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

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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 Planning 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

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*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 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 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 qualityprob-

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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 non-point 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, the International Joint Commission Menomonee River pilot watershed study, the Kinnickinnic River watershed planning program, the Pewaukee floodland information project, the Sussex floodland information project, and the Pewaukee floodland management project. 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.


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

\[\text{See SEWRPC’s Kinnickinnic River Watershed Planning Program Prospectus, November 1974.}\]

\[\text{See SEWRPC Community Assistance Planning Report No. 9, Floodland Information Report for the Pewaukee River, October 1976.}\]

\[\text{See SEWRPC Community Assistance Planning Report No. 11, Floodland Information Report for Sussex Creek and Willow Creek, Village of Sussex, December 1976.}\]

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.\textsuperscript{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.\textsuperscript{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).


\textsuperscript{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.

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 3

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

LEGEND
THIessen POLYGON:

TIHeessen POLYGON NETWORK USING ALL PRECIPITATION STATIONS
THIessen POLYGON NETWORK USING DAILY PRECIPITATION STATIONS

STATIONS:
DAILY PRECIPITATION ONLY
DAILY PRECIPITATION AND DAILY TEMPERATURES
HOURLY PRECIPITATION ONLY
DAILY AND HOURLY PRECIPITATION, DAILY TEMPERATURES
DAILY AND HOURLY PRECIPITATION, DAILY TEMPERATURES, VELOCITY, HUMIDITY, CLOUD COVER, % SUNSHINE, AND DEWPOINT TEMPERATURE
DAILY AND HOURLY PRECIPITATION, DAILY TEMPERATURES, VELOCITY, HUMIDITY, CLOUD COVER, % SUNSHINE, AND DEWPOINT TEMPERATURE

GPC
DP

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.

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

LEGEND

OUTPUT

INPUT

SUBROUTINE

STORAGE

FUNCTION

HEAT

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**

<table>
<thead>
<tr>
<th>Data Set</th>
<th>Units</th>
<th>Frequency</th>
<th>Origin of Data</th>
<th>Use in Hydrologic Submodel</th>
<th>Use in Water Quality Submodel</th>
<th>Use in Synthesizing Other Meteorological Input Data for the Submodels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precipitation</td>
<td>10^{-2} inches</td>
<td>Hourly or more frequent</td>
<td>Daily</td>
<td>X</td>
<td>Rain or snowfall applied to the land Data from hourly stations used to disaggregate data from daily stations</td>
<td>--</td>
</tr>
<tr>
<td>Radiation</td>
<td>Langley/Day^a</td>
<td>Daily</td>
<td>Semimonthly</td>
<td>X</td>
<td>Snowmelt</td>
<td>Water temperature-heat flux to water by short wave solar radiation</td>
</tr>
<tr>
<td>Potential Evaporation</td>
<td>10^{-3} inches</td>
<td>Daily</td>
<td>Semimonthly</td>
<td>X</td>
<td>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</td>
<td>--</td>
</tr>
<tr>
<td>Temperature</td>
<td>°F</td>
<td>Daily</td>
<td>(maximum and minimum)</td>
<td>X</td>
<td>Snowmelt Density of new snow Occurrence of precipitation as snow</td>
<td>Water temperature-heat flux to water surface by long wave solar radiation Water temperature-heat flux from water by conduction-convective</td>
</tr>
<tr>
<td>Wind Movement</td>
<td>Miles/Day</td>
<td>Daily</td>
<td>--</td>
<td>X</td>
<td>Snowmelt by condensation-convective Evaporation from snow</td>
<td>Water temperature-heat flux loss from water surface by evaporation Lake reaeration</td>
</tr>
<tr>
<td>Dewpoint Temperature^b</td>
<td>°F</td>
<td>Daily</td>
<td>Semimonthly</td>
<td>X</td>
<td>Snowmelt by condensation-convective Evaporation from snow</td>
<td>Water temperature-heat flux loss from water surface by evaporation</td>
</tr>
<tr>
<td>Cloud Cover</td>
<td>Decimal fraction</td>
<td>Daily</td>
<td>Semimonthly</td>
<td>X</td>
<td>--</td>
<td>Water temperature-heat flux to water surface by long wave solar radiation.</td>
</tr>
<tr>
<td>Sunshine</td>
<td>Percent possible</td>
<td>Daily</td>
<td>--</td>
<td>X</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>

---

^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/cm² or 3.97 x 10^{-3} BTU/cm². 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/cm²/day or 3.97 x 10^{-3} BTU/cm²/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>
<thead>
<tr>
<th>Parameter</th>
<th>Definition or Meaning</th>
<th>Unit</th>
<th>Primary Source of Numerical Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 K1</td>
<td>Ratio of average annual segment precipitation to average annual precipitation at measuring station</td>
<td>None</td>
<td>Isohyetal map of annual precipitation</td>
</tr>
<tr>
<td>2 A</td>
<td>Impervious area factor related to directly connected impervious area in segment as a percent of total area</td>
<td>None</td>
<td>Aerial photographs</td>
</tr>
<tr>
<td>3 EPXM</td>
<td>Maximum interception storage</td>
<td>Inches</td>
<td>Extent and type of vegetation as determined from aerial photographs and field examination</td>
</tr>
<tr>
<td>4 UZSN</td>
<td>Nominal transient groundwater storage in the upper soil zones</td>
<td>Inches</td>
<td>A function of LZSN and therefore determined primarily by calibration</td>
</tr>
<tr>
<td>5 LZSN</td>
<td>Nominal transient groundwater storage in the lower soil zones</td>
<td>Inches</td>
<td>Related to annual precipitation but determined primarily by calibration</td>
</tr>
<tr>
<td>6 K3</td>
<td>Evaporation loss index: percent of segment area covered by deep-rooted vegetation</td>
<td>None</td>
<td>Extent and type of vegetation as determined from aerial photographs and field examination</td>
</tr>
<tr>
<td>7 K24L</td>
<td>Decimal fraction of the groundwater recharge that percolates to deep or inactive groundwater storage</td>
<td>None</td>
<td>Soils and topographic data</td>
</tr>
<tr>
<td>8 K24EL</td>
<td>Decimal fraction of land segment with shallow groundwater subject to direct evapotranspiration</td>
<td>None</td>
<td>Field reconnaissance</td>
</tr>
<tr>
<td>9 INFILTRATION</td>
<td>Nominal infiltration rate</td>
<td>None</td>
<td>Calibration</td>
</tr>
<tr>
<td>10 INTERFLOW</td>
<td>Index of interflow</td>
<td>None</td>
<td>Calibration</td>
</tr>
<tr>
<td>11 L</td>
<td>Average length of overland flow</td>
<td>Feet</td>
<td>Topographic maps</td>
</tr>
<tr>
<td>12 SS</td>
<td>Average slope of overland flow</td>
<td>None</td>
<td>Topographic maps</td>
</tr>
<tr>
<td>13 NN</td>
<td>Manning roughness coefficient for overland flow</td>
<td>None</td>
<td>Field reconnaissance</td>
</tr>
<tr>
<td>14 IRC</td>
<td>Interflow recession rate</td>
<td>None</td>
<td>Hydrograph analysis</td>
</tr>
<tr>
<td>15 KK24</td>
<td>Groundwater recession rate</td>
<td>None</td>
<td>Hydrograph analysis</td>
</tr>
<tr>
<td>16 KV</td>
<td>Variable to permit the KK24 to vary with the groundwater slope</td>
<td>None</td>
<td>Hydrograph analysis</td>
</tr>
<tr>
<td>17 RADCON</td>
<td>Adjust theoretical snowmelt equations to field conditions</td>
<td>None</td>
<td>Hydrograph analysis</td>
</tr>
<tr>
<td>18 CONDS-CONV</td>
<td>Adjust theoretical snowmelt equations to field conditions</td>
<td>None</td>
<td>Hydrograph analysis</td>
</tr>
<tr>
<td>19 SCF</td>
<td>Adjust snowfall measurements to account for typical catch deficiency</td>
<td>None</td>
<td>Hydrograph analysis</td>
</tr>
<tr>
<td>20 ELDIF</td>
<td>Elevation of segment above mean elevation of temperature station</td>
<td>$10^2$ feet</td>
<td>Topographic maps</td>
</tr>
<tr>
<td>21 IDNS</td>
<td>Density of new snow at $0^\circ$F</td>
<td>None</td>
<td>Aerial photographs</td>
</tr>
<tr>
<td>22 F</td>
<td>Decimal fraction of land segment with forest cover</td>
<td>None</td>
<td>Aerial photographs</td>
</tr>
<tr>
<td>23 DGM</td>
<td>Groundmelt rate attributable to conduction of heat from underlying soil to snow</td>
<td>Inches/day</td>
<td>Hydrograph analysis</td>
</tr>
<tr>
<td>24 WC</td>
<td>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</td>
<td>None</td>
<td>Hydrograph analysis</td>
</tr>
<tr>
<td>25 MPACK</td>
<td>Water equivalent of snowpack when segment is completely covered by snow</td>
<td>Inches</td>
<td>Hydrograph analysis</td>
</tr>
<tr>
<td>26 EVAPSNOW</td>
<td>Adjust theoretical snow evaporation equations to field conditions</td>
<td>None</td>
<td>Hydrograph analysis</td>
</tr>
<tr>
<td>27 MELEV</td>
<td>Mean elevation of segment</td>
<td>Feet</td>
<td>Topographic map</td>
</tr>
<tr>
<td>28 TSNOW</td>
<td>Air temperature below which precipitation occurs as snow</td>
<td>$^\circ$F</td>
<td>Hydrograph analysis</td>
</tr>
</tbody>
</table>

*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.


*Source: Hydrocomp, Inc., and SEWRPC.*
### Table 5
**HYDRAULIC CHANNEL PARAMETERS REQUIRED FOR EACH REACH**

#### DISCHARGE-RELATED PARAMETERS FOR STREAMS

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

#### CROSS SECTION-RELATED PARAMETERS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Definition of Meaning</th>
<th>Unit</th>
<th>Primary Source of Numerical Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>Length of reach</td>
<td>Miles</td>
<td>Map of watershed subbasins and stream system</td>
</tr>
<tr>
<td>8</td>
<td>Channel bottom elevation at upstream end of reach</td>
<td>Feet</td>
<td>Channel bottom profile</td>
</tr>
<tr>
<td>9</td>
<td>Channel bottom elevation at downstream end of reach</td>
<td>Feet</td>
<td>--</td>
</tr>
<tr>
<td>10</td>
<td>Channel bottom width</td>
<td>Feet</td>
<td>Generalized, representative reach floodland cross-section constructed from detailed cross-sections prepared for Hydraulic Submodel 2</td>
</tr>
<tr>
<td>11</td>
<td>Channel bank-to-bank width</td>
<td>Feet</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Channel depth</td>
<td>Feet</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Lateral slope of the floodplains</td>
<td>None</td>
<td></td>
</tr>
</tbody>
</table>
Table 5 (continued)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Definition of Meaning</th>
<th>Unit</th>
<th>Primary Source of Numerical Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>N-CH</td>
<td>Manning roughness coefficient for the channel</td>
<td>None</td>
<td>Coefficients established for Hydraulic Submodel 2 revised as needed during calibration</td>
</tr>
<tr>
<td>N-FP</td>
<td>Manning roughness coefficient for both floodplains</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>KC</td>
<td>Storage constant when lake is below bankfull</td>
<td>Cubic Feet per Second per Acre-Foot</td>
<td>Storage-discharge curves derived from hydrographic and structure surveys</td>
</tr>
<tr>
<td>HEXC</td>
<td>Storage exponent when lake is below bankfull</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>KF</td>
<td>Storage constant when lake is above bankfull</td>
<td>Cubic Feet per Second per Acre-Foot</td>
<td></td>
</tr>
<tr>
<td>HEXF</td>
<td>Storage exponent when lake is above bankfull</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>VB</td>
<td>Lake volume at bankfull</td>
<td>Acre-Foot</td>
<td></td>
</tr>
<tr>
<td>VL</td>
<td>Lake volume at spillway crest</td>
<td>Acre-Foot</td>
<td></td>
</tr>
</tbody>
</table>

*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. 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

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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.

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

---

*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

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

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

IDENTIFY METEOROLOGIC DATA SOURCES

GATHER METEOROLOGIC DATA

REFORMAT DATA OBTAINED ON TAPES

VERIFY FORMATTED DATA

FILL PERIODS OF MISSING DATA

CODE AND KEYPUNCH DATA OBTAINED ON HARD COPY

ADJUST WIND DATA TO REPRESENT MEASUREMENT OF 2 FEET ABOVE GROUND

FINAL CHECK DEWPOINT DATA

FINAL CHECK TEMPERATURE DATA

CONVERT PERCENT SUNSHINE DATA TO SOLAR RADIATION DATA

FINAL CHECK CLOUD COVER DATA

DOUBLE MASS ANALYSIS OF PRECIPITATION DATA

ADJUST PRECIPITATION DATA TO CORRECT DOUBLE MASS ANOMALIES

FINAL CHECK WIND DATA

FINAL CHECK SOLAR RADIATION DATA

READ DATA INTO HSP DATA STORAGE SYSTEM

FINAL CHECK PRECIPITATION DATA

DISAGGREGATE DAILY PRECIPITATION DATA

FINAL CHECK DAILY/HOURLY PRECIPITATION DATA

CALCULATE EVAPORATION DATA

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

Source: SEWRPC.
<table>
<thead>
<tr>
<th>Station</th>
<th>Data Set</th>
<th>Data Source(s)</th>
<th>Period of Available Record</th>
<th>Corrections or Adjustments Made</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antioch</td>
<td>Daily Precipitation</td>
<td>NCC, SC, OP</td>
<td>April 1, 1941 - March 31, 1977</td>
<td>-</td>
</tr>
<tr>
<td>Beaver Dam</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Not used</td>
</tr>
<tr>
<td>Beloit</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Not used</td>
</tr>
<tr>
<td>Burlington</td>
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<td>August 1, 1948 - March 31, 1977</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Temperature</td>
<td>NCC, SC, OP</td>
<td>October 18, 1951 - March 31, 1977</td>
<td>-</td>
</tr>
<tr>
<td>Burnett</td>
<td>Hourly Precipitation</td>
<td>NCC, ACOE</td>
<td>January 1, 1940 - November 1970</td>
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</tr>
<tr>
<td>Chilton</td>
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<td>NCC, ACOE</td>
<td>April 1, 1940 - December 31, 1974</td>
<td>13 scattered months estimated</td>
</tr>
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<td>-</td>
</tr>
<tr>
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<td>April 1, 1948 - December 1974</td>
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</tr>
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<td>-</td>
</tr>
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<td>Temperature</td>
<td>NCC, SC, OP</td>
<td>June 1, 1948 - March 31, 1977</td>
<td>-</td>
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<td>NCC, SC, OP</td>
<td>January 1, 1945 - March 31, 1977</td>
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</tr>
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<td></td>
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<td>June 1, 1948 - March 31, 1977</td>
<td>6 months estimated</td>
</tr>
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<td>January 1, 1940 - March 31, 1977</td>
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</tr>
<tr>
<td></td>
<td>Temperature</td>
<td>NCC, SC, OP</td>
<td>January 1, 1940 - March 31, 1977</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Daily Precipitation</td>
<td>NCC</td>
<td>January 1, 1940 - March 31, 1977</td>
<td>-</td>
</tr>
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<td>Hartford</td>
<td>Daily Precipitation</td>
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<td>August 22, 1948 - March 31, 1977</td>
<td>16 months estimated</td>
</tr>
<tr>
<td></td>
<td>Temperature</td>
<td>NCC, SC, OP</td>
<td>June 1, 1953 - March 31, 1977</td>
<td>1 month estimated</td>
</tr>
<tr>
<td>Horizon</td>
<td>Hourly Precipitation</td>
<td>NCC</td>
<td>-</td>
<td>Data lack required precision</td>
</tr>
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<td>Daily Precipitation</td>
<td>NCC</td>
<td>January 1, 1945 - September 30, 1975</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Temperature</td>
<td>NCC, OP, SC</td>
<td>June 1, 1947 - September 30, 1975</td>
<td>-</td>
</tr>
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<td>Kenosha</td>
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<td>NCC, SC, OP</td>
<td>January 5, 1941 - December 31, 1974</td>
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</tr>
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<td>Temperature</td>
<td>NCC, SC, OP</td>
<td>January 1, 1945 - March 31, 1977</td>
<td>-</td>
</tr>
<tr>
<td>Lake Geneva</td>
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<td>April 1, 1940 - March 31, 1977</td>
<td>11 months estimated</td>
</tr>
<tr>
<td></td>
<td>Temperature</td>
<td>NCC, SC, OP</td>
<td>April 10, 1945 - March 31, 1977</td>
<td>3 months estimated</td>
</tr>
<tr>
<td>Lake Mills</td>
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<td>-</td>
<td>-</td>
<td>Not used</td>
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<td>NCC, SC, OP</td>
<td>January 1, 1940 - March 31, 1977</td>
<td>12 months estimated</td>
</tr>
<tr>
<td></td>
<td>Temperature</td>
<td>NCC, SC, OP</td>
<td>March 31, 1977</td>
<td>9 months estimated</td>
</tr>
<tr>
<td>Milwaukee-Mount Mary</td>
<td>Daily Precipitation</td>
<td>NCC</td>
<td>January 1, 1940 - March 31, 1977</td>
<td>-</td>
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<tr>
<td>Milwaukee-North Side</td>
<td>Daily Precipitation</td>
<td>NCC</td>
<td>October 1949 - December 1959 and January 1966 - September 1976</td>
<td>31 months missing</td>
</tr>
<tr>
<td></td>
<td>Temperature</td>
<td>NCC</td>
<td>October 1949 - December 1959 and January 1966 - September 1976</td>
<td>-</td>
</tr>
<tr>
<td>Oconomowoc</td>
<td>Daily Precipitation</td>
<td>NCC, SC, OP</td>
<td>January 1, 1940 - March 31, 1977</td>
<td>5 months estimated</td>
</tr>
<tr>
<td>Plymouth</td>
<td>Daily Precipitation</td>
<td>NCC, SC, OP</td>
<td>January 1, 1940 - March 31, 1977</td>
<td>5 months estimated</td>
</tr>
<tr>
<td>Port Washington</td>
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<td>3 months estimated</td>
</tr>
<tr>
<td></td>
<td>Temperature</td>
<td>NCC, SC, OP</td>
<td>January 1, 1940 - March 31, 1977</td>
<td>2 months estimated</td>
</tr>
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<td>Station</td>
<td>Data Set</td>
<td>Data Source(s)a</td>
<td>Period of Available Record</td>
<td>Corrections or Adjustments Madeb</td>
</tr>
<tr>
<td>--------------</td>
<td>---------</td>
<td>----------------</td>
<td>----------------------------</td>
<td>----------------------------------</td>
</tr>
<tr>
<td>Racine</td>
<td>Daily Precipitation</td>
<td>NCC, SC, OP, Racine Journal Times</td>
<td>January 1, 1940 - March 31, 1977</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>Temperature</td>
<td>NCC, SC, OP, Racine Journal Times</td>
<td>January 1, 1940 - March 31, 1977</td>
<td>--</td>
</tr>
<tr>
<td>Rockford I</td>
<td>Daily Precipitation</td>
<td>NCC</td>
<td>January 1, 1940 - December 31, 1950</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>Temperature</td>
<td>NCC</td>
<td>January 1, 1940 - December 31, 1960</td>
<td>--</td>
</tr>
<tr>
<td>Rockford II</td>
<td>Daily Precipitation</td>
<td>NCC, SC, OP</td>
<td>January 1, 1940 - March 31, 1977</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>Temperature</td>
<td>NCC, SC, OP</td>
<td>January 1, 1961 - March 31, 1977</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>Hourly Precipitation</td>
<td>NCC, SC, OP</td>
<td>January 1, 1961 - April 31, 1977</td>
<td>--</td>
</tr>
<tr>
<td>Sheboygan</td>
<td>Daily Precipitation</td>
<td>NCC, SC, OP</td>
<td>January 1, 1940 - March 31, 1977</td>
<td>--</td>
</tr>
<tr>
<td>Union Grove</td>
<td>Daily Precipitation</td>
<td>NCC, SC, OP</td>
<td>January 1, 1945 - March 31, 1977</td>
<td>5 months estimated</td>
</tr>
<tr>
<td></td>
<td>Temperature</td>
<td>NCC, SC, OP</td>
<td>January 1, 1940 - March 31, 1977</td>
<td>1 month estimated</td>
</tr>
<tr>
<td>Watertown</td>
<td>Daily Precipitation</td>
<td>NCC, SC</td>
<td>January 1, 1940 - September 30, 1975</td>
<td>1 month estimated</td>
</tr>
<tr>
<td></td>
<td>Temperature</td>
<td>NCC, SC</td>
<td>January 1, 1940 - September 30, 1975</td>
<td>1 month estimated</td>
</tr>
<tr>
<td>Waukegan</td>
<td>Daily Precipitation</td>
<td>NCC, SC, OP, Lake County Public Works Department</td>
<td>January 1, 1940 - March 31, 1977</td>
<td>1 month estimated</td>
</tr>
<tr>
<td></td>
<td>Temperature</td>
<td>NCC, SC, OP, Lake County Public Works Department</td>
<td>January 1, 1940 - March 31, 1977</td>
<td>1 month estimated</td>
</tr>
<tr>
<td></td>
<td>Hourly Precipitation</td>
<td>NCC, SC, OP, Lake County Public Works Department</td>
<td>January 1, 1940 - September 30, 1968</td>
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</tr>
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<td>Daily Precipitation</td>
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<td>January 1, 1940 - March 31, 1977</td>
<td>--</td>
</tr>
<tr>
<td>West Allis</td>
<td>Daily Precipitation</td>
<td>NCC, SC, OP</td>
<td>January 1, 1940 - March 31, 1977</td>
<td>--</td>
</tr>
<tr>
<td>West Bend</td>
<td>Daily Precipitation</td>
<td>NCC, SC, OP</td>
<td>January 1, 1940 - September 30, 1975</td>
<td>--</td>
</tr>
<tr>
<td>Whitewater</td>
<td>Daily Precipitation</td>
<td>NCC, SC, OP</td>
<td>June 1, 1948 - March 31, 1977</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>Temperature</td>
<td>NCC, SC, OP</td>
<td>October 13, 1949 - March 31, 1977</td>
<td>--</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Land Use and Cover Classification</th>
<th>Characteristic Percent Impervious</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rural</td>
<td>1.5-3</td>
</tr>
<tr>
<td>Low-Density Development</td>
<td>11</td>
</tr>
<tr>
<td>Medium-Density Development</td>
<td>30</td>
</tr>
<tr>
<td>High-Density Development</td>
<td>50</td>
</tr>
<tr>
<td>Very High-Density Development</td>
<td>60</td>
</tr>
</tbody>
</table>

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 dotcounted 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.

### Table 10

<table>
<thead>
<tr>
<th>Water Quality Land Use and Cover Classification</th>
<th>Corresponding Hydrologic Land Use and Cover</th>
</tr>
</thead>
<tbody>
<tr>
<td>Golf Course</td>
<td>Rural</td>
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<tr>
<td>Other Recreation</td>
<td>Rural</td>
</tr>
<tr>
<td>Row Crop</td>
<td>Rural</td>
</tr>
<tr>
<td>Grain</td>
<td>Rural</td>
</tr>
<tr>
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<td>Hay</td>
<td>Rural</td>
</tr>
<tr>
<td>Orchard and Nursery</td>
<td>Rural</td>
</tr>
<tr>
<td>Sod Farm</td>
<td>Rural</td>
</tr>
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<td>Woodland</td>
<td>Rural</td>
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<td>Industrial</td>
<td>High density</td>
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<td>High density</td>
</tr>
<tr>
<td>Extractive</td>
<td>High density</td>
</tr>
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Source: SEWRPC.

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 $12 \times 32 \times 7 \times 5$ 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 $12 \times 32 \times 7 \times 21$ 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. 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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LOCATIONS OF SURVEYED HYDRAULIC STRUCTURES AND CHANNEL CROSS SECTIONS USED IN SIMULATION MODELING FOR THE AREAWIDE WATER QUALITY MANAGEMENT PLAN FOR SOUTHEASTERN WISCONSIN

LEGEND

- Reaches having cross-section data developed as part of areawide water quality management planning programs
- Reaches having cross-section data developed as part of SEWRPC watershed planning programs
- Hydraulic structures surveyed as part of areawide water quality management planning program
- Hydraulic structures surveyed as part of SEWRPC watershed planning programs
- Number of surveyed structures at that site

Source: SEWRPC
### Table 11

**TYPICAL VALUES ASSIGNED TO STREAM REACTION WATER QUALITY PARAMETERS**

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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

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<td>CONC</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
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</table>

54
### Table 12 (continued)

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Loading Limits</th>
<th>Parameter&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Low Residential</th>
<th>Medium Residential</th>
<th>High Residential</th>
<th>Very High Residential</th>
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<tbody>
<tr>
<td>Biochemical Oxygen Demand</td>
<td>15</td>
<td>YI 0.28</td>
<td>0.08</td>
<td>0.08</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>YP 0.04</td>
<td>0.02</td>
<td>0.04</td>
<td>0.06</td>
<td>0.08</td>
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<tr>
<td></td>
<td></td>
<td>CONC 0.1</td>
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<td>2</td>
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</tr>
<tr>
<td>Ammonia-Nitrogen</td>
<td>15</td>
<td>YI 0.15</td>
<td>0.002</td>
<td>0.002</td>
<td>0.002</td>
<td>0.002</td>
</tr>
<tr>
<td></td>
<td></td>
<td>YP 0.026</td>
<td>0.008</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
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<td></td>
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<td>CONC 0.06</td>
<td>0.06</td>
<td>0.06</td>
<td>0.06</td>
<td>0.06</td>
</tr>
<tr>
<td>Nitrate-Nitrogen</td>
<td>20</td>
<td>YI 0.03</td>
<td>0.006</td>
<td>0.006</td>
<td>0.006</td>
<td>0.006</td>
</tr>
<tr>
<td></td>
<td></td>
<td>YP 0.002</td>
<td>0.003</td>
<td>0.004</td>
<td>0.006</td>
<td>0.006</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CONC 6</td>
<td>1.5</td>
<td>4</td>
<td>6</td>
<td>6</td>
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<tr>
<td>Phosphate-Phosphorus</td>
<td>15</td>
<td>YI 0.006</td>
<td>0.002</td>
<td>0.002</td>
<td>0.002</td>
<td>0.002</td>
</tr>
<tr>
<td></td>
<td></td>
<td>YP 0.005</td>
<td>0.002</td>
<td>0.004</td>
<td>0.008</td>
<td>0.008</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CONC 0.015</td>
<td>0.015</td>
<td>0.015</td>
<td>0.015</td>
<td>0.015</td>
</tr>
<tr>
<td>Fecal Coliform</td>
<td>20</td>
<td>YI 800</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
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<tr>
<td></td>
<td></td>
<td>YP 800</td>
<td>36</td>
<td>46</td>
<td>95</td>
<td>95</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CONC 1000</td>
<td>500</td>
<td>500</td>
<td>500</td>
<td>500</td>
</tr>
<tr>
<td>Organic Nitrogen</td>
<td>20</td>
<td>YI 0.04</td>
<td>0.002</td>
<td>0.002</td>
<td>0.002</td>
<td>0.002</td>
</tr>
<tr>
<td></td>
<td></td>
<td>YP 0.04</td>
<td>0.002</td>
<td>0.003</td>
<td>0.004</td>
<td>0.005</td>
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<tr>
<td></td>
<td></td>
<td>CONC 1</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

<sup>a</sup> 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**

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

<sup>a</sup> 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

<table>
<thead>
<tr>
<th>Station Location</th>
<th>Gage Number</th>
<th>Drainage Area (square miles)</th>
<th>Period of Record</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milwaukee River at New Fane</td>
<td>4086200</td>
<td>54.1</td>
<td>April 1968 - March 1977</td>
</tr>
<tr>
<td>Milwaukee River at Kewaskum</td>
<td>4086150</td>
<td>138.0</td>
<td>April 1968 - March 1977</td>
</tr>
<tr>
<td>Milwaukee River at Fillmore</td>
<td>4086340</td>
<td>148.0</td>
<td>April 1968 - March 1977</td>
</tr>
<tr>
<td>Milwaukee River at Waubeka</td>
<td>4086360</td>
<td>432.0</td>
<td>March 1968 - March 1977</td>
</tr>
<tr>
<td>Cedar Creek at Cedarburg</td>
<td>4086500</td>
<td>120.0</td>
<td>August 1930 - September 1970 and July 1973 - March 1977</td>
</tr>
<tr>
<td>Milwaukee River at Milwaukee</td>
<td>4087000</td>
<td>686.0</td>
<td>April 1974 - March 1977</td>
</tr>
<tr>
<td>Fox River at Waukesha</td>
<td>5543830</td>
<td>127.0</td>
<td>January 1963 - March 1977</td>
</tr>
<tr>
<td>Mukwonago River at Mukwonago</td>
<td>5644200</td>
<td>76.2</td>
<td>July 1973 - March 1977</td>
</tr>
<tr>
<td>White River at Burlington</td>
<td>5545300</td>
<td>97.5</td>
<td>April 1973 - March 1977</td>
</tr>
<tr>
<td>Fox River at Wilmot</td>
<td>5545650</td>
<td>868.0</td>
<td>October 1939 - March 1977</td>
</tr>
<tr>
<td>Oak Creek at South Milwaukee</td>
<td>4087204</td>
<td>25.0</td>
<td>October 1963 - March 1977</td>
</tr>
<tr>
<td>Root River at Franklin</td>
<td>4087220</td>
<td>49.3</td>
<td>October 1963 - March 1977</td>
</tr>
<tr>
<td>Root River Cana at Franklin</td>
<td>4087233</td>
<td>57.2</td>
<td>October 1963 - March 1977</td>
</tr>
<tr>
<td>Root River at Racine</td>
<td>4087240</td>
<td>187.0</td>
<td>October 1971 - March 1977</td>
</tr>
<tr>
<td>Pike River at UW-Parkside</td>
<td>4087257</td>
<td>38.7</td>
<td>October 1971 - March 1977</td>
</tr>
<tr>
<td>Menomonee River at Wauwatosa</td>
<td>4087120</td>
<td>123.0</td>
<td>October 1961 - September 1975</td>
</tr>
<tr>
<td>Des Plaines River at Russell Road</td>
<td>5527800</td>
<td>123.0</td>
<td>June 1967 - March 1977</td>
</tr>
<tr>
<td>Turtle Creek at Clinton</td>
<td>5431500</td>
<td>202.0</td>
<td>September 1939 - March 1977</td>
</tr>
<tr>
<td>Kinnickinnic River at Milwaukee</td>
<td>4087160</td>
<td>20.4</td>
<td>September 1976 - March 1977</td>
</tr>
</tbody>
</table>

Source: SEWRPC.

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


<table>
<thead>
<tr>
<th>Rk-B</th>
<th>Rock River Watershed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Turtle Creek at STH 140, Rock County near Clinton</td>
</tr>
<tr>
<td>Rk-10</td>
<td>Whitewater Creek at N. Fremont Street</td>
</tr>
<tr>
<td>Rk-A</td>
<td>Scuppernong River at County Line, CTH Z</td>
</tr>
<tr>
<td>Rk-9</td>
<td>Bark River at USH 1B</td>
</tr>
<tr>
<td>Rk-8</td>
<td>Oconomowoc River at CTH BB</td>
</tr>
<tr>
<td>Rk-5</td>
<td>Ashippun River at CTH CW</td>
</tr>
<tr>
<td>Rk-4</td>
<td>Rubicon River at Goodland Road</td>
</tr>
<tr>
<td>Rk-6</td>
<td>Oconomowoc River at STH 83</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>October 11, 1976 - November 2, 1976 and March 27, 1977 - March 31, 1977</th>
</tr>
</thead>
<tbody>
<tr>
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<td>October 11, 1976 - November 2, 1976 and March 27, 1977 - March 31, 1977</td>
</tr>
<tr>
<td></td>
<td>October 11, 1976 - November 2, 1976 and March 27, 1977 - March 31, 1977</td>
</tr>
<tr>
<td></td>
<td>October 11, 1967 - November 2, 1976 and March 27, 1977 - March 31, 1977</td>
</tr>
<tr>
<td></td>
<td>October 11, 1976 - November 2, 1976 and March 27, 1977 - March 31, 1977</td>
</tr>
<tr>
<td></td>
<td>October 11, 1976 - November 1, 1976 and March 27, 1977 - March 31, 1977</td>
</tr>
</tbody>
</table>

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.\(^{14}\)

\(^{13}\) 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

LEGEND

- WATER QUALITY INDEX SAMPLING SITE LOCATION
- LAKES WHERE LAKE STUDY DATA WERE SUITABLE FOR USE IN CALIBRATION
- WATERSHED BOUNDARIES
- MENOMONEE RIVER WATERSHED, SAMPLING DISCUSSED IN SEWRPC PLANNING REPORT NO. 26 AND IN INTERNATIONAL JOINT COMMISSION REPORTS ON THE MENOMONEE RIVER PILOT WATERSHED STUDY
- SEWRPC LONG-TERM WATER QUALITY SAMPLING STATION (87); PROVIDING DATA FOR USE TO CHECK SIMULATION RESULTS
- USGS CONTINUOUS STREAMFLOW RECORDING STATION

Source: SEWRPC.
### Table 16

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

<table>
<thead>
<tr>
<th>Lake</th>
<th>County</th>
<th>Source Report</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pewaukee</td>
<td>Waukesha</td>
<td>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</td>
</tr>
<tr>
<td>Eagle</td>
<td>Racine</td>
<td>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</td>
</tr>
<tr>
<td>Little Cedar</td>
<td>Washington</td>
<td>Camp Dresser &amp; McKee Limnetics, March 1977, An Environmental Study of Little Cedar Lake and the Hydrologic and Water Quality Characteristics of its Associated Watershed</td>
</tr>
<tr>
<td>Big Cedar</td>
<td>Washington</td>
<td>Camp Dresser &amp; McKee Limnetics, March 1977, An Environmental Study of Big Cedar Lake and the Hydrologic and Water Quality Characteristics of its Associated Watershed</td>
</tr>
<tr>
<td>Silver</td>
<td>Washington</td>
<td>Camp Dresser &amp; McKee Limnetics, March 1977, An Environmental Study of Silver Lake and the Hydrologic and Water Quality Characteristics of its Associated Watershed</td>
</tr>
<tr>
<td>Pike</td>
<td>Washington</td>
<td>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</td>
</tr>
</tbody>
</table>

*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

Start

Calibration Data:
Water Quality

Calibration Data:
Streamflow

Land Data

Meteorological Data

Channel Data

Diffuse Source Data

Point Source Data

Operate
Hydrologic Submodel, Hydraulic Submodel

Adjust Land
and Channel Parameters

Do
Submodels
Adequately Simulate
Historic Discharge?

NO

Operate
Water Quality Submodel

Does
Submodel
Adequately Simulate
Historic Water
Quality?

NO

Calibrated Water Quality Submodel Ready
for Application

YES

Stop

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

LEGEND
- **EXISTING LAND USE CONDITIONS**
- **YEAR 2000 PLAN LAND USE CONDITIONS WITH POINT SOURCE CONTROL ONLY**
- **YEAR 2000 PLAN LAND USE CONDITIONS WITH POINT SOURCE CONTROL AND A 50 PERCENT REDUCTION IN DIFFUSE SOURCE LOADS AND BENTHIC OXYGEN DEMAND**

WATER QUALITY IMPROVEMENT

CORRESPONDING WATER QUALITY ACHIEVEMENT CHART AT SAME LOCATION

APPLICABLE STANDARD MET 98 PERCENT COMPLIANCE

APPLICABLE STANDARD MET 65 PERCENT COMPLIANCE

APPLICABLE STANDARD MET 60 PERCENT COMPLIANCE

LEGEND
- **E** EXISTING LAND USE CONDITIONS AND POINT SOURCE CONTROLS
- **P** YEAR 2000 LAND USE CONDITIONS WITH POINT SOURCE CONTROLS AND NO REDUCTION IN DIFFUSE SOURCE LOADS AND BENTHIC OXYGEN DEMAND
- **M** YEAR 2000 LAND USE CONDITIONS WITH POINT SOURCE CONTROLS AND A MODERATE (50%) LEVEL OF REDUCTION IN DIFFUSE SOURCE LOADS AND BENTHIC OXYGEN DEMAND

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 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**

<table>
<thead>
<tr>
<th>Watershed</th>
<th>Run Number</th>
<th>Alternatives Analyzed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Menomonee River</td>
<td>1</td>
<td>Existing conditions</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Existing land use, with recommended point source controls</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Plan year 2000 land use and channel conditions with recommended point source controls</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Plan year 2000 land use and channel conditions with 50 percent reduction in nonpoint source loads and recommended point source controls</td>
</tr>
<tr>
<td>Kinnickinnic River</td>
<td>1</td>
<td>Existing conditions</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Plan year 2000 land use and channel conditions with recommended point source controls</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Plan year 2000 land use and channel conditions with 25 percent reduction in nonpoint source loads and recommended point source controls</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Plan year 2000 land use and channel conditions with 50 percent reduction in nonpoint source loads and recommended point source controls</td>
</tr>
<tr>
<td>Oak Creek</td>
<td>1</td>
<td>Existing conditions</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Plan year 2000 land use conditions with recommended point source controls</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Plan year 2000 land use conditions with 50 percent reduction in nonpoint source loads and recommended point source controls</td>
</tr>
<tr>
<td>Pike River</td>
<td>1</td>
<td>Existing conditions</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Plan year 2000 land use conditions with recommended point source controls</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Plan year 2000 land use conditions with 25 percent reduction in nonpoint source loads and recommended point source controls</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Plan year 2000 land use conditions with 50 percent reduction in nonpoint source loads and recommended point source controls</td>
</tr>
<tr>
<td>Root River</td>
<td>1</td>
<td>Existing conditions</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Plan year 2000 land use and channel conditions with initial point source controls</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Plan year 2000 land use and channel conditions with 25 percent reduction in nonpoint source loads and initial point source controls</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Plan year 2000 land use and channel conditions with 50 percent reduction in nonpoint source loads and initial point source controls</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>Plan year 2000 land use and channel conditions with 75 percent reduction in nonpoint source loads and initial point source controls</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>Plan year 2000 land use and channel conditions with 75 percent reduction in nonpoint source loads and point source control modifications</td>
</tr>
<tr>
<td>Watershed</td>
<td>Run Number</td>
<td>Alternatives Analyzed</td>
</tr>
<tr>
<td>-----------------------------------------</td>
<td>------------</td>
<td>---------------------------------------------------------------</td>
</tr>
<tr>
<td>Des Plaines River</td>
<td>1</td>
<td>Existing conditions</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Plan year 2000 land use conditions with initial point source controls</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Plan year 2000 land use conditions with 50 percent reduction in nonpoint source loads and initial point source controls</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Plan year 2000 land use conditions with 50 percent reduction in nonpoint source loads and point source modifications</td>
</tr>
<tr>
<td>Fox River</td>
<td>1</td>
<td>Existing conditions</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Plan year 2000 land use conditions with initial point source controls</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Plan year 2000 land use conditions with 50 percent reduction in nonpoint source loads and initial point source controls</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Plan year 2000 land use conditions with 50 percent reduction in nonpoint source loads and point source control modifications</td>
</tr>
<tr>
<td>Milwaukee River</td>
<td>1</td>
<td>Existing conditions</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Plan year 2000 land use conditions with initial point source controls</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Plan year 2000 land use conditions with 50 percent reduction in nonpoint source loads</td>
</tr>
<tr>
<td>Sauk Creek</td>
<td>1</td>
<td>Existing conditions</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Plan year 2000 land use conditions with recommended point source controls</td>
</tr>
<tr>
<td>Sheboygan River</td>
<td>1</td>
<td>Existing conditions</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Plan year 2000 land use conditions with recommended point source controls</td>
</tr>
<tr>
<td>Streams Directly Tributary to Lake Michigan</td>
<td>1</td>
<td>Existing conditions</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Plan year 2000 land use conditions with recommended point source controls</td>
</tr>
<tr>
<td>Barnes Creek</td>
<td>1</td>
<td>Existing conditions</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Plan year 2000 land use conditions with recommended point source controls</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Plan year 2000 land use conditions with 50 percent reduction in nonpoint source loads and recommended point source controls</td>
</tr>
<tr>
<td>Pike Creek</td>
<td>1</td>
<td>Existing conditions</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Plan year 2000 land use conditions with recommended point source controls</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Plan year 2000 land use conditions with 25 percent reduction in nonpoint source loads and recommended point source controls</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Plan year 2000 land use conditions with 50 percent reduction in nonpoint source loads and recommended point source controls</td>
</tr>
</tbody>
</table>
Table 18 (continued)

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

*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.