e., the population, land use, channel, and point source conditions expected in the year 2000 in the absence of an areawide water quality management plan—were simulated for each watershed. Point sources were simulated based on the treatment levels recommended in the adopted regional sanitary sewerage system plan for southeastern Wisconsin. Like existing conditions, projected design year 2000 conditions provided a basis against which conditions under alternative water quality management proposals could be evaluated.

Design Year 2000 Conditions with 25 Percent, 50 Percent, or 75 Percent Reduction in Nonpoint Source Loads

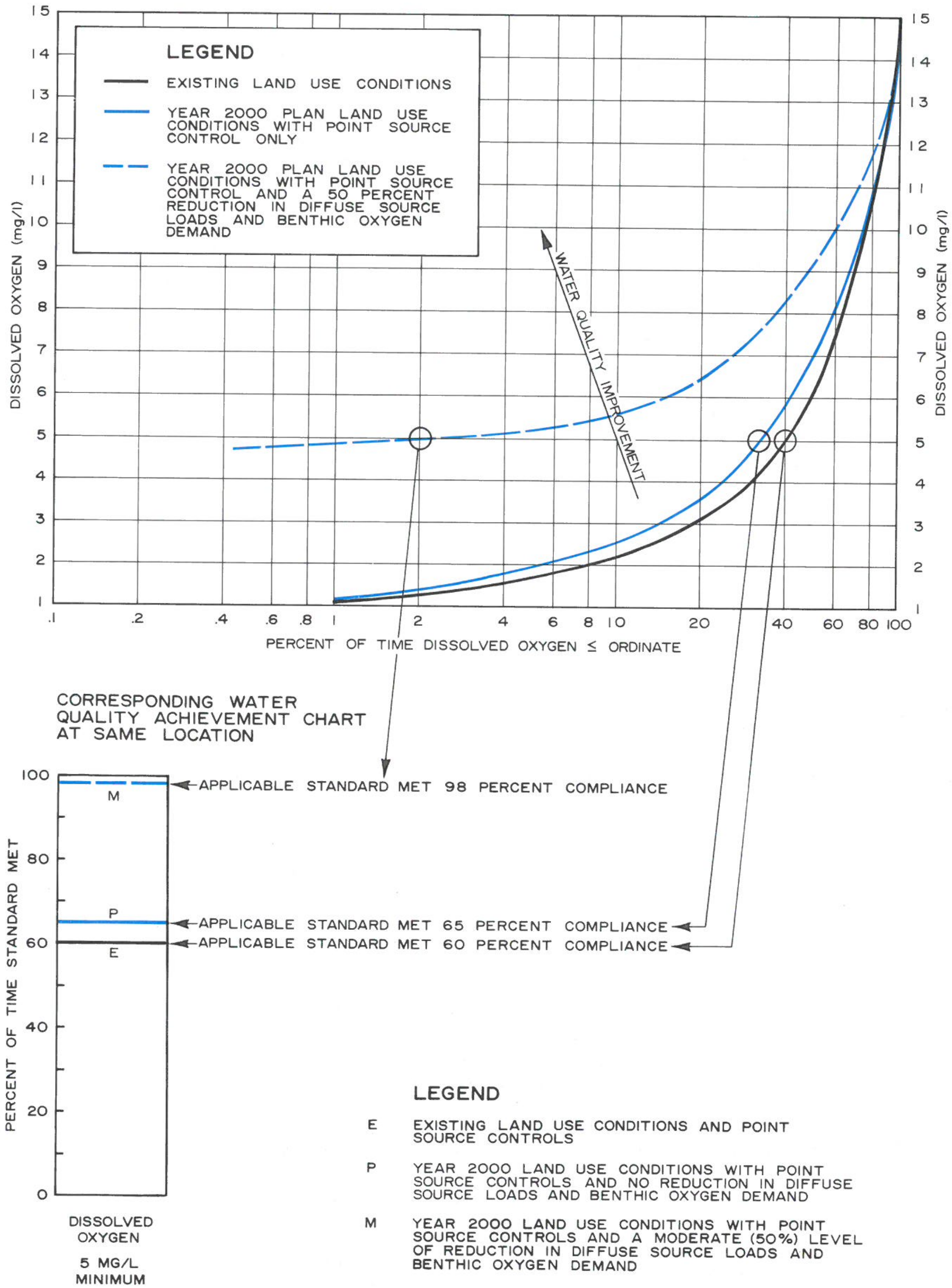
Design year 2000 conditions with a specified percentage reduction in nonpoint source loads were simulated with plan year 2000 land use and channel conditions and point source effluent quality as recommended in the adopted regional sanitary sewerage system plan. The nonpoint source loads—surface accumulation and stream bottom releases—were, however, reduced to reflect the effects of the specified percentage reductions. The results indicated the level of water quality which could be expected to be achieved under various reductions in nonpoint sources. The analysis of these results and the development of the alternatives are discussed in Chapter IV, Volume Two of SEWRPC Planning Report No. 30, A Regional Water Quality Management Plan for Southeastern Wisconsin: 2000.

Design Year 2000 Conditions with 25 Percent, 50 Percent, or 75 Percent Reduction in Nonpoint Source Loads and with Selected Additional Point Source Treatment Levels Beyond Those Recommended in the Regional Sanitary Sewerage System Plan

As discussed in Chapter II, Volume Two of SEWRPC Planning Report No. 30, the reduction of phosphorus is important to the avoidance of nuisance aquatic plant growth in the lakes and streams. Accordingly, one plan alternative—ultimately taken to public meetings and formal hearing—was the reduction of total phosphorus to 0.1 milligram per liter (mg/l) in the effluent of 18 sewage treatment plants in the Region. In other cases, land application and the resulting elimination of selected wastewater discharges was considered. In selected cases, other parameters—primarily ammonia-nitrogen—were adjusted in these final simulation runs. These alternatives—along with plan design year 2000 population and land use conditions, other point

Figure 7

EXAMPLE OF A WATER QUALITY FREQUENCY CURVE AND ACHIEVEMENT CHART—DISSOLVED OXYGEN



Source: SEWRPC.

Table 17

EXAMPLE MASS TABLE: ROOT RIVER OUTPUT LOCATION RT-10—WEST BRANCH OF THE ROOT RIVER NEAR CTH K

Pollutant	Pounds per Year Transported					
	Existing Conditions	2000 Conditions	2000 With 25 Percent Reduction in Nonpoint Sources	2000 With 50 Percent Reduction in Nonpoint Sources	2000 With 75 Percent Reduction in Nonpoint Sources	2000 With 50 Percent Reduction in Nonpoint Source and Point Source Modifications
Nitrate-Nitrogen. . . .	272,000	462,000	355,000	249,000	140,000	271,150
Ammonia-Nitrogen . .	57,400	36,210	26,410	17,540	15,120	16,160
Biochemical Oxygen Demand . .	667,000	N/A	384,000	327,000	174,000	136,990
Phosphate-Phosphorus	17,200	9,860	8,130	6,410	5,420	4,006
Organic Nitrogen . . .	109,000	109,000	90,800	71,730	41,030	48,310

NOTE: N/A indicates data not available.

Source: SEWRPC.

source abandonments and controls, and selected nonpoint source control levels—were simulated for selected watersheds and subwatersheds. It was in these simulation analyses that the most cost-effective combinations of point and nonpoint source controls were evaluated.

Because of the many point sources of water pollution—including both existing and proposed sources—and the many alternative measures and combinations of measures which could be considered for control of these sources, any specific evaluation of the alternatives simulated by the Commission requires a review of the precise assumptions underlying the generalized simulations, set forth in Table 18.

SUMMARY

A quantitative analysis of streamflow and water quality conditions under existing and possible alternative future conditions is a fundamental requirement of any comprehensive water quality planning effort. Discharge and water quality at any point and time within the stream system of a watershed are a function of three factors: meteorological conditions and events, the nature and use of the land, and the characteristics of the stream system.

The ideal way to investigate the behavior of the hydrologic-hydraulic water quality system would be to make direct measurements of the phenomena involved. Such a direct approach is not generally feasible because of the extremely high costs, the improbability of the occurrence of critical events, and the inability to evaluate the impacts of possible future land and stream conditions. Hydrologic-hydraulic water quality simulation, accomplished with a set of interrelated digital computer programs, is an effective way to conduct the quantitative analysis required for water quality planning. Such a water resource simulation model was developed for and tested in the Commission's Menomonee River watershed planning program and was used in the areawide water quality management planning program. The various submodels comprising the model were selected from existing computer programs so that a composite model could be developed by combination with selected programs prepared by the Commission staff so as to meet the Commission's water resources study needs. The hydrologic-hydraulic water quality simulation model used in the areawide water quality management program consists of the following three submodels: the Hydrologic Submodel, the Hydraulic Submodel, and the Water Quality Submodel.

Table 18

ALTERNATIVE WATER QUALITY MANAGEMENT CONDITIONS ANALYZED

Watershed	Run Number	Alternatives Analyzed
Menomonee River	1	Existing conditions
	2	Existing land use, with recommended point source controls
	3	Plan year 2000 land use and channel conditions with recommended point source controls
	4	Plan year 2000 land use and channel conditions with 50 percent reduction in nonpoint source loads and recommended point source controls
Kinnickinnic River	1	Existing conditions
	2	Plan year 2000 land use and channel conditions with recommended point source controls
	3	Plan year 2000 land use and channel conditions with 25 percent reduction in nonpoint source loads and recommended point source controls
	4	Plan year 2000 land use and channel conditions with 50 percent reduction in nonpoint source loads and recommended point source controls
Oak Creek	1	Existing conditions
	2	Plan year 2000 land use conditions with recommended point source controls
	3	Plan year 2000 land use conditions with 50 percent reduction in nonpoint source loads and recommended point source controls
Pike River	1	Existing conditions
	2	Plan year 2000 land use conditions with recommended point source controls
	3	Plan year 2000 land use conditions with 25 percent reduction in nonpoint source loads and recommended point source controls
	4	Plan year 2000 land use conditions with 50 percent reduction in nonpoint source loads with recommended point source controls
Root River	1	Existing conditions
	2	Plan year 2000 land use and channel conditions with initial point source controls
	3	Plan year 2000 land use and channel conditions with 25 percent reduction in nonpoint source loads and initial point source controls
	4	Plan year 2000 land use and channel conditions with 50 percent reduction in nonpoint source loads and initial point source controls
	5	Plan year 2000 land use and channel conditions with 75 percent reduction in nonpoint source loads[a] and initial point source controls
	6	Plan year 2000 land use and channel conditions with 75 percent reduction in nonpoint source loads[a] and point source control modifications

Table 18 (continued)

Watershed	Run Number	Alternatives Analyzed
Des Plaines River	1	Existing conditions
	2	Plan year 2000 land use conditions with initial point source controls
	3	Plan year 2000 land use conditions with 50 percent reduction in nonpoint source loads and initial point source controls
	4	Plan year 2000 land use conditions with 50 percent reduction in nonpoint source loads and point source modifications
Fox River	1	Existing conditions
	2	Plan year 2000 land use conditions with initial point source controls
	3	Plan year 2000 land use conditions with 50 percent reduction in nonpoint source loads and initial point source controls
	4	Plan year 2000 land use conditions with 50 percent reduction in nonpoint source loads and point source control modifications[a]
Milwaukee River	1	Existing conditions
	2	Plan year 2000 land use conditions with initial point source controls
	3	Plan year 2000 land use conditions with 50 percent reduction in nonpoint source loads[a] and point source control modifications
Sauk Creek	1	Existing conditions
	2	Plan year 2000 land use conditions with recommended point source controls
Sheboygan River	1	Existing conditions
	2	Plan year 2000 land use conditions with recommended point source controls
Streams Directly Tributary to Lake Michigan		
Barnes Creek	1	Existing conditions
	2	Plan year 2000 land use conditions with recommended point source controls
	3	Plan year 2000 land use conditions with 50 percent reduction in nonpoint source loads and recommended point source controls
Pike Creek	1	Existing conditions
	2	Plan year 2000 land use conditions with recommended point source controls
	3	Plan year 2000 land use conditions with 25 percent reduction in nonpoint source loads and recommended point source controls
	4	Plan year 2000 land use conditions with 50 percent reduction in nonpoint source loads and recommended point source controls

Table 18 (continued)

Watershed	Run Number	Alternatives Analyzed
Sucker Creek	1	Existing conditions
	2	Plan year 2000 land use conditions
Lower Rock River (Turtle Creek)	1	Existing conditions
	2	Plan year 2000 land use conditions with initial point source controls
	3	Plan year 2000 land use conditions with 50 percent reduction in nonpoint source loads and point source control modifications
Middle Rock River (Bark River)	1	Existing conditions
	2	Plan year 2000 land use conditions with initial point source controls
	3	Plan year 2000 land use conditions with point source control modifications
Upper Rock River (Rubicon River)	1	Existing conditions
	2	Plan year 2000 land use conditions with initial point source controls
	3	Plan year 2000 land use conditions with point source control modifications

[a] *Only portions of the watershed were simulated for this alternative.*

Source: SEWRPC.

The principal function of the Hydrologic Submodel is to determine the volume and temporal distribution of runoff from the land to the stream system. The basic physical unit on which this submodel operates is the hydrologic land segment, which is defined as a land drainage unit exhibiting a specific combination of meteorological factors, land use cover, and soils. The submodel, operating on a time interval of one hour or less, continuously and sequentially maintains a water balance within and between the various interrelated hydrological processes as they occur with respect to the land segment. Meteorologic data and land data constitute the two principal types of input for operation of the Hydrologic Submodel. The key output from the submodel consists of a continuous series of runoff quantities for each hydrologic land segment in a watershed.

The function of the Hydraulic Submodel is to accept as input the runoff from the land surface as produced by the Hydrologic Submodel, to aggregate it, and to route it through the stream system, thereby producing a continuous series of discharge values at predetermined locations along the surface water system of a watershed. Application of this submodel requires that a stream system be divided into reaches and impoundment sites. Input for the Hydraulic Submodel consists of parameters describing the reaches and impoundment sites as well as the output from the Hydrologic Submodel.

The Water Quality Submodel simulates the time-varying concentrations, or levels, of up to 13 water quality indicators at selected points throughout the surface water system. The indicators include temperature, dissolved oxygen, fecal coliform bacteria, phosphate-phosphorus, total dissolved solids, carbonaceous biochemical oxygen demand, ammonia-nitrogen, nitrate-nitrogen, nitrite-nitrogen, algae, zooplankton, chlorides, and conservative substances. Operating on a reach-by-reach basis, the submodel continuously determines water quality as a function of reach inflow and outflow, dilution, and biochemical processes. Input to the Water Quality Submodel consists of output from the Hydrologic Submodel, channel data, meteorologic data, and nonpoint and point source data. Output from the submodel consists of a continuous series of water quality levels at selected points on a watershed stream system.

The largest single work element in the preparation and application of the water quality simulation model consists of data base development. This includes the acquisition, verification, and coding of the data needed to operate, calibrate, test, and apply the model. The model data base for a watershed consists of a large, primarily computer-based file subdivided into five categories: meteorologic data, land data, channel data, nonpoint source data, and point source data. The meteorologic data set is the largest because it contains 37 years of semimonthly, daily, or hourly information for seven types of meteorologic data. The data base was assembled using data collected under other Commission planning programs, inventory data collected by the Commission and consultants under the areawide water quality management planning program, and data from other sources such as the National Climatic Center.

Many of the algorithms incorporated into the hydrologic-hydraulic water quality simulation model are approximations of complex natural phenomena and, therefore, before the model could be used to simulate hypothetical watershed conditions, it was necessary to calibrate the model. Calibration consists of comparing simulation model results with factual historic data and, if a significant difference is found, making parameter adjustments to adapt the model to the effects of the natural and man-made features of the planning region and the watershed. The two types of validation data available for calibration of the simulation model were streamflow data and water quality data.

The iterative calibration process, which consisted essentially of model runs followed by parameter adjustments, was carried out for each of the watersheds in the Region until close agreement was achieved between historic and simulated annual runoff volumes and runoff event hydrographs.

The Water Quality Submodel was calibrated to the surface water system of the watershed by means of data obtained from a detailed sampling program carried out under the areawide water quality management planning program. These data represented a wide range of meteorologic and hydrologic conditions, and, when used in conjunction with model input parameters developed in previous Commission work programs, acceptable calibration was achieved for each of the 12 watersheds.

The calibrated model was then used to predict water quality under various alternative water quality management proposals. The simulations of existing conditions were compared to the Commission's long-term water quality sampling data, and, finally statistical analyses of the predicted water quality were used to evaluate the alternative plans.

EVALUATION OF A WATER QUALITY STANDARD FOR TOTAL PHOSPHORUS IN FLOWING STREAMS IN SOUTHEASTERN WISCONSIN

by David B. Kendziorski, Senior Planner, SEWRPC

INTRODUCTION

To support beneficial water uses, the quality of water must be within a certain range of conditions. The range can be described in terms of the physical, biological, and chemical characteristics of the water. Water quality standards serve to define this range of conditions. Without such standards there would be no way to measure the existing, and no way to predict the probable future, suitability of a given water resource for a particular water use. Moreover, technically sound water resource planning requires that measurable standards be utilized as a basis for the comparison of alternative plan proposals, and for determining the extent to which such proposals meet established water use objectives.

In 1966 SEWRPC published Technical Report No. 4, Water Quality and Flow of Streams in Southeastern Wisconsin. At that time, the Commission recommended a set of water quality standards to support the numerous categories of water use objectives then recommended for various stream reaches in the Region. Subsequently, the U. S. Public Health Service, operating through the Wisconsin Department of Resource Development, adopted water quality standards for the interstate waters—and later for the intrastate waters—of Wisconsin. These actions provided the basis for the administration of water quality management programs in Wisconsin by the Wisconsin Department of Natural Resources (DNR), which, after 1967, was the successor agency to the Department of Resource Development.

This approach, however, was significantly modified in 1972 when the federal Water Pollution Control Act amendments established as a national goal "the achievement, wherever attainable, of water quality which will provide for the protection and propagation of fish, shellfish, and wildlife, and for recreation in and on the water of the United States." More simply stated, the attainment of fishable and swimmable waters became a national goal. In 1974, the Regional Planning Commission was formally designated by Governor Patrick J. Lucey to undertake an areawide water quality management program. As part of the program, the Commission established a set of recommended water quality standards to support the recommended water use objectives in the Region. These objectives and standards formed the basis for the development of the regional water quality management plan. Standards were established for water temperature, pH, dissolved oxygen, fecal coliform, residual chlorine, un-ionized ammonia-nitrogen, and total phosphorus.

During the regional water quality management planning effort, the public perception of water quality problems in southeastern Wisconsin was increased by the intensive public participation efforts of the Commission in cooperation with the University of Wisconsin-Extension Service. It was concluded that nuisance aquatic plant growth does represent a real water quality problem in southeastern Wisconsin, and does result in the impairment of the intended water uses. Accordingly, after appropriate technical studies, the Regional Planning Commission staff concluded that an instream total phosphorus standard of 0.1 milligram per liter (mg/l) could be expected to prevent excessive aquatic plant growth in flowing streams in the Region. This article documents the basis for the selection of that phosphorus standard as one of the important standards to be met if the desired water use objectives are to be achieved. For water quality standards to be sound, it must be demonstrated that they properly address the specific pollutants that are significant factors in the water pollution problems concerned, and that the achievement of the recommended level of the pollutants in the streams or lake waters would mitigate the water quality problem sufficiently to achieve the intended water use objectives. Because of the dynamic nature of water resources, particularly the flowing streams, it is not always possible to design a standard that protects all surface waters from adverse impacts under all conditions while at the same time providing a basis for cost-effective controls. This is particularly the case with regard to the establishment of an instream phosphorus standard.

Many streams in southeastern Wisconsin are choked by excessive algae and weed growths that are aesthetically displeasing; interfere with recreational uses such as boating, swimming, and fishing; and create undue stress on the aquatic environment, as these plants die and decompose and thereby reduce the oxygen content of the streams (see Figure 1). These streams not only become unsuitable for recreational use, but also become unable to support the particular species and populations of fish and other aquatic life that are indicative of healthy, stable environments. Such polluted streams may also cause localized economic hardships and result in a region that is a less desirable place in which to live. The conclusion that these pollution problems are—in a significant part—caused by excessive phosphorus levels in streams is the basis for the phosphorus standard.

The instream effects of nutrient levels have been largely ignored by water quality researchers, such researchers having concentrated their efforts on lake ecosystems. However, K. M. Mackenthun, in Toward a Cleaner Aquatic Environment (1973), states:

> A considered judgment suggests that to prevent biological nuisances, total phosphorus should not exceed 100 μg/l (0.1 mg/l) P at any point within the flowing stream, nor should 50 μg/l (0.05 mg/l) be exceeded where waters enter a lake, reservoir, or other standing water body.

These criteria have not, to date, been adopted as standards by the U. S. Environmental Protection Agency (EPA) or the DNR. However, the EPA's Quality Criteria for Water (1976) and several DNR river basin reports have referred to the 0.1 mg/l total phosphorus level as a desired goal for the prevention of aquatic plant nuisance growths in streams. The Commission, in Planning Report No. 16, A Regional Sanitary Sewerage System Plan for Southeastern Wisconsin, published in 1974, and in Planning Report No. 26, A Comprehensive Plan for the Menomonee River Watershed, published in 1976, recognized the effect of phosphorus levels on aquatic plant growth and proposed that 0.1 mg/l be designated as the water quality standard for total phosphorus. However, these plans were not designed for the strict achievement of this standard because it was assumed that the background levels of phosphorus in southeastern Wisconsin often exceeded the standard. This assumption was made in Planning Report No. 16 because nonpoint source pollutant loads were not addressed by the plan, and in Planning Report No. 26 because it was determined that nonpoint source pollutant loads could not be reduced sufficiently.

ANALYSIS AND RESULTS

The Commission's areawide water quality management planning program evaluated natural background levels of phosphorus, recognized the advancing state-of-the-art of point and nonpoint source control, and further studied phosphorus as a limiting factor for plant growth. From these studies it was concluded that reduced phosphorus levels were achievable, and that reduced phosphorus levels should reduce aquatic plant growth in most streams.

The water quality simulation model analyses conducted under the areawide water quality management planning program tended to substantiate certain phenomena which previously had only been assumed. The findings concerning these phenomena, and the findings of other studies conducted under the areawide water quality planning program relevant to a phosphorus standard, may be summarized as follows:

1. On a long-term or annual basis, phosphorus-limited algae growth rates are generally assumed to be related to the phosphate-phosphorus concentration. A phosphate concentration of 0.03 mg/l is estimated to

Figure 1

EXCESSIVE ALGAE GROWTH IN THE PEWAUKEE RIVER AT CTH F, WAUKESHA COUNTY: AUGUST 1978

Excessive weed and algae growths interfere with the recreational use of many streams in the Region and result in stressful environments for fish and aquatic life. The Pewaukee River reach depicted here is located downstream of the Pewaukee sewage treatment plant. The phosphorus concentration in this stream exceeds the Commission recommended standard.

SEWRPC Photo

support about one-half of the maximum phosphorus-limited algae growth rate. Thus, the "half-saturation constant" is estimated at 0.03 mg/l or less.[1] On a short-term basis, however, this assumption may not be valid since some algae may accumulate luxury amounts of phosphorus during high concentrations and utilize these nutrients during conditions of limited phosphorus availability.

2. Although seasonal variations occur, the measured water quality data used to calibrate the water quality simulation model indicate that, during the spring and fall, approximately 60 percent of the total phosphorus in streams in southeastern Wisconsin is in the phosphate form. For example, a phosphate-phosphorus concentration of 0.06 mg/l would correspond to a total phosphorus concentration of 0.1 mg/l—the recommended standard. Because the water quality model simulated phosphate-phosphorus and not total phosphorus, simulated phosphate-phosphorus levels were applied to the phosphorus standard in the areawide water quality management plan.

3. The water quality simulation model was used to determine whether light, temperature, phosphorus, or nitrogen is likely to be the factor limiting the algae growth rates. Generally, plant growth rates are limited by that factor that is most critically in short supply. Additional factors, such as zooplankton grazing rates or rates of streamflow for dilution, also affect the amount of plant material or biomass present within a stream. Analyses of simulated hourly water quality conditions indicate that algae growth in nearly all streams of the Region is limited by phosphate-phosphorus during those periods when nuisance growth conditions occur. Therefore, a reduction in the phosphorus concentration may be expected to reduce excessive algae growths in most streams. The model did not have the capability to simulate macrophyte (rooted weed) growth. Macrophytes may assimilate their required nutrients from the water column and/or from the bottom substrate through their roots. It is not known to what extent the macrophytes present in streams in southeastern Wisconsin are limited by phosphorus, although in many lakes in southeastern Wisconsin the macrophytes are considered to be limited by phosphorus.

4. It is important to evaluate phosphate-phosphorus levels on an annual basis. If phosphate-phosphorus concentrations are analyzed only during the growing season, they will be found to be relatively low because the phosphate-phosphorus is utilized and stored as organic phosphorus in the aquatic plant tissue. Therefore, applying a phosphorus standard to phosphate-phosphorus levels only during this period would erroneously lead to the conclusion that phosphorus levels are sufficiently low. However, if a standard is satisfied during the entire year, then the phosphate-phosphorus levels prior to uptake by aquatic plants are usually low enough to prevent excessive growths.

5. Background, or "precultural," phosphate-phosphorus concentrations are believed to be below 0.1 mg/l in many—if not most—streams in the Region. Figures 2 through 6 show simulated water quality frequency-duration curves for phosphate-phosphorus for selected streams in the Region that neither drain highly urbanized areas nor receive wastes from significant point source discharges. Simulated phosphate-phosphorus concentrations in these streams are well below a level of 0.1 mg/l at least 90 percent of the time, which is the recommended compliance level. This indicates that a level of 0.1 mg/l phosphate-phosphorus can—with adequate point and nonpoint source pollution controls—usually be achieved. Measured water quality values for relatively unpolluted streams in the Region also indicate that total phosphorus levels are often less than 0.1 mg/l. Table 1 presents total phosphorus concentrations measured from 1968 to 1975 for selected streams in the Region that are relatively unaffected by pollution.

6. No single phosphorus standard can reflect the varying effects of physical, hydrologic, hydraulic, and benthic conditions in streams. Impounded or slow-flowing streams, streams that receive long periods of direct sunlight, or streams without excessive turbidity may be expected to support

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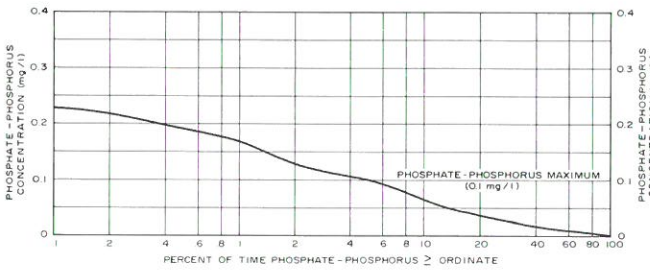
[1] *G. H. Fruhs, et al., "Characteristics of Phosphate Limited Plankton Algae,"* Nutrients and Nitrification, *ed. G. E. Likens, American Society of Limnology and Oceanography, 1972.*

Figure 2

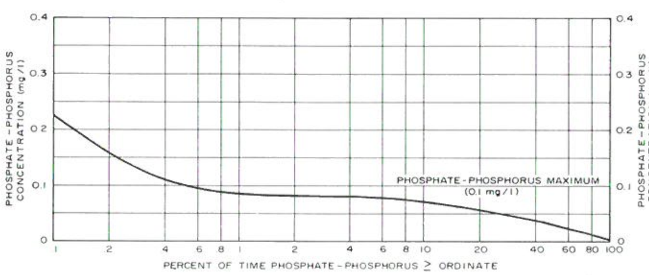
SIMULATED WATER QUALITY FREQUENCY-DURATION CURVES FOR PHOSPHATE-PHOSPHORUS FOR SAUK CREEK, SOUTH OF STH 32, OZAUKEE COUNTY



Source: SEWRPC.

Figure 3

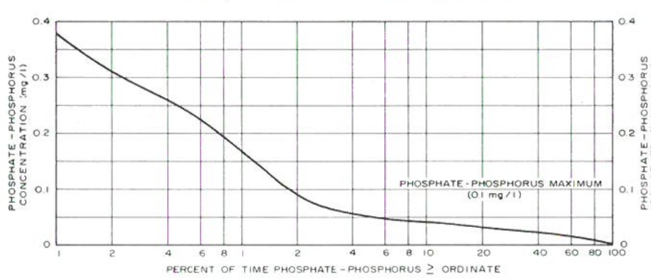
SIMULATED WATER QUALITY FREQUENCY-DURATION CURVES FOR PHOSPHATE-PHOSPHORUS FOR THE EAST BRANCH OF THE MILWAUKEE RIVER, EAST OF CTH S, FOND DU LAC COUNTY



Source: SEWRPC.

Figure 4

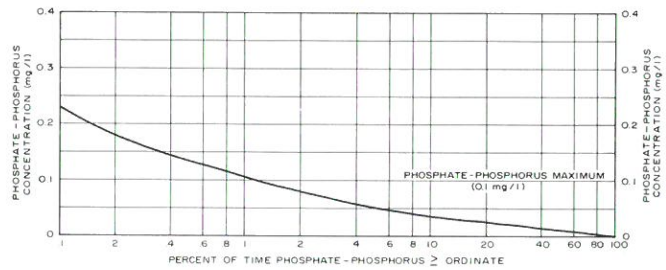
SIMULATED WATER QUALITY FREQUENCY-DURATION CURVES FOR PHOSPHATE-PHOSPHORUS FOR KEWASKUM CREEK, SOUTH OF BADGER ROAD, WASHINGTON COUNTY



Source: SEWRPC.

Figure 5

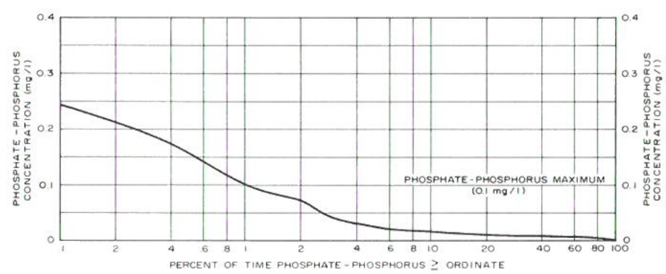
SIMULATED WATER QUALITY FREQUENCY-DURATION CURVES FOR PHOSPHATE-PHOSPHORUS FOR THE WEST BRANCH OF THE MILWAUKEE RIVER, SOUTH OF THE FOND DU LAC COUNTY LINE, WEST OF CTH S, WASHINGTON COUNTY



Source: SEWRPC.

Figure 6

SIMULATED WATER QUALITY FREQUENCY-DURATION CURVES FOR PHOSPHATE-PHOSPHORUS FOR NIPPERSINK CREEK AT THE WISCONSIN STATE LINE, WALWORTH COUNTY



Source: SEWRPC.

excessive plant growths at a lower phosphorus concentration than that required to support the same conditions in fast-flowing streams, streams that are shaded from direct sunlight, or streams that are very turbid. Figure 7 presents an example of excessive plant growth in a stream impoundment with a simulated phosphate-phosphorus level below 0.1 mg/l at least 90 percent of the time. As shown in the figure, plant growth upstream and downstream of this impoundment is limited, presumably by the velocity of streamflow. However, even in impoundments, a reduction in phosphorus concentrations would be expected to reduce the severity and duration of nuisance aquatic plant growths.

Table 1

MEASURED TOTAL PHOSPHORUS CONCENTRATIONS AT SELECTED RELATIVELY UNPOLLUTED STREAM SITES IN THE REGION: 1968-1975

Watershed	Stream Site Location	Measured Total Phosphorus Concentrations (mg/l)[a]			Percent Samples Exceeding 0.1 mg/l[b]
		Minimum	Mean	Maximum	
Fox River	Mukwonago River at STH 83	0.01	0.04	0.08	0
Rock River	Oconomowoc River at STH 83	0.06	0.09	0.11	12
Rock River	Oconomowoc River at USH 16	0.01	0.02	0.03	0

[a] *Water quality measurements at 87 sampling stations were taken under the Regional Planning Commission's benchmark sampling program for the period of 1964-1975. Total phosphorus measurements were only taken from 1968-1975. These data are documented in SEWRPC Technical Report No. 17, Water Quality of Lakes and Streams in Southeastern Wisconsin: 1964-1975.*

[b] *A total phosphorus concentration of 0.1 mg/l is the recommended standard to support a recreational water use objective.*

Source: SEWRPC.

7. Phosphorus reductions are technically achievable with stringent controls. Point source treatment systems have been developed that can achieve a 0.1 mg/l total phosphorus effluent concentration.[2] Point source discharges can also be essentially eliminated through land application of effluent. As indicated in SEWRPC Technical Report No. 21, Sources of Water Pollution in Southeastern Wisconsin: 1975, the majority of nonpoint source phosphorus loads are contributed by livestock operations, construction activities, and malfunctioning septic tank systems. These sources are relatively easy to control. Control of these sources is recommended throughout the Region.

8. Reduced phosphorus levels reduce algal growth rates and subsequently reduce concentrations of chlorophyll-a, which provides the green pigment necessary for photosynthesis to occur and is an indicator of algal standing crop. To demonstrate this point, simulated phosphate-phosphorus and chlorophyll-a concentrations are shown in Table 2 for the East Branch of the Milwaukee River at the New Fane impoundment in Fond du Lac County, about one-half mile north of the Region. Water quality at this site was simulated under assumed year 2000 conditions under three alternatives which differed only in the assumed quality of the discharged effluent from the proposed Forest Lake wastewater treatment facility upstream. These three alternatives assumed either 1) no phosphorus removal; 2) conventional chemical precipitation for phosphorus removal; or 3) land application, with no effluent entering the stream (zero discharge). The results, tabulated in Table 2, indicate that lower phosphate-phosphorus concentrations in the treatment facility effluent will lead to lower instream phosphate-phosphorus concentrations that will produce lower concentrations of algal standing crop (measured in units of chlorophyll-a). The conventional phosphorus removal alternative does not result in higher summer instream phosphate-phosphorus levels than those found

[2]*See Appendix E of SEWRPC Technical Report No. 18, State of the Art of Water Pollution Control in Southeastern Wisconsin, Volume One, Point Sources.*

Figure 7

EFFECTS OF AN IMPOUNDMENT ON AQUATIC PLANT GROWTH IN STREAMS, THE EAST BRANCH OF THE MILWAUKEE RIVER NEAR NEW FANE

FLOWING STREAM ABOUT 1 MILE UPSTREAM OF NEW FANE IMPOUNDMENT

IMPOUNDMENT AT NEW FANE

FLOWING STREAM ABOUT 0.5 MILE DOWNSTREAM OF NEW FANE IMPOUNDMENT

Impoundments reduce the velocity of streamflow, thereby creating conditions more susceptible to excessive weed and algae growths. The water quality simulation model analyses indicate that the East Branch of the Milwaukee River near New Fane has a phosphate-phosphorus concentration of less than 0.06 milligram per liter (mg/l) at least 90 percent of the time, and therefore, satisfies the recreational use phosphorus standard of 0.1 mg/l. The flowing stream reaches of the East Branch, as shown above, are not affected by excessive aquatic plant growth. However, the impoundment at New Fane does exhibit aquatic plant growths that would interfere with the recreational use of the stream. This indicates that satisfying the phosphorus standard will not prevent excessive plant growths in all stream reaches or impoundments in the Region.

SEWRPC Photos

under the land application alternative, which involves no effluent discharge to surface waters, because the additional phosphate-phosphorus in the effluent is consumed by the increased algal growth, as shown by an increase of 26 percent in the mean summer chlorophyll-a concentration. This phenomenon makes the development of phosphorus control recommendations difficult to analyze. However, review of annual simulated instream phosphate-phosphorus levels indicates that the conventional phosphorus removal alternative does result in a higher average annual phosphate-phosphorus concentration than that which results from the land application

Table 2

SIMULATED YEAR 2000 PHOSPHATE-PHOSPHORUS AND CHLOROPHYLL-A VALUES FOR THE EAST BRANCH OF THE MILWAUKEE RIVER AT THE NEW FANE IMPOUNDMENT UNDER ALTERNATIVE TREATMENT LEVELS AT THE PROPOSED FOREST LAKE WASTEWATER TREATMENT FACILITY

Alternative Treatment Level	Treatment Facility Effluent Phosphate-Phosphorus Concentration (mg/l)	Stream Phosphate-Phosphorus Concentration (mg/l)				Value Exceeded 10 Percent of Year[b] (mg/l)	Stream Chlorophyll-a Concentration (µg/l)			
		Minimum[a]	Maximum[a]	Mean[a]	Standard Deviation[a]		Minimum[a]	Maximum[a]	Mean[a]	Standard Deviation[a]
No Phosphorus Removal . .	5.0	0.007	0.405	0.048	0.066	0.20	0.1	186.2	41.8	59.7
Conventional Phosphorus Removal . . .	0.7	- -	0.040	0.014	0.004	0.08	0.1	69.1	15.6	23.2
Land Application of Sewage Effluent	No effluent discharge	0.004	0.041	0.016	0.008	0.06	0.1	57.8	12.4	19.7

[a] *Simulated phosphate-phosphorus and chlorophyll-a values are for May through August, when maximum algae growth would occur.*

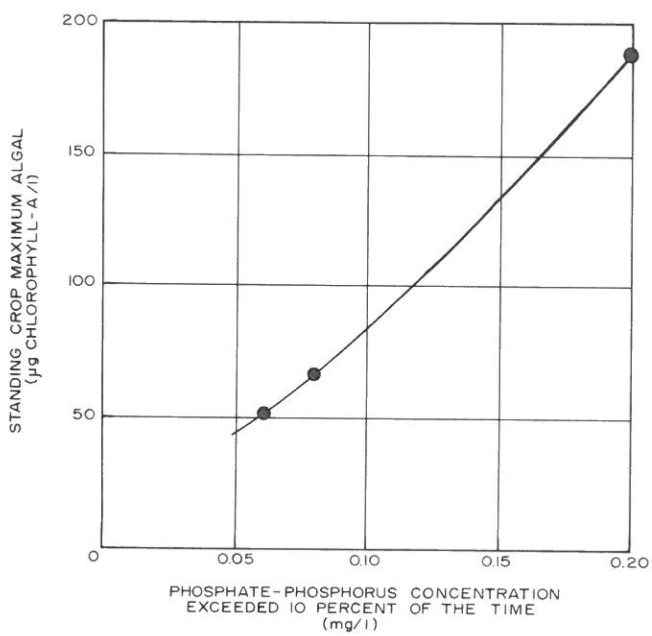
[b] *The phosphate-phosphorus level exceeded 10 percent of the time annually is shown because the recreational water use phosphorus standard of 0.1 mg/l was applied to this duration-compliance level under the areawide water quality management planning program.*

Source: SEWRPC.

alternative. Figure 8 graphically demonstrates the relationship between the simulated phosphate-phosphorus concentration and maximum algal standing crop at the New Fane impoundment site. Under the no phosphorus removal alternative, the instream phosphate-phosphorus concentration exceeded 0.2 mg/l 10 percent of the year. The maximum "bloom" chlorophyll-a value and the mean summer chlorophyll-a concentration are expected to be more than 220 percent higher than the concentrations with the land application, or no effluent discharge, alternative.

Figure 8

COMPARISON OF THE PHOSPHATE PHOSPHORUS CONCENTRATION EXCEEDED 10 PERCENT OF THE TIME TO THE ASSOCIATED MAXIMUM SUMMER CHLOROPHYLL-A CONCENTRATION BASED ON THE SIMULATION OF THE EAST BRANCH OF THE MILWAUKEE RIVER AT THE NEW FANE IMPOUNDMENT



Source: SEWRPC.

Water quality samples obtained by the Regional Planning Commission in the fall of 1976 further substantiated the assumption that higher phosphorus levels tend to result in larger algae growths. Table 3 sets forth the phosphate-phosphorus, total phosphorus, and chlorophyll-a measurements for the fall of 1976 for eight sites within the Fox River watershed. The chlorophyll-a measurements are given for phytoplankton (algae suspended in the water column) and for periphyton (algae that grow attached to underwater substrates). The data indicate, as shown in Figure 9, that those streams with lower phosphate-phosphorus and total phosphorus levels tend to support lower algal standing crops. This conclusion applies to suspended algae and even more so to attached algae. It should be noted that there are a great many variables—such as stream size, flow, depth, shading, tem-

Table 3

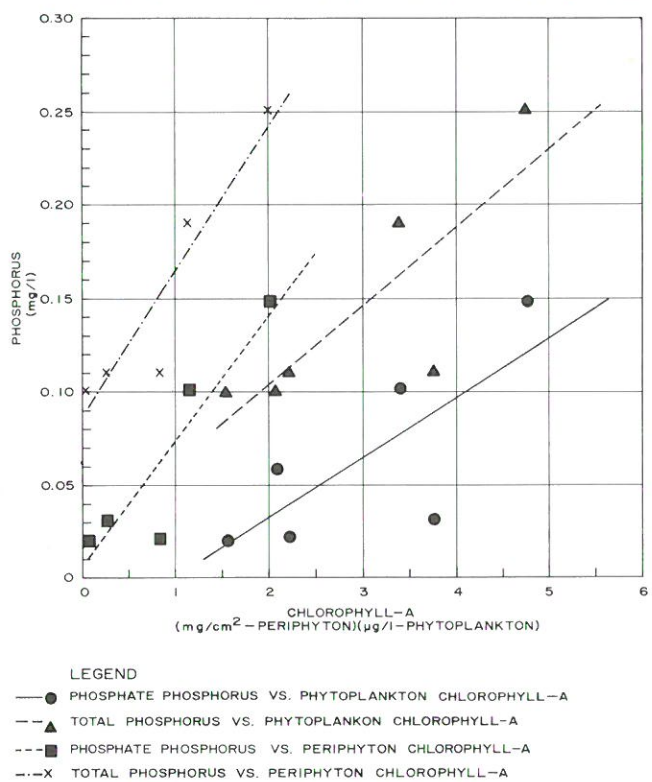
PHOSPHATE-PHOSPHORUS, TOTAL PHOSPHORUS, AND CHLOROPHYLL-A MEASUREMENTS IN THE FOX RIVER WATERSHED: FALL 1976

						Algal Standing Crop			
		Phosphate-Phosphorus		Total Phosphorus		Phytoplankton		Periphyton	
Stream	Location	Mean (mg/l)	Sample Period	Mean (mg/l)	Sample Period	Mean Chlorophyll-a (ug/l)	Sample Period	Mean Chlorophyll-a (mg/cm^2)	Sample Period
Mukwonago River. . .	At STH 83, Waukesha County	0.020	10/11-11/2	0.10	10/11-11/2	1.55	10/12-11/2	0.03	9/15-11/2
Sugar Creek	At Potters Road, Walworth County	0.022	10/11-11/2	0.11	10/11-11/2	2.21	10/12-11/2	0.84	9/15-11/2
Poplar Creek.	At Bluemound Road, Waukesha County	0.031	10/11-11/2	0.11	10/11-11/2	3.78	10/12-11/2	0.26	9/15-11/2
White River	At STH 11, Walworth County	0.058	9/7-10/6	0.10	9/7-10/6	2.09	9/29	- -	- -
Honey Creek.	At Carver Road, Walworth County	0.101	10/11-11/2	0.19	10/11-11/2	3.40	10/12-11/2	1.14	9/15-11/2
Fox River	At CTH C, Kenosha County	0.109	9/7-10/6	0.22	9/7-10/6	79.11	9/29	4.41	9/15-11/2
Fox River	At CTH W, Racine County	0.113	9/15-11/2	0.23	9/15-11/2	83.04	9/29-11/2	- -	- -
Fox River	At State Street, Waukesha County	0.147	10/11-11/2	0.25	10/11-11/2	4.78	10/12-11/2	2.01	9/15-11/2

Source: SEWRPC.

Figure 9

COMPARISON OF PHOSPHATE-PHOSPHORUS AND TOTAL PHOSPHORUS LEVELS TO CHLOROPHYLL-A LEVELS IN THE FOX RIVER WATERSHED: FALL 1976



Source: SEWRPC.

perature, zooplankton grazing, seed organisms, and benthic conditions—which also affect the standing crops of algae in a stream. Therefore, the data in Table 3 for the Fox River in Kenosha and Racine Counties are not represented in Figure 9 because the high chlorophyll-a levels—relative to those of the other, smaller streams—supported by this relatively large stream are probably a greater function of the decreased water turbulence than of the phosphorus levels.

CONCLUSION

Findings of the Commission water quality and biological sampling analyses and of simulation modeling studies indicate that 1) a restriction on phosphorus levels is warranted; 2) reductions in phosphorus concentrations are achievable; and 3) aquatic plant growth in most streams of the Region can be reduced. However, even if the proposed phosphorus standard of 0.1 mg/l is satisfied, many stream impoundments and selected reaches of streams will continue to have excessive aquatic plant growths that will interfere with the use of such waters. However, the duration and severity of these excessive growths will be reduced. Excessive aquatic plant growths in most flowing streams in the Region can be expected to be all but eliminated if the recommended instream standard is achieved.

BIBLIOGRAPHY OF LAKE MICHIGAN SHORE EROSION AND NEARSHORE PROCESS STUDIES

by Norman P. Lasca, Professor, Department of Geological Sciences and
Center for Great Lakes Studies, University of Wisconsin-Milwaukee, and
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ACKNOWLEDGMENTS

The bibliographic project on shore erosion and nearshore processes was funded by a grant from UW-Extension and by the Center for Great Lakes Studies in the University of Wisconsin-Milwaukee. We wish to express our thanks to Mr. Richard Karsten who encouraged us at the outset of the project and to Mr. Scott D. Burns and Mr. Wynn A. Gajkowski for their careful reading of the preliminary manuscript.

SCOPE AND USE OF BIBLIOGRAPHY

As originally proposed, we planned to prepare a bibliography of shore erosion and nearshore process studies that either were, or are being, conducted in the four southeastern Wisconsin counties bordering Lake Michigan: 1) Kenosha, 2) Racine, 3) Milwaukee, and 4) Ozaukee. However, as such a bibliography would not supply enough information to potential users, the scope of the work was expanded to include references concerning shore erosion and nearshore processes in general, with emphasis on the Great Lakes and the Lake Michigan shoreline of Wisconsin in particular.

As our work progressed, we realized that, because of both fiscal considerations and time constraints, many of the bibliographic entries could not be personally examined and annotations compiled. Therefore, entries are annotated only when we were able to personally verify the contents of the entry, and then only in cases where the title of the reference was not self-explanatory.

We feel that the bibliography will provide investigators with background information concerning previous scientific and engineering studies of Great Lakes shore erosion. In addition, pertinent references concerning the dominant physical processes involved in shore erosion are included, as are annotated references on Lake Michigan. Several references concerning shore erosion and shore protection methods used on Great Lakes other than Lake Michigan are also included as examples of the types of studies that can be undertaken successfully.

The body of the bibliography is subdivided as follows:

1. Topographic map references, and Great Lakes bathymetric charts—map and chart references for Wisconsin shores only.

2. General geology, geomorphology, and physiography—Lake Michigan basin and shoreline exclusively.

3. Lake currents, water levels, and general water quality.

4. Physical processes—selected references dealing with the dominant physical processes active on the Lake Michigan shore.

5. Shoreline protection—general reference works concerning the design, construction, and effects of protective structures.

6. Bibliographies—other bibliographies that may contain references in addition to those listed in the main body of this work.

7. General studies—includes Corps of Engineers public information circulars of interest to the layman, Great Lakes regional scientific studies, state and federal regulations and law, and land use and coastal zone management guidelines.

8. Lake Michigan—section is subdivided by state, i.e., Wisconsin, Illinois, and Michigan. The Lake Michigan section is the most extensive portion of this bibliography. References to shore erosion or nearshore process studies in Wisconsin and Illinois are treated in great detail. Where available, private, unpublished engineering data are included, along with the procedure for obtaining said engineering data.

9. Examples of shore erosion studies from areas other than Lake Michigan—includes studies from Ohio, Pennsylvania, and New York.

RESEARCH PROCEDURES AND AGENCIES CONTACTED

Conventional library research methods were used to assemble basic bibliographic data on published information sources. To supplement that data, we contacted the governmental agencies listed below requesting information regarding shore-erosion investigations conducted in their area. All local governmental units whose municipalities have Lake Michigan frontage within the four southeastern Wisconsin counties were contacted by mail. Depending upon the information supplied by the municipalities, additional potential sources of information were contacted by telephone and personal interview.

Wisconsin Municipalities Contacted:

- City of Cudahy
- City of Kenosha
  - Chief Engineer
  - Water Utility
- City of Milwaukee
- City of Oak Creek
- City of Port Washington
- City of Racine
- City of St. Francis
- City of South Milwaukee
- County of Kenosha
  - County Soil Conservation Service
  - County Parks Commission
- County of Milwaukee
  - Park Commission
  - Department of Public Works
- County of Ozaukee
- County of Racine
  - Planning and Zoning Department
  - Parks Department
  - County Soil Conservation Service
- Port of Milwaukee
- Town of Belgium
- Town of Caledonia
- Town of Grafton
- Town of Mequon
- Town of Mt. Pleasant
- Town of Pleasant Prairie
- Town of Somers
- Village of Bayside
- Village of Fox Point
- Village of Shorewood
- Village of Whitefish Bay
- Village of Wind Point

State and Federal Agencies Contacted:

- Milwaukee District Office, Wisconsin Department of Natural Resources
- Southeastern Wisconsin Regional Planning Commission
- State of Wisconsin, Chief State Planner
- Technology Section, Illinois State Geological Survey
- United States Army Corps of Engineers, Chicago District
- United States Army Corps of Engineers, North Central Division
- United States Geological Survey
- University of Michigan Sea Grant Program
- University of Wisconsin-Extension, Environmental Resource Unit, Madison, Wisconsin
- University of Wisconsin Sea Grant Program
- Wisconsin Coastal Zone Management Program
- Wisconsin Geological and Natural History Survey

In addition, we contacted numerous private engineering firms in order to catalog their unpublished work related to shore erosion and nearshore processes. Finally, a listing of available foundation exploration borings for buildings close to the lake bluff was developed. Large buildings within a 300-yard distance from the lake were noted. The current occupants of such structures were contacted by telephone to determine if foundation boring log records were available.

Supplementing the published reports and papers, the following is a list of structures and properties immediately adjacent to the Lake Michigan shore that have foundation exploration borings available from the sources indicated. The existence and location of drilling records were verified by officials at the property in question. In most cases, we were unable to personally inspect the records due to clearance and release procedures involved for the release of boring records. The properties are listed by county, beginning with Kenosha County and proceeding north.

Kenosha County:

Kemper Hall Boarding and Day School, 86th Street, Kenosha. Boring logs are available through the business office.

American Motors Company Plant, 55th Street and 8th Avenue, Kenosha. Boring logs are available through the office of the plant engineer.

Kenosha Water Utility Intake, Kenosha. Borings are available through the office of the Kenosha City Engineer. Construction work was done by Falcon Marine Engineering, Waukegan, Illinois.

Carthage College, Kenosha. Boring logs are available through the Business Office. Records for all college buildings are available.

Racine County:

Continental Can Company, Chicoree Road and Route 32, Racine. Borings are available through the office of the plant engineer, Continental Can Company Metal Operations Engineering Division, 1350 W. 76th Street, Chicago, Illinois.

Case Manufacturing Company, Racine. Detailed foundation borings of this large complex are available through the plant engineer. Case, Inc., has experienced considerable shore erosion difficulty and has conducted boring both through the lake bluff and slightly off-shore.

Racine Water Pollution Facility, Racine. Boring records of water intake and plant are available through the Racine Municipal Engineer.

Gateway Technical Institute, Racine. Foundation records and boring logs are available through Durant, Derringer, Domman, Cramer, and Gordon, Engineers, Watertown, Wisconsin.

Siena Center, Convent of St. Catherine, Wind Point. Foundation boring logs for this large structure, and the now defunct College of Racine (approximately 0.5 mile north of the convent) are available through the architectural firm of Barry and Kay, Chicago, Illinois.

Milwaukee County:

Vulcan Materials Company, Oak Creek, Wisconsin. Complete boring logs are available through Vulcan Materials Company, Sandusky, Ohio, or locally through Rush, Schroeder, Holt and Associates, Architects, 212 W. Wisconsin Avenue, Milwaukee, Wisconsin.

Peter Cooper Corporation, Division of U. S. Glue, Oak Creek. Records of recent borings in the lake bluff, and the entire building foundation, including subterranean pipeline system, are available through the Andrew Tomaro Company, Cudahy, Wisconsin.

South Milwaukee Filtration Plant, South Milwaukee. Borings are available through the office of the City Engineer.

Everbrite Electric Signs, Inc., Cudahy. Foundation design drawings and excavation records are available in the company offices.

Lake Shore Tower Apartments, 6260 S. Lakeshore Drive, Milwaukee. Boring records are available through the Milwaukee County Society of Civil Engineers' files housed at Marquette University, Department of Civil Engineering.

Trinity Memorial Hospital, Lakeshore Drive, Milwaukee. Boring logs are available through the firm of Johnson, Wagner, Isley, Widen, and Hipp, 605 E. Wisconsin Avenue, Milwaukee, Wisconsin. Borings for a new wing of the hospital were being taken at the time of this writing.

Cudahy Senior High School, Cudahy. Boring logs are available through the office of the City Engineer.

St. Francis High School, St. Francis. Boring logs are available through the City Engineer.

DeSales Prep Seminary, 3501 S. Lake Drive, Milwaukee. Boring logs are available through the architectural firm of Brust and Brust, Milwaukee, Wisconsin.

In addition to the above structures, the Wisconsin Electric Power Company has records of the foundation exploratory borings for its lakeshore power plants located in Edgewater, Wisconsin; Port Washington, Wisconsin; Oak Creek, Wisconsin; Lakeside, Wisconsin; and Pleasant Prairie, Wisconsin (proposed).

Foundation boring logs and shore erosion-environmental impact statements for these power facilities may be obtained through the Wisconsin Electric Power Company, Department of Environmental Engineering, 215 W. Michigan Avenue, Milwaukee, Wisconsin, 53203.

While the numbers of shore protection structures found along the Wisconsin shoreline are numerous, the number of contractors and marine engineering firms responsible for the construction is quite small. We recommend, therefore, that the reader contact the following marine engineering firms for further information regarding activity within the private sector: Edward E. Gillan Engineering Company, Milwaukee, Wisconsin; and Falcon Marine Engineering Company, Waukegan, Illinois.

The two firms are the largest two marine engineering consultants on the western shore of Lake Michigan, and, therefore, their files contain vast quantities of useful information.

Individuals are required to secure a permit from 1) the Corps of Engineers, 2) Wisconsin Department of Natural Resources, and 3) usually the local governmental unit prior to the construction of any shoreline protective work. As applications for said permits, complete with drawings and specifications, must be filed with each agency as appropriate, additional information concerning individual shore protection and beach nourishment structures may be obtained from the records of the respective agencies. The Corps of Engineers' entire file of construction permit applications for the Lake Michigan basin is housed at the Chicago District Office of the U. S. Army Corps of Engineers, Regulatory Functions Board, 219 S. Dearborn Street, Chicago, Illinois, 60604. The Wisconsin Department of Natural Resources maintains separate records, as do local governmental units.

Unfortunately, not all structures along the Wisconsin shoreline were built following the proper permit application procedure. However, for those that were, the permit application files of the Corps are computerized, with each permit application indexed with the following information:

1. Permit Number
2. Name of Applicant
3. Permit Count—number of other permit structures in that particular reach of shoreline
4. Action—Corps internal decision block
5. Issue—date of permit issue
6. Structure (type)
7. Waterway Mile
8. Bank (left or right)
9. County
10. Quadrangle
11. Engineer Contractor
12. Usage Classification (i.e., private, industrial, or public)
13. Data
14. Taffs Number—Corps internal processing number
15. State Permit Number
16. Miscellaneous

As a result, one may selectively retrieve Lake Michigan shore protection structure permits for selected regions and specific types of structures. Once the permit number is known, the plans and specifications may be located in the actual application files.

TOPOGRAPHIC MAPS AND GREAT LAKES BATHYMETRIC CHARTS

Berrien, J. M., 1936, Survey of the entrance to Milwaukee, Wisconsin - 1836, surveyed by Lieuts. A. J. Center and E. Rose, Scale 12" = 1 mile, 16 1/4 x 25 inches; Exerpt from Report of Secretary of War, 1836. (+)

Cheetham, R. N., and Wilke, R. F., 1969, The watershed and Green Bay shore drainage of Brown County, Wisconsin: U. S. Dept. Agriculture, Soil Conservation Service, Southeastern Wisconsin River Basin, Tech. Rpt. no. 3, 54 p., illus., maps. (*)

> Using current topographic maps and aerial photographs, thirty-three watersheds and bay shore drainage areas were delineated in Brown County, Wisconsin.

Hands, E. B., 1970, A geomorphic map of Lake Michigan shoreline: p. 250-265 in Proc. (13th) Conf. on Great Lakes Research, SUNY-Buffalo, N. Y.. April 1970: Internat. Assoc. Great Lakes Research, Part I. (!)

Hole, F. D., Beatty, M. E., and Klingelhoets, A. J., 1968, Soils of Wisconsin, colored wall map, Scale 1:710,000: Wisconsin Geol. and Nat. History Survey. (!)

__________, 1974, Soil regions of Wisconsin: Wisconsin Geol. and Nat. History Survey. (+)

> A generalized soil map of Wisconsin's soils. Scale approx. 1:2,700,000.

Illinois State Geological Survey, (on going), Maps - 1:2400. (+)

> Nearshore maps (strandline to a depth of 25 feet) between Evanston, Ill. and Wisconsin boundary.

Lapham, I. A., 1849, Map of Milwaukee, stained to show contour of Bay if Lake Michigan were 25 feet higher, Scale 660 feet = 1 inch, 19 3/4 x 24 inches. (*)

McKee, E. M., 1968, Lake Michigan - top to bottom: Limnos, v. 1, no. 1, p. 12-16. (!)

> The first published drawing of the floor of Lake Michigan.

U. S. Army Corps of Engineers, 1963, U. S. lake survey catalog of charts of the Great Lakes and outflow rivers: U. S. Army Engineer District, Lake Survey, Detroit, Michigan, 24 p.

> Lists of charts and where to purchase them.

U. S. Dept. of Commerce, NOAA Lake Survey Center, Lake Survey Center Chart Catalog, Detroit: NOAA periodically published pamphlet. Gives ordering procedures for detailed navigation charts of the entire Great Lakes. (+)

Charts of Interest:	#74	Waukegan to Port Washington
	#745	Racine
	#743	Milwaukee
Adjoining Sheets:	#75	Lake Michigan, south of Waukegan
	#73	Port Washington to Kewaunee
	#735	Manitowoc and Sheboygan

U. S. Dept. of the Interior, Geological Survey, 1200 South Eads Street, Arlington, Virginia 22202. (!)

> The following topographic maps are available from the Geological Survey. Applicable maps are listed by geographic location from north to south.

A. Sheboygan Falls (1954) - 15 minute
B. Port Washington (1959) - 15 minute
   1. Port Washington East (1958) - 7.5 minute
   2. Cedarburg (1959) - 7.5 minute
C. Milwaukee and Vicinity (1959) - 15 minute
   1. Milwaukee (1958) - 7.5 minute
   2. Thiensville (1958) - 7.5 minute
D. South Milwaukee (1958) - 15 minute
   1. South Milwaukee (1958) - 7.5 minute
   2. Racine North (1958) - 7.5 minute
E. Racine (1959) - 15 minute
   1. Racine South (1958) - 7.5 minute
   2. Kenosha (1958) - 7.5 minute
F. Waukegan, Illinois (1960) - 15 minute
   1. Zion (1960) - 7.5 minute

> In addition, aerial photographs for the southeastern Wisconsin four-county shorelines are available. Aerial surveys were conducted in 1939, 1950, 1961, and 1973.

GENERAL GEOLOGY, GEOMORPHOLOGY, AND PHYSIOGRAPHY

Ayers, J. C., 1967, The surficial bottom sediments of Lake Michigan: p. 247-253 in Ayers, J. C., and Chandler, D. C., (eds.)., Studies on the Environment and Eutrophication of Lake Michigan: Michigan Univ.-Ann Arbor, Great Lakes Research Div., Spec. Rpt. 30. (*)

Berkson, J. M., Lineback, J. A., and Gross, D. L., 1975, A side-scan sonar investigation of small-scale features on the floor of southern Lake Michigan: Illinois Geol. Survey Environmental Geology Notes, no. 74, 18 p. (!)

> Discusses ripple marks, sediment patches, linear ridges and their possible origin.

Black, R. F., 1974, Lake Pleistocene shorelines and stratigraphic relations in the Lake Michigan Basin: Geol. Soc. America Bull., v. 84, p. 659-660, a discussion. (!)

Callender, E., 1969, Geochemical characteristics of Lakes Michigan and Superior sediments: p. 124-160 in Proc. (12th) Conf. on Great Lakes Research: Internat. Assoc. of Great Lakes Research. (!)

Carlson, R. E., 1971, Lakeshore physiography and use: Limnos, v. 4, no. 2, p. 3-15. (!)

> Statistics on land use and classification along Lake Michigan's shoreline.

Collinson, C., Gross, D. L., White, W. A., Lineback, J. A., and Ayer, N. J., 1970, Stratigraphy of lacustrine sediments in southwestern Lake Michigan: Geol. Soc. America Abs. with Programs, v. 2, no. 6, p. 382-383. (!)

Dolan, R., 1971, Coastal landforms: crescentic and rhythmic: Geol. Soc. America Bull., v. 82, no. 1, p. 177-180. (!)

> A study of the Cape Hatteras area, N. C.

Evenson, E. B., 1973, Lake Pleistocene shorelines and stratigraphic relations in the Lake Michigan Basin: Geol. Soc. America Bull., v. 84, no. 7, p. 2281-2297. (!)

Goldthwait, J. W., 1907, The abandoned shorelines of eastern Wisconsin: Wisconsin Geol. and Nat. History Survey Bull., no. 17, p. 134. (!)

Goldthwait, J. W., 1908, The altitude of the Algonquin beach and its significance (abs.): Science, v. 28, p. 382-383. (!)

> The beach is now at an altitude at which it stood when first formed, and that it has been undisturbed by differential uplift.

______________, 1910, Isobases of Algonquin and Iroquis beaches and their significance: Geol. Soc. America Bull., v. 21, p. 231, map; discussion, v. 21, p. 761-762. (+)

Gross, D. L., and Lineback, J. A., 1970, Age and stratigraphy of Pleistocene sediments in southern Lake Michigan (abs.): Geol. Soc. America Abs. with Programs, v. 2, no. 7, p. 563-564. (!)

__________, (and others), 1970, Preliminary stratigraphy of unconsolidated sediments from the southwestern part of Lake Michigan: Illinois Geol. Survey Environmental Geology Notes, no. 30, Urbana, Ill., 20 p. (!)

__________, Lineback, J. A., Shimp, N. F., and White, W. A., 1972, Composition of Pleistocene sediments in southern Lake Michigan, U. S. A.: p. 215-222 in Proc. (24th) Internat. Geological Congress, section 8. (!)

Harza Engineering Company, 1969, Marine seismic survey, Lake Michigan: Harza Eng. Co., unpublished rpt., Chicago, Ill., 8 p. (!)

> Bedrock coring and geophysical profiling done offshore near Chicago for the City of Chicago.

Hobbs, W. H., 1911, The late glacial and post glacial uplift of the Michigan Basin: Michigan Geol. and Biol. Survey, Pub. 5, p. 1-96, illus. (+)

> This early publication discusses the post glacial uplift of the Michigan Basin. Particular emphasis is placed on the action of this uplift with regard to the shoreline features of Lake Michigan.

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__________, 1954, Geologic history of the Great Lakes beaches: p. 79-100 in Proc. (4th) Conf. Coastal Engineering: Am. Soc. Civil Engineers. (*)

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Hough, J. L., 1966, Geological studies of Lake Michigan: Illinois Univ., Urbana, Ill., Dept. of Geology, 7 p. (+)

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___________, 1967, Geological studies of Lake Michigan: Michigan Univ.-Ann Arbor, Great Lakes Research Div., Spec. Rpt. no. 30, p. 228-246. (*)

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This article examines the general geology, hydrology, ecology, thermal structure, circulation, oscillations, and eutrohpication of the Great Lakes.

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Shea, J. H., 1964, Petrology and stratigraphy of sediments from southern and central Lake Michigan: Illinois Univ., Urbana, Ill., unpublished Ph.D. Thesis, 92 p. (+)

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Taylor, F. B., 1894, A reconnaissance of the abandoned shorelines of Green Bay: Am. Geologist, v. 13, p. 317-327. (!)

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The remnant of the lacustrine plain in the region is suffering rapid removal by wave erosion of Lake Michigan.

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Bruce, W. G., 1942, Milwaukee in 1941: Ports and Harbors, v. 4, no. 4, p. 14-17. (+)

Engineering improvements and dredging in 1941.

Chamberlin, T. C., 1883, Soils and subsoils of Wisconsin: P. 678-688 in Geology of Wisconsin, v. 1, pt. 3, ch. 5: Wisconsin Geol. Survey. (+)

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Drescher, W. J., Dreber, F. C., and Brown, P. N., 1953, Water resources of the Milwaukee area, Wisconsin: U. S. Geol. Survey Circ. 247, 42 p., illus., map. (+)

The report summarizes and interprets all available water resources information for all of Milwaukee County and the eastern half of Waukesha County.

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A study of Terry Andrae State Park.

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Luckowicz, L. J., 1971, Nearshore sedimentary structures off Terry Andrae-Kohler State Park, Wisconsin (Western Lake Michigan): Wisconsin Univ.-Milwaukee, unpublished report. (+)

Meyer, R. P., 1969, Geological-geophysical survey of Green Bay - 1968: Wisconsin Univ.-Madison, Dept. of Geology and Geophysics, 31 p. (+)

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Napoli, J., 1975, The coasts of Wisconsin: Wisconsin Univ.-Madison, Sea Grant Program, WIS-SG-75-122, 33 p. (!)

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______________, 1975, Sedimentation in lower Green Bay, Wisconsin: p. 123-132 in Proc. (19th) Internat. Assoc. Theoretical Applied Limnology, pt. 1. (+)

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______________, 1972, The Port of Milwaukee, Wisconsin, pt. 2, U.S.A.C.E., The Board of Engineers for Rivers and Harbors, 57 p. (+)

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g) Lake currents in the nearshore areas of southern Lake Michigan: Researchers - Monahan, Collinson, Gross, and Cartwright.

h) Hydrography of the Lake Michigan nearshore: Researchers - Collinson, Brown, Olson, Murphy, Ursic, Muhs, Drake, and Hensen.

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SHORE EROSION STUDIES FROM AREAS OTHER THAN LAKE MICHIGAN

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Pincus, H. J., (editor), 1951, Investigations of Lake Erie Shore Erosion: Ohio Department of Natural Resources, Div. of Geol. Report of Investigations No. 18, 138 p. (!) Lake Erie shoreline is divided into natural units of study.

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Regional Marine Resources Council, 1973, Guidelines for Long Island Coastal Management, New York: Nassau-Suffolk Regional Planning Board. (+)

In addition to the studies cited above, the literature concerning California beach erosion studies is voluminous, and may be of considerable interest to the reader. The Engineering Index has extensive listings of applicable California studies under the headings "Beaches" and "Shore Protection". The processes and remedies dominant in California are very similar to the erosion problems on Lake Michigan.

(!) The reference cited was physically sighted by the authors.

(*) The citation was given in at least two secondary sources.

(+) The citation was found in one secondary source.

A BACKWARD GLANCE—HISTORIC EVOLUTION OF THE LOCAL GOVERNMENTAL STRUCTURE IN SOUTHEASTERN WISCONSIN

by Eileen Hammer

PRE-STATEHOOD

Four hundred years ago southeastern Wisconsin was a wilderness of hills and swamps, rivers and lakes, forests and prairies. Its only inhabitants were native American Indians who resided in scattered settlements and subsisted in a late stone age and early copper age culture. Various tribes dominated given territories that were bounded by waterways and other natural demarcations. European man had not yet set foot upon the land.

Three hundred years ago southeastern Wisconsin looked much the same, but by then Western European culture had stepped in, however imperceptibly. Great Britain claimed the land as part of her empire by virtue of John Cabot's discovery of North America in 1497. France established her claim through exploration and occupancy in the early 1600's. Thus began the Region's first tenuous ties to modern civilization, which ultimately prevailed as pioneers built settlements and divided the Region into organized, manageable units of government.

The dual claim over southeastern Wisconsin was ended in 1763 by the Treaty of Paris when France ceded the territory to Great Britain after she lost the French and Indian War. Great Britain's title to the area lasted for only 20 years and ended as a result of the Revolutionary War. In a treaty signed by Great Britain and the United States on September 3, 1783, the United States gained possession of the Region.

Because the western frontier was moving rapidly into the Great Lakes region, it soon became apparent that some form of local government would be needed. Consequently, Congress created territories and provided for the appointment of territorial governors. Residents were given voting privileges to elect territorial legislatures and a delegate to Congress.

Initially, Wisconsin, along with all the lands north and west of the Ohio River, was designated as part of the vast Northwest Territory by an act of Congress in 1787. This Northwest Ordinance called for smaller territorial divisions, and ultimately states, to be carved out of the larger territory as population densities warranted.

One of the divisional boundaries stipulated by the Northwest Ordinance was an east-west line drawn through the southern tip of Lake Michigan. That line initially divided Wisconsin and Illinois, but no longer serves as the division because of the clever tongue of an Illinois loyalist. Details of that boundary issue will be discussed later.

Editor's Note: There are currently 154 general-purpose local units of government in the Southeastern Wisconsin Region: 7 counties, 28 cities, 54 villages, and 65 towns. This relatively complex governmental framework has evolved over time from very simple beginnings. With this issue of the Technical Record, the Commission begins a three-part series examining the development of the local governmental structure in the Region. This first article traces the governmental development of the Region from pre-statehood through the establishment of the seven county boundaries as they exist today. The second article in the series will examine the development of the boundaries of the civil towns in the Region. The third and final installment in the series will examine the historic development of incorporated municipalities.

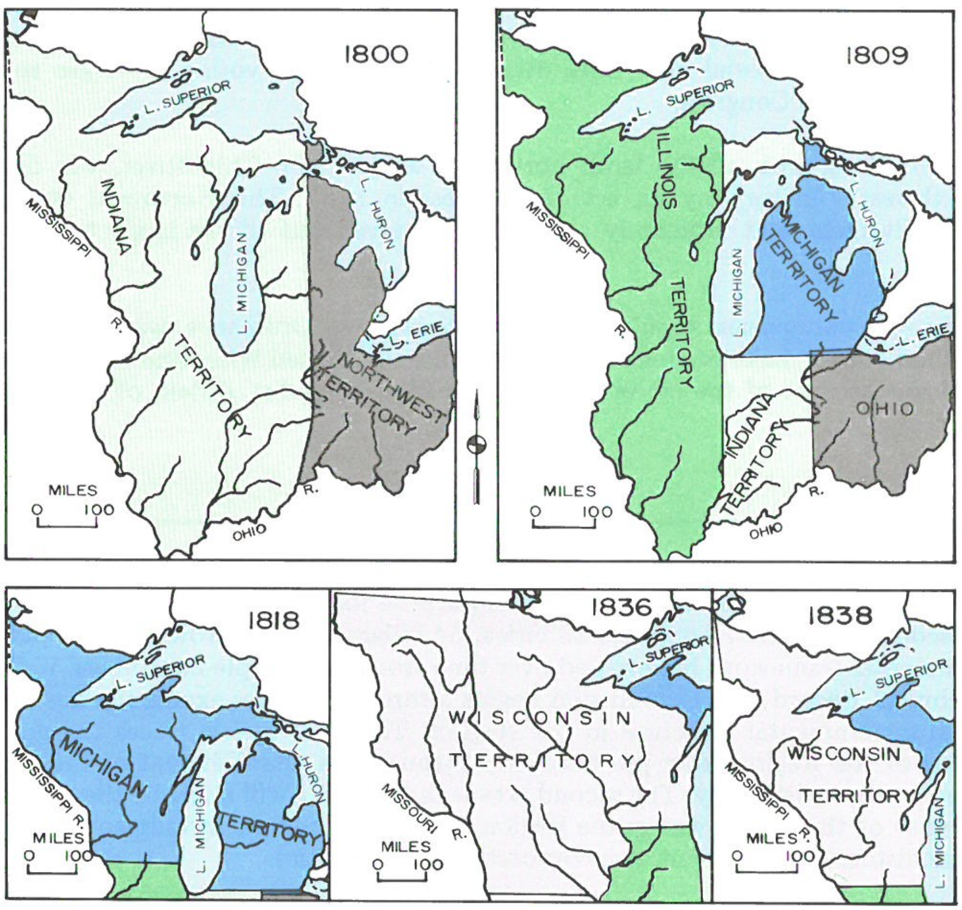
During the 50 years following passage of the Northwest Ordinance, several territorial units were created, placing southeastern Wisconsin under a variety of authorities. It became part of the Indiana Territory in 1800, the Illinois Territory in 1809, the Michigan Territory in 1818, and finally the Wisconsin Territory in 1836 (see Map 1).

As Europeans settled the "new country," they had to deal with the Indians who claimed sovereignty over the land by virtue of being the original inhabitants. Great Britain had a policy that Indian tribes were independent nations whose land should be acquired by treaty. The United States adopted that policy and designated commissioners to hold treaty sessions where differences were resolved and agreements were made on terms of purchase and arrangements for transfer of the land. Indian leaders signed the documents, which then were sent to Congress for ratification or rejection.

Most Wisconsin land was sold by treaty to the United States during the 1830's. The largest portion of what is now the Southeastern Wisconsin Region lay in land held by Chippewa, Ottawa, and Potawatomi tribes and was deeded to the United States in 1833. The roughly triangular area so deeded is located between the Rock River on the west and the Milwaukee River and Lake Michigan on the east. A narrow finger of land between the Milwaukee River and the lake was sold by the Menominee Indians in 1831. Purchase of Indian land was completed by the time Wisconsin became a territory in 1836.

Map 1

TERRITORIAL CHANGES AFFECTING WISCONSIN: 1800-1838



Source: Alice B. Smith, History of Wisconsin, Vol. 1 (Madison: State Historical Society, 1973).

The year 1818 has particular significance for southeastern Wisconsin. In that year the Illinois Territory became the State of Illinois, leaving Wisconsin to become attached to the Michigan Territory. It was during Illinois' push for statehood that its northern boundary—and Wisconsin's southern boundary—was changed to a line extending west from a point 60 miles north of Lake Michigan's southern tip. In other words, the boundary was placed 60 miles north of the line originally established by the Northwest Ordinance.

Nathaniel Pope, an enterprising territorial delegate from Illinois, is responsible for the boundary change. He argued for the extra territory by telling Congress that Illinois must have greater access to the Great Lakes and to commerce in the North, and threatened that she might switch her allegiance to the southern states if the Union divided in two, were the change not granted.

Pope's reasoning was not questioned by members of Congress, delegates from the Michigan Territory, or residents of Wisconsin. The extra territory gave Illinois jurisdiction over the Chicago area, the Galena lead region, and a large section of prairie land, a total of about 8,500 square miles.

While there was apparently no opposition to Pope's move at the time, Wisconsinites complained loudly and bitterly in years to follow. When Wisconsin was in the process of becoming a territory, and when it was moving toward statehood, the boundary question became a heated issue in which Wisconsinites insisted that the disputed land rightfully belonged to Wisconsin.

At one point during the statehood effort, at least one Wisconsin delegate to Congress threatened that the territory might separate itself from the union unless it were compensated for the lost land. Later, a territorial boundaries committee suggested that the boundary question be taken to the United States Supreme Court. Ultimately, in a desire not to jeopardize chances of becoming a state, Wisconsin representatives stopped fighting the border war once and forever. Thus, in 1848 Wisconsin became a state with the boundaries that exist today.

FORMATION OF COUNTIES

The first counties in Wisconsin were huge expanses of land that served as administrative districts for the limited degree of local government required by the sparse population. In 1818, when the State of Illinois was formed from a portion of the Illinois Territory, the remainder of the Illinois Territory was attached to the already existing Michigan Territory. The area so attached included all of what would ultimately become the State of Wisconsin as well as portions of what would become the State of Minnesota and a part of the Upper Peninsula of the State of Michigan.

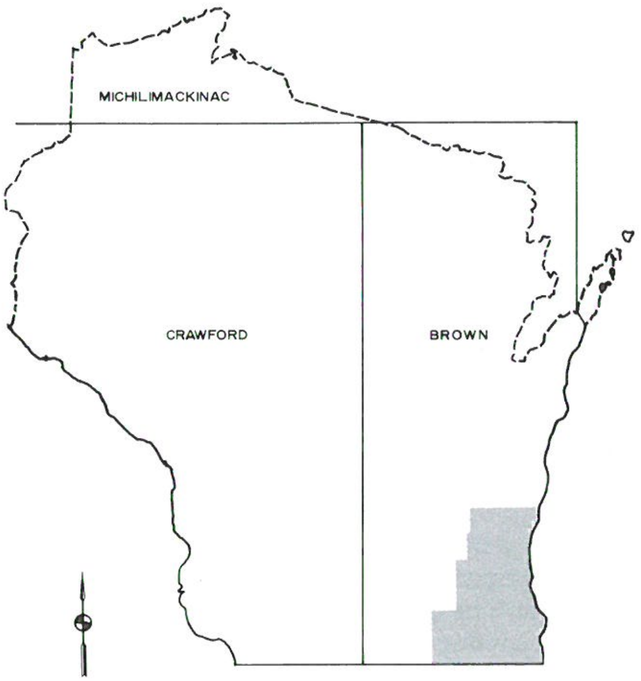
At the time of the attachment of this area to the Michigan Territory, three counties were created in what would eventually become the State of Wisconsin (see Map 2): a western county, Crawford; an eastern county, called Brown; and a far northern county, called Michilimackinac. The entire Southeastern Wisconsin Region was located in Brown County. Its western boundary was a line extending due north from the Illinois border through the middle of the portage between the Fox and Wisconsin Rivers, to the southern border of Michilimackinac County. The border between Brown County and Michilimackinac County was defined as "a line drawn due west, from the dividing ground between the rivers which flow into Lake Superior, and those which flow south . . . to a point due north from Sturgeon Bay; thence south to said bay; thence by the nearest line. . ." to a line drawn through the middle of Lake Michigan. The line through the middle of Lake Michigan constituted the eastern boundary of Brown County, and the Illinois State Line, the southern boundary.

As population continued to grow in the Michigan Territory, new counties were created. By 1836, when the Wisconsin Territory was organized from all that part of the former Michigan Territory which lay west of the present limits of the State of Michigan, four counties existed in what would ultimately become the State of Wisconsin (see Map 3).

In addition to being the year in which the Wisconsin Territory was organized, 1836 marked the completion of the U. S. Public Land Survey over the area that now comprises the Southeastern Wisconsin Region. This survey, which was established by an act of the U. S. Congress in 1785, formed an important basis for

Map 2

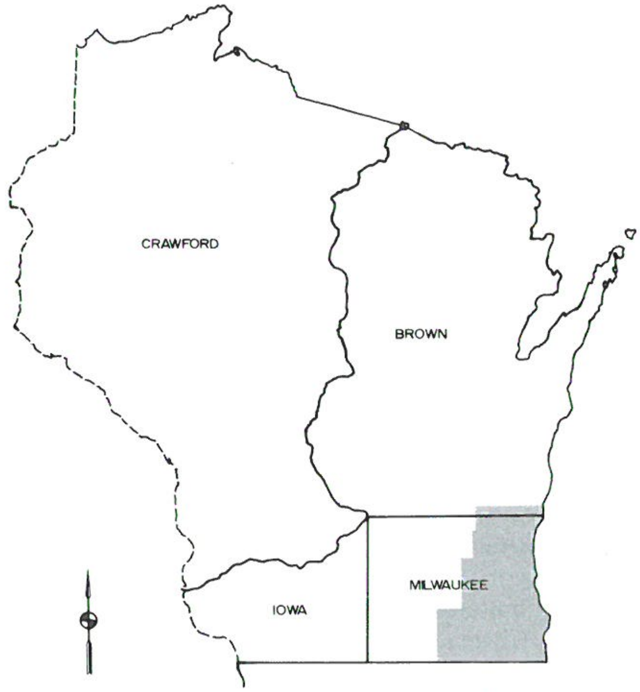
WISCONSIN COUNTIES: 1818



Source: Laws of Michigan: 1818; and John Farmer, Map of the Territories of Michigan and Ouisconsin, Detroit, 1830.

Map 3

WISCONSIN COUNTIES: 1836



Source: Alice B. Smith, History of Wisconsin, Vol. 1, (Madison: State Historical Society, 1973).

defining county and minor civil division boundaries and stands today as the basis for all division of land and for all real property boundary description in the Region. A discussion in an historic context of the U. S. Public Land Survey in southeastern Wisconsin is set forth in the SEWRPC Technical Record, Vol. 1, No. 2, December 1963-January 1964.

In the public land survey, the northern boundary of Illinois was established as the baseline for surveys to the north, and, as such, as one axis of a coordinate system from which the tiers of townships were numbered north from the baseline. The fourth principal meridian, the second axis for the public land survey system in southeastern Wisconsin, was extended due north from the baseline near the present community of Hazel Green in Grant County. The meridian became the eastern boundary of present day Grant County, and the basis for numbering ranges of townships east and west of the principal meridian.

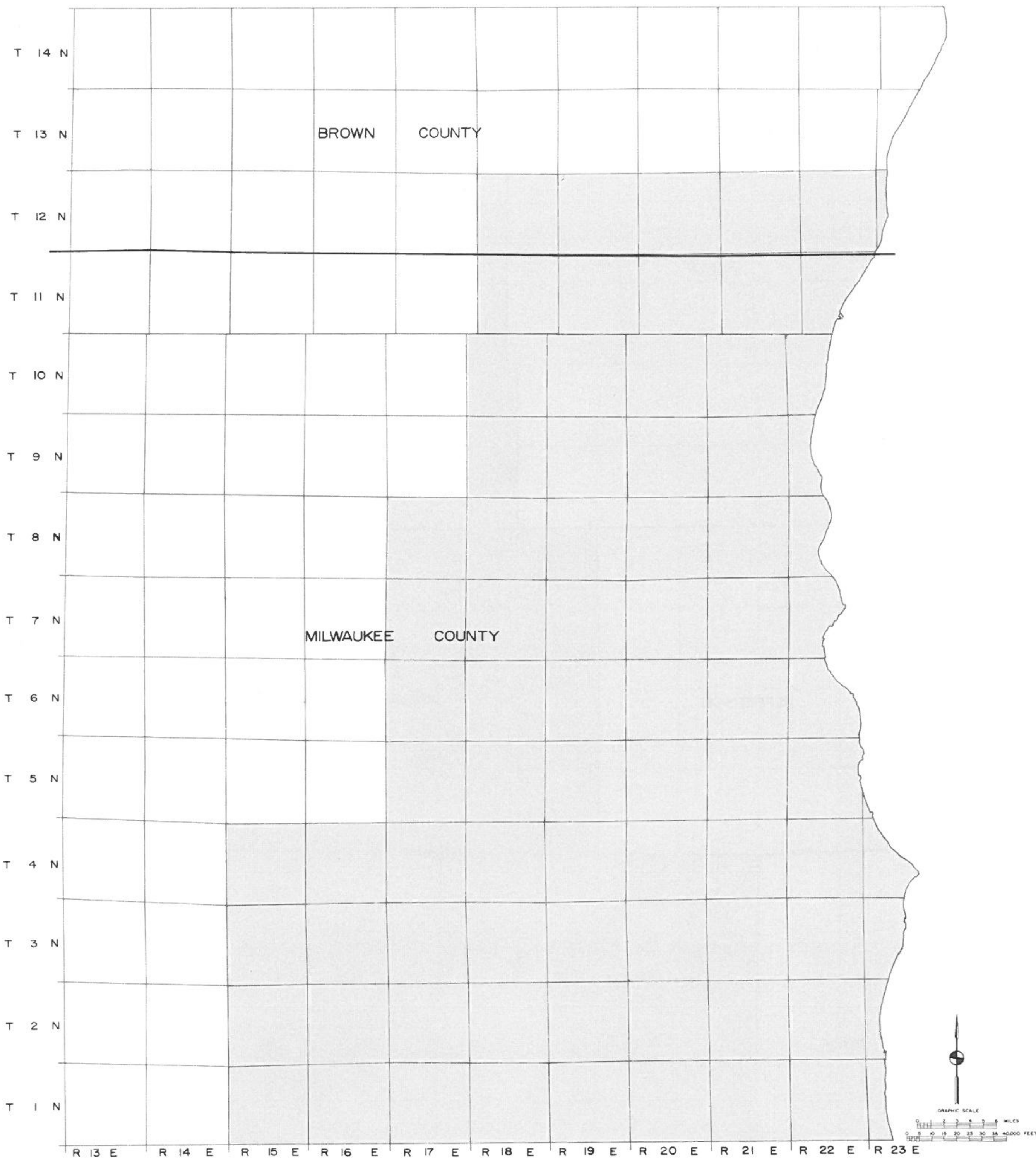
A Four-County Region

At a special session of the Michigan Territorial Legislature in 1834, Brown County was divided in two along the line between Townships 11 and 12 (see Map 4). The northern half remained Brown County. The southern half became Milwaukee County, an area that comprised what is now southeastern Columbia County; most of Dodge, Washington, and Ozaukee Counties; part of Dane County; and all of Kenosha, Jefferson, Milwaukee, Racine, Rock, Walworth, and Waukesha Counties. "Old Milwaukee County," as it is sometimes called, remained in this form for only two years, and for part of that time was attached to Brown County for judicial purposes.

When Wisconsin became a territory in 1836, the Territorial Legislature in its very first session subdivided Milwaukee and Brown Counties. Four counties were created in what is now the seven-county Southeastern Wisconsin Region (see Map 5).

Map 4

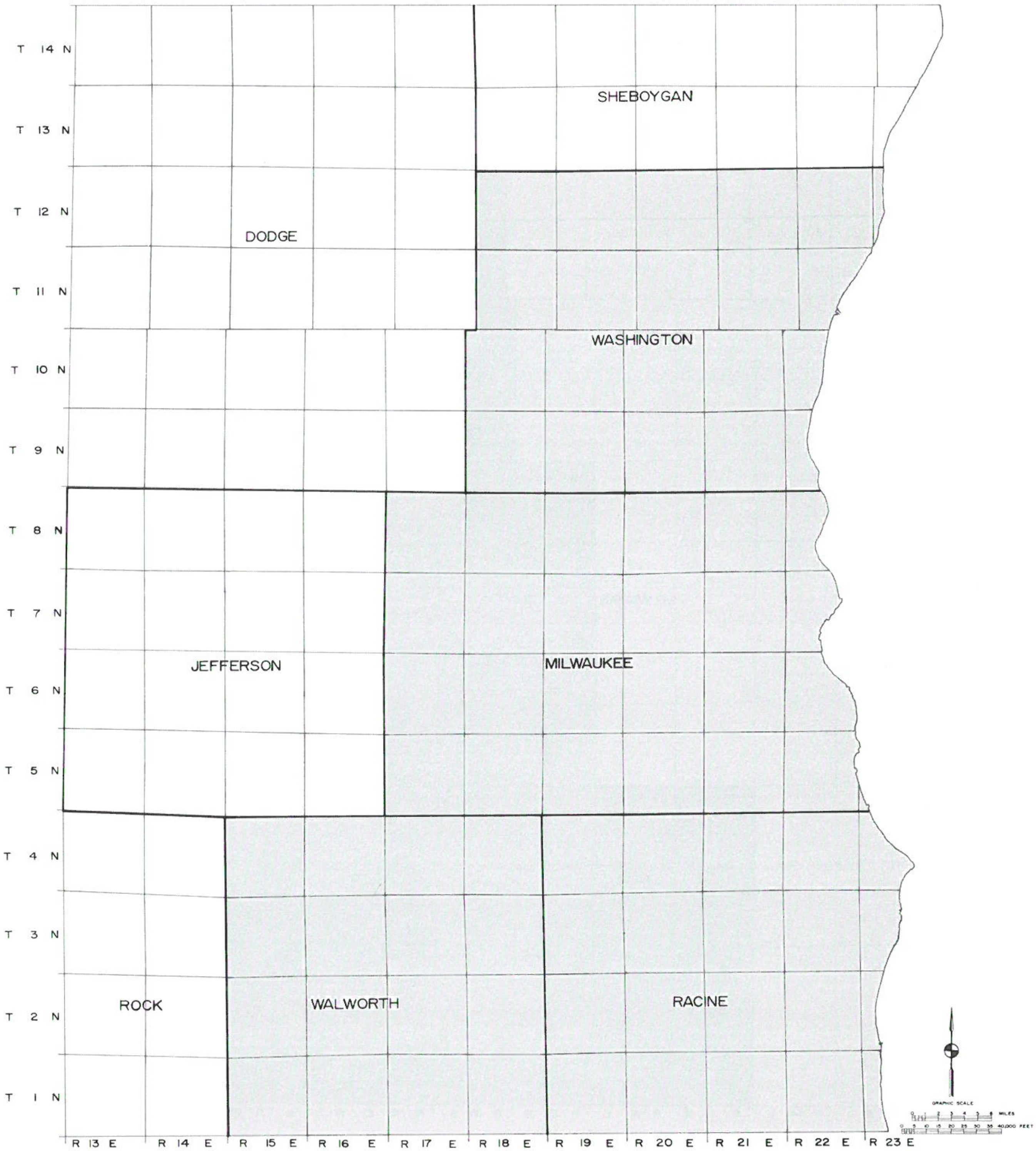
BROWN AND MILWAUKEE COUNTIES: 1834



Source: Wisconsin Historical Records Survey, Origin and Legislative History of County Boundaries in Wisconsin, Madison, 1942; and SEWRPC.

Map 5

MILWAUKEE, RACINE, WALWORTH, AND WASHINGTON COUNTIES: 1836



Source: Wisconsin Historical Records Survey, Origin and Legislative History of County Boundaries in Wisconsin, Madison, 1942; and SEWRPC.

Walworth County is the only one of these four counties that has retained its original boundaries, which included all of U. S. Public Land Survey Townships 1, 2, 3, and 4 North in Ranges 15, 16, 17, and 18 East of the fourth principal meridian. Milwaukee and Waukesha Counties were originally one entity known as Milwaukee County, which included all of Townships 5, 6, 7, and 8 North in Ranges 17, 18, 19, 20, 21, 22, and 23 East. Racine and Kenosha Counties were one unit called Racine County, which included all of Townships 1, 2, 3, and 4 North in Ranges 19, 20, 21, 22, and 23 East. Washington and Ozaukee Counties were originally formed as Washington County, with a northern boundary that included one tier of townships that had been in Brown County before 1834. The County included all Townships 9, 10, 11, and 12 North in Ranges 18, 19, 20, 21, 22, and 23 East.

The Creation of Waukesha County

Waukesha County seceded from Milwaukee County in 1846 at the instigation of four young politicians. The men behind the division are familiar names in Waukesha County annals: Alexander Pratt, William Barstow, Alexander Randall, and Andrew Elmore.

A convenient argument used by them in their effort to separate from Milwaukee County was that the City of Milwaukee was getting more than its fair share of county dollars for public improvements. In 1845 the four men succeeded in persuading the Territorial Legislature to designate Prairieville (now the City of Waukesha) as the county seat of Milwaukee County, although an actual relocation of government never took place. Through effective political organizing in late 1845, they managed to get several of their cronies elected to the Legislature, where the ultimate battle over county division would take place.

In early 1846, the Legislature acted to divide Milwaukee County in two, and to reestablish Milwaukee as the seat of government for Milwaukee County. The measure to divide the County called for affected residents to vote on the separation in a spring referendum. A lively and sometimes bitter campaign ensued, with the final outcome favoring a county division. There were charges of voter fraud but the outcome of the balloting prevailed, and Waukesha became a separate county in 1846.

The division left Milwaukee County with substantially less territory than was given to the newly created Waukesha County. The latter consisted of all of Townships 5, 6, 7, and 8 North in Ranges 17, 18, 19, and 20 East (see Map 6). After the division, Milwaukee County consisted of all of Townships 5, 6, 7, and 8 North in Ranges 21, 22, and 23 East.

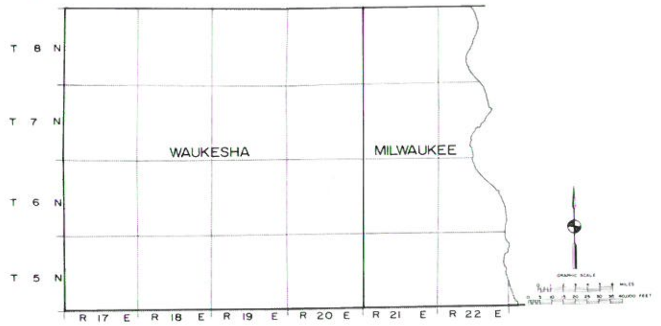
The Creation of Kenosha County

Similar forces were at play in the division of Racine County in 1850. The creation of Kenosha County was instigated by a petition from the president and trustees of Southport—now the City of Kenosha—who influenced the State Legislature to act in 1850 to change the village into a city and at the same time establish Kenosha County as a unit independent of Racine County. When the Racine County Board of Supervisors found out what had happened, they protested vigorously. In balloting to object to the Legislature's action, only three supervisors cast opposing votes, indicating that even representatives from the Kenosha area did not favor the change if it meant deviating from established political alliances. Legislative arguments, charges of unconstitutionality, and agitation for and against the move persisted for several years. More than 30 years later, in 1881 and 1882, efforts were still being made to reunite Racine and Kenosha Counties, but to no avail. The push for reunion was never successful.

Following the division, Kenosha County consisted of all of Township 1 North and Sections 25 through 30 of Township 2 North in Range 19 East plus all of Townships 1 and 2 North in Ranges 20, 21, 22, and 23 East (see Map 7). Racine County was left with roughly its northern half, consisting of Sections 1 through 24 of Township 2 North and all of Townships 3 and 4 North in Range 19 East plus all of Townships 3 and 4 North in Ranges 20, 21, 22, and 23 East. Because civil towns had been formed in Racine County prior to the division, the boundary between the Counties was established along an existing civil town boundary through Township 2 North in Range 19 East. Using the boundary between Township 2 North and Township 3 North in Range 19 East would have divided the Town of Burlington into two parts.

Map 6

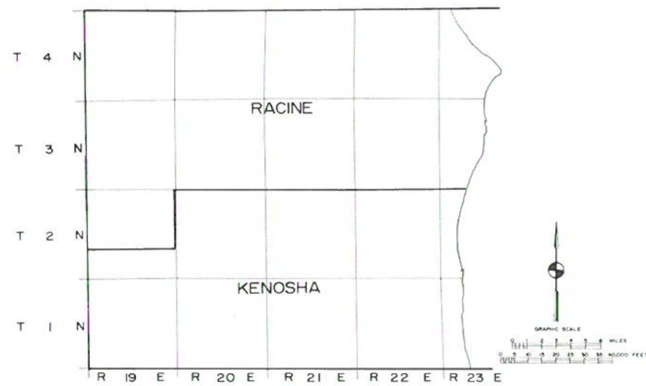
MILWAUKEE AND WAUKESHA COUNTIES: 1846



Source: Wisconsin Historical Records Survey, Origin and Legislative History of County Boundaries in Wisconsin, Madison, 1942; and SEWRPC.

Map 7

KENOSHA AND RACINE COUNTIES: 1850



Source: Wisconsin Historical Records Survey, Origin and Legislative History of County Boundaries in Wisconsin, Madison, 1942; and SEWRPC.

The Creation of Ozaukee County

When an exasperated State Legislature divided Washington County in 1853, the move was an unpopular resolution of an acrimonious and protracted 13-year dispute over where to locate the county seat. The dispute involved five indecisive referenda on selecting a site for the county seat and a decisive vote against dividing the county into northern and southern units, naming the southern county Tuskola, and setting its county seat at Cedarburg.

Even the 1853 law creating Ozaukee County did not entirely settle the matter: records were abducted before they could be sent from Port Washington to the new county seat at West Bend.

Historians say that the problem grew out of the peculiar socioeconomic characteristics of Washington County in the mid-nineteenth century. The County was inhabited by a diverse group of immigrants who were not used to governing themselves and perhaps felt a false sense of personal power in their new-found freedom. Their sense of citizenship, however, did not extend beyond their immediate localities, and the move to divide the County became a sectional fight among several communities, each with a great deal of support.

A brief review of the events begins in 1836 when the Territorial Legislature created Washington County and designated Wisconsin City (renamed Port Washington in 1844) as the county seat. That designation meant little, however, because the County was attached to Milwaukee County for administrative and judicial purposes.

Wisconsin City had fallen into decline and decay by 1840 when Washington County's organizational act was passed. Several other localities, however, had prospered and were likely possibilities for the county seat. In 1841 the Legislature authorized a county vote that resulted in the selection of Hamburg (now the Village of Grafton) as the county seat. Another provision of the law, however, said the county board could meet wherever it wanted. Generally, the board met at the home of a county commissioner.

This system continued until 1846, when the Territorial Legislature called for a uniform system of town government and authorized citizens of each county to hold an election to choose a county seat. Contenders in balloting that year were Port Washington, Cedarburg, Hamburg, West Bend, a "good location near the center," and the County Farm in the Town of Jackson. As no site received a majority of votes, the referendum was declared indecisive, and a county seat was not selected.

In 1847 the Legislature established Port Washington as a temporary county seat for five years to give county residents more time to agree on a suitable site. Their only point of agreement, however, was that Port Washington was not a suitable site.

Once again the Legislature was forced to step in, and in 1848 it authorized a series of three elections to choose a permanent site for Washington County's seat of justice. The first election had seven contenders: Cedarburg, West Bend, Port Washington, Newark (now Barton), Saukville, Newburg, and the County Farm.

Since there was no majority winner, a second election was held later in 1848 to choose among Cedarburg, West Bend, and Port Washington. Again there was no majority winner. In the third election, held on January 1, 1849, the contest was between Cedarburg and West Bend, but a healthy balloting for "neither" again denied residents of a majority winner. That final election also was marred by blatant evidence of ballot box stuffing.

In desperation, the Washington County Board unanimously agreed to ask the Legislature to end the sectional fights by establishing a county seat through state law. Instead, the Legislature proposed to divide the County into northern and southern sections, making the southern county Tuskola and declaring Cedarburg the county seat. Port Washington was to be the county seat for Washington County to the north. This measure called for a referendum "for" or "against" the county division. Balloting in 1850 resulted in a resounding vote against the proposed division.

Despite the outcome of the referendum, the county seat issue went to the Wisconsin Supreme Court on the question of a writ of mandamus ordering Washington County to construct county buildings in accordance with the bill dividing the County. That writ eventually was denied by the court.

By 1852, five years had expired since Port Washington was named temporary county seat, so the Legislature once again took matters into its hands by declaring Grafton the county seat and calling for an election in which residents would vote for or against moving the county seat to West Bend. The vote was against removal, but the election was met with heavy protests from all quarters because of widespread voting irregularities and accusations of flagrant fraud in the Town of Belgium, where 763 votes were cast even though only 300 voters lived in the community.

Residents once again carried their dispute to the halls of the Legislature, this time literally, as people from all sections of Washington County gathered in the Capitol's lobby with their protests, petitions, affidavits, and demands. Tired of dealing with this issue in session after session, and spurred by a newly formed alliance between leaders of West Bend and Port Washington, the Legislature finally voted in 1853 to divide the County into today's Washington and Ozaukee Counties and to name West Bend and Port Washington, respectively, as the county seats.

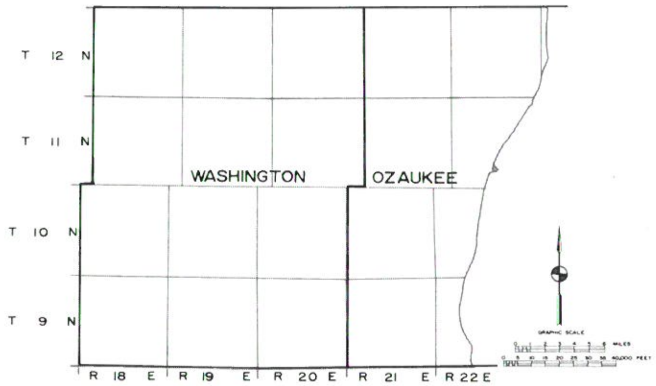
Dissatisfaction over that apparent resolution again sent the matter to the Wisconsin Supreme Court on a test of the division's constitutionality. Meanwhile, most of the original county officers found the new law especially repugnant because they lived in Port Washington and did not want to relinquish their authority to people from West Bend. They agreed to consider the new law unconstitutional and void. The one exception was Adam Schantz, Register of Deeds, who lived near West Bend and favored removal of his records to that city.

After Schantz's opponents obtained an injunction preventing him from moving his records, he got his lawyers to travel a great distance to find a circuit judge who could sign an order lifting the injunction and designating a deputy to remove the files from Port Washington to West Bend. The order lifting the injunction was shown to Schantz and his deputy, but apparently not to Schantz's opponents. The deputy was told to collect Schantz's records the next night.

A zealous sheriff who probably didn't know about the lifted injunction saw lights in the room where the deputy was gathering the records and proceeded to conduct a raid. The resulting commotion brought indignant residents to the scene as the intruder was escorted away. The next morning everyone was surprised to discover that all the records in the register's office had disappeared during the night.

Map 8

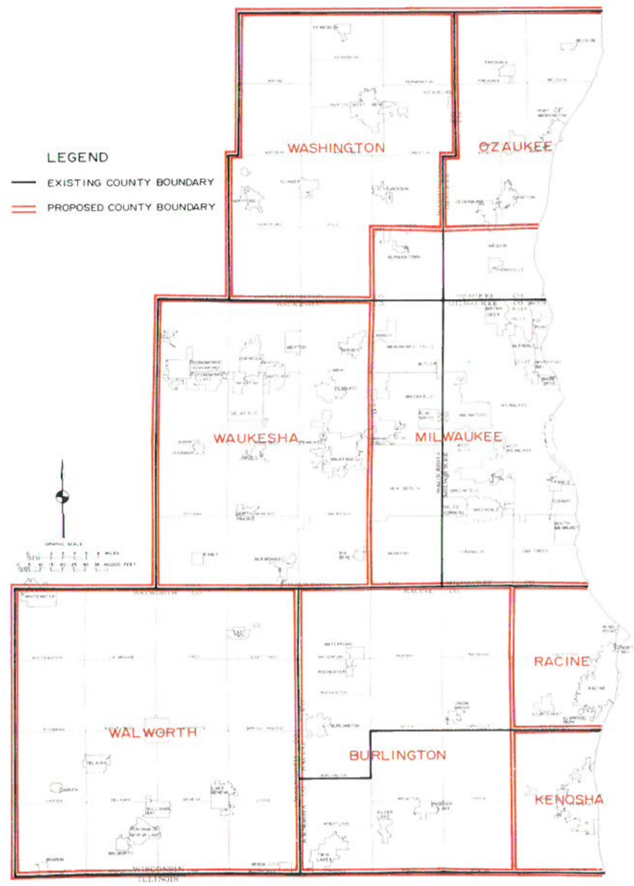
OZAUKEE AND WASHINGTON COUNTIES: 1853



Source: Wisconsin Historical Records Survey, Origin and Legislative History of County Boundaries in Wisconsin, Madison, 1942; and SEWRPC.

Map 9

PROPOSED REALIGNMENT OF COUNTY BOUNDARIES IN SOUTHEASTERN WISCONSIN: 1972



Source: Wisconsin Metropolitan Alliance, Inc.

Several months later, the records reappeared almost as mysteriously as they had disappeared. They turned up following the Supreme Court's ruling that the law to divide Washington County was indeed constitutional. About that time a local newspaper editor notified county officials that the missing records had been delivered to his home. He invited county officials to pick up the records if they did so unobtrusively. Once again, under the cloak of darkness, the Washington County records in question were prepared for a move. This time, the move ended triumphantly, as West Bend leaders carried the missing documents into the City the next day, waving banners and handkerchiefs tied to poles.

All but one of the missing documents were recovered at that time or shortly thereafter. One document remained missing for a quarter of a century; it was found between the brick walls and plastering of a Port Washington building where the records had been hidden.

Thus ended the protracted dispute that resulted in the division of Washington County into two smaller units, Washington County and Ozaukee County. Ozaukee County consisted of all of Townships 9, 10, 11, and 12 North in Ranges 21 and 22 East (see Map 8). The new Washington County contained substantially more than half the land in the original county, consisting of Townships 9, 10, 11, and 12 North in Ranges 18, 19, and 20 East.

CONCLUDING COMMENT

The county boundaries in southeastern Wisconsin have remained stable since 1853. From time-to-time, however, interest still arises in changing county boundaries to meet changing needs. The most recent example of such interest in the Southeastern Wisconsin Region is a proposal presented in the early 1970's to the Committee on Metropolitan Problems established by then Governor Patrick J. Lucey. In an appearance before that study committee, Mr. Russell Knetzger, a consulting planner working in the Region and at that time Chairman of the Wisconsin Metropolitan Alliance, Inc., a citizen group interested in improving local government in Wisconsin, presented a proposal to adjust county boundaries in southeastern Wisconsin in the manner identified on Map 9. Under this proposal, there would have been a total of eight counties within southeastern Wisconsin, rather than seven as at present. Milwaukee County would be expanded to include the four adjacent survey townships of Waukesha County, as well as adjacent townships in Washington and Ozaukee Counties. Waukesha, Washington, and Ozaukee Counties would have been substantially reduced in size under this proposal. In addition, the proposal called for the creation of a new county west of IH 94 in Kenosha and Racine Counties. Existing Kenosha and Racine Counties would thus be confined to the area east of IH 94. Walworth County would remain unchanged under this proposal. This proposal was never implemented.

SOUTHEASTERN WISCONSIN REGIONAL PLANNING COMMISSION

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