HYDROGEOLOGY AND HYDROCHEMISTRY OF DUNES AND WETLANDS ALONG THE SOUTHERN SHORE OF LAKE MICHIGAN, INDIANA

By Robert J. Shedlock, David A. Cohen, Thomas E. Imbrigiotta, and Todd A. Thompson

Prepared in cooperation with the
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CONVERSION FACTORS, VERTICAL DATUM ABBREVIATED WATER-QUALITY TERMS, AND ACRONYMS

Multiply	By	To obtain
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
square foot (ft^2)	0.0929	square meter
square mile (mi^2)	2.590	square kilometer
foot per day (ft/d)	0.3048	meter per day
inch per year (in/yr)	2.54	centimeter per year
foot squared per day (ft^2/d)	0.929	meter squared per day
cubic foot per second (ft^3/s)	0.028317	cubic meter per second

Temperature in degrees Celsius (°C) can be converted to degrees Fahrenheit(°F) as follows:

$$°F = 1.8 \times °C + 32$$

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

Abbreviated water-quality units used in report:

Abbreviation	Description
mg/L	milligrams per liter
pCi/L	picocuries per liter

Chemical symbols used in this report:

Ca	calcium
Cl	chloride
CO_3	carbonate
HCO_3	bicarbonate
K	potassium
Mg	magnesium
Na	sodium
SO_4	sulfate

HYDROGEOLOGY AND HYDROCHEMISTRY OF DUNES AND WETLANDS ALONG THE SOUTHERN SHORE OF LAKE MICHIGAN, INDIANA

By Robert J. Shedlock, David A. Cohen, Thomas E. Imbrigiotta, *and* Todd A. Thompson[1]

ABSTRACT

The southern shore of Lake Michigan contains three well-preserved, dune-beach complexes deposited inland during the Pleistocene and Holocene Epochs. The major lowlands between the dune-beach complexes and many of the smaller lowlands within the dune-beach complexes are wetlands.

These dunes and wetlands are underlain by a complex aquifer system composed of unconsolidated glacial, lacustrine, and eolian sediments deposited on carbonates and shales of Paleozoic age. The aquifer system consists of a bedrock aquifer, three confined sand aquifers, and an areally extensive surficial sand aquifer.

Regional, intermediate, and local scale ground-water flow systems were identified in the unconsolidated sediments and in the upper parts of the underlying shale and carbonate bedrock. The regional and intermediate flow systems are recharged in end moraines that form uplands south of the dune-beach complexes. The regional system, which is recharged in the Valparaiso moraine south of the study area, extends down into the upper bedrock. It discharges by upward leakage through the unconsolidated sediments into Lake Michigan and into the largest interdunal wetland in the area, the Great Marsh. The water in the regional system evolves from a calcium magnesium bicarbonate type near the recharge area to a sodium calcium magnesium bicarbonate type in the unconsolidated sediments underlying the Great Marsh farther down the flow path. Closer to the shoreline of Lake Michigan, the water in the regional flow system evolves to either a sodium calcium chloride bicarbonate type or a sodium chloride type.

The intermediate flow system, which is recharged in the Lake Border moraine, extends into a confined sand aquifer underlying the moraine and the western part of the Great Marsh. This system discharges into the Little Calumet River south of the Lake Border moraine and by upward leakage into the surficial deposits in the Great Marsh north of the moraine. The water in the intermediate systems is either a calcium magnesium bicarbonate or a magnesium calcium bicarbonate type.

[1]Indiana Geological Survey, Bloomington, Ind.

The local flow systems in the surficial aquifer are recharged in the major dune-beach complexes and discharge into streams, ditches, or ponded areas in the adjacent interdunal wetlands. The dune-beach complex along the shoreline is underlain by a broad, flat, water-table mound whose crest is a water-table divide. Only shallow ground water north of this divide discharges directly into Lake Michigan.

An uncalibrated model was constructed to simulate vertical flow patterns in the confined aquifers of the intermediate and regional flow systems in the eastern half of the study area. The simulated flow patterns were consistent with available hydrochemical data and published values of the hydraulic characteristics of the confined aquifers.

The chemistry of shallow ground and surface water in the wetlands is dependent on position in the ground-water flow system and the extent of the underlying confined aquifers. In the dune-beach complexes and the intradunal wetlands, local flow systems predominate; and the shallow ground and wetland waters are dilute calcium bicarbonate and calcium bicarbonate sulfate types. More mineralized bicarbonate water types having variable proportions of calcium, magnesium, and sodium are found in interior parts of the Great Marsh because the marsh is a probable discharge zone for the regional and the intermediate flow systems that extend into the confined aquifers.

Transient water-table mounds of differing size and duration were observed in the dune-beach complexes at the margins of wetlands. These water-table mounds can affect water chemistry and the position of ground-water seepage faces at the dune-wetland margins. The water-table profiles observed during the study of the mounds indicate that a substantial portion of the recharge to the dune complexes occurs near the wetlands.

INTRODUCTION

Indiana Dunes National Lakeshore (fig. 1), along the southern shore of Lake Michigan in northwestern Indiana, contains three well-preserved, dune-beach complexes (fig. 2) deposited inland during the Pleistocene and Holocene Epochs when the level of Lake Michigan was higher than it is now. The major lowlands between the dune-beach complexes and many of the smaller lowlands within these complexes are wetlands. Sponsors of preservation of the dunes and the wetlands have competed with developers of industrial and urban sites since the early 1900's (Moore, 1959; Cook and Jackson, 1978, p. 77–83). The major industrial development was the construction of several steel mills in the early 1900's in what is now the Gary-Hammond area. The growth of steel mills and related industries and the simultaneous development of urban and residential areas resulted in the draining of many wetlands and the leveling of dunal areas.

The first official act to preserve part of the dunes and wetlands along the southern shore of Lake Michigan (hereafter referred to as Indiana Dunes) was the creation of Indiana Dunes State Park in 1925 (Moore, 1959, p. 596-601; Cook and Jackson, 1978, p. 81) between Dune Acres and Beverly Shores (fig. 1). As residential and industrial development continued after World War II, support grew for a national park in the area. In 1966, most of the remaining areas of undeveloped dunes and wetlands were authorized for inclusion in Indiana Dunes National Lakeshore (hereafter referred to as the Lakeshore). The park, which was established formally in 1973, extends from Gary to Michigan City, Ind. A few of the nine separate land units in the Lakeshore are isolated preserves several miles inland from Lake Michigan (fig. 1). Boundaries of the Lakeshore are irregular and discontinuous because the parklands are interspersed with industrial areas and residential communities.

The National Park Service is charged with the preservation and the management of aesthetic, scientific, and recreational resources of the Lakeshore. The scientific resources involve several fields of interest including ecology, geology, and hydrology. The ecologic resource includes well-preserved examples of plant succession along the dune-beach complexes of different ages (McIntosh, 1987). Much of the pioneering work on plant ecology by Dr. Henry Cowles was based on his observations at Indiana Dunes (Cook and Jackson, 1978, p. 53, 80). The geologic interest in the area is the preservation of the geomorphic features in the dune-beach complexes. One of the most complete geologic records of the final stages of glaciation and the development of proglacial lakes in the Great Lakes basin is preserved in the shallow sediments (Mark Reshkin, Chief Scientist, Indiana Dunes National Lakeshore, oral commun., 1982). The hydrology of the wetland basins is of interest because of the effects of different hydrologic conditions on the distribution of plant communities and the development and evolution of peatlands.

The National Park Service needs basic scientific information on the geology, hydrology, and water chemistry in the Lakeshore to formulate rational and achievable management plans. To obtain such information, the National Park Service and the U.S. Geological Survey (USGS) have been cooperating in scientific studies of the Lakeshore since 1973.

A study was begun in 1979 to develop a hydrogeologic data base for the Lakeshore and an appreciation of regional variations in ground-water flow and chemistry. This regional information is to be used to facilitate the planning of detailed studies of the geology, hydrology, and ecology of the Lakeshore.

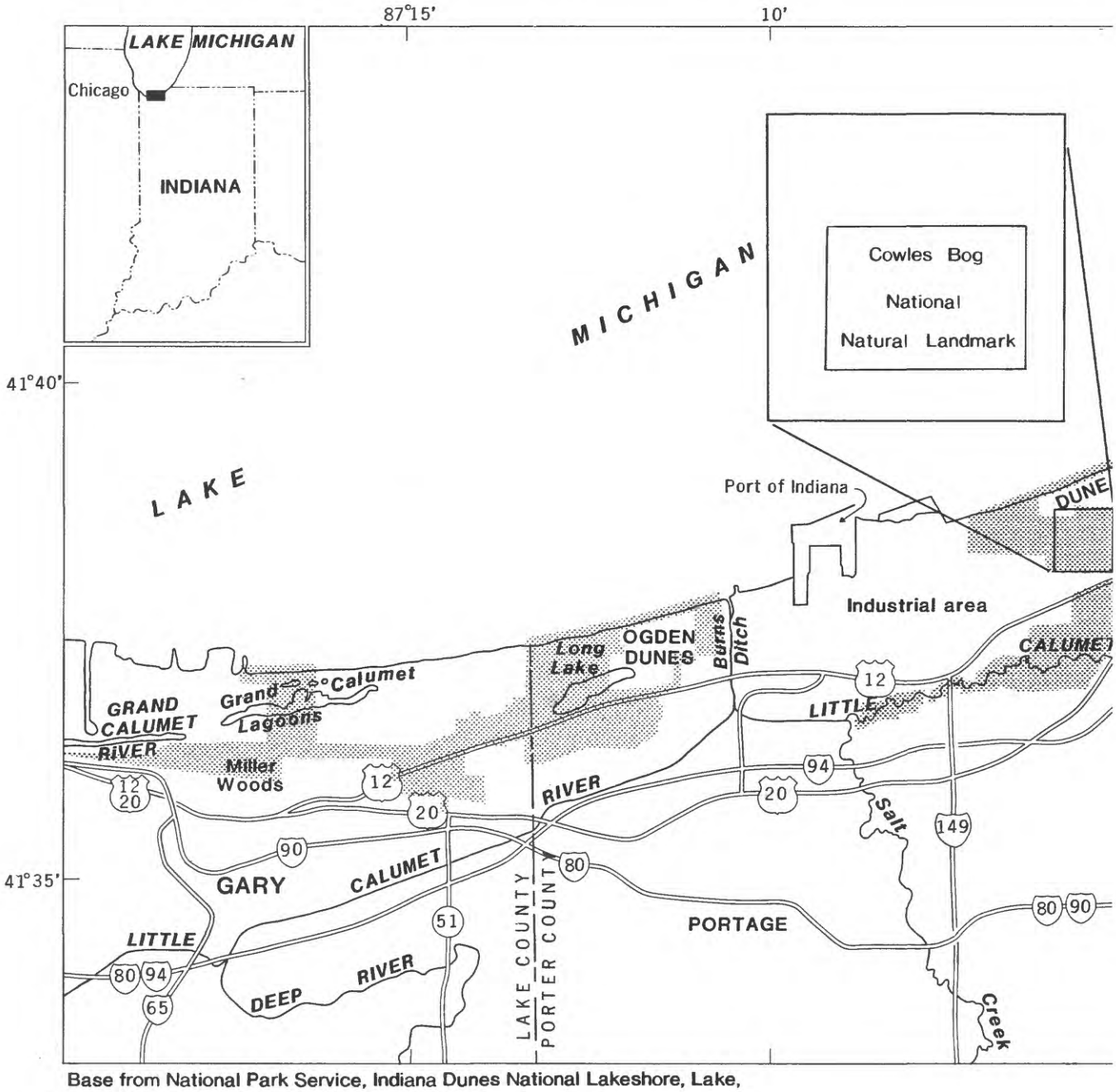
Purpose and Scope

This report describes the hydrogeology and hydrochemistry of dunes and wetlands at Indiana Dunes National Lakeshore and the surrounding area. The report describes (1) the geometry and the extent of the major aquifers in the unconsolidated glacial and lacustrine sediments underlying the dunes and the wetlands, (2) ground-water flowpaths in the unconsolidated and upper bedrock aquifer system, and (3) variations in water chemistry along these flow paths and in the wetlands.

The interpretations in this report are based on geologic, geophysical, hydraulic, and water-chemistry data collected from 1979 through 1986 at Indiana Dunes National Lakeshore and the surrounding area. The report describes regional, intermediate, and local ground-water flow systems in the unconsolidated glacial and lacustrine sediments and upper bedrock, and the variations in water chemistry within these flow systems. An analysis of seasonal variation in water chemistry is not included in the scope of this report. A two-dimensional digital cross-section model (McDonald and Harbaugh, 1988) was used to evaluate the reasonableness of the authors' conceptual model of the ground-water flow system in the eastern half of the Lakeshore. The report also discusses the effect of those different flow systems on the hydrology and the hydrochemistry of the wetlands between and within the dune-beach complexes.

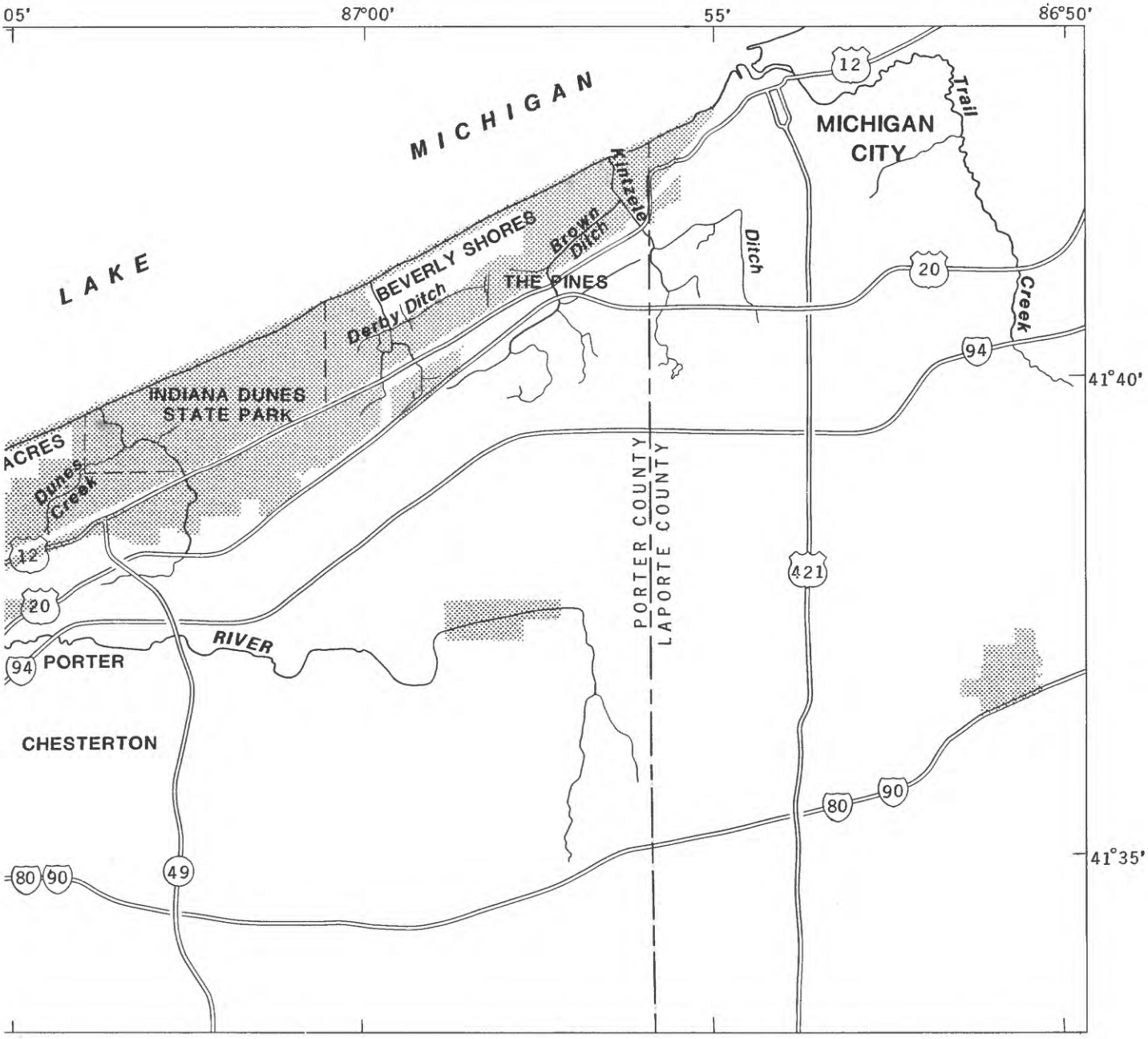
Previous Studies

The first hydrogeologic studies of the Lakeshore area were general assessments of ground-water resources of Lake, Porter, and LaPorte Counties—the three counties that make up the Indiana shoreline of Lake Michigan (Rosenshein and Hunn, 1968a and 1968b). The U.S. Geological Survey and the National Park Service have been studying the hydrology and the hydrochemistry of Indiana Dunes since 1973. The first study of the National Lakeshore was a general assessment of surface- and ground-water quality throughout the Lakeshore (Arihood, 1975). A more detailed study of surface-water quality and of biological and chemical characteristics was done by Hardy (1984).



Base from National Park Service, Indiana Dunes National Lakeshore, Lake, Laporte, and Porter Counties, Indiana, 1986

Figure 1. Indiana Dunes National Lakeshore, northwestern Indiana.



EXPLANATION

INDIANA DUNES NATIONAL LAKESHORE

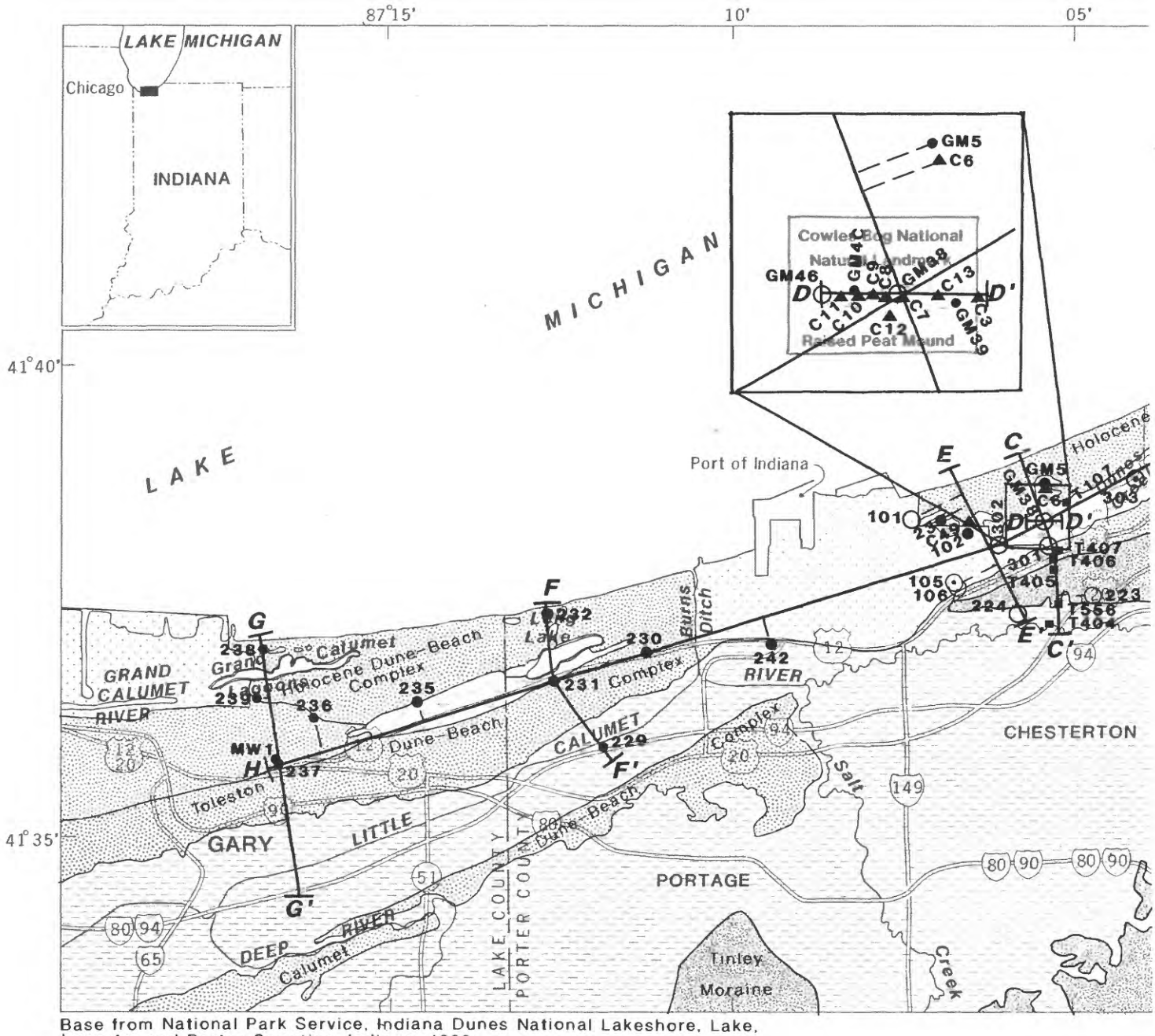
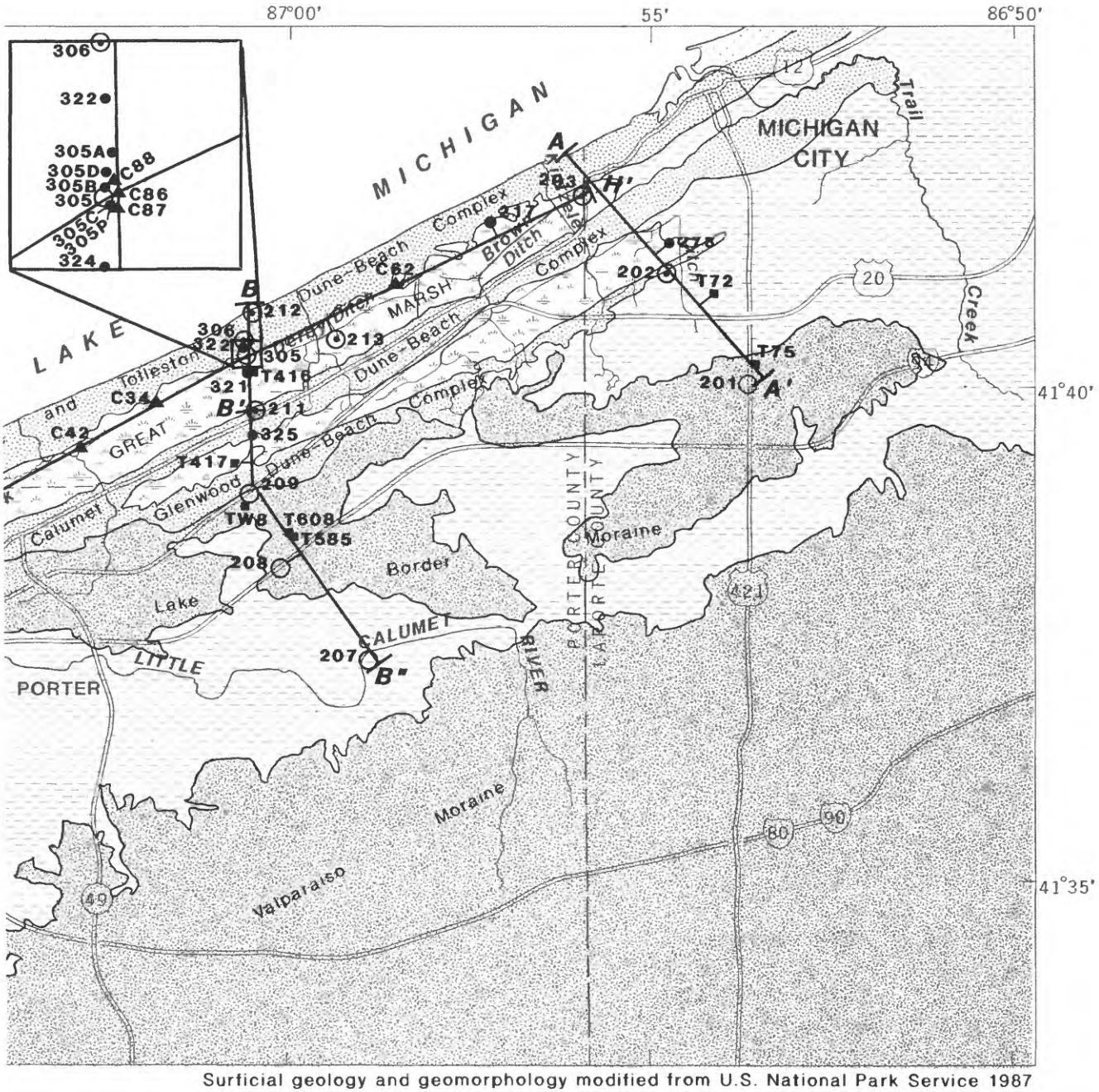


Figure 2. Geomorphology and surficial geology at Indiana Dunes National Lakeshore, nortwestern Indiana. (Exaggeration of scales in inset boxes are x 5.05 for left inset and x 8.24 for right inset.)



Surficial geology and geomorphology modified from U.S. National Park Service 1987

EXPLANATION

TILL AND GLACIAL-LACUSTRINE, CLAY AND SILT

A—A' CROSS-SECTION LOCATION

OBSERVATION WELL--Number is site location number

242● Screened in surficial aquifer

101○ Screened in confined aquifer

105⊙ Screened in surficial and confined aquifers

C34▲ CONTINUOUS CORE 5 TO 23 FEET DEEP--No well set. Number is site location number

T417■ TEST HOLE--No well set. Number is site location number

Most of the previous work was done in the area around Cowles Bog National Natural Landmark (fig. 1), a 56-acre tract at the western end of the Great Marsh. The Great Marsh is a large interdunal wetland south of the dune-beach complex paralleling the modern shoreline of Lake Michigan (fig. 2). Cowles Bog contains a raised peat mound (fig. 2) that supports a unique assemblage of wetland vegetation in a small area (Wilcox and others, 1986).

Several thousand feet west of Cowles Bog is an industrial area that contains two steel mills and a coal-fired electric power plant. From 1973 through 1981, the power company was attempting to construct a nuclear-powered generator next to the coal-fired plant. Several studies were done to assess the potential for changes in the altitude of the water table and in shallow ground-water quality caused by seepage from fly-ash settling ponds and from dewatering of the excavation for the nuclear power plant. Construction of the nuclear power plant was abandoned in September 1981, and the excavation was back-filled with sand.

Hardy (1981) investigated the effects of seepage from the fly-ash ponds on the quality of shallow ground and surface water in adjoining areas of the Lakeshore. Numerical model simulations of the effects of the seepage and the dewatering during excavation were done by Marie (1976) and Meyer and Tucci (1979) before much detailed information was available about the stratigraphy and the shallow ground-water flow regime throughout the Lakeshore, particularly around Cowles Bog. After a ground-water mound was discovered at the peat mound, Gillies and Lapham (1980) modified the model of Meyer and Tucci by increasing the hydraulic connection between the surficial and the confined aquifers below the peat mound. Their modification included a simulated ground-water mound in the surficial aquifer. Of more importance, however, was the recognition of the need for a more detailed hydrogeologic investigation of the Lakeshore area.

Subsequent work in the Cowles Bog area resulted in three detailed investigations of the area. Cohen and Shedlock (1986) investigated changes in water levels and quality of water after the sealing of leaky fly-ash ponds southwest of the peat mound. Water chemistry and ecology at the mound, as well as the history of the growth of the peat mound, are described by Wilcox and others (1986). General relations between ground-water flow paths and variations in ground-water chemistry are described by Shedlock and others (1988).

These studies were followed by a detailed sedimentological study by Thompson (1987) of the areal and the vertical variations in the surficial sediments. Thompson described variations in the thickness and the distribution of the different types of sediments that make up the surficial aquifer north of the Lake Border moraine.

Methods

Much of the hydrogeologic information for this study was obtained from 58 test holes (fig. 3) drilled by the mud-rotary method to the bedrock surface. One to three observation wells were installed at each of these sites (fig. 4) on the basis of the vertical distribution of aquifer layers defined by the drillers' logs. The natural gamma-radiation log recorded for the deepest well at each site was compared to the driller's log for interpreting vertical lithologic changes. Eight test holes, 50- to 90-ft deep, were later drilled with an auger rig to distinguish tills from lacustrine clays at mid-levels in the glacial drift. Sedimentological and stratigraphic variations in the near-surface sediments (0 to 25 ft deep) were determined from 92 continuous cores obtained with a vibracorer modified from the design of Finkelstein and Prins (1981).

Observation wells finished in confined aquifers were constructed of 4-inch inside-diameter polyvinylchloride (PVC) pipe and 5-foot lengths of slotted PVC screens. Wells in the surficial aquifer at sites accessible to a drill rig were constructed either of PVC pipe or 2-inch inside-diameter galvanized steel pipe and 3-foot lengths of slotted screens. Wells in the surficial aquifer within the wetlands were hand-driven, 2-inch inside-diameter, stainless steel or galvanized pipe with 3-foot lengths of slotted, stainless-steel screens.

All observation wells referenced in this report have a two-part well designation, as in observation well 201-205 or observation well GM25-11. The first part, preceding the dash, is a site location number. Site location numbers for all referenced observation wells are shown on figure 4. The second part of the well designation, following the dash, is the approximate depth below the ground surface of the bottom of the well screen. Thus, observation well 201-205 is located at site 201 in figure 4, and the bottom of the screen is approximately 205 ft below ground surface. Similarly, observation well GM25-11 is located at site GM25 in figure 4, and the bottom of the screen is approximately 11 ft below ground surface.

Modifications of the techniques described by Wood (1976) were used to collect water samples from wells in the surficial and the confined aquifers. Wells were purged of at least three volumes of standing water in the casings before samples were collected. Additional water samples were collected from the peat surface (wetland water) at well sites in the Great Marsh. Field measurements of the samples included temperature, pH, specific conductance, dissolved oxygen, oxidation reduction potential (REDOX), and alkalinity. Samples were collected, filtered, and preserved for later determination of major ions, nutrients, trace elements, dissolved organic carbon, and dissolved solids, as well as tritium in selected samples. All samples were analyzed at the USGS National Water Quality Laboratories.

The data collected in the field were used to construct a series of short hydrogeologic sections perpendicular to the modern shoreline of Lake Michigan and one long section parallel to the shoreline (fig. 2). Geometry of the aquifers, general directions of ground-water flow, and chemical type of the water in the different aquifers are depicted on most of the sections.

Acknowledgments

We are grateful to the following individuals for their contributions: Douglas A. Wilcox of the U.S. Fish and Wildlife Service (formerly with the National Park Service) and Ronald Hiebert of the National Park Service for their support and assistance in providing access, facilities, and personnel during the major phase of data collection. Ned Bleuer and Gordon Fraser of the Indiana Geological Survey provided invaluable assistance in the collection and the interpretation of the geologic and the geophysical data. Douglas A. Wilcox provided review comments that greatly improved the manuscript. The work described in this report was augmented by much assistance and advice from the Indiana Geological Survey.

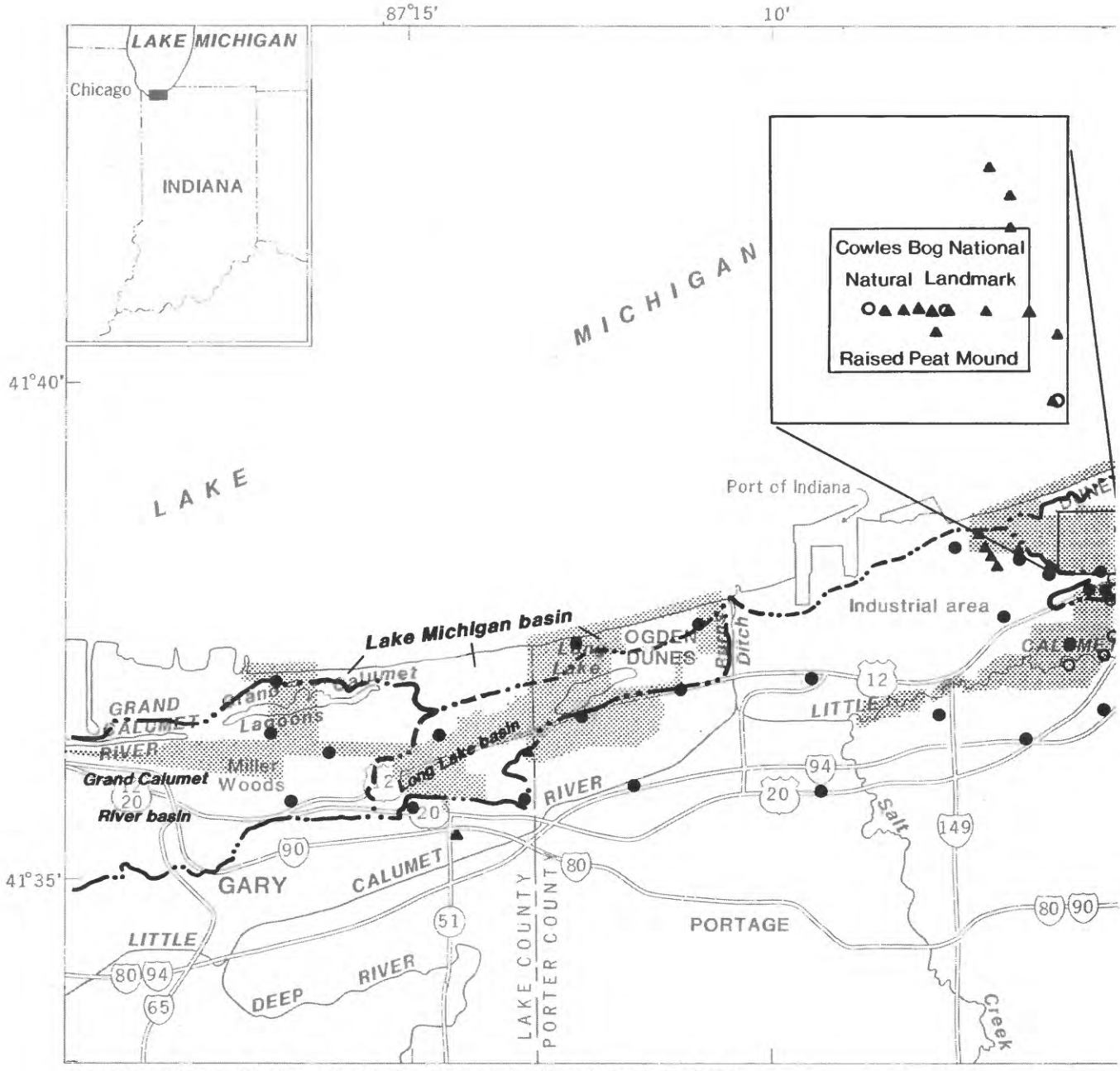
PHYSIOGRAPHIC SETTING

by Helen A. Lindgren

Geomorphology and Surficial Geology

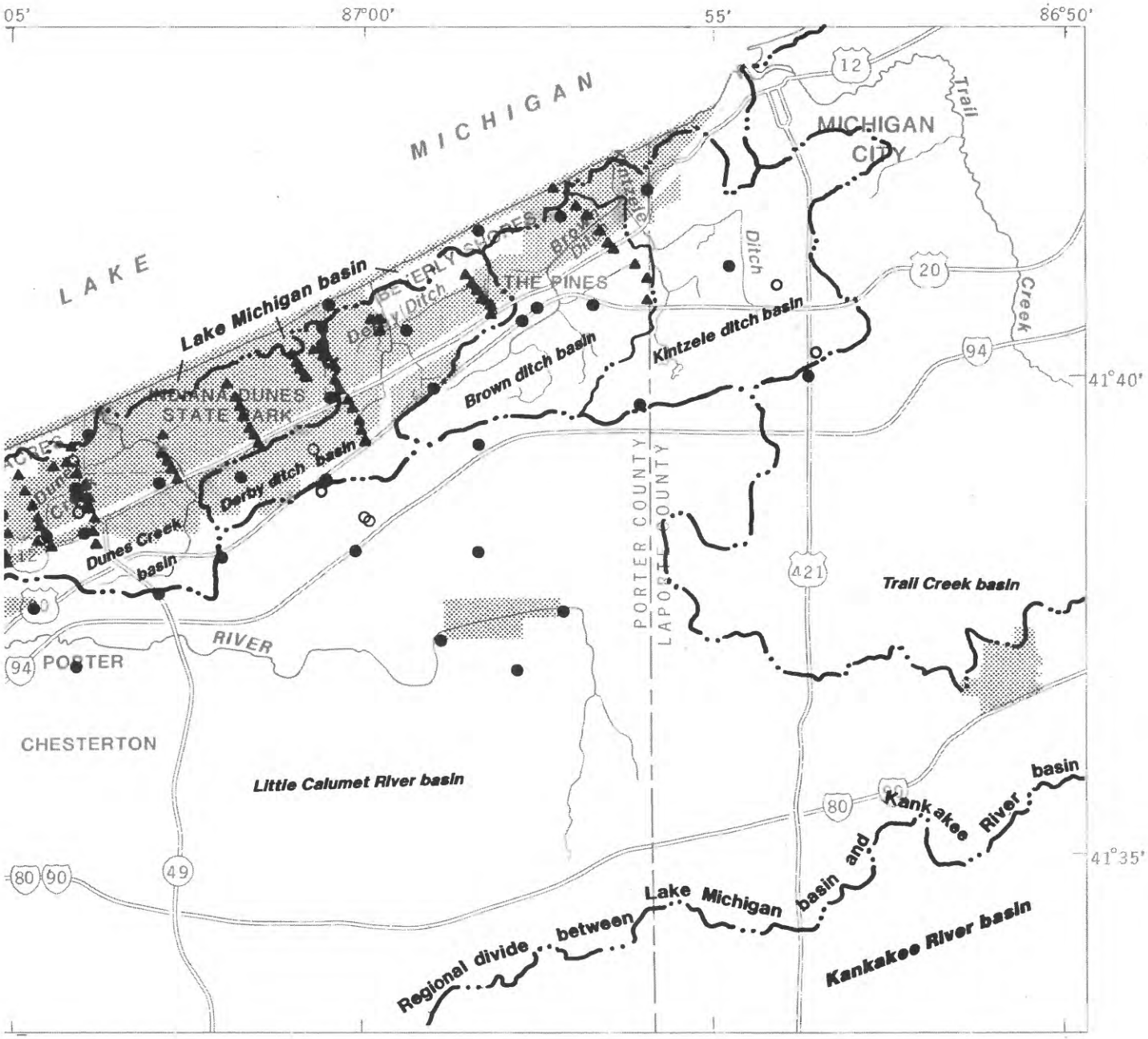
Most of the National Lakeshore is within the physiographic province called the Calumet Lacustrine Plain (Schneider, 1966). This province is primarily an abandoned lake bottom of late-glacial and postglacial lakes that occupied the southern part of the Lake Michigan basin. It is bounded on the south by several end moraines of the Valparaiso Morainal Area (the Valparaiso, Tinley, and Lake Border moraines) that form a series of arc-shaped uplands along the southern shore of Lake Michigan (fig. 2). The surficial sediment in the Valparaiso Morainal Area is primarily a pebbly clay that extends northward beneath the Calumet Lacustrine Plain. This clay is the foundation on which the dune, beach, and lacustrine sediments were deposited.

Three dune-beach complexes were deposited in the Calumet Lacustrine Plain (fig. 2). These complexes, now stabilized by vegetation, extend across the Calumet Lacustrine Plain approximately parallel to the shoreline. The dune-beach complexes are primarily eolian sand, but coastal sand and sandy gravel may be present along the northern margin of each complex. The sedimentology and stratigraphy of the dune-beach complexes in the eastern part of the Lakeshore were described by Thompson (1987). No detailed study of the stratigraphy in the dune-beach complexes is available for the western part of the Calumet Lacustrine Plain.



Base from National Park Service, Indiana Dunes National Lakeshore, Lake, Laporte, and Porter Counties, Indiana, 1986

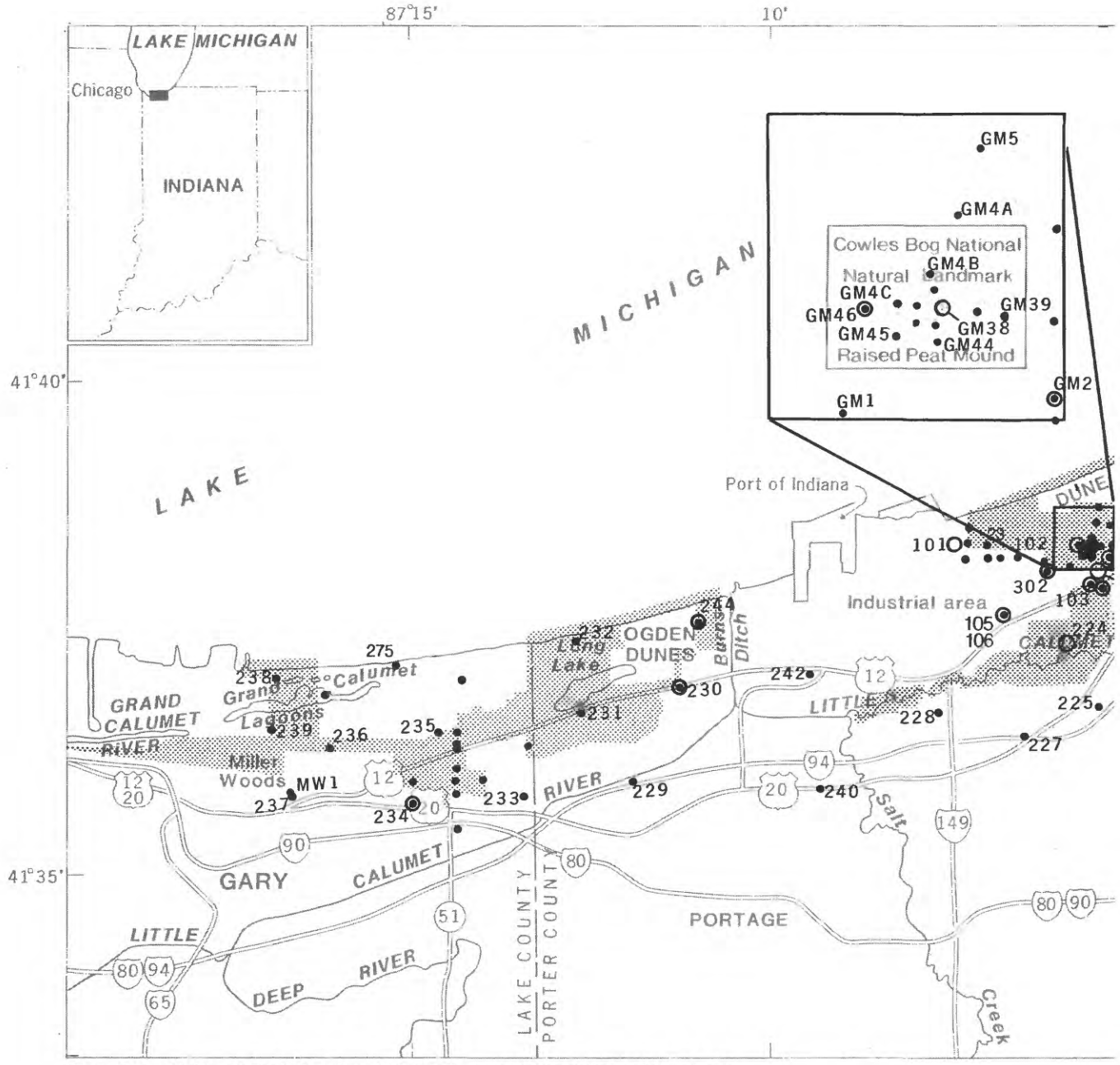
Figure 3. Data-collection network and drainage basins at Indiana Dunes National Lakeshore,



EXPLANATION

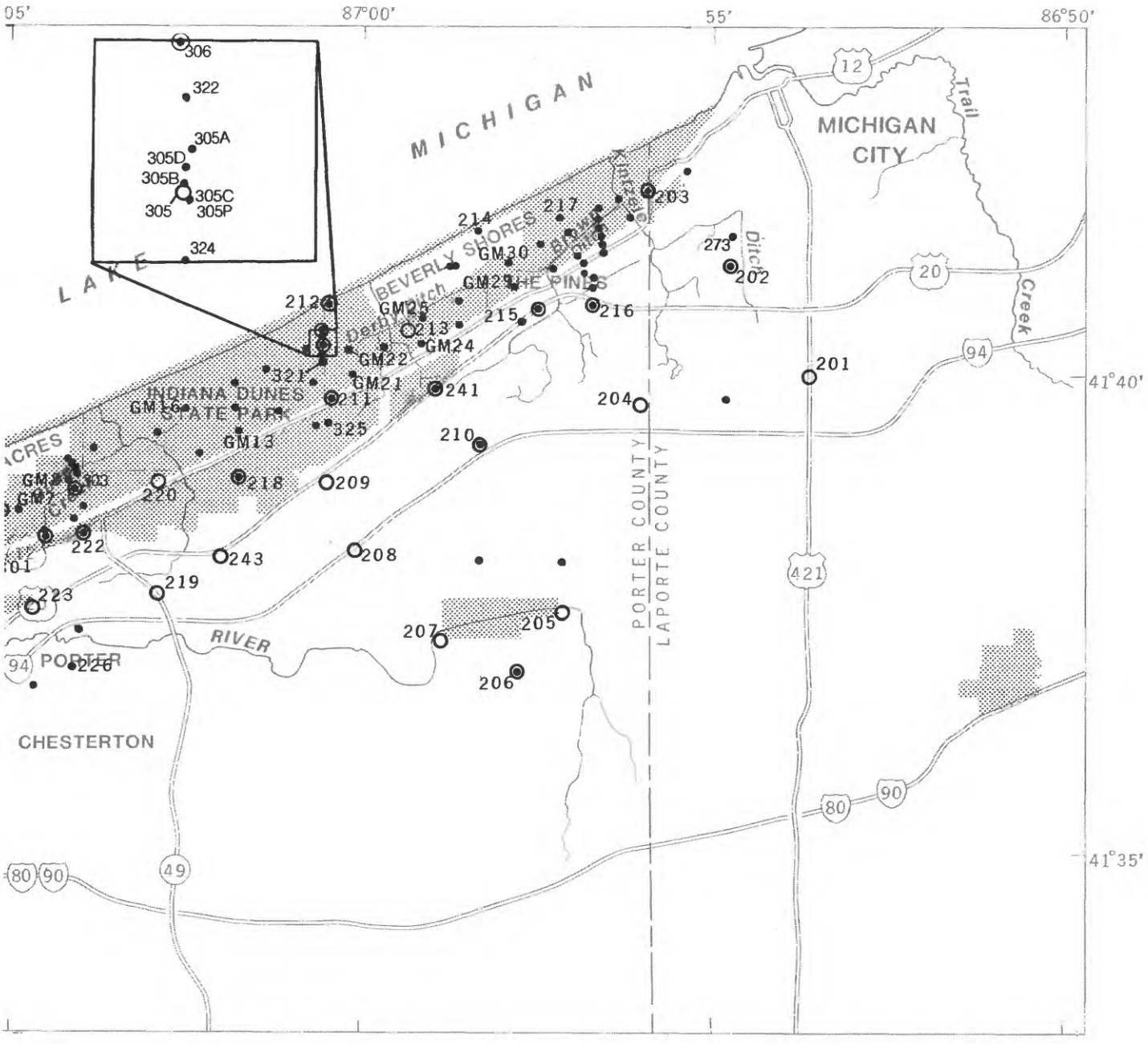
- INDIANA DUNES NATIONAL LAKESHORE
- DRAINAGE BASIN BOUNDARY--Dashed where approximately located
- TEST HOLE DRILLED TO BEDROCK
- TEST HOLE 50 TO 150 FEET DEEP
- CONTINUOUS CORE 5 TO 23 FEET DEEP

northwestern Indiana.



Base from National Park Service, Indiana Dunes National Lakeshore, Lake, Laporte, and Porter Counties, Indiana, 1986

Figure 4. Observation-well network at Indiana Dunes National Lakeshore, northwestern Indiana



EXPLANATION

INDIANA DUNES NATIONAL LAKESHORE

• OBSERVATION WELL--Screened in surficial aquifer

○ OBSERVATION WELL--Screened in confined aquifer

◎ OBSERVATION WELLS--Screened in surficial aquifer and confined aquifer

GM5 SITE LOCATION NUMBER

(exaggeration of scales in inset boxes are x5.05 for left inset and x8.24 for right inset).

Wetlands are found in a variety of geomorphic settings in the Calumet Lacustrine Plain (fig. 5). The most areally extensive wetlands are the interdunal wetlands that occupy the lowlands between the major dune-beach complexes. The largest wetland in the National Lakeshore is the Great Marsh, an interdunal wetland between the Calumet and Tolleston dune-beach complexes in the eastern half of the National Lakeshore (fig. 2). Cowles Bog (fig. 2) is at the western end of the Great Marsh. Wetlands of much smaller area than the Great Marsh are found in the lowlands within the dune-beach complexes and are referred to as intradunal wetlands.

Long narrow wetlands and ponds are found in the western end of the Lakeshore in an area known as Miller Woods (fig. 1). These wetlands (depicted as the ridge/swale region in fig. 5) occupy the swales between a series of low, parallel beach ridges. This type of wetland is common west of the study area in the Calumet Lacustrine Plain.

Although the wetlands associated with the dune-beach complexes were the focus of this study, other types of wetlands are present south of the dune-beach complexes (fig. 5). Wetlands are found in depressions in the morainal uplands. Riverine wetlands are found in the study area mainly in the valley of the Little Calumet River.

Drainage

All the surface drainage in the study area (fig. 3) is to Lake Michigan. The crest of the Valparaiso moraine (fig. 2) in the southeastern part of the study area is a regional surface-water divide between the Lake Michigan and the Kankakee River basins. This crest is also a subcontinental drainage divide between the St. Lawrence and the Mississippi River basins.

Similarly, the crest of the Lake Border moraine (fig. 2) is a drainage divide for the eastern half of the study area. North of the divide, surface flow is to four small basins that drain the dunes and interdunal wetlands. The three easternmost basins—Derby, Brown, and Kintzele Ditches—are manmade ditch systems constructed in the late 1800's and early 1900's (Cook and Jackson, 1978) to drain the Great Marsh and the next interdunal wetland south of the Great Marsh. The westernmost basin is Dunes Creek, a natural wetland stream that drains to Lake Michigan through a breach in the shoreline dunes. Drainage in all these basins has been enhanced by the construction of small tributary ditches, most of which are too small to be shown in figure 3.

South of the crest of the Lake Border moraine, surface drainage is to the Little Calumet River which flows west and discharges into Lake Michigan through Burns Ditch, just east of the community of Ogden Dunes. Burns Ditch, constructed in 1924, has substantially altered the natural drainage pattern of the Little Calumet River. Before construction of Burns Ditch, the Little Calumet River flowed west into Illinois as a sluggish stream in a broad interdunal valley that was largely a wetland. Burns Ditch drained this riverine wetland through a channel cut through the intervening dune complexes and also partially drained Long Lake (fig. 1) to the north of the valley. More importantly, flow was reversed in the Little Calumet River west of the mouth of Burns Ditch. Thus, in the study area, the Little Calumet River has two reaches that flow toward each other to discharge into Lake Michigan through the main north-south channel of Burns Ditch.

Much of the western half of the study area is in the Burns Ditch drainage basin. As with the ditch systems to the east, Burns Ditch has many tributary ditches along the main roads and highways. In addition, the channel of the Little Calumet River east and west of the mouth of the ditch has been deepened and straightened.

The westernmost part of the study area is in the Grand Calumet River basin, where the drainage pattern also has been greatly altered by ditching. The present headwaters of the Grand Calumet River are in the western part of the Lakeshore; however, in pre-development times, the Grand Calumet River discharged into Lake Michigan in

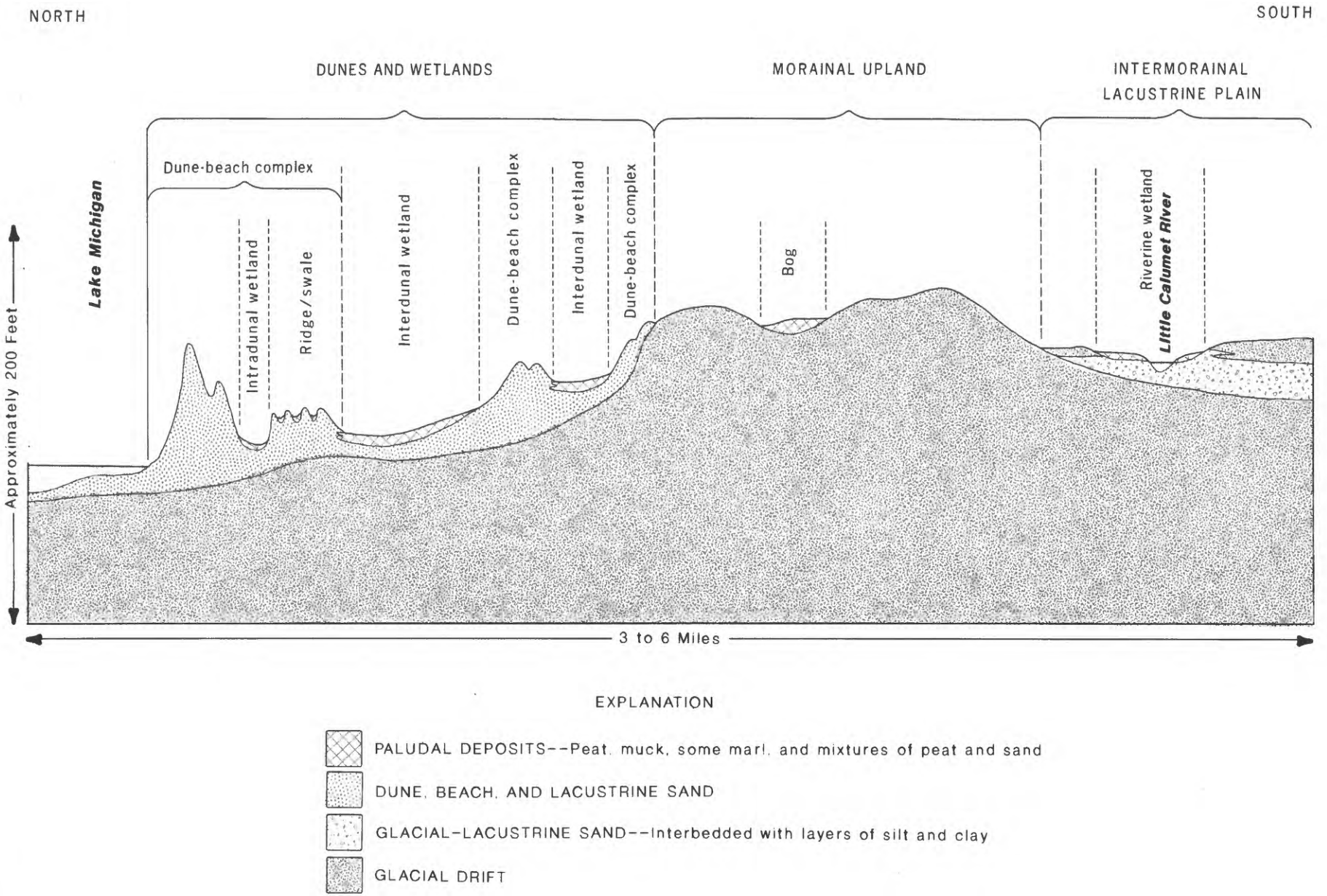


Figure 5. Diagrammatic section showing geomorphic setting of wetlands at Indiana Dunes National Lakeshore, northwestern Indiana. (Modified from Shedlock and other, 1988, figure 2.)

this area. In fact, the Grand Calumet and the Little Calumet Rivers are now sections of what was once a single stream. The ancestral Calumet River originated in the valley between the Lake Border and the Valparaiso moraines and flowed west through the Little Calumet River valley into Illinois. The channel made a hairpin turn in Illinois and flowed back east into Indiana through the Grand Calumet River valley and discharged into Lake Michigan, just east of the present-day Grand Calumet Lagoons (fig. 1).

The lagoons are the present-day remains of the channel of the ancestral Calumet River near its former mouth. The construction of canals to Lake Michigan in the late 1800's and early 1900's in extreme northwestern Indiana and adjoining areas of Illinois slowed and eventually reversed the eastward flow of water in the ancestral Calumet River. The mouth of the ancestral Calumet River was closed eventually by littoral drift of sand along the Lakeshore. The Grand Calumet Lagoons are now the headwaters of the modern Grand Calumet River. The lagoons are connected to the most upstream channelized section of the stream through two buried culverts (Hardy, 1984).

HYDROGEOLOGY

Subsurface Geology and Aquifer System

The study area is underlain by 90 to 212 ft of unconsolidated glacial, lacustrine, eolian, and paludal sediments of Pleistocene and Holocene age that were deposited on a bedrock surface modified by pre-Pleistocene erosion (fig. 6). The bedrock consists of shale and carbonate rocks of Mississippian, Devonian, and Silurian age. Thompson (1987, p. 6) divided the unconsolidated sediments in the study area into three informal lithostratigraphic units that are parts of the Lagro, the Atherton, and the Martinsville Formations in Indiana, and the Wedron and Lake Michigan Formations in Illinois (Shaver and others, 1970).

Thompson's basal unit consists of randomly interbedded clay, sand, gravel, and till. This unit is generally less than 50-ft thick and of uncertain origin and age. The basal unit is more recognizable in the eastern half of the study area, and its extent in the western half is uncertain. The overlying intermediate unit consists of interbedded till, glacial-lacustrine clay, and sand and gravel. The top of this unit is the till surface of the Lake Border moraine, which crops out in the eastern half of the study area (fig. 2). The uppermost lithostratigraphic unit of Thompson (1987) consists of lacustrine and eolian sand and peat deposited on the buried till surface of the Lake Border moraine. This surficial unit also contains minor amounts of gravel, clay, and discontinuous lenses of calcareous mud and marl interbedded with sand and peat.

The unconsolidated sediments in the study area have been divided into four aquifers in this report. The relations of these aquifers to the lithostratigraphic units of Thompson (1987) and aquifer designations of previous hydrologic studies are given in table 1.

Table 1. Relation of aquifer designations in this report to aquifer designations of previous studies

<table>
<tr><th rowspan="2">Lithostratigraphic units</th><th colspan="3">Aquifer designation</th></tr>
<tr><th>This report</th><th>Rosenshein and Hunn (1968a, 1968b)</th><th>Hartke and others (1975)</th></tr>
<tr><td>Dune, beach, and lacustrine sands and gravels of Holocene and Pleistocene age; marls and calcareous muds; peats</td><td>Surficial aquifer</td><td rowspan="4">Unit 1</td><td rowspan="4">Calumet aquifer</td></tr>
<tr><td rowspan="3">Glacial and lacustrine sands of Pleistocene age with interbedded clays and silts. Includes basal and intermediate units of Thompson (1987) and tills of the Lake Border and Valparaiso moraines</td><td>Subtill aquifer</td></tr>
<tr><td rowspan="2">Unit 4</td></tr>
<tr><td>Basal sand aquifer</td><td>-?-?-?-?-?-?-</td></tr>
<tr><td>Valparaiso aquifer</td><td>Confined part of Unit 3</td><td>Valparaiso aquifer</td></tr>
<tr><td>Shale and carbonate rocks of Mississippian, Devonian, and Silurian age</td><td>Bedrock aquifer</td><td>Bedrock</td><td>Bedrock</td></tr>
</table>

The underlying shale and carbonate rocks are referred to as the bedrock aquifer. The four unconsolidated aquifers and upper part of the bedrock aquifer comprise a complex aquifer system in the study area. The general geometry and conceptual flow system of this aquifer system for the eastern and western parts of the study area is depicted in the north-south schematic sections in figure 7 (sections A and B, respectively). The geometry of the aquifer system from west to east is shown in figure 8.

The surficial aquifer consists primarily of lacustrine and eolian sands and is the most extensive of the four unconsolidated aquifers in the study area. It is designated as Unit 1 by Rosenshein and Hunn (1968a and 1968b) and as the Calumet aquifer by Hartke and others (1975). The surficial aquifer is found everywhere in the study area except in the outcrop areas of the Lake Border and Valparaiso moraines. The saturated thickness (fig. 9), which ranges from 0 to greater than 80 ft, generally increases from the eastern to the western part of the study area. In general, the surficial aquifer is unconfined throughout most of the study area; however, in some areas, the surficial aquifer contains lenses of calcareous clay in the subsurface (fig. 8). These clays represent back-barrier deposits and function as local confining layers for the underlying parts of the surficial aquifer.

The saturated-thickness map (fig. 9) differs from an earlier map by Rosenshein and Hunn (1968b). The earlier map shows a greater saturated thickness for the surficial aquifer in the Great Marsh. Few test-hole data were available for the Great Marsh at the time of Rosenshein and Hunn's work. As indicated in table 1, Rosenshein and Hunn's saturated-thickness map for the surficial aquifer probably includes parts of the subtill aquifer in the western part of the Great Marsh. The clay layer separating the surficial aquifer and the underlying subtill aquifer is generally thin in the western part of the Great Marsh (fig. 8).

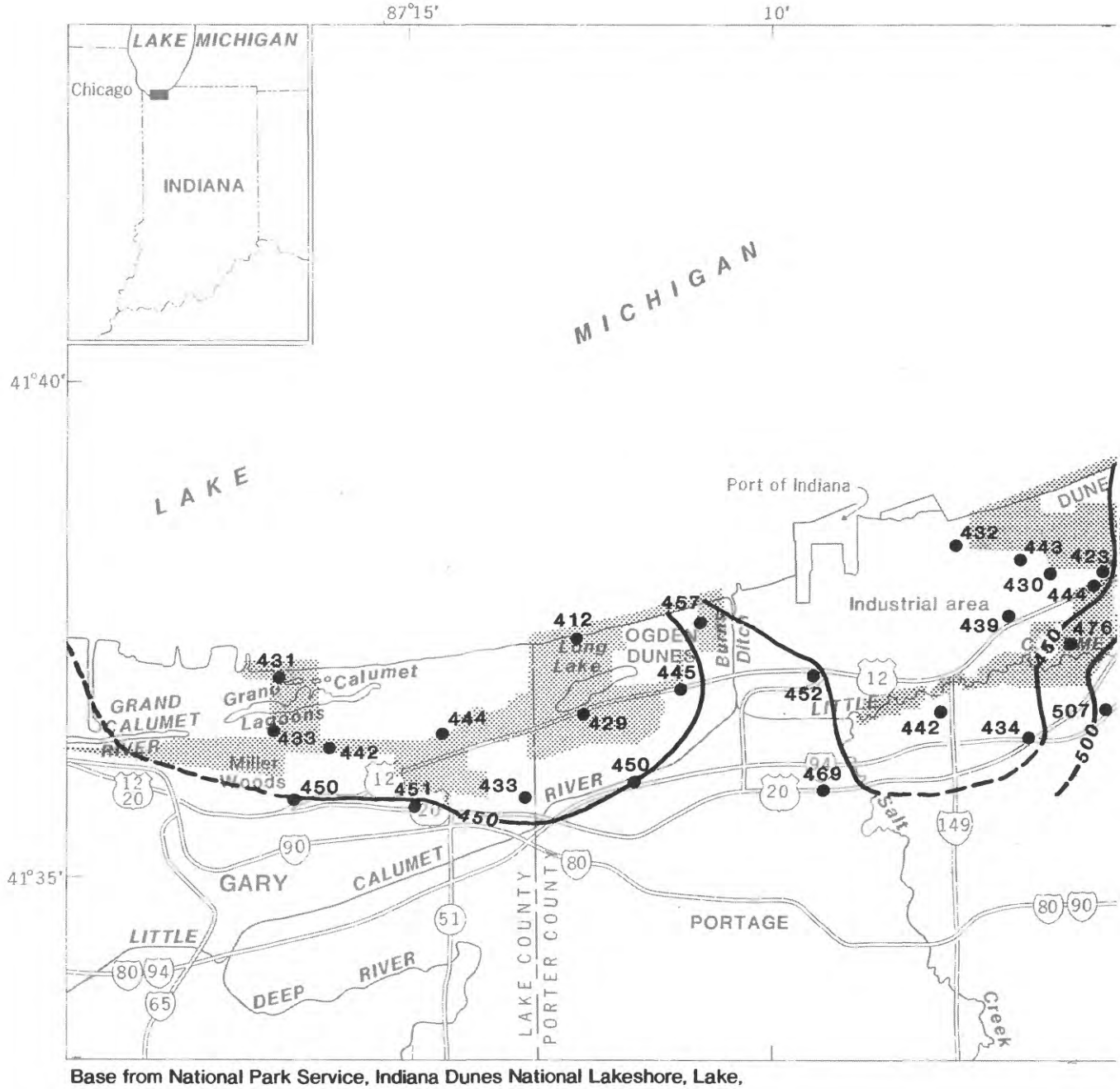
The areal extent of each of the three confined aquifers in the unconsolidated sediments is shown in figure 10. These aquifers are present mainly in the eastern half of the study area. With the exception of a few outliers, no confined aquifers are present in the unconsolidated sediments in the western one-half of the study area.

The subtill aquifer (figs. 7 and 8) is a zone of the intermediate lithostratigraphic unit of Thompson (1987) that consists mainly of sand with interbedded lenses of clay. The subtill aquifer underlies virtually the entire area of the Lake Border moraine (fig. 2) and extends north of the moraine into the western half of the Great Marsh in the middle of the study area (fig. 10). The subtill aquifer was not recognized as a separate aquifer in either Rosenshein and Hunn (1968b) or Hartke and others (1975). Rosenshein and Hunn (1968b) included upper parts of this aquifer in their Unit 1 and lower parts in their Unit 4 (table 1).

The basal sand aquifer is composed of discontinuous sandy zones of Thompson's basal lithostratigraphic unit and probably is the same as the permeable layers in Unit 4 of Rosenshein and Hunn (1968a and 1968b). This aquifer seems to be thickest and most extensive in the eastern one-third of the study area (figs. 8 and 10). The exact extent of the basal sand aquifer is less well-known than that of the subtill aquifer. Discontinuous lenses of sand and gravel in the basal lithostratigraphic unit of Thompson (1987) in the middle and western parts of the study area are interpreted as outliers of the basal sand aquifer in this report.

The Valparaiso aquifer was first named by Hartke and others (1975) and consists of sands and gravels that underlie the exposed and buried tills of the Valparaiso moraine (fig. 7A). The aquifer extends over the southeastern part of the study area, virtually in the outcrop area of the Valparaiso moraine and adjacent areas of the Little Calumet River valley to the north (fig. 10). South of the study area the Valparaiso aquifer grades into the Kankakee aquifer of Hartke and others (1975) (fig. 7A). Rosenshein and Hunn (1968b) designated the Valparaiso aquifer as Unit 3. The tills of the Valparaiso moraine that function as the upper confining layer of the Valparaiso aquifer are designated as Unit 2 in Rosenshein and Hunn. The Valparaiso aquifer does not underlie any of the wetlands in the Lakeshore associated with the dune-beach complexes.

The bedrock aquifer consists of shale and carbonate rocks of Silurian, Devonian, and Mississippian age. Detailed investigation of

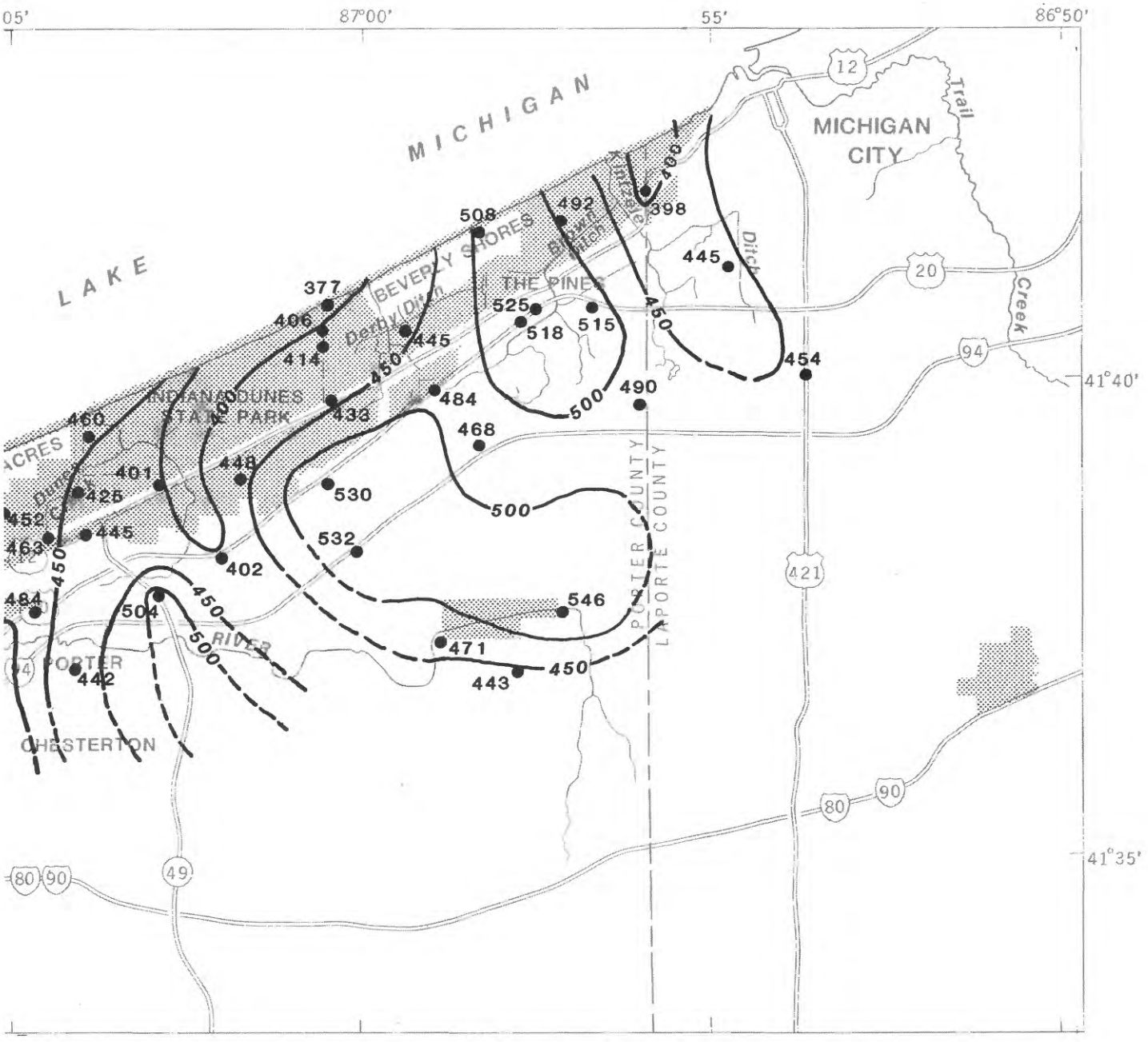


Base from National Park Service, Indiana Dunes National Lakeshore, Lake, Laporte, and Porter Counties, Indiana, 1986

0 1 2 3 4 MILES

0 1 2 3 4 KILOMETERS

Figure 6. Altitude and configuration of bedrock surface.



EXPLANATION

INDIANA DUNES NATIONAL LAKESHORE

450 BEDROCK CONTOUR--Shows altitude of bedrock surface. Dashed where approximately located. Contour interval 50 feet. Datum is sea level

402 DATA POINT--Number is altitude of bedrock surface, in feet above sea level

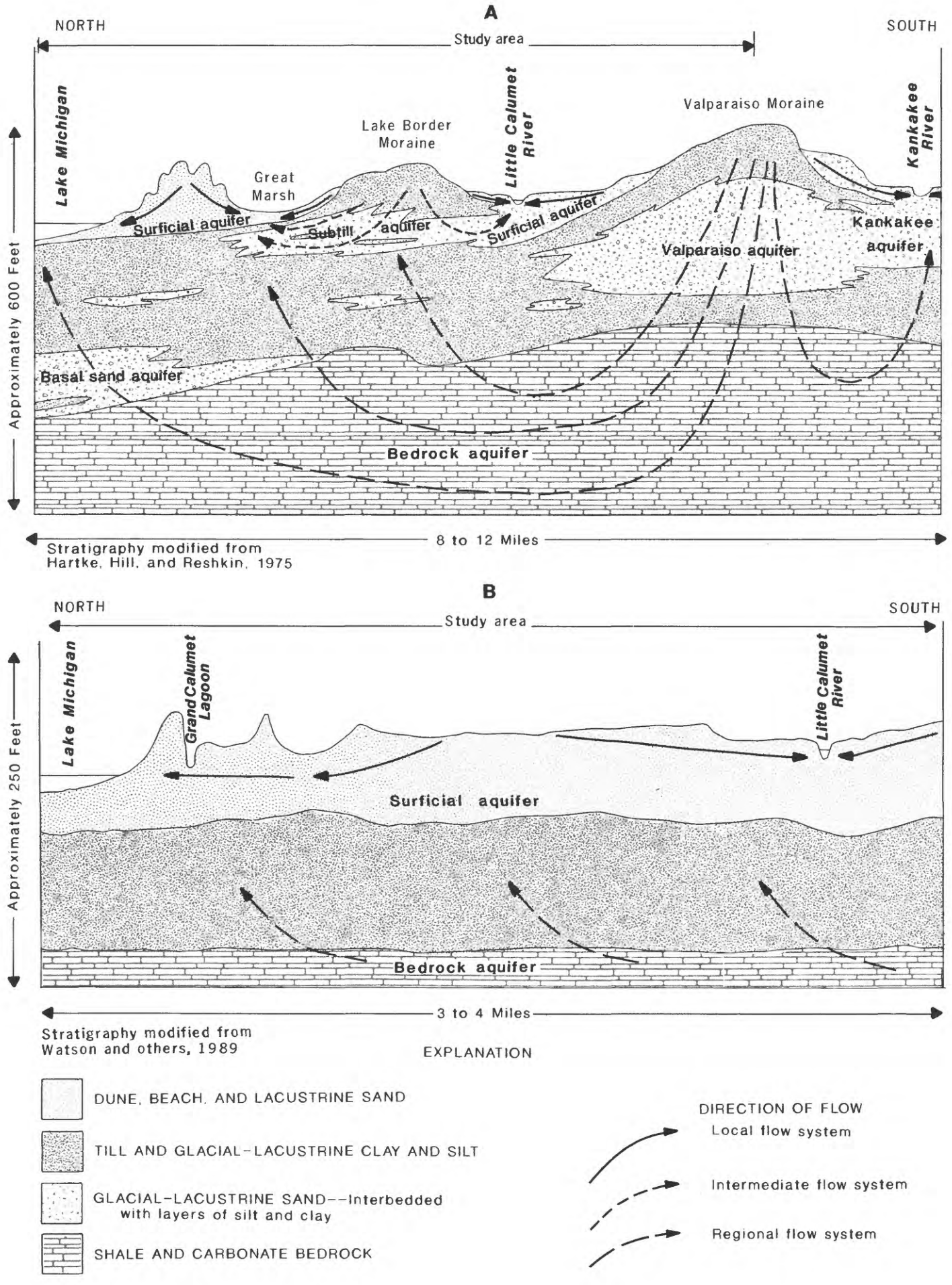


Figure 7. Diagrammatic hydrogeologic sections showing conceptual ground-water flow in the (A) eastern and (B) western halves of the Indiana Dunes National Lakeshore, northwestern Indiana.

the bedrock aquifer was beyond the scope of this study, and no new data were collected in the study area. Inferences made about the bedrock aquifer in this report are based on previous work by Rosenshein and Hunn (1968a, 1968b), data from wells near the base of the unconsolidated sediments, and previously unpublished USGS data (Water Resources Division, Indiana District) outside the study area.

Regional, Intermediate, and Local Ground-Water Flow Systems

Ground-water flow systems of regional, intermediate, and local scale (as described by Toth, 1963) have been identified in the study area. The conceptual models of these systems for the eastern and western halves of the study area (fig. 7) are based on potentiometric and hydrochemical data collected during this study and the previous work of Rosenshein and Hunn (1968a and 1968b) and Thompson (1987).

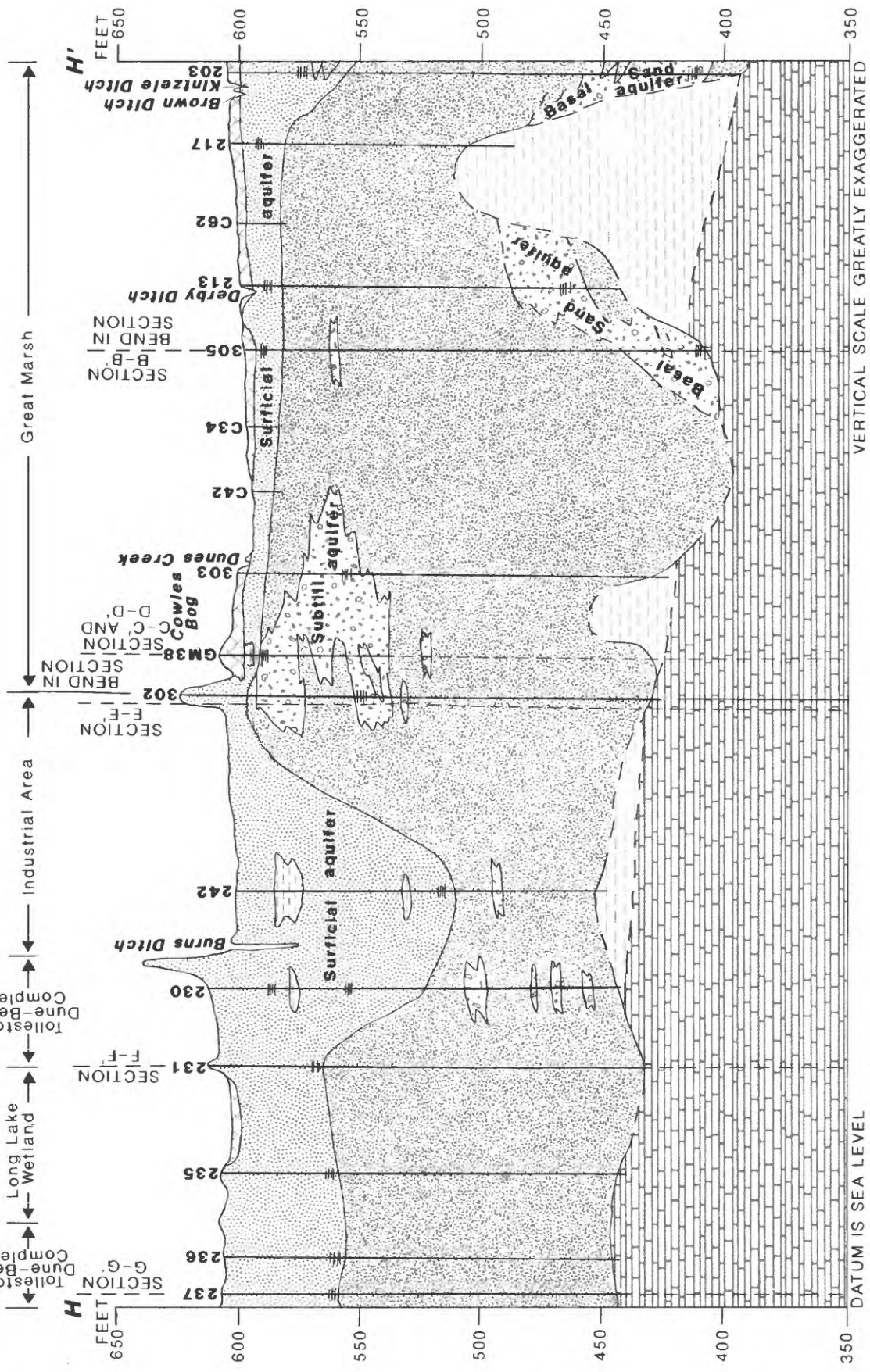
In the conceptual model, recharge to the regional flow system occurs at water-table highs in the Valparaiso moraine several miles south of the study area (fig. 7A). The crest of this moraine is a subcontinental, surface-drainage divide between the Great Lakes and the St. Lawrence River basin to the north and the Mississippi River basin to the south. Rosenshein and Hunn (1968a, p. 13, 25) identified corresponding ground-water divides in the glacial deposits and the underlying shale and carbonate bedrock aquifer beneath the Valparaiso moraine. Ground water flows down through the glacial deposits under the Valparaiso moraine, into the upper bedrock, laterally through the bedrock toward Lake Michigan, and discharges into the glacial deposits north of the Little Calumet River (fig. 7). Flowing wells in the basal sand aquifer north of the Lake Border moraine probably tap the distal part of this flow system. The water in the regional flow system discharges by upward leakage into the subtill aquifer, the surficial aquifers (which include the Great Marsh), and into Lake Michigan offshore. The details of the discharge into Lake Michigan were not investigated.

Recharge to the intermediate flow system of the conceptual model occurs at the water-table high in the Lake Border moraine, and flow extends down into the underlying subtill aquifer (fig. 7A). Water flows from this water-table high south to the Little Calumet River and north to Dunes Creek or the Derby, Brown, and Kintzele Ditch systems in the Great Marsh. Nearly all the discharge from the intermediate flow system is by upward leakage into the surficial aquifer through the buried till sheet of the Lake Border moraine. The intermediate flow system does not exist in the western half of the study area (fig. 7B).

Local flow systems within the surficial aquifer are recharged in the dune-beach complexes and discharge into streams, ditches, and ponded areas in the interdunal wetlands (fig. 7). The shallow ground-water flow system is typified by broad, flat, water-table mounds that function as ground-water divides underlying the topographically high dune-beach complexes. Shallow ground water flows north and south from these divides and discharges to adjacent low-lying areas and wetlands. The only shallow ground water discharging directly into Lake Michigan is north of the crest of the water-table divide underlying the shoreline dune-beach complex.

Simulations of Ground-Water Flow

A two-dimensional numerical model was constructed during the early stages of the study to simulate vertical and lateral flow in a diagrammatic hydrogeologic section representative of the intermediate and regional flow systems in the eastern half of the study area. The model was used as an investigative tool to help refine and evaluate the reasonableness of the authors' conceptual model of the aquifer system in the eastern half of the Lakeshore (fig. 7A). The model was not calibrated because it was not used to reproduce measured hydraulic heads of any particular hydrogeologic section presented later in this report. The hydraulic gradients and the geometry of the aquifers and confining beds differed enough among these sections that a separate model would be needed for each if a calibrated model were the desired product.


H
H'
FEET
650
600
550
500
450
400
350
Great Marsh
Industrial Area
Long Lake Wetland
Tolleston Dune-Beach Complex
SECTION G-G'
SECTION F-F'
SECTION E-E'
BEND IN SECTION
SECTION B-B'
BEND IN SECTION
SECTION C-C' AND D-D'
Kintzele Ditch
Brown Ditch
Derby Ditch
Dunes Creek
Burns Ditch
Cowles Bog
GM38
203
217
C62
213
305
C34
C42
303
302
242
230
231
235
236
237
Surficial aquifer
Subtill aquifer
Basal sand aquifer
VERTICAL SCALE GREATLY EXAGGERATED
DATUM IS SEA LEVEL
TRACE OF SECTION H-H' SHOWN IN FIGURE 2

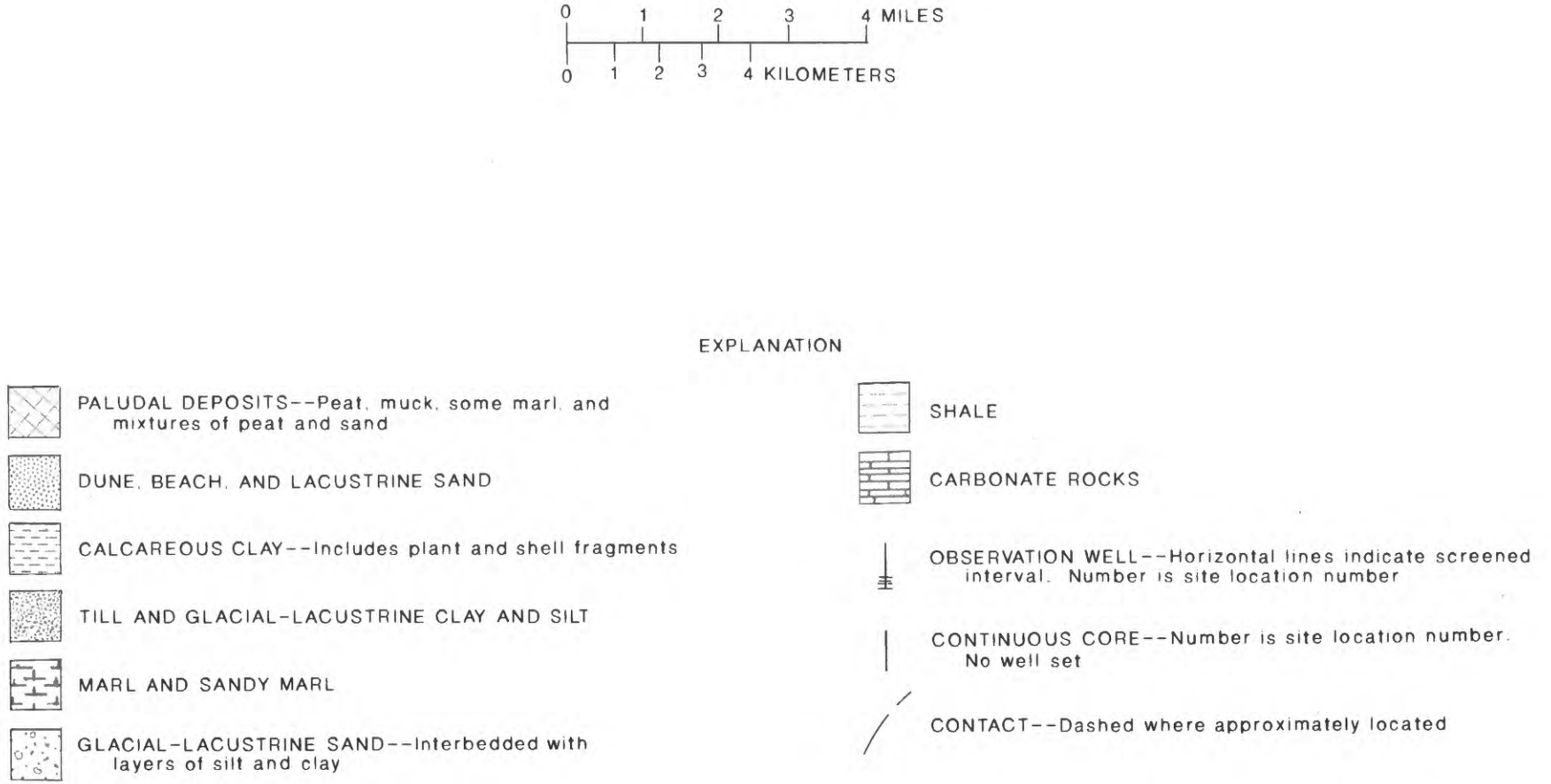
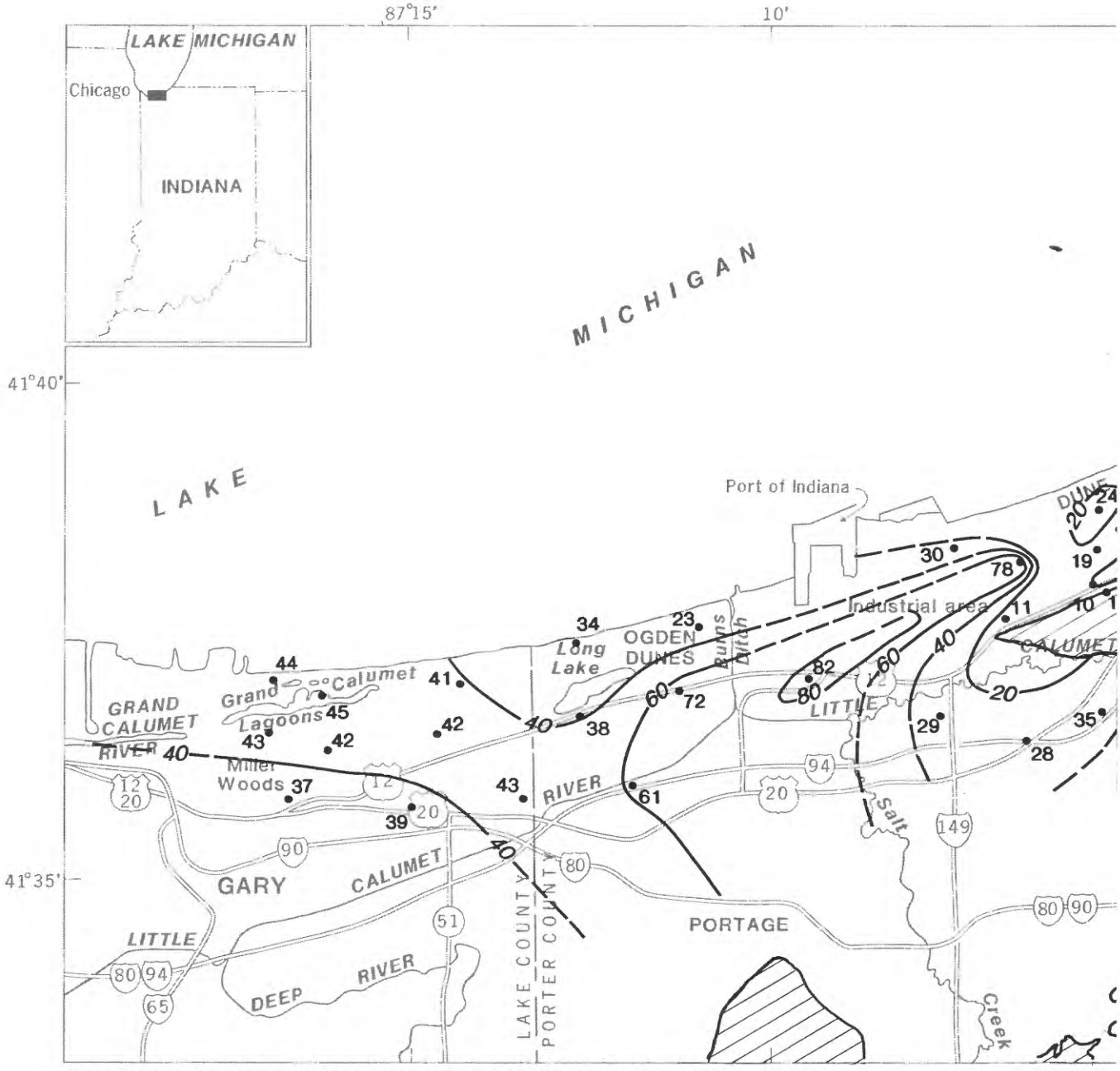
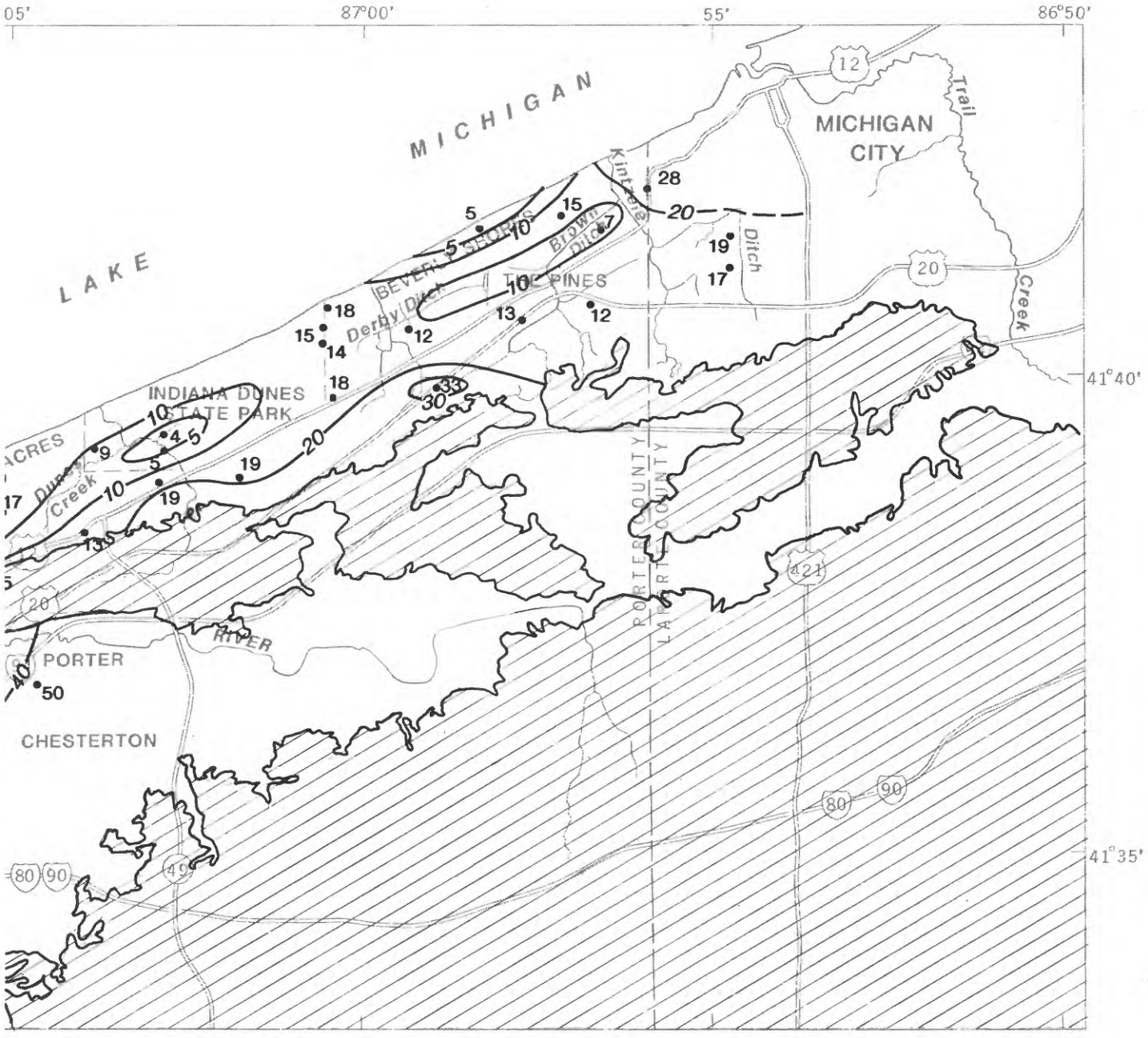


Figure 8. Hydrogeologic section *H–H'*. (Modified from Shedlock and other, 1988, figure 3.)



Base from National Park Service, Indiana Dunes National Lakeshore, Lake, Laporte, and Porter Counties, Indiana, 1986

Figure 9. Saturated thickness of surficial aquifer.

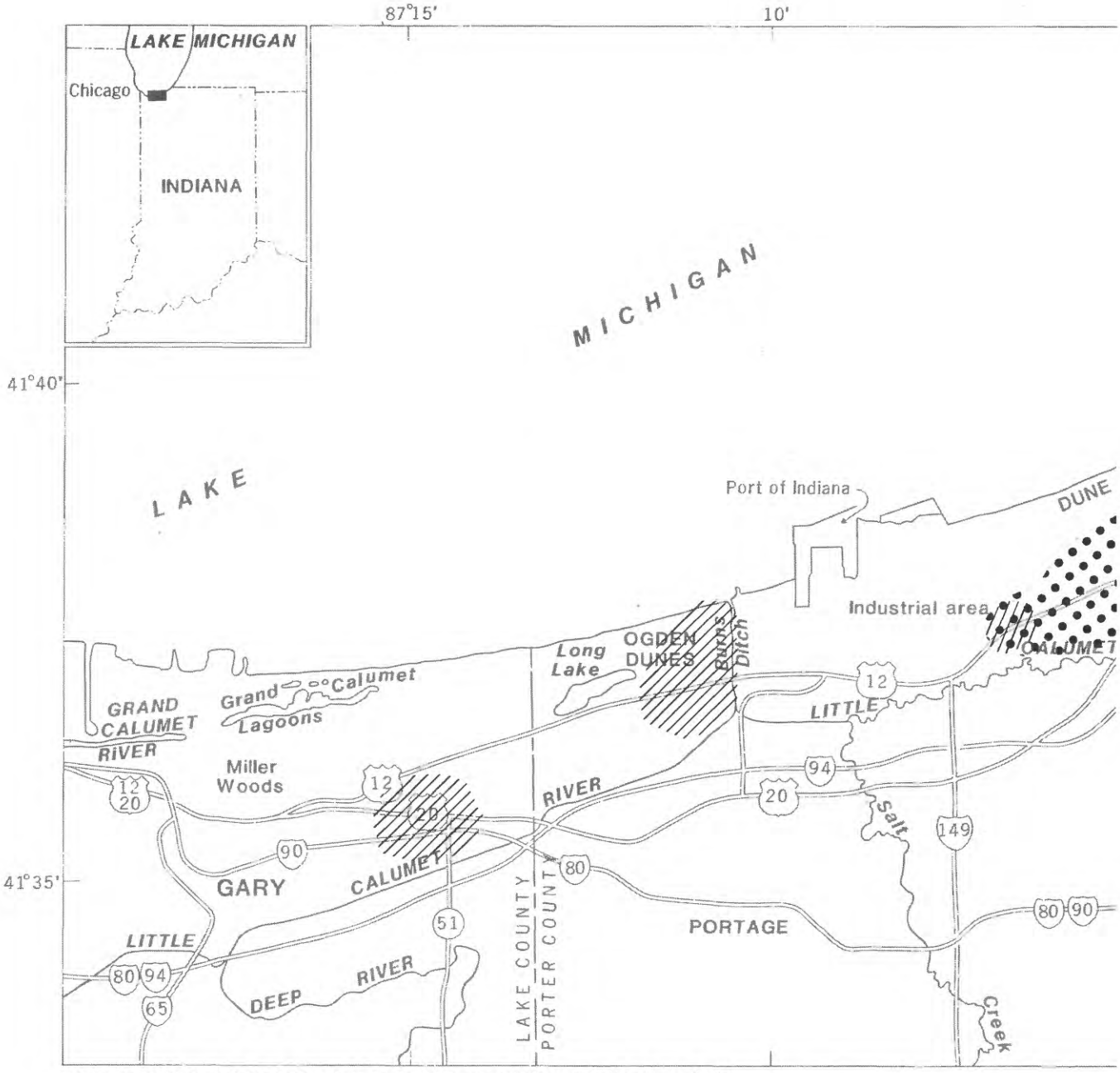


EXPLANATION

SURFICIAL AQUIFER ABSENT

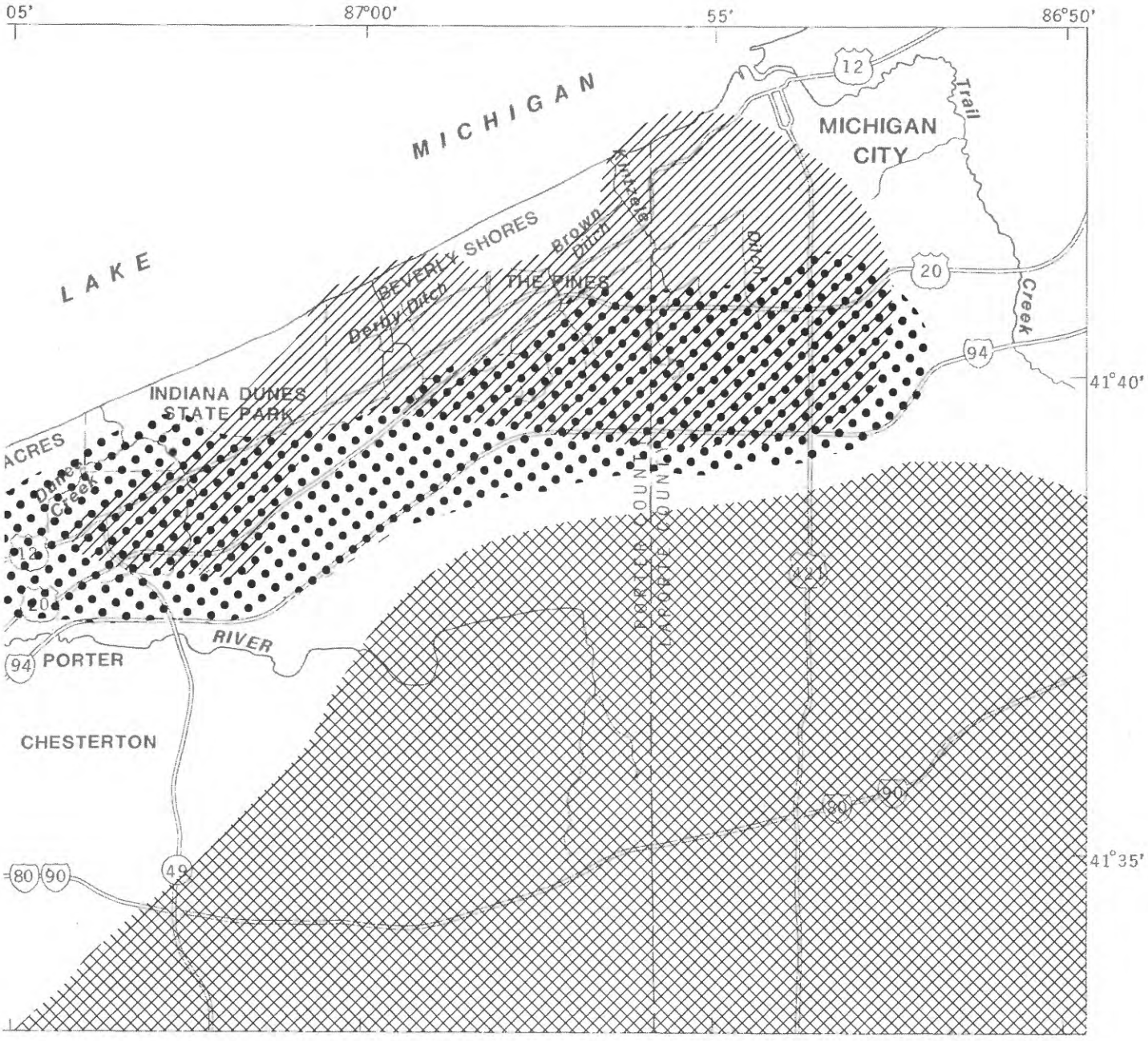
—40— LINE OF EQUAL THICKNESS OF SATURATED MATERIAL--Intervals 5, 10, and 20 feet. Dashed where approximate

•17 DATA POINT--Number is saturated thickness, in feet



Base from National Park Service, Indiana Dunes National Lakeshore, Lake, Laporte, and Porter Counties, Indiana, 1986

Figure 10. Approximate areal extent of confined aquifers.



EXPLANATION

- APPROXIMATE EXTENT OF SUBTILL AQUIFER
- APPROXIMATE EXTENT OF BASAL SAND AQUIFER
- APPROXIMATE EXTENT OF VALPARAISO AQUIFER

The model was constructed for the eastern half of the study area because regional and intermediate flow systems affect wetlands only in this part of the Lakeshore. Ground-water flow simulations for an area that include much of the western half of the Lakeshore are presented in Watson and others (1989).

A diagrammatic hydrogeologic section was drawn to illustrate the major lithologic characteristics of the eastern half of the study area (fig. 11A). Water levels in observation wells screened in the subtill and basal sand aquifers indicate that the principal hydraulic gradients in aquifers are towards the Lake Michigan shoreline. The diagrammatic hydrogeologic section was drawn perpendicular to the shoreline so that the line of the modeled section is along the major direction of ground-water flow in the confined aquifers. The model analysis presented here is based on the assumption that any components of flow not aligned along the direction of the generalized section are small and do not substantially affect the vertical and lateral flow patterns in the confined systems being simulated.

The available lithologic and geophysical data indicate that the spatial distribution and interconnection of sand and clay layers in the subtill aquifer is highly variable. The spatial distribution of the confined sands representing the subtill aquifer shown in figure 11A is only one of several possible interpretations and was used as an arbitrary starting point.

Model Design and Boundary Conditions

One layer of a modular, finite-difference model (McDonald and Harbaugh, 1988) was used to simulate ground-water flow in the diagrammatic hydrogeologic section. The modeled area was divided into a uniformly-spaced grid of 17 rows by 23 columns with grid dimensions of 25 ft vertical by 1,000 ft horizontal (fig. 11B). Flow along rows represents horizontal flow along the line of the generalized section, and flow along columns represents vertical flow. A streamline (no-flow) boundary was simulated at the bottom and the northern margins of the model to simulate northward flow in the bedrock and upward discharge into Lake Michigan, the major ground-water sink in the area. The effects of these boundaries on the final head distributions in the model interior were minimized by setting the bottom boundary 175 ft into bedrock and by setting the northern boundary 3,000 ft north of the Lake Michigan shoreline.

The upper boundary was set at the water table and was specified as a constant head. The altitude of the water table used in the model is an approximate average of water-level measurements from 1978 through 1988 in observation wells screened in the surficial aquifer (Cohen and Shedlock, 1986; unpublished data on file, U.S. Geological Survey, Indiana District); this water-table configuration represents average long-term conditions. A water-table profile was estimated for the Lake Border moraine. Dunes Creek and the Little Calumet River were simulated as constant-head boundaries 587 and 617 ft, respectively. These elevations are the approximate mean stages for these streams along the generalized hydrogeologic section. Lake Michigan also was simulated as a constant head, 580 ft—the approximate mean stage for 1983.

A general head boundary (McDonald and Harbaugh, 1988, p. 11-1 to 11-27) was used along the southern boundary underlying the Little Calumet River. In the general head boundary, a ground-water flux is calculated between each node along this boundary and a known head outside the modeled area. This flux calculation is based on the head difference between each boundary node and the known head outside the modeled area, and on the hydraulic conductivities and lateral thicknesses of the materials between these two points. The known head used in this calculation was 780 ft, the approximate hydraulic head in the potentiometric high in the Valparaiso aquifer about 6 mi south of the model boundary (Rosenshein and Hunn, 1968b). The lithologies of the subsurface

materials in this 6-mi interval are not as well known as those to the north within the study area. On the basis of a regional schematic section in Hartke and others (1975, p. 29), however, the unconsolidated deposits in this 6-mi interval were estimated to be 5.4 mi of glacial-lacustrine sand and 0.6 mi of till. The bedrock in the 6-mi interval is predominantly limestone. The hydraulic conductivities used for these materials in the general head boundary calculations were the same as those used in the simulations.

The horizontal hydraulic conductivity used for the bedrock aquifer in each simulation was 7 ft/d, the value given by Rosenshein and Hunn (1968a) for the Silurian limestone in Lake County. A value 0.015 ft/d was used for the horizontal hydraulic conductivity of the till. This value is in the mid-range of values for till given by Freeze and Cherry (1979, p. 29). The horizontal hydraulic conductivity used for the confined sands in each simulation was 40 ft/d. This value is in the mid-range of values reported by Rosenshein and Hunn (1968a and 1968b) for other confined sand aquifers in northwestern Indiana. Rosenshein and Hunn report a range from less than 13 to approximately 107 ft/d for their Unit 4 and estimate an average of 87 ft/d for their Unit 3 (Valparaiso aquifer).

In the model code of McDonald and Harbaugh (1988, p. 5-39), only one value per layer can be specified for anisotropy, the ratio of vertical hydraulic conductivity to horizontal hydraulic conductivity. Anisotropy was set to 0.1 for all simulations. That is, the hydraulic conductivity along columns was 0.1 times the hydraulic conductivity along rows. This is the same value for anisotropy used by Meyer and Tucci (1979, p. 56) and Gillies and Lapham (1980, p. 15) in their simulations of ground-water flow in the sand aquifers in the same general area. The anistropy ratio, however, may be much smaller than 0.1 in the underlying bedrock (R.H. Johnston, U.S. Geological Survey, oral commun., 1992). All simulations were run at steady-state conditions.

Results of Simulations

Three simulations using values for the hydraulic properties described previously are shown in figure 12. The first simulation (fig. 12A) used the spatial distribution of confined sands representing the subtill aquifer shown in the generalized hydrogeologic section in figure 11A. In the second simulation (fig. 12B) the degree of vertical interconnection of these sandbeds was decreased. In the third simulation (fig. 12C), the vertical interconnection was increased.

Flow patterns in the first two simulations (figs. 12A and 12B) generally match the regional and intermediate flow patterns in the conceptual model in figure 7A. Flow patterns in the third simulation (fig. 12C) are similar to those of the conceptual model, with the exception of a southward shift in the flow divide underlying the Lake Border moraine.

Because this was an uncalibrated model, these simulations are not presented as evidence or proof of the accuracy or validity of the authors' conceptual model of ground-water flow. Rather, the similarities between the simulated flow patterns and those of the conceptual model shown in figure 7A suggest that the conceptual model is plausible and can be reconciled with available hydrochemical data (presented later in this report) and published values (Rosenshein and Hunn, 1968a and 1968b) of the hydraulic characteristics of the confined sand aquifers and the upper bedrock.

The simulations also imply that the conceptual model in figure 7A could be representative of the vertical flow system for most of the eastern half of the study area, even though the layering of sand and clay in the subtill aquifer varies across the area.

Shallow Ground-Water Flow in the Dunes and the Wetlands

The altitude of the water table in the surficial aquifer for October 1980 is shown in figure 13. The major dune-beach complexes are shown to be underlain by broad water-table mounds.

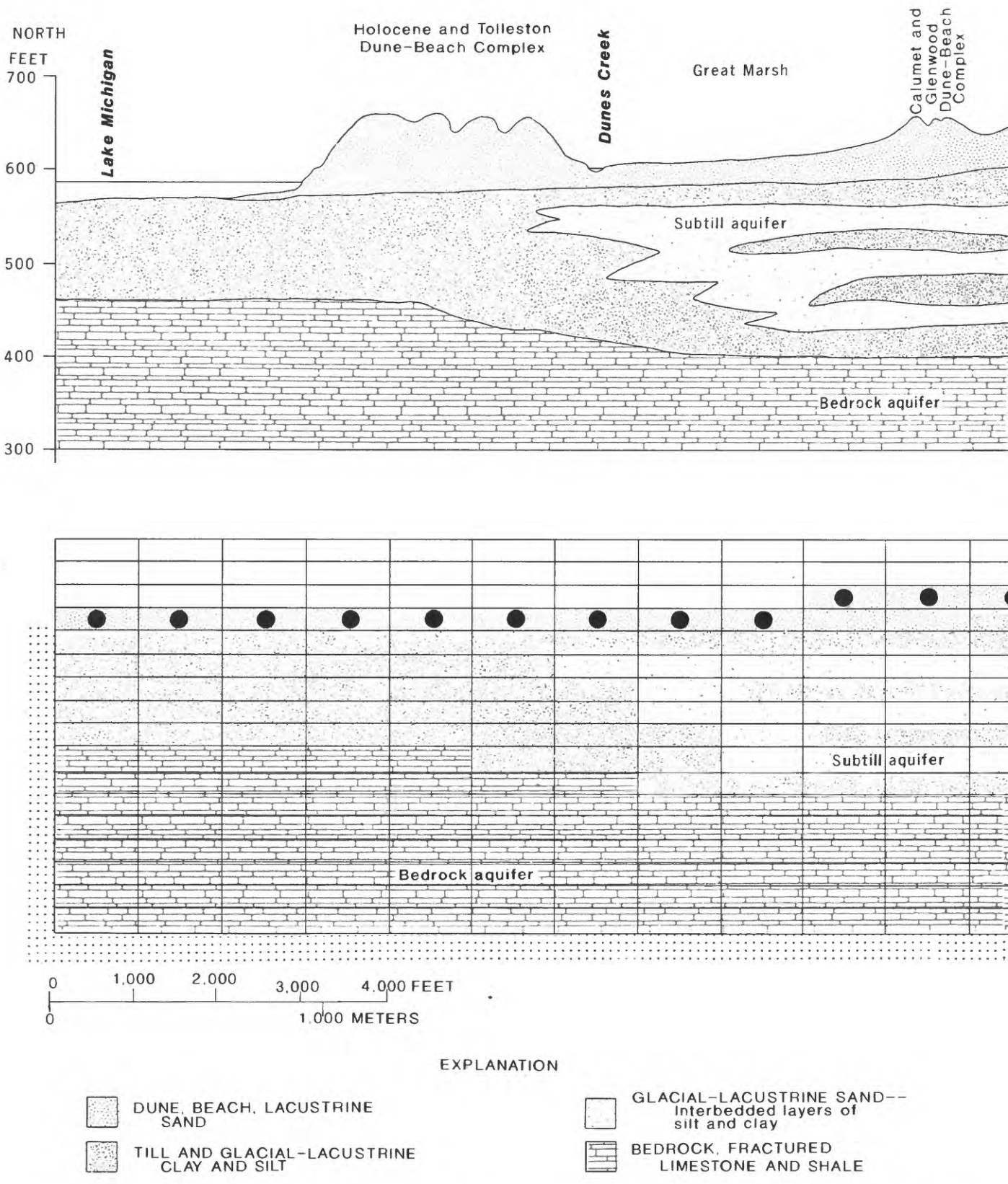
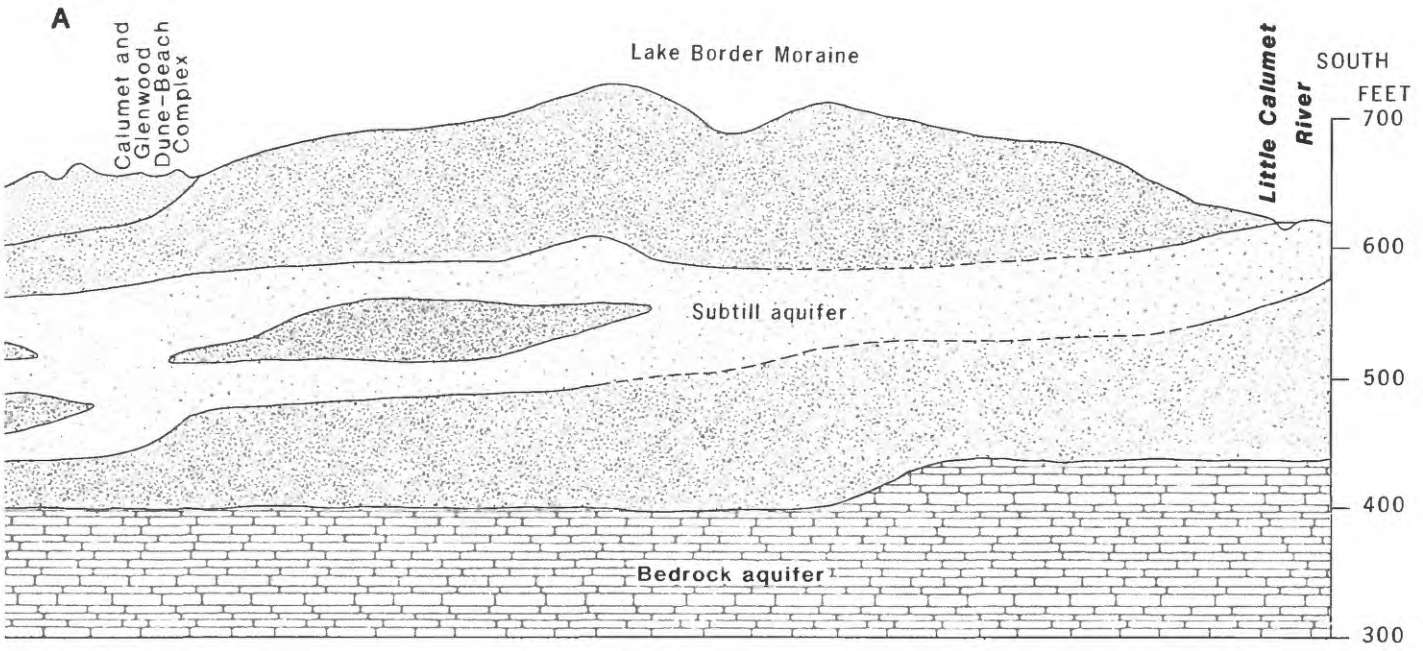
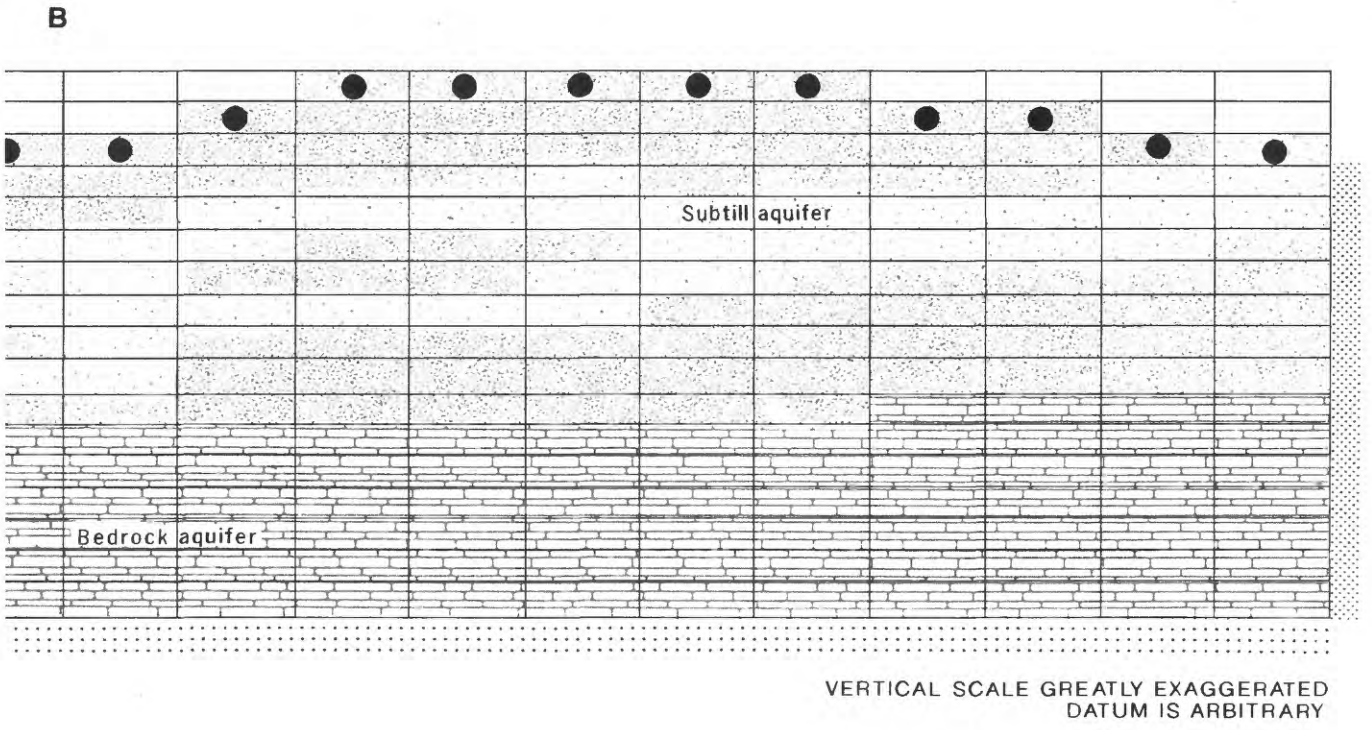


Figure 11. (A) Diagrammatic hydrogeologic section and (B) model grid for the eastern half of Indiana Dunes National Lakeshore, northwestern Indiana.





VERTICAL SCALE GREATLY EXAGGERATED
DATUM IS ARBITRARY

CONSTANT-HEAD NODES

GENERAL-HEAD BOUNDARY

STREAMLINE (NO-FLOW) BOUNDARY

CONTACT--Dashed where approximately located

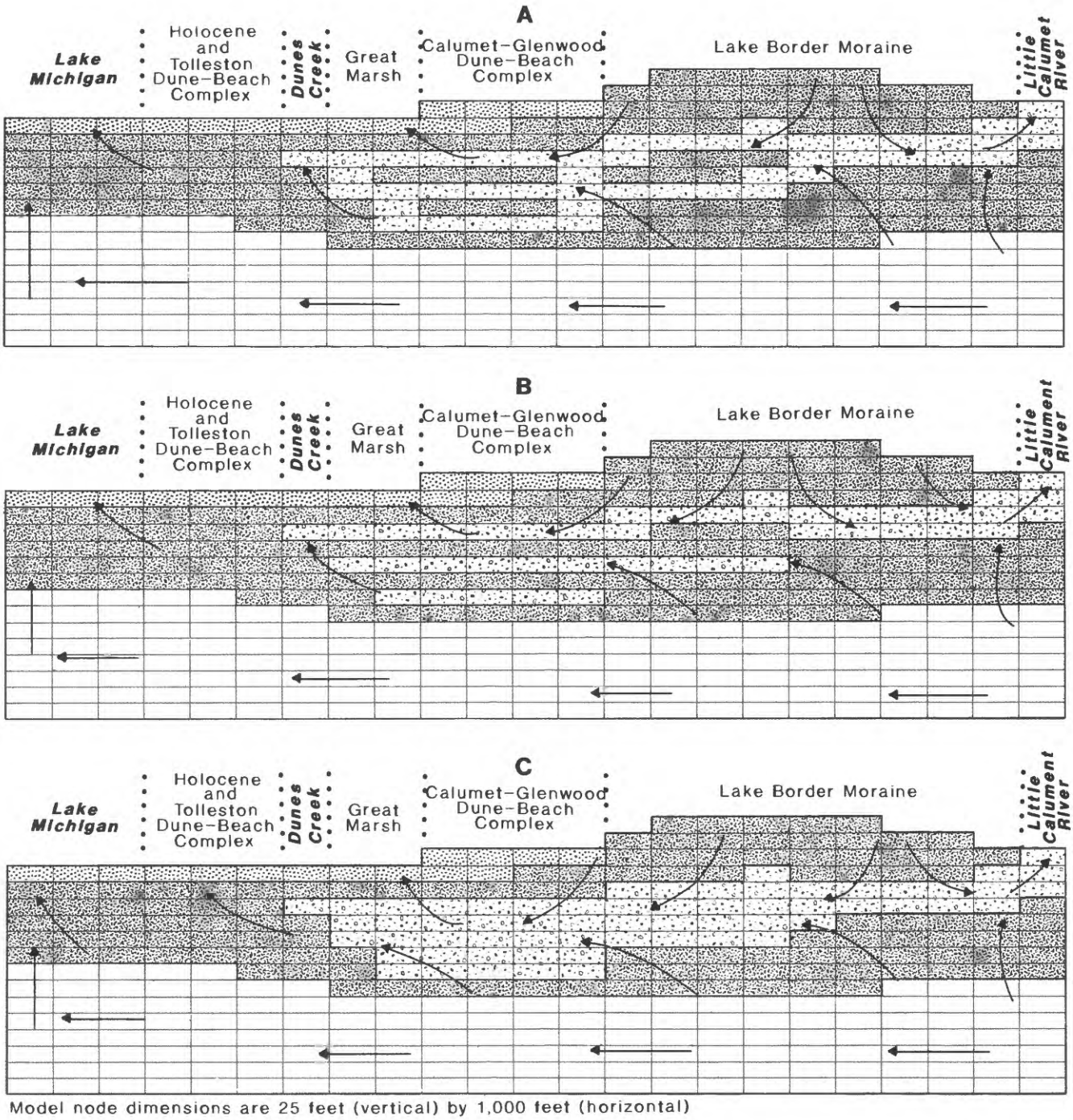


Figure 12. Simulated ground-water flow patterns.

The general pattern of flow is from the dune-beach complexes to the interdunal wetlands in the area north of the Lake Border moraine. Discharge from the interdunal wetlands is by seepage into streams, ditches, and ponded areas, and by evapotranspiration during the growing season. This pattern also is evident in the western part of the study area in the area north of Little Calumet River. The pattern is altered locally where streams or ditches cut through the dune-beach complexes. In addition, where the dune-beach complexes are narrow, water-table divides do not develop (such as along the north flank of the Lake Border moraine). South of the Lake Border moraine and in the southwestern part of the mapped area, shallow ground water flows into streams from water-table divides in the interfluvial areas between the streams.

Shallow ground-water flow in two subareas of figure 13 is described in three other reports. Shedlock and Harkness (1984) presented water-table maps and profiles for the Brown Ditch basin and part of the Derby Ditch basin at the eastern end of the Lakeshore. A detailed water-table map of the area surrounding Cowles Bog is presented in Cohen and Shedlock (1986). A more detailed water-table map and a hydrogeologic section illustrating flow in and around the raised peat mound in Cowles Bog is presented in Wilcox and others (1986).

A noteworthy feature of the map in figure 13 and of those in the preceding reports is the flatness of the water-table mounds beneath the dune-beach complexes. These complexes contain many individual dunes with differences in altitude of 50 to 100 ft between the tops of the dunes and the intradunal lowlands. This detailed topography of the dunes, however, is not reflected in the configuration of the water table.

A significant feature of the water-table configuration is the localization of flow in the surficial aquifer. As a result, water in the surficial aquifer discharges directly into Lake Michigan in only a small region between the modern shoreline and the first water-table divide inland from the lake (fig. 13). This fact is hydrologically important for at least two reasons. First, direct discharge of shallow ground-water contaminants into Lake Michigan is restricted to areas north of the water-table divide shown in figure 13. Therefore, possible contaminants in the shallow ground water south of this divide would reach the lake only by discharging into streams and ditches that drain into the lake. Second, the Great Marsh and the other interdunal wetlands are not directly connected hydraulically to Lake Michigan. The altitude of the water table in the interdunal wetlands ranges from 10 to 40 ft above the level of Lake Michigan. The water-table divide in the dune-beach complex along the shoreline of Lake Michigan is a hydrologic boundary between the lake and the interdunal wetlands.

Interactions between Shallow Ground Water and Wetlands

Another important feature of ground-water flow in the surficial aquifer is transient change in the water table near the margins of wetlands. Transient changes were investigated to understand recharge-discharge relations near the wetlands.

Water-table fluctuations were most closely monitored in a transect of wells equipped with automatic data recorders along section B-B′ (fig. 2). Water-table profiles along this section are shown for spring and fall 1985 (fig. 14). In both profiles, the Great Marsh is a water-table low relative to the adjacent dunes. In addition, the change in the water table from spring to fall varies along the section. The greatest changes between the spring and fall levels are in the Great Marsh and in the dunes at the wetland margins. The smallest changes occur under the topographic highs in the dune-beach complex.

Most of the wells shown in figure 14 were equipped with automatic data recorders that monitored water levels hourly. A rain gage was installed approximately 200 ft west of section B-B′ to monitor rainfall hourly. Three water-table profiles and rainfall from September 25 to October 3, 1986, along the northern dune-wetland margin of section B-B′ are shown in figure 15.

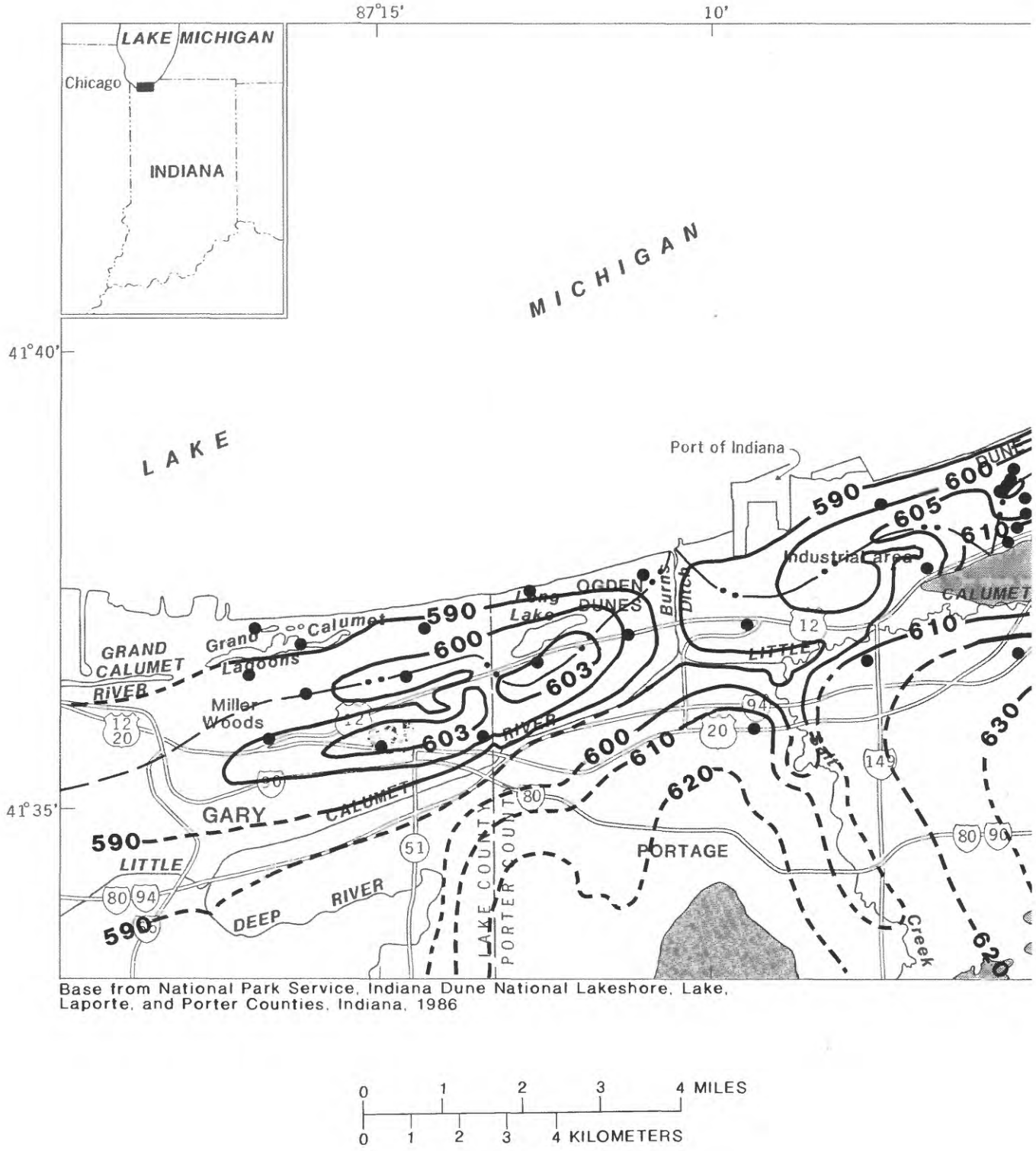
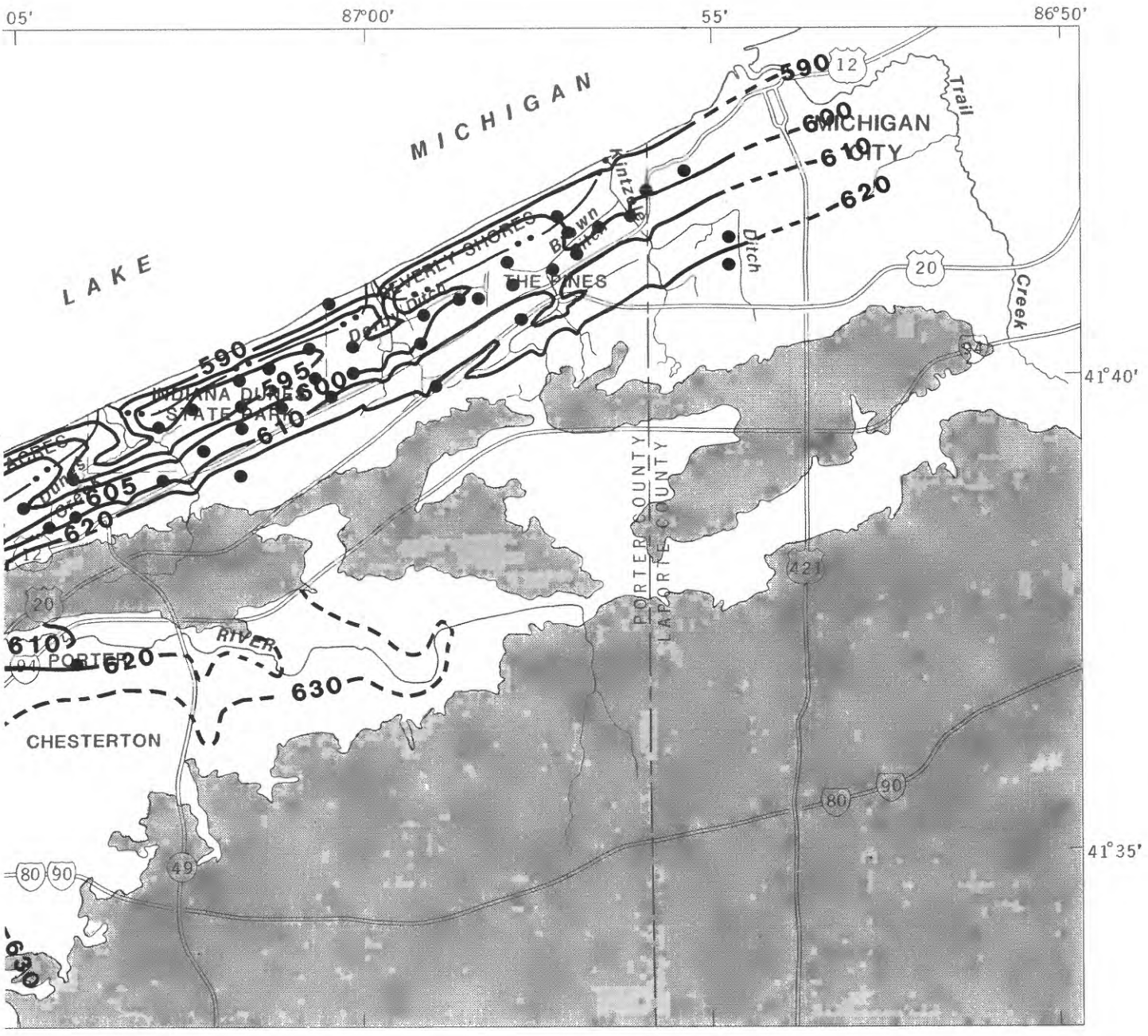


Figure 13. Altitude of water table in surficial aquifer, October 1980.



EXPLANATION

SURFICIAL AQUIFER ABSENT

620 WATER-TABLE CONTOUR--Shows altitude of water table. Interval in feet is variable. Dashed where approximately located. Datum is sea level

WATER-TABLE DIVIDE--Dashed where approximately located

DATA POINT

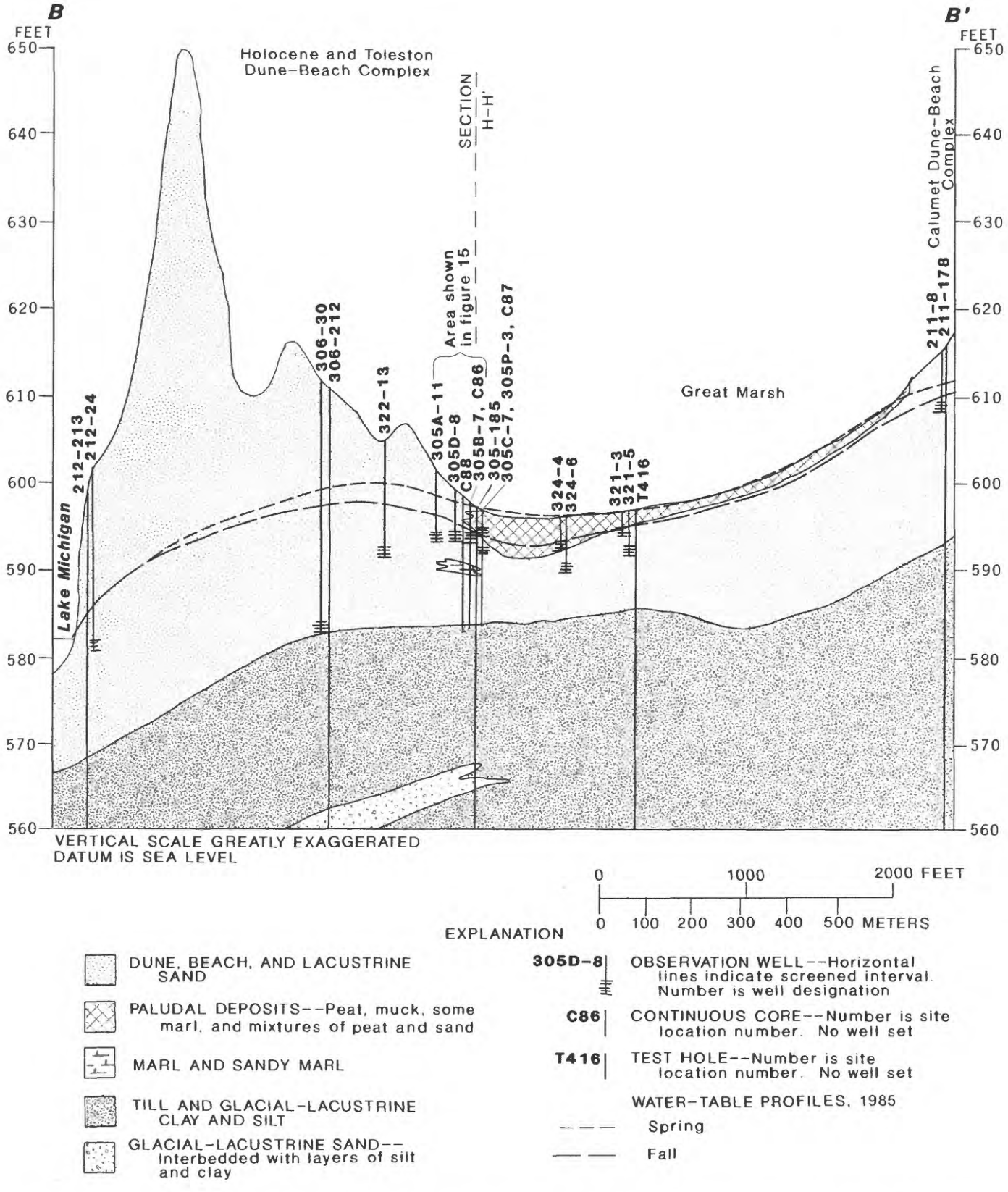


Figure 14. Seasonal water-table fluctuations along section *B–B'*. (Modified from Shedlock and others, 1988, figure 5.)

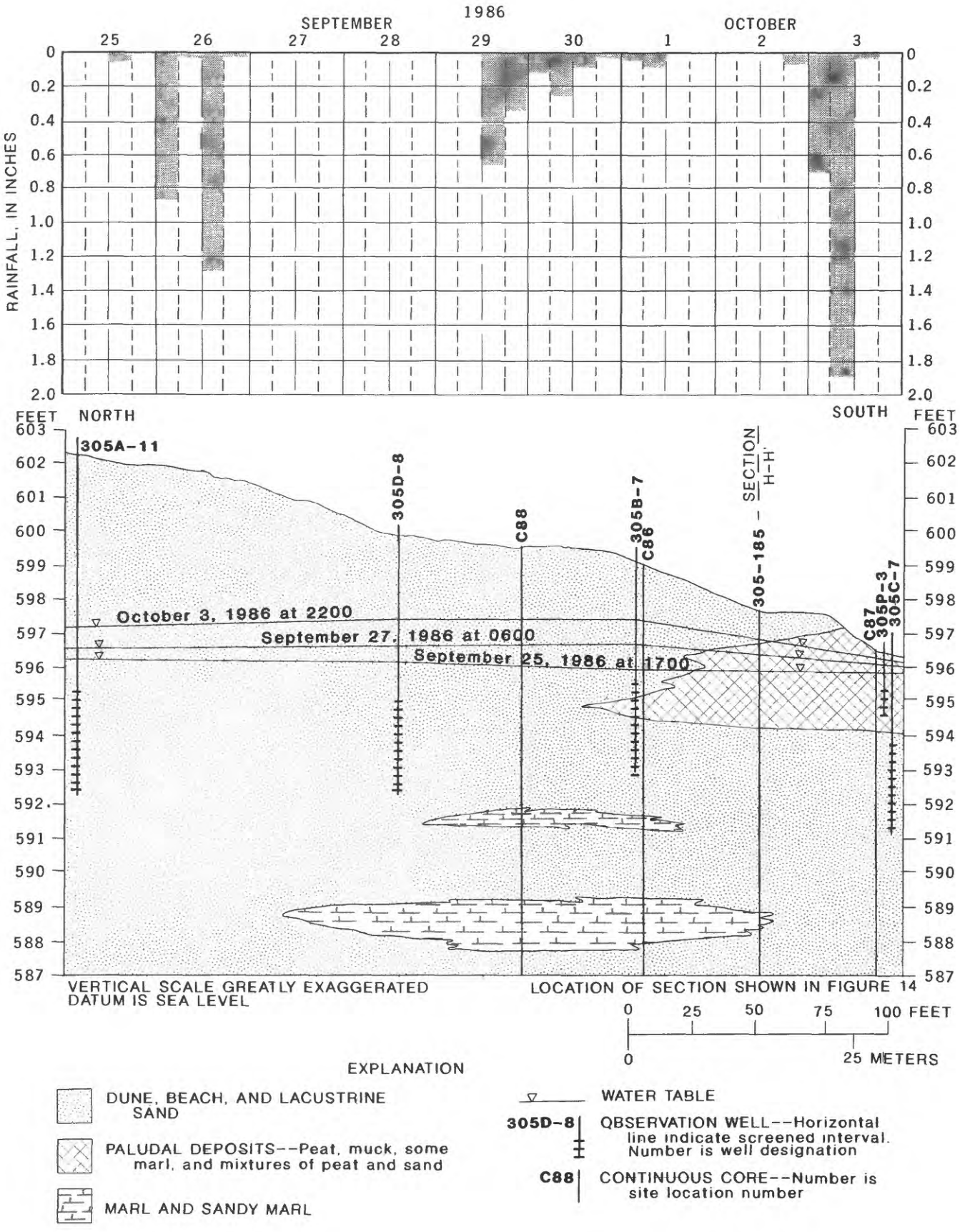


Figure 15. Water-table profiles and precipitation at dune-wetland margin along midpart of section *B–B'*.

During dry periods, the water table slopes gently from the dune-beach complex to the Great Marsh (water-table profile for September 25 in figure 15). During wet periods, the water-table gradient can change substantially and transient water-table mounds can develop at the dune-wetland margin and persist for several days (profiles for September 27 and October 3 in figure 15). In addition to transient water-table mounds and flow reversals at the edge of the Great Marsh, reversals in the water-table gradient have been observed at the margins of smaller wetlands within the dune-beach complexes. These reversals were subtle, usually 0.10 ft or less, and were detected only after significant rainfall.

The mounding phenomenon seems to be the same as that simulated by Winter (1983) and has since been observed by others (Munter, 1979; Rosenberry, 1987; Shedlock and others, 1987). The duration of the mounding is generally several hours to several days, and the frequency of flow reversals appears to be no more than one or two times per month. Neither the mounding nor the flow reversals seems to influence the flow system for more than several days; however, the transient changes in the water-table profile indicate that the distribution of recharge in this environment is complex in time and space.

The water-table profiles in figures 14 and 15 indicate that the dune complexes are recharged more actively around the edges of the interdunal and intradunal wetlands than under topographic highs. Water levels under topographic highs in the dunes declined during water-level rises at the dune-wetland margin. Similar characteristics have been reported by Phillips and Shedlock (1988) for freshwater wetlands in northern Delaware. This recharge pattern is analogous to, if not the same as, depression-focused recharge described by Lissey (1968).

HYDROCHEMISTRY

Water samples for chemical analysis were collected from wells completed in the unconsolidated confined and surficial aquifers, and from wetland surface waters at selected sites in the wetlands. The samples were analyzed for major ions and nutrients, selected trace elements, and dissolved organic carbon. Concentrations of tritium in selected wells and surface waters were determined also. The sampling was done to investigate differences in water chemistry between (1) the wetlands and the underlying and adjacent ground water, (2) the different aquifers, and (3) the various parts of the ground-water flow system.

From 1977 to 1986, 120 wells were sampled, although many of the wells were sampled two to four times. Analysis of seasonal variation in water quality is beyond the scope of this report. To avoid any seasonal bias, the authors based the statistical summary and schematic plots of water-quality data presented in this section on a slightly smaller set of wells (77) sampled during spring 1980. Water-quality data for ground-water samples are listed in tables 2 through 4, and water-quality data for wetland surface-water samples are listed in table 5 (at back of report).

General Chemical Characteristics

Statistical summaries of eight chemical constituents and four properties are given for each unconsolidated aquifer and wetland surface water in schematic plots (fig. 16). A summary of median values for these and other and constituents and properties is given in table 6. A broad range of chemical composition was observed in the ground and surface waters in the study area. Water chemistry differed not only from aquifer to aquifer but also within an aquifer, depending on the depth of the well and the position of the site in the overall ground-water flow system. For most sites where the chemical composition of waters in adjacent aquifers was similar, the similarity could be explained in terms of ground-water flow paths. Such relations will be discussed in the section, "Relations between Water Chemistry and Patterns of Ground-Water Flow."

Confined Unconsolidated Aquifers

The chemical composition of waters from the confined unconsolidated aquifers (table 2, at back of report) have been plotted on the trilinear diagram in figure 17. The convention for naming

chemical types of water used in this report has been modified from that used by Back (1966) because of the many mixed water types. As can be seen in figure 17, the fields in the cation and the anion parts of a trilinear diagram have been subdivided in a manner similar to that of Kimball (1981). A single ion is considered dominant if it represents greater than 60 percent of the total cation or anion milliequivalents per liter. The interiors of the cation and anion parts of the diagram contain a central triangular-shaped field of mixed water types where each of the three end members ranges from 20 to 60 percent. This triangular field is flanked by trapezoidal fields in which two of the end members are between 20 and 60 percent, and the third is less than 20 percent. Examples of the two-ion fields are the calcium-magnesium and the bicarbonate-sulfate fields.

In this report, the hydrochemical type of a water will be given by listing the appropriate cations and anions in order of dominance. For mixed water types, any ion present in concentration greater than 20 percent of the total cation or anion equivalents is considered significant and is named in the hydrochemical type.

The range in composition of water in the basal sand aquifer is substantial, but less variation is seen in the composition of water in the subtill and the Valparaiso aquifers. The waters in the basal sand aquifer are various mixed types, with the exception of several sodium chloride waters. Progressive changes in water type were observed in this aquifer from the southern part of the study area to the Lake Michigan shoreline. These changes seem to be related to surficial geologic and geomorphic features. Waters from wells that underlie the Lake Border moraine (wells 201-205, 204-125, and 243-165 in table 2) are calcium magnesium bicarbonate and magnesium calcium sodium bicarbonate types. North toward Lake Michigan, the concentration of sodium in the waters in the basal sand aquifer becomes proportionately greater. Water types in the basal sand aquifer from wells below the Great Marsh (wells 203-193 and 213-135 in table 2) are sodium magnesium calcium bicarbonate and sodium magnesium calcium bicarbonate chloride types. Closer to Lake Michigan, the concentration of chloride in the waters in the basal sand aquifer becomes proportionately greater. Waters in this aquifer beneath the shoreline dunes and along the Lake Michigan shoreline (wells 212-213 and 230-128 in table 2) are sodium chloride and sodium bicarbonate chloride types.

Several chemical characteristics of waters from the basal sand aquifer are distinctive from those of waters from the other aquifers. As shown in figure 16, the basal sand aquifer has higher median values and generally higher ranges of values for sodium, pH, fluoride, and boron. The higher values of these constituents could be due to leakage of water from the bedrock into the basal sand aquifer. Waters from wells approximately 8 mi west of the study area in Lake County, Ind., finished in the underlying Silurian carbonate bedrock (wells BR1-500 and BR2-583 in table 2) are generally higher in these constituents than waters from any of the unconsolidated aquifers in the study area. Rosenshein and Hunn, (1968b, p. 5) indicate that highly mineralized water in their Unit 4 (see table 1) could be caused by leakage from the underlying bedrock.

Waters from the subtill aquifer are mostly calcium magnesium bicarbonate, magnesium calcium bicarbonate, and various mixed water types. Their compositions are less variable than those of waters from the basal sand aquifer, but the compositional fields of the subtill and basal sand aquifers overlap. The area of overlap in the trilinear diagram (fig. 17) includes wells completed in the subtill aquifer that underlie the Lake Border moraine (wells 201-32, 209-78, 223-115, 243-85, 204-59, 208-72, and 219-72 in table 2). Water from the subtill aquifer has higher median values and ranges of values for alkalinity and magnesium (fig. 16 and table 6) than other ground waters. In addition, the concentration of sulfate is substantially higher in water from the subtill aquifer than in water from either the basal sand aquifer or the Valparaiso aquifer. Water from the subtill aquifer also has the highest median value of total hardness, although the range of values for hardness is somewhat lower than that of water in the surficial aquifer.

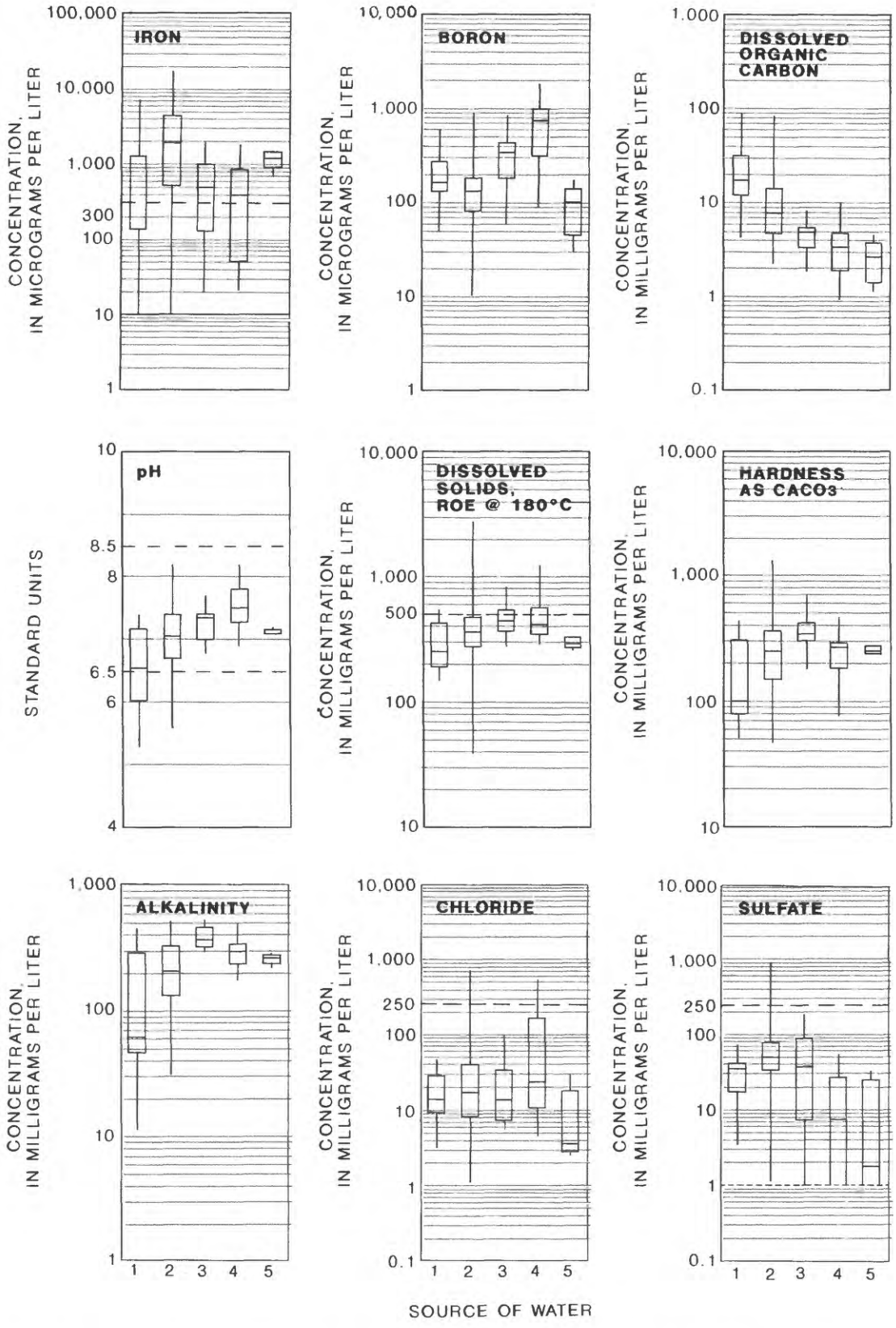
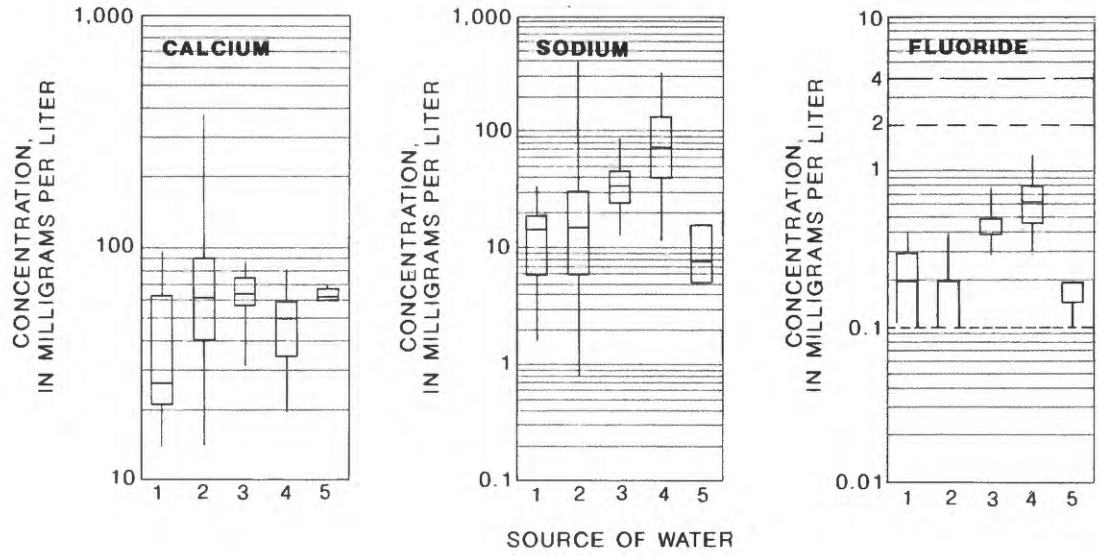
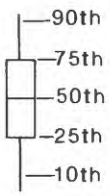


Figure 16. Common constituents and properties of water at Indiana Dunes National Lakeshore, by source, spring 1980.



EXPLANATION



PERCENTILE--Percentage of analyses equal to or less than indicated values

U.S. ENVIRONMENTAL PROTECTION AGENCY DRINKING-WATER REGULATIONS

—— —— Maximum contaminant level (MCL)

— — — - Secondary maximum contaminant level (SML)

REPORTING LIMIT

- - - - - - - Minimum reporting concentration for analytical method used

SOURCE OF WATER (NUMBER OF ANALYSES)

1 Wetland-surface water (20)

2 Surficial aquifer (46)

3 Subtill aquifer (12)

4 Basal sand aquifer (14)

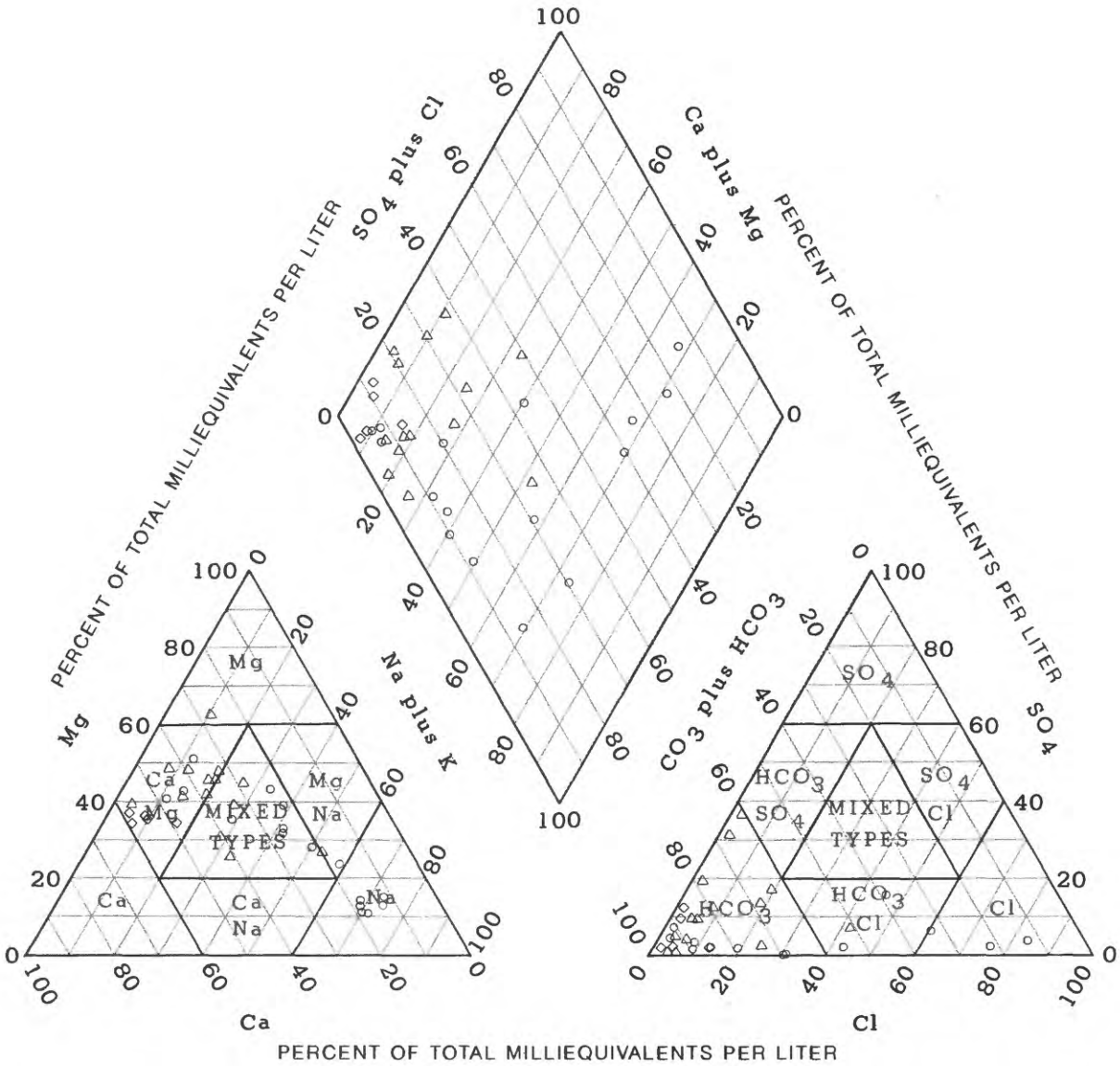
5 Valparaiso aquifer (5)

Table 6. Median values of selected water-quality constituents and properties at Indiana Dunes National Lakeshore, by source, spring 1980

[Unless stated otherwise, unit of measure is milligrams per liter; REDOX, oxidation reduction potential; °C, degrees Celsius; ROE, residue on evaporation]

Water-quality constituent or property	Water source				
	Wetland surface water	Surficial aquifer	Subtill aquifer	Basal sand aquifer	Valparaiso aquifer
Specific conductance[1]	275	535	767.5	750	54
pH[2]	6.55	7.05	7.35	7.50	7.10
REDOX potential[3]	337	148.0	137.5	111	78
Temperature (°C)	11.65	11.20	11.85	12.25	10.80
Dissolved oxygen	1.2	.025	.1	.1	.1
Calcium	26	60.5	63.5	49.5	61
Magnesium	9.45	22	48.5	30.5	24
Sodium	14.5	16	34.5	75	7.9
Potassium	1.7	1.5	2.75	3.8	2.1
Alkalinity, as calcium carbonate	60	190	365	290	270
Sulfate	35	51	37.5	7.65	1.8
Chloride	13.5	15	13.5	23.5	3.6
Dissolved solids, ROE @ 180°C	249	356	428.5	410.5	287
Boron[4]	160	130	365	730	100
Iron[4]	415	1,950	490	385	120
Manganese[4]	120	130	85	35	50
Dissolved organic carbon	17.0	7.9	4.4	3.3	2.6
Number of samples	20	46	12	14	5

[1]Unit of measure is microsiemens per centimeter at 25 degrees Celsius. [2]In Standard Units. [3]Unit of measure is millivolts. [4]Unit of measure is micrograms per liter.



EXPLANATION

WELLS SCREENED IN THE

△ Subtill aquifer

◇ Valparaiso aquifer

○ Basal sand aquifer

Figure 17. Chemical composition of water in confined unconsolidated aquifers.

Two samples of water in the subtill aquifer from wells in the east end of the study area had unusual compositions compared to other water samples from the subtill aquifer. One of the water samples, a magnesium sulfate type, was collected from well 204-59 (table 2) in fall 1980 and is not included in the spring 1980 data set. The other sample is a magnesium bicarbonate type from well 201-32 (table 2) collected in spring 1980. The two samples have dissolved-solids concentrations exceeding those of all the other samples from the subtill aquifer (2,170 mg/L for well 204-59; 822 mg/L for well 201-32). Origins of these waters are unknown, but they may be from areas of the Lake Border moraine that are either mineralogically different from most other areas of the moraine or are isolated hydraulically from the main body of the subtill aquifer.

Water from the Valparaiso aquifer is a calcium magnesium bicarbonate type. The reason for the lack of compositional variation in the data from this aquifer probably is that all five analyses are from wells in a 2-square-mile area of the Little Calumet River valley, just north of the Valparaiso moraine. The compositional field of the water from the Valparaiso aquifer is adjacent to those of the other two aquifers but with little overlap (fig. 17).

Surficial Aquifer

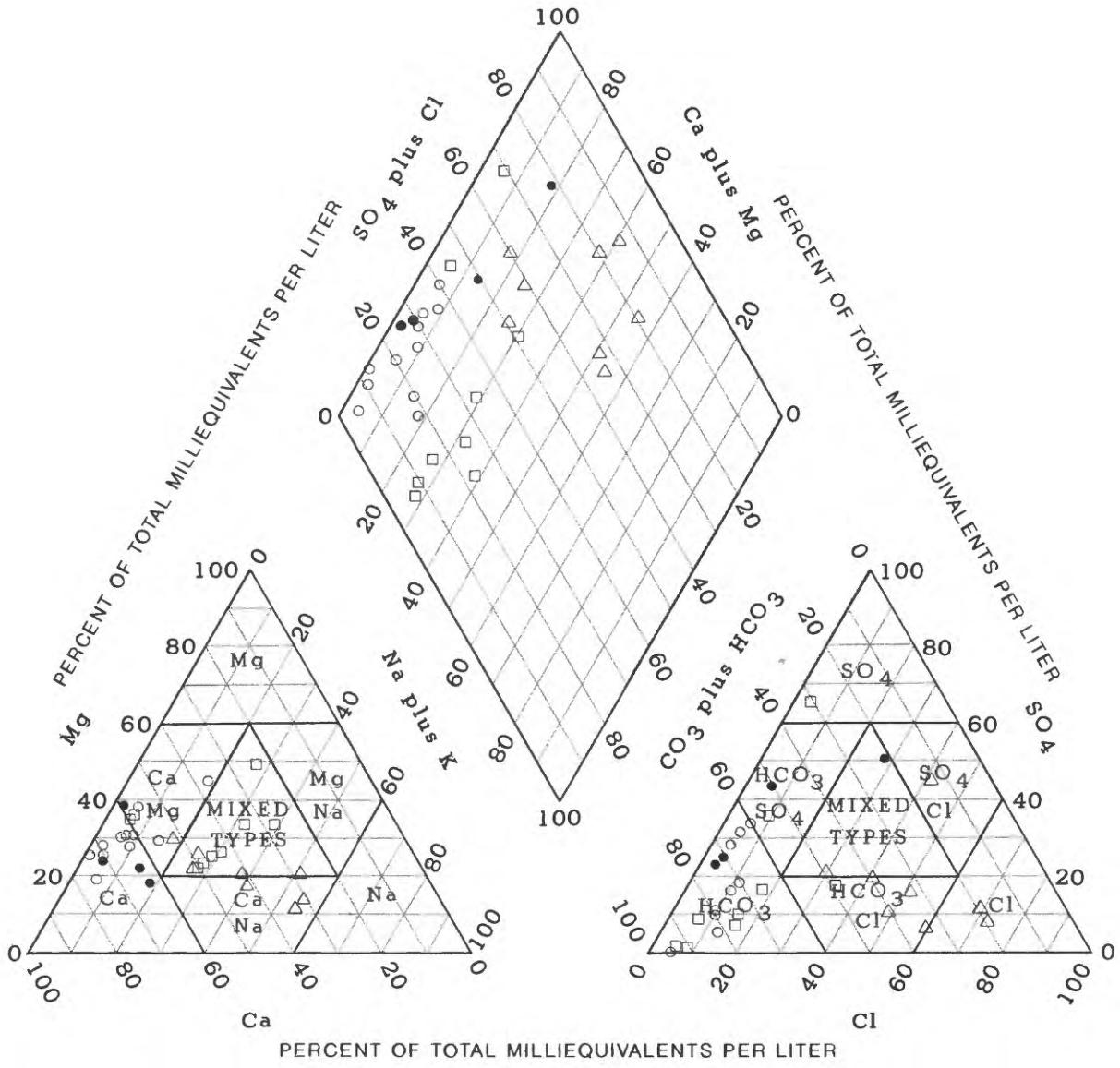
Water in the surficial aquifer is more chemically variable than water in any other aquifer in the study area. Median values of alkalinity and pH are lower and median values of dissolved organic carbon, iron, and manganese in the surficial aquifer are higher than those values for waters from the confined aquifers (table 6). Analyses of water from the surficial aquifer (tables 3 and 4) have been plotted in two groups on separate trilinear diagrams (figs. 18 and 19). Water samples in the first group (fig. 18 and table 3; table 3 at back of report) are from an areal network of wells distributed across the study area in the surficial aquifer. Water samples in the second group (fig. 19 and table 4) are from shallow wells in the Great Marsh that are screened in sands just below the surficial organic sediments.

The range of chemical composition of samples from the areal network (fig. 18 and table 3) is broad. The various water types seem to be related to different geomorphic features of the study area. The largest cluster of points is in a zone that extends from calcium bicarbonate to calcium magnesium bicarbonate and magnesium calcium bicarbonate types. Waters of these compositions are mainly found in wells completed in the middle and lower parts of the surficial aquifer beneath the major dune-beach complexes (wells 202-26, 231-45, 232-45, 239-65, 244-65, 212-24, 235-45, 211-25, and 306-30 in table 3) and in the Little Calumet River valley in the central third of the study area (wells 227-52, 228-53, 229-65 and 225-56 in table 3).

Ground waters from wells finished in the upper 10 ft of saturated thickness of the surficial aquifer (wells 217-13, 230-24, 305A-11, and 322-13 in table 3) are generally more dilute (dissolved solids less than 200 mg/L) than most other waters in the surficial aquifer. Furthermore, in each of these waters the sulfate concentration represents more than 25 percent of the total milliequivalents per liter of anions in the water.

Well 230-24 is near a major highway (U.S. Route 12) about 0.6 mi west of Burns Ditch (fig. 4). Although road-salting is common along this highway in the winter, the water from this well (the shallow well at this site) has low concentrations of sodium and chloride relative to other major ions. The shallow ground water at this site does not seem to be affected by road salt.

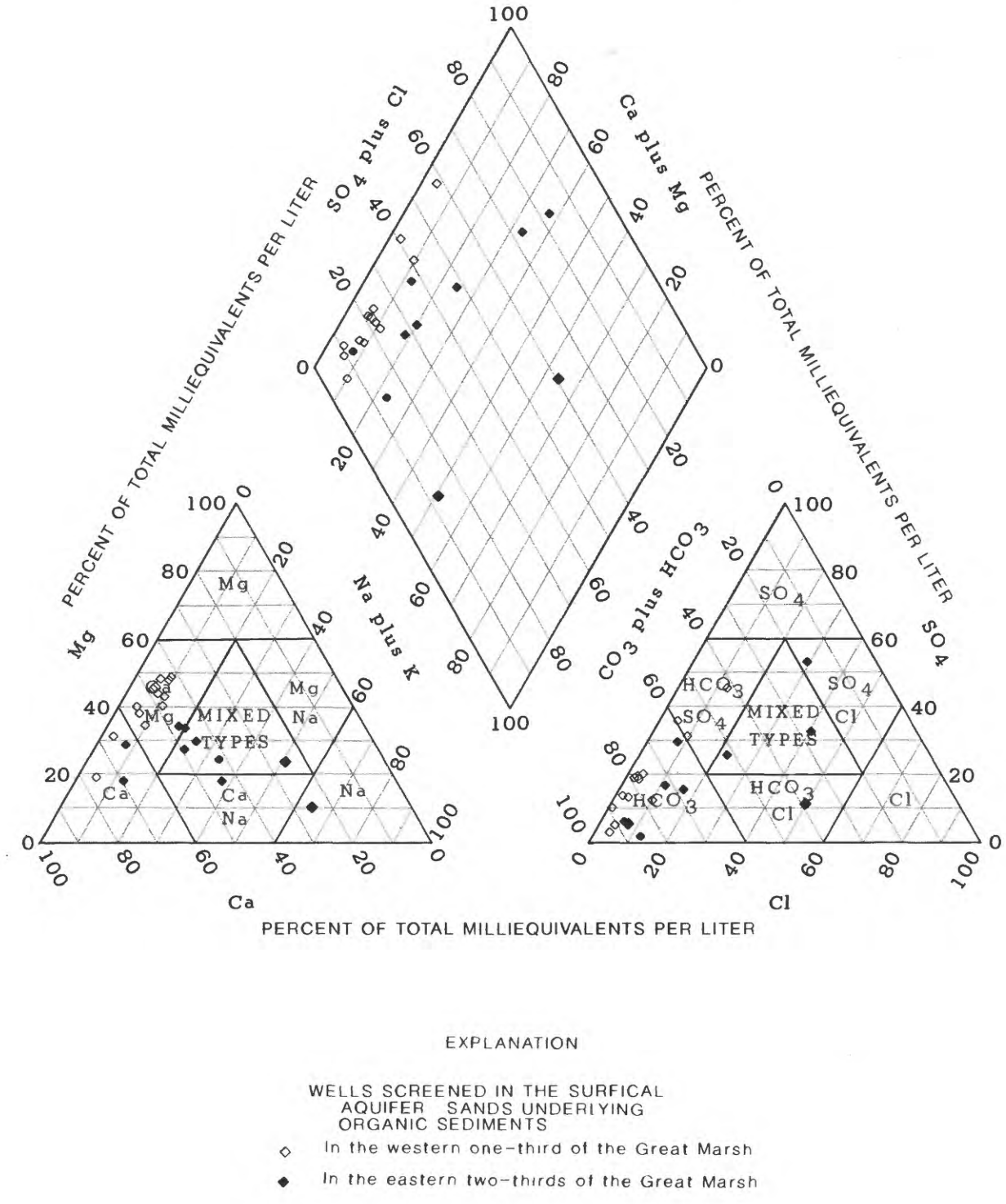
Water from the deeper well completed at the base of the surficial aquifer at this site (well 230-58 in table 3) and waters from several other wells in the western half of the study area (wells 237-45, 233-49, 236-45, 238-65, 226-65, 275-24, and 240-61 in table 3) do contain substantial percentages of sodium and chloride. These waters generally have higher dissolved solids concentrations than most other waters in the surficial aquifer and are from wells finished in the middle to lower parts of the surficial aquifer.



EXPLANATION

- ○ WELLS COMPLETED IN THE MIDDLE AND LOWER PARTS OF THE SURFICIAL AQUIFER BENEATH THE MAJOR DUNE BEACH COMPLEXES, AND IN THE LITTLE CALUMET RIVER VALLEY IN THE CENTRAL THIRD OF THE STUDY AREA
- • WELLS COMPLETED IN THE UPPER 10 FEET OF SATURATED THICKNESS OF THE SURFICAL AQUIFER
- △ WELLS COMPLETED IN THE MIDDLE AND LOWER PARTS OF THE SURFICAL AQUIFER IN THE WESTERN HALF OF THE STUDY AREA
- □ REMAINING WELLS IN THE SURFICAL AQUIFER

Figure 18. Chemical composition of water in the surfical aquifer.



EXPLANATION

WELLS SCREENED IN THE SURFICAL AQUIFER SANDS UNDERLYING ORGANIC SEDIMENTS

◇ In the western one-third of the Great Marsh

◆ In the eastern two-thirds of the Great Marsh

Figure 19. Chemical composition of shallow ground water under wetlands.

These spatial concentration patterns suggest that the sodium and chloride in the middle to lower sections of the surficial aquifer in the western part of the study area could be from a source other than road salt. A possible source of the sodium and chloride in these waters is upward leakage of brackish water from the bedrock. Upper leakage of brackish water also is consistent with the high dissolved-solids concentrations of these waters relative to other waters in the surficial aquifer.

Analyses of water samples from shallow wells in the Great Marsh (table 4, at back of report) that range in depth from 7 to 23 ft below land surface are plotted in figure 19. These wells are screened in sands just below the surficial organic sediments.

Calcium magnesium bicarbonate and magnesium calcium bicarbonate types compose the largest cluster of points. These waters (wells GM4C-14, GM45-15, GM44-19, GM2-11, GM8-7, GM13-7, GM21-7, GM1-12, GM46-23, GM38-19, GM39-9, and GM4B-15 in table 4) are mostly from wells in the western one-third of the Great Marsh, including Cowles Bog, (fig. 4) where the subtill aquifer is the first confined aquifer below the surficial aquifer (figs. 8 and 10). Waters in which sodium is more than 20 percent of the total cation milliequivalents per liter (wells GM25-11, GM29-7, GM24-7, GM16-7, 321-5, and 211-8 in table 4) are from wells in the eastern two-thirds of the Great Marsh where the basal sand aquifer is the first confined aquifer below the surficial aquifer (figs. 8 and 10). These differences in composition probably are related to differences in the flow regime across the Great Marsh. Upward leakage in the western third of the Great Marsh is from the subtill aquifer, which contains mostly calcium magnesium bicarbonate- and magnesium calcium bicarbonate-type waters. To the east, however, the concentration of sodium in shallow ground water in the Great Marsh becomes progressively higher, probably owing to upward leakage of mixed types of water from the basal sand aquifer. In these mixed water types, sodium is more than 20 percent of the total cation milliequivalents per liter.

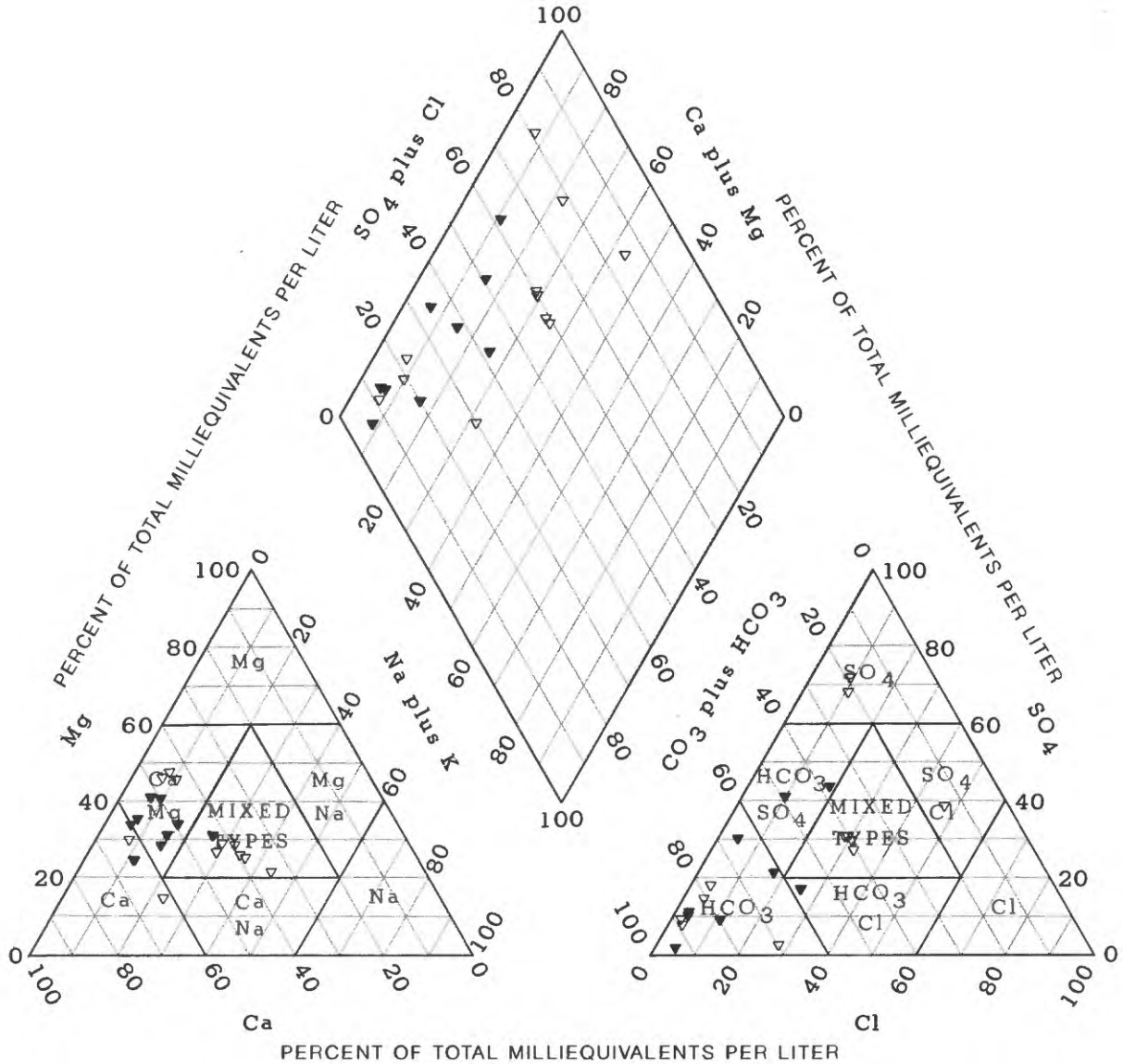
Surface Water in the Great Marsh

The compositions of wetland surface waters (table 5) at the sites of the shallow wells in the Great Marsh are plotted in figure 20. The distribution of points in figure 20 is similar to the distribution in figure 19. Surface-water samples from interior sections of the Great Marsh (sites GM-4C, GM45, GM38, GM39, GM4B, GM44, GM25, GM22, and GM30 in table 5 and fig. 4) are mostly calcium magnesium bicarbonate and magnesium calcium bicarbonate types. Samples from the margins of the Great Marsh (sites GM29, GM21, GM24, GM7, GM5, GM2, GM8, GM4A, GM13, GM16, and GM1 in table 5 and fig. 4) are mostly calcium sulfate and various mixed water types. The scope of the report does not permit a comparison of surface and ground-water compositions at each site. The similarities in the distribution of points in figures 19 and 20, however, are evidence that the surface water in the Great Marsh probably is derived in large part from discharge of shallow ground water.

Water-Quality Constituents of Concern

Although water samples were analyzed primarily to provide a broad description of the variations in water chemistry in the major unconsolidated aquifers, a few general statements can be made about ground-water quality with regard to drinking-water regulations of the U.S. Environmental Protection Agency (1986a and 1986b). Concentrations or levels of constituents set to protect human health are referred to as Maximum Contaminant Levels (MCL's). Concentrations or levels set to safeguard human welfare, or to provide acceptable aesthetic or taste characteristics, are referred to as Secondary Maximum Contaminant Levels (SMCL's).

The only MCL that was exceeded in all the analyses of water samples in the study area was for arsenic (50 µg/L). The high concentrations of arsenic were 67 µg/L from well 238-65 (table 3) in spring 1981 and 89 µg/L from well 239-65 (table 3)



EXPLANATION

WETLAND SURFACE-WATER SITE

▼ From interior parts of the Great Marsh

▽ From the margins of the Great Marsh

Figure 20. Chemical composition of surface water in wetlands.

in fall 1980. These wells are completed in the surficial aquifer at the western end of the study area (fig. 4). The MCL was exceeded for only one of three samplings of each of these wells. Although the two wells are near an industrial landfill, the source of the arsenic is uncertain because well 239-65 is upgradient from the landfill, and well 238-65 is downgradient.

The SMCL's that were exceeded were those for iron, manganese, chloride, and sulfate. The median concentrations of dissolved iron are above the SMCL (0.3 mg/L) in all the aquifers and wetland surface waters. Except in the basal sand aquifer, the median concentrations of dissolved manganese are above the SMCL (0.05 mg/L). Although there might be several site-specific and process-related reasons for the high concentrations of iron and manganese, the high concentrations of dissolved organic carbon in the ground and surface waters could be one of the principal causes. The analytical concentrations of iron and manganese might be elevated because these constituents are complexed in the dissolved-organics compounds.

The SMCL for chloride (250 mg/L) was exceeded in five wells in the surficial aquifer (wells 227-24, 236-45, 237-45, 238-65 and 275-24 in table 3) and three wells in the basal sand aquifers (wells 230-128, 212-213, and 222-183 in table 2). The SMCL for sulfate (250 mg/L) was exceeded in one well in the surficial aquifer (well 238-65 in table 3). Although some of the high concentrations for chloride and sulfate in the surficial aquifer might be due to human activities (road salting and landfills), those in the basal sand aquifer probably are due to brackish or mineralized natural waters.

Boron, arsenic, strontium, and molybdenum, in addition to iron and manganese, were the only trace elements whose median concentrations were above their reporting levels. In general, the median concentrations of boron (table 6) show an upward trend from shallow to deeper aquifers. This trend probably is related to discharge from the regional flow system. The highest boron concentrations are in water samples from the basal sand aquifer (fig. 16). No identifiable trends were observed in the concentrations of arsenic, strontium, and molybdenum.

The MCL for dissolved nitrate (10 mg/L) was not exceeded in any of the ground-water samples. Furthermore, the median concentrations of nitrate for all the aquifers are well below 3.0 mg/L (as nitrogen), the concentration indicative of influence by human factors such as leaching from farm fertilizers, manures, or septic tank effluent (Ragone and others, 1980; Bachman, 1984). Most of the dissolved nitrogen in the ground waters is in the form of reduced nitrogen, either as ammonium or dissolved organic nitrogen. The two highest concentrations of dissolved nitrogen (mostly as dissolved organic nitrogen) are, in descending order, those of the surface water in the Great Marsh and of the ground water in the surficial aquifer.

Only one site seemed to be affected by agricultural chemicals. Well 210-31 (table 3) is on a highway berm at the edge of a farm field on the south side of the Lake Border moraine (figs. 2 and 4). The well is screened about 10 to 15 ft below the surface of the field. In spring 1980, the water from the well had concentrations of 55 mg/L potassium, 37 mg/L organic nitrogen, and 2.4 mg/L ammonium. In fall 1980, the concentrations were 72 mg/L potassium, no detectable organic nitrogen, and 29 mg/L ammonium. The organic nitrogen probably was transformed to ammonium between the spring and the fall, but the total nitrogen was still high. The concentrations of potassium are an order of magnitude higher than virtually all other ground-water samples collected in the study area. The source of the potassium and the nitrogen in well 210-31 probably is farm fertilizer leached from the soils in the field above the well.

RELATIONS BETWEEN WATER CHEMISTRY AND PATTERNS OF GROUND-WATER FLOW

The framework of the unconsolidated aquifer system and the ground-water flow patterns differ notably between the eastern and the western halves of the study area (fig. 7A and 7B). The fundamental hydrogeologic difference between these two areas can be attributed to stratigraphic and topographic differences caused by the

processes that formed the Lake Border moraine. The conceptual models of the ground-water flow system in each of these areas were developed from an understanding of the framework of the aquifers and the confining units, and vertical and lateral changes in hydraulic head and water chemistry.

A series of hydrogeologic sections (whose traces are shown in fig. 2) are presented in the next two sections of this report. Shown on these hydrogeologic sections are geometry and thickness of the aquifers, patterns of ground-water flow, and spatial differences in water chemistry.

Eastern Half of Study Area

Hydrogeologic sections A-A′ through D-D′ (figs. 21-23 and 25-26) extend from the Lake Border moraine to Lake Michigan (section traces shown in fig. 2). General directions of ground-water flow are represented by arrows on these sections, and chemical type of the water in different parts of the aquifer system are designated by chemical symbols. Although the geometry of the aquifers and confining units and the hydrochemistry vary from section to section, all sections have elements of the regional, intermediate, and local flow systems depicted in the conceptual model in figure 7A. In waters near the base of the unconsolidated deposits, sodium is the most abundant cation—a characteristic consistent with upward discharge of sodic waters from the bedrock in the distal part of the regional flow system. Ground water from wells approximately 8 mi west of the study area screened in the underlying Silurian carbonate bedrock (wells BR1-500 and BR2-583 in table 2) contain sodium in excess of 97 percent of the total cation milliequivalents per liter. In waters of the intermediate flow system (which originate in the Lake Border moraine) calcium and magnesium in roughly equal proportions are the most abundant cations, and bicarbonate is the dominant anion.

The waters in the surficial aquifer are the most chemically variable. Those entirely within local flow systems are primarily bicarbonate types with variable proportions of calcium, magnesium, and sulfate. Some waters in the wetlands, however, are mixed chemical types that probably are representative of upward leaking waters from the regional and (or) intermediate flow systems that are mixed with shallow ground water and wetland surface water.

The first section, A-A′ (fig. 21), is at the eastern end of the National Lakeshore. Two major unconsolidated sand deposits are depicted in this section. The uppermost sand deposit is the surficial aquifer. The lower sand deposit is a confined aquifer that underlies the entire length of the section. The southern half of this confined sand aquifer probably consists of deposits that form the subtill and the basal sand aquifers to the west. The confining layers that separate the sandy deposits of the subtill and basal sand aquifers to the west are absent along this section.

The upward-directed arrows from the bedrock into the base of the glacial drift represent the distal part of the regional flow system. The evidence for the upward flow is twofold. First, the heads in the deep wells at sites 202 and 203 tapping the basal sand aquifer are higher than the water table in the surficial aquifer. At site 203, the hydraulic head of the deep well is 10 to 15 ft above land surface. Second, the waters in the deep wells at sites 201, 202, and 203 (wells 201-205, 202-153, and 203-193 in table 2) show an increasing dominance of sodium toward the north where the upward gradient between the surficial and basal sand aquifers seems to be highest. The presence of substantial proportions of sodium in the ground water at the base of the basal sand aquifer indicates that these waters probably have been mixed with water from the underlying bedrock. The downward-directed arrows drawn on the section beneath the Lake Border moraine represent the intermediate flow system. The flow lines extend down into the subtill and basal sand aquifers beneath the moraine and actually curve back toward the surface north of the moraine. Water from the subtill and basal sand aquifers probably is discharging into the base of the surficial aquifer throughout much of section A-A′.

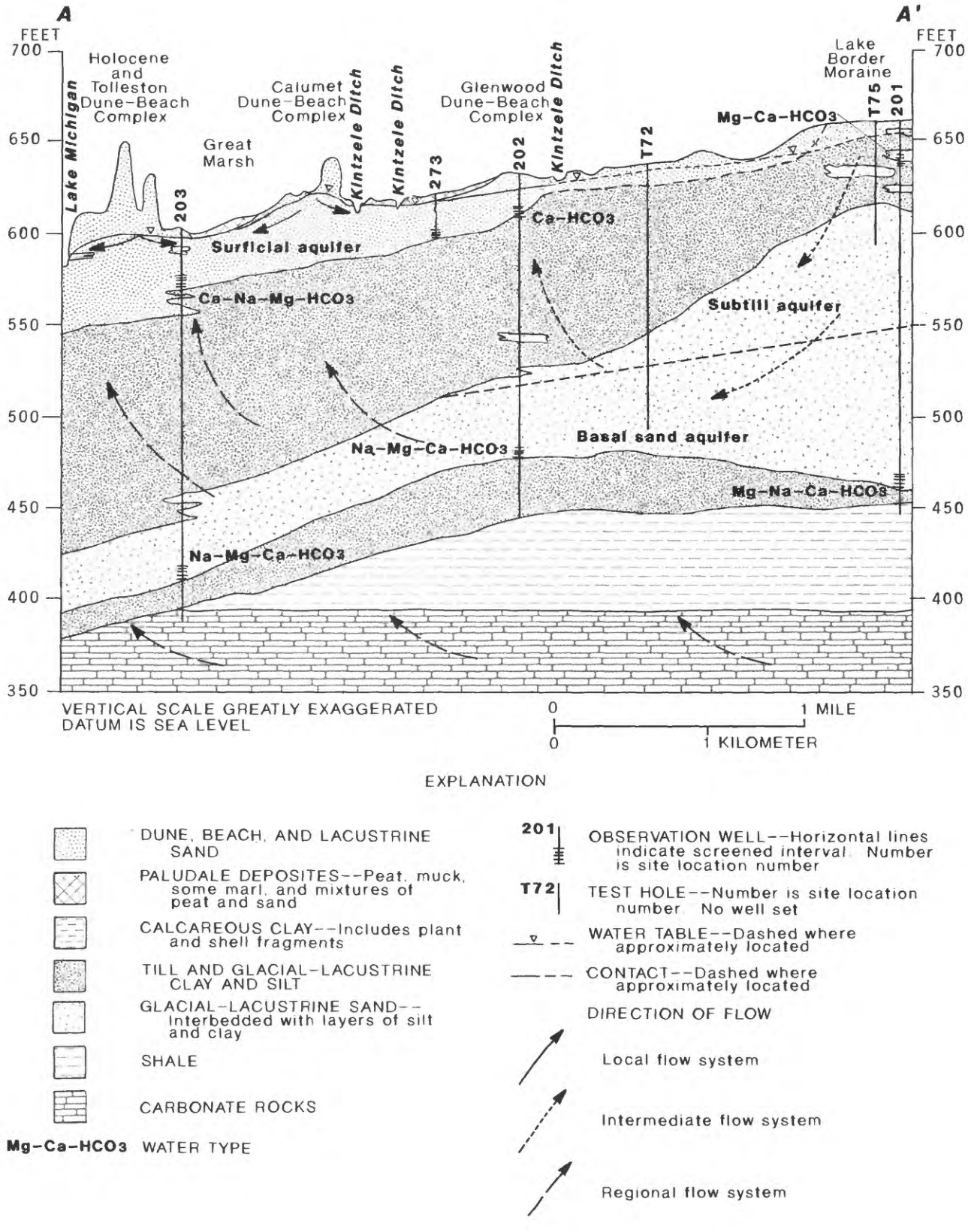


Figure 21. Hydrogeologic section *A–A'*.

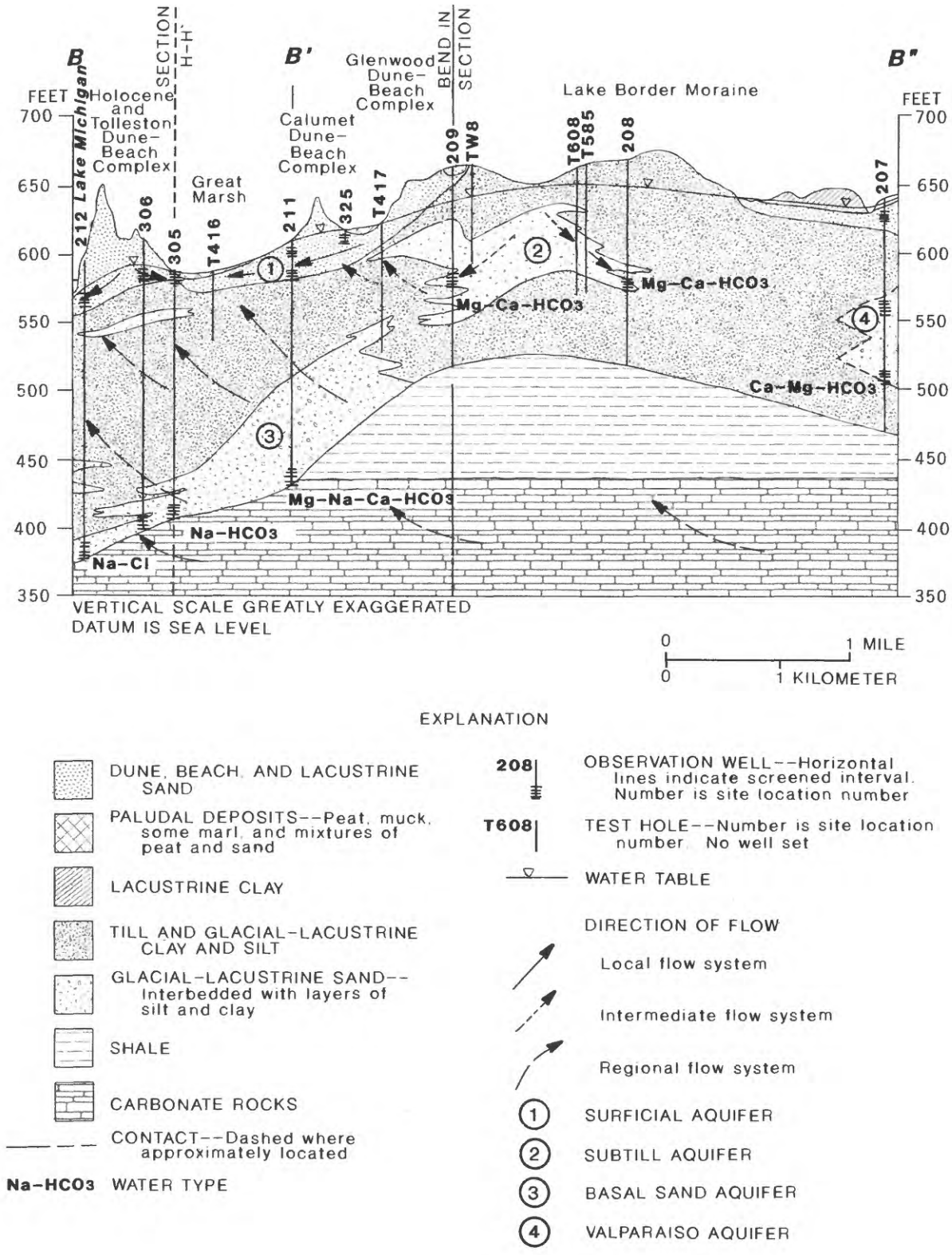


Figure 22. Hydrogeologic section *B–B'–B"*. (Modified from Shedlock and others, 1988, figure 4.)

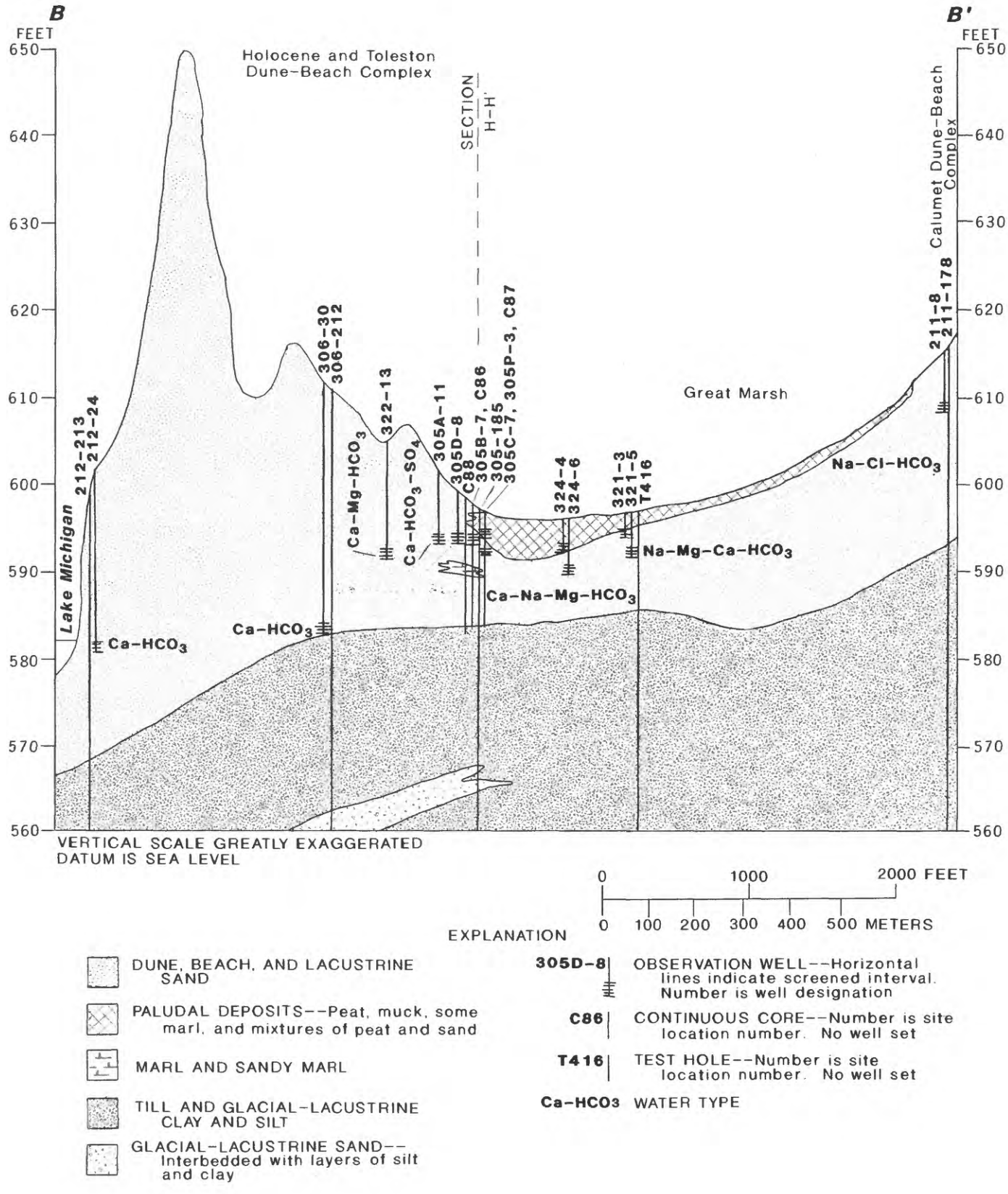
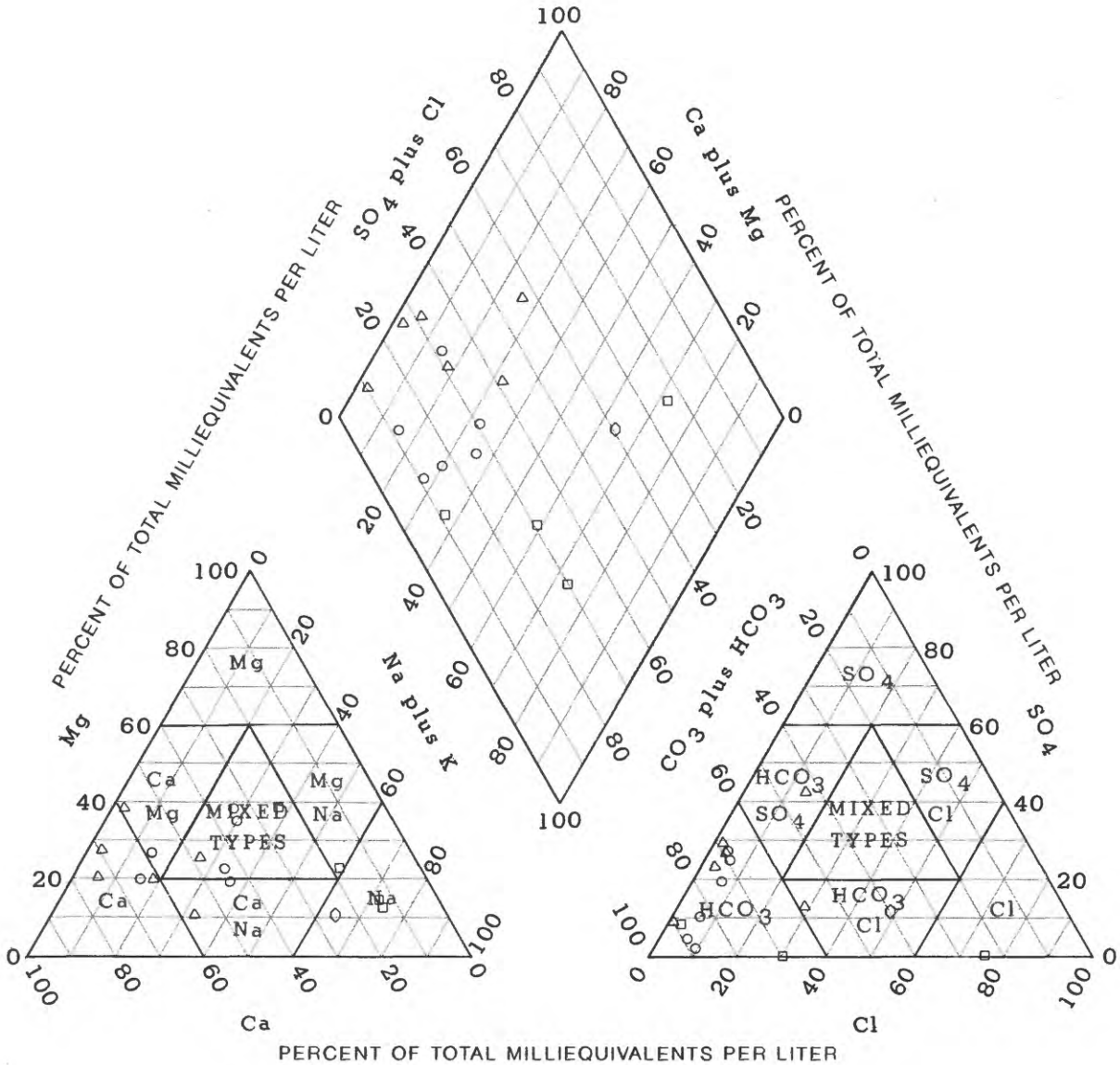


Figure 23. Hydrogeologic section *B–B'*. (Modified from Shedlock and others, 1988, figure 5.)



EXPLANATION

WELLS SCREENED

- △ In the shallow sand at the northern edge of the Great Marsh and in the Holocene and Tolleston dune–beach complex
- ○ In or immediately below the peat in the Great Marsh
- □ In the basal sand aquifer
- ◇ In the shallow sand at the southern edge of the Great Marsh

Figure 24. Chemical composition of ground water along hydrogeologic section *B–B′*.

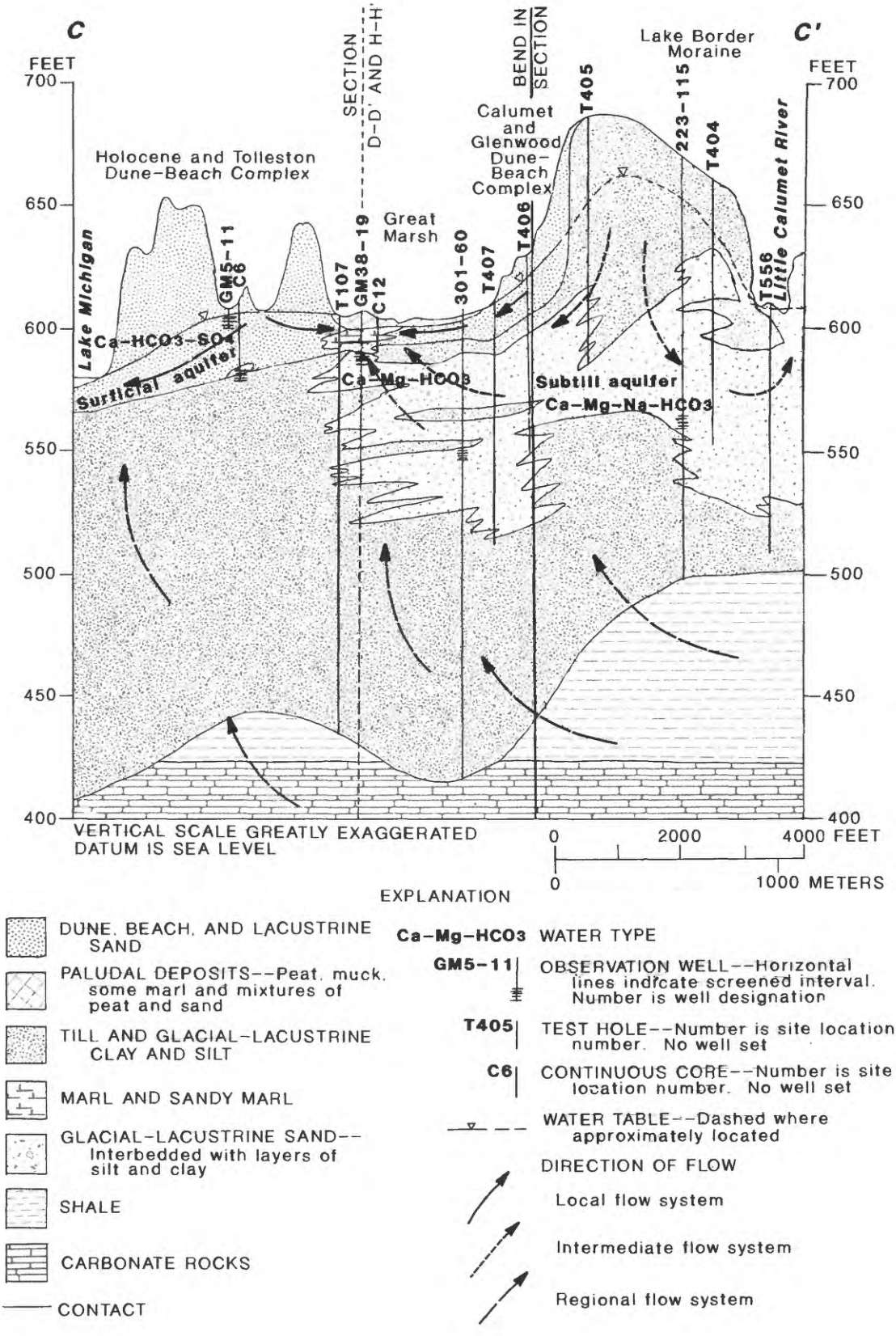


Figure 25. Hydrogeologic section *C–C'*. (Modified from Shedlock and others, 1988, figure 7.)

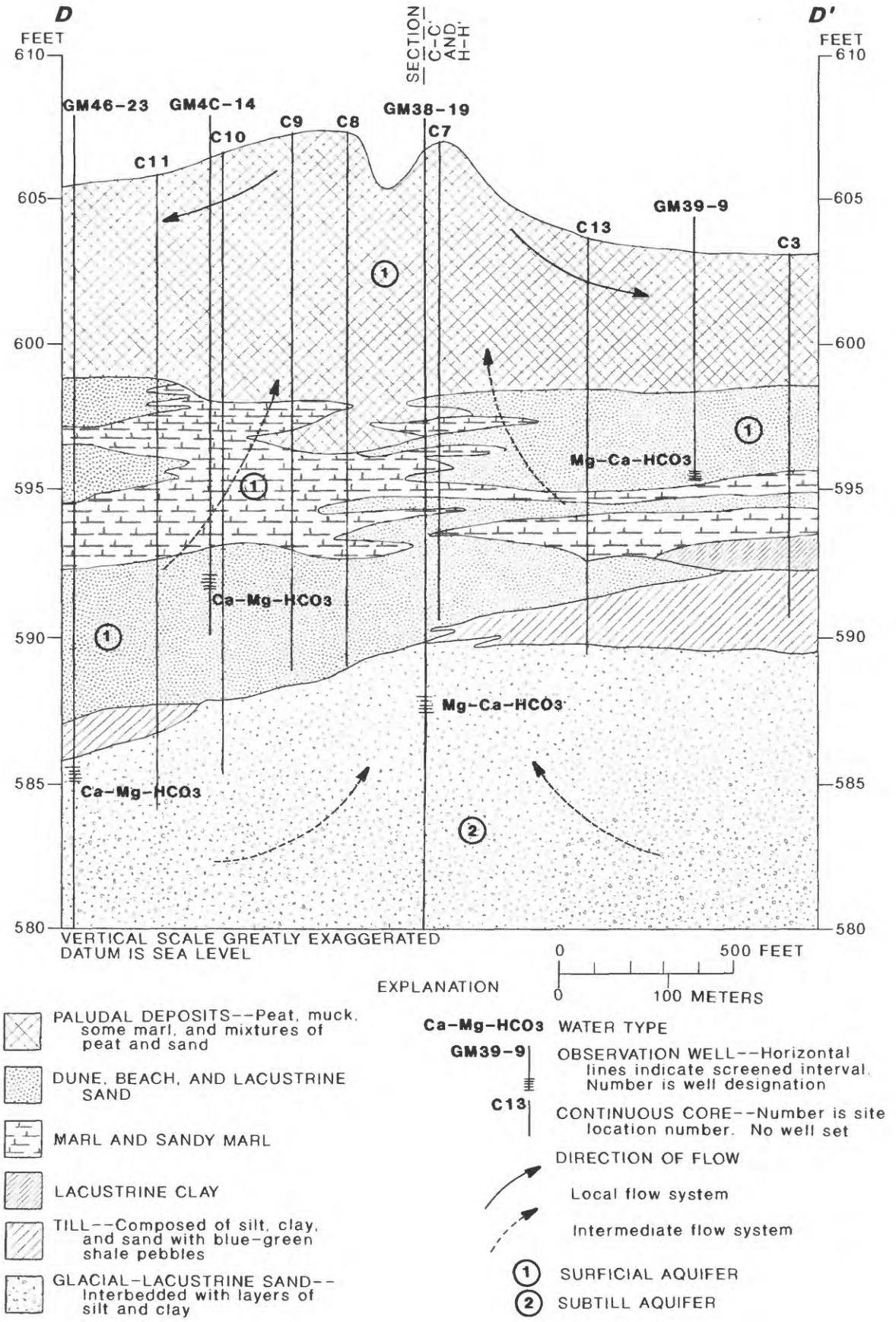


Figure 26. Hydrogeologic section *D–D'*. (Stratigraphy modified from Wilcox and others, 1986.)

The flow arrows in the surficial aquifer represent local flow systems that are recharged in the dune-beach complexes and discharge to the wetlands between the dune-beach complexes. In waters of the surficial aquifer, calcium is the dominant cation and bicarbonate is the dominant anion. Appreciable proportions of sodium and magnesium (27 and 23 percent of cation equivalents) in water from the well at site 203 near the bottom of the surficial aquifer (well 203-35 in table 3) indicate that water from the underlying basal sand aquifer probably is discharging into the base of the surficial aquifer.

The shallow well at site 201 is screened at an altitude of about 640 ft in the second sand lens in the upper part of the subtill aquifer at the south end of section A-A′. The water from this well (well 201-32 in table 2) is a magnesium bicarbonate type with higher chloride, sulfate, and dissolved-solids concentrations than most other waters from the subtill aquifer. The chemistry of this water is one of the unusual compositions in the subtill aquifer that were mentioned earlier in the section "Hydrochemistry." The unusual composition could indicate that the second sand lens at the southern end of section A-A′ is in poor hydraulic connection with the subtill aquifer below. In waters from several other wells on the Lake Border moraine in the eastern part of the Lakeshore (wells 204-59 and 210-109 in table 2), magnesium is the dominant cation and chloride or sulfate are significant or dominant anions. The origin of these waters is unknown, but they could be older waters trapped in the sands by over-compacted glacial clays.

Regional, intermediate, and local flow systems also are depicted in section B-B′-B″ (fig. 22), but the geometry and the hydrochemistry of the aquifer system differ from those of section A-A′. The subtill and the basal sand aquifers are distinct units in section B-B′-B″. Also shown is the part of the aquifer system south of the Lake Border moraine which, in this section, consists of a thin surficial aquifer and a confined aquifer within the underlying glacial-lacustrine clay. This confined aquifer represents the northern edge of the Valparaiso aquifer of Hartke and others (1975).

As in section A-A′, the flow arrows from the bedrock into the base of the glacial deposits represent the distal part of the regional flow system. All the wells shown in the basal sand aquifer have heads above land surface. In addition, sodium is the most abundant cation in the waters from the three northernmost wells in the basal sand aquifer. The waters from these three wells (wells 305-165, 306-212, and 212-213 in table 2) have an increasing dominance of chloride toward Lake Michigan—an indication of mixing with brackish waters that probably are from deeper parts of the bedrock aquifer.

The intermediate flow system in section B-B′-B″ (fig. 22), as in section A-A′, is recharged in the Lake Border moraine. The subtill aquifer is not directly connected to any other aquifer layers and discharges mainly by leakage through the surrounding confining layers. Most of this discharge probably is upward into the surficial aquifer, but some might be downward into the lower parts of the aquifer system. Waters in the subtill aquifer are primarily magnesium calcium bicarbonate and calcium magnesium bicarbonate types. Although no samples were collected from the bedrock within the study area, water samples from two bedrock wells approximately 8 mi west of the study area (wells BR1-500 and BR2-583 in table 2) are sodium bicarbonate types. Mixing of such water with water from the subtill aquifer is a plausible explanation for the sodium magnesium calcium bicarbonate type in much of the basal sand aquifer. Such mixing also is consistent with the general flow patterns conceptualized in figure 7A and simulated in the model. All the wells in the basal sand aquifer in figure 22 have hydraulic heads higher than the water table.

The local flow system in the surficial aquifer in section B-B′-B″ is different from that of A-A′, for subtle geomorphic reasons. The Calumet dune-beach complex south of the Great Marsh is not underlain by a water-table mound. One of the reasons for the absence of a water-table mound is that the Calumet dune-beach complex is not as wide here as in section A-A′ and does not have

lowlands within the complex that might focus recharge. Secondly, there are no major streams or large ditches to drain the wetland between the Calumet and Glenwood dune-beach complexes. Thirdly, the difference in altitude between this wetland and the Great Marsh to the north is greater in section B-B′-B″ than in section A-A′. Therefore, the difference in water-table altitude between the wetland between the Calumet and Glenwood dune-beach complexes and the Great Marsh is greater in section B-B′-B″ than in section A-A′.

Local flow systems in the surficial aquifer are recharged primarily by infiltration of rainfall and snowmelt in the dune-beach complexes. The flow arrows in B-B′-B″ also indicate that the base of the surficial aquifer probably is receiving upward leakage from the regional flow system. This upward leakage is further supported by a more detailed view of the hydrochemistry in the Great Marsh along the northern part of this section as shown in section B-B′ (fig. 23).

The variability of water chemistry along section B-B′ (fig. 23) has been discussed previously by Shedlock and others (1988) and by Loiacono (1987). Several water types are found in ground water in the dune complex north of the Great Marsh. Calcium bicarbonate and calcium magnesium bicarbonate types are found in interior sections of the dune complex (wells 212-24, 306-30, and 322-12 in table 3). Shallow ground water in the dune complex at the edge of the Great Marsh is a calcium bicarbonate sulfate type (well 305A-11 in table 3). Mixed water types, including sodium magnesium calcium bicarbonate and calcium sodium magnesium bicarbonate types, however, are found in shallow ground water in the interior of the Great Marsh (wells 324-4 and 321-5 in table 4). Sodium chloride bicarbonate water is found at the south margin of the Great Marsh (well 211-8 in table 4) and probably results from infiltration of leachate from road salt on a major highway just upgradient from this site.

The water analyses of samples from wells along section B-B′ are plotted on a trilinear diagram in figure 24. The plots of waters in the interior of the Great Marsh are along a line between plots for the waters from wells in the basal sand aquifer and those from wells in the dune-beach complex just north of the Great Marsh. These plots are an indication that the shallow ground water in the interior of the Great Marsh probably consists of differing mixtures of water from the basal sand aquifer and shallow ground water from the adjacent dunes. The hydrochemical data thus could indicate that water from the regional flow system is discharging into the surficial aquifer in the Great Marsh by upward leakage along the section.

Section C-C′ (fig. 25) extends through the Cowles Bog National Natural Landmark (figs. 1 and 2). This area has been studied more extensively than any other part of the Lakeshore. Relations among hydrology, hydrochemistry, and ecology of the raised peat mound in Cowles Bog have been described in detail by Wilcox and others (1986). Hydrochemistry of the area represented by section C-C′ has been discussed by Shedlock and others (1988) and shallow groundwater flow in the area surrounding Cowles Bog has been described by Cohen and Shedlock (1986).

The geometry of the aquifer system differs from that of sections A-A′ and B′-B″ in several ways. First, the basal sand aquifer is missing. Second, the subtill aquifer extends from the northern edge of the Great Marsh to the Little Calumet River. In addition, the Calumet and the Glenwood dune complexes are stacked upon each other. Consequently, there is no interdunal wetland between them. Several east-to-west trends can be seen by an examination of the three hydrologic sections presented to this point and the surficial geology map in figure 2. The same geomorphic features are found in all three sections, but the distance between them is compressed from east to west. In addition, the relative extents of the basal sand and the subtill aquifers differ greatly. The basal sand aquifer is more extensive to the east near sections A-A′ and B-B′-B″, and the subtill aquifer is more extensive to the west near section C-C′ (figs. 2 and 10).

The effects of the differences in geometry can be seen in the flow and in the chemistry of the ground and wetland waters. In section A-A′ (fig. 21), the surficial aquifer in the Great Marsh receives discharge by upward leakage from the regional and the intermediate flow systems. In section B-B′-B″, (fig. 22) the surficial aquifer in the Great Marsh receives discharge by upward leakage mainly from the regional flow system.

In section C-C′, however, the surficial aquifer in the Great Marsh receives discharge by upward leakage primarily from the intermediate flow system, which is recharged in the Lake Border moraine and characterized by calcium magnesium bicarbonate water. In addition, the regional flow system probably is discharging up into the subtill aquifer and ultimately into the surficial aquifer. Water samples from wells screened at the base of the subtill aquifer (wells 223-115, 241-85, 210-109, and 209-78 in table 2) generally have a higher proportion of sodium than those from wells screened near the top of the subtill aquifer (wells 201-32, 204-59, and 219-72 in table 2). Nevertheless, the water leaking up into the surficial aquifer in the Great Marsh probably is dominated by that from the intermediate flow system. The local flow system is similar to that in section B-B′-B″ (fig. 22), and the Great Marsh receives inflow from both adjacent dune complexes. As in section B-B′, shallow ground water in the local flow systems north of the Great Marsh is a calcium bicarbonate sulfate type (well GM5-11 in table 4) whose alkalinity and dissolved-solids concentration is less than that of water from the subtill aquifer.

Cowles Bog is distinguished from any other area in the Lakeshore by its raised peat mound—the reason that this area has been studied more extensively than any other. The stratigraphy of this area is detailed in figure 26, section D-D′. The peat mound developed over a breach in the confining unit that separates the surficial aquifer from the underlying subtill aquifer (Wilcox and others, 1986).

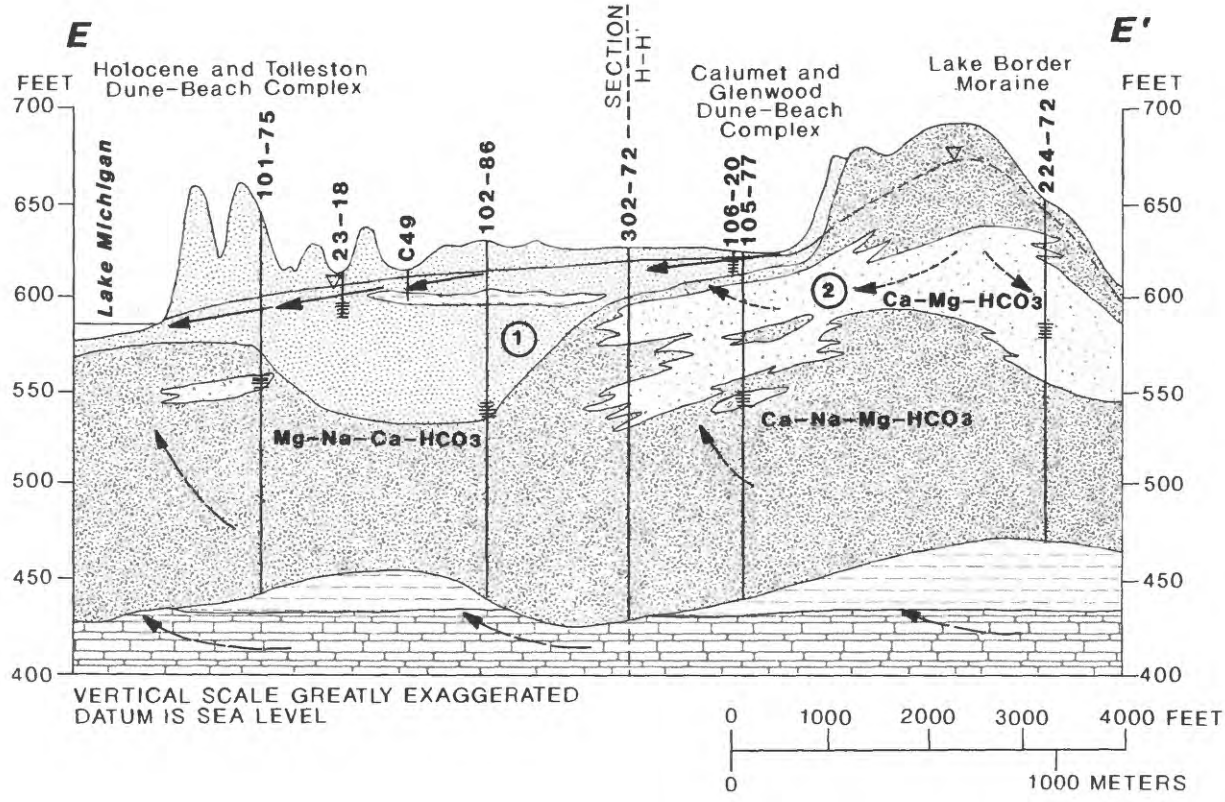
The breach in the confining unit facilitates upward discharge of water from the subtill aquifer into the overlying sand, marl, and peat. The chemistry of peat-pore water at the surface of the mound is similar to that of water from wells screened in the sands at the underlying breach in the confining unit (Wilcox and others, 1986, p. 1111-1112). Heads in wells screened in these sands are above the surface of the peat.

Upward discharge of water from these sands into the peat is further indicated by the concentrations of tritium in the ground waters and pore waters of the peat near Cowles Bog. Although the tritium data are discussed in detail by Wilcox and others (1986), a few comments about these data are appropriate here. The concentrations of tritium in the pore waters ranged from 19 to 40 pCi/L; whereas, the concentration of tritium in shallow ground water, which is presumably derived from precipitation in the late 1970's, in the dunes around Cowles Bog exceeded 120 pCi/L. The concentration of tritium in water from wells in the subtill aquifer is less than 5 pCi/L.

The tritium data are consistent with the hydraulic data and suggest that the pore waters in the peat on the raised mound are a mixture of recent precipitation and older (pre-1952) water from the underlying subtill aquifer. In addition, concentrations of tritium and proportions of major ions in water from wells in areas of the Great Marsh surrounding—but not on—the raised peat mound are an indication that upward leakage probably is a significant part of the water budget of the local flow system in this area.

Western Half of Study Area

The geometry of the aquifer system in the industrial area west of Cowles Bog is illustrated in section E-E′ (fig. 27). As can be seen in this section and in the longitudinal section H-H′ in figure 8, the distribution and thickness of the aquifers change substantially a short distance west of Cowles Bog. The most significant changes are



EXPLANATION

- DUNE, BEACH, AND LACUSTRINE SAND
- CALCAREOUS CLAY--Includes plant and shell fragments
- TILL AND GLACIAL-LACUSTRINE CLAY AND SILT
- GLACIAL-LACUSTRINE SAND--Interbedded with layers of silt and clay
- SHALE
- CARBONATE ROCKS
- Ca-Mg-HCO3 WATER TYPE
- WATER TABLE--Dashed where approximately located
- 102-86 OBSERVATION WELL--Horizontal lines indicate screened interval. Number is well designation
- C49 CONTINUOUS CORE--Number is site location number
- DIRECTION OF FLOW
  - Local flow system
  - Intermediate flow system
  - Regional flow system
- (1) SURFICIAL AQUIFER
- (2) SUBTILL AQUIFER

Figure 27. Hydrogeologic section *E-E'*.

in the spatial distribution of the subtill aquifer and in the overlying till sheet that functions as a confining unit. This till sheet dips sharply into the subsurface just west of Cowles Bog (fig. 8) and truncates the subtill aquifer. The northern boundary of the subtill aquifer curves to the south (fig. 10) and, as shown in figure 27, the subtill aquifer underlies only the southeastern part of the industrial area.

These changes in the subsurface correspond to changes in two major geomorphic features at the surface (fig. 2). The first is the widening of the dune complex north and west of Cowles Bog. Although now obscured by the construction of the industrial area, this dune complex once extended over most of what is now the industrial area. Before industrial construction, the Great Marsh was narrower west of Cowles Bog than it is now and was connected to the valley of the Little Calumet River by a narrow lowland, the Baillytown Sag (Cook and Jackson, 1978). The second major geomorphic change near the industrial area is that the Lake Border moraine pinches out at the surface (fig. 2).

Owing to these surface and subsurface changes, the industrial area is one of fundamental change in the hydrogeologic framework of the study area. The surficial aquifer is thicker west of the industrial area, and the wetlands do not seem to be discharge areas for larger scale flow systems as they are in the eastern part of the Lakeshore. Absence of the morainal upland formed by the Lake Border moraine precludes an intermediate flow system as is present in the eastern part of the Lakeshore. Although water from the regional flow system probably discharges into the base of the surficial aquifer, the water-level and hydrochemical data collected in this study offer no evidence that this water discharges into the ponds and the wetlands of the western part of the study area. The ponds and wetlands west of the industrial area seem to be influenced only by discharge from local ground-water flow systems in the surficial aquifer.

These local flow systems are illustrated in section F-F′ (fig. 28), which extends through an area where the hydrogeologic framework and the hydrochemistry are simple relative to the eastern half of the Lakeshore. A water-table mound between the Little Calumet River and Lake Michigan is depicted in this section. North of the crest of this mound, ground water flows north toward Lake Michigan; whereas south of the crest, the flow is south toward the Little Calumet River. Long Lake Wetland and much smaller wetlands in the dune-beach complexes are within the local ground-water flow systems depicted in this section.

The waters from the three wells in section F-F′ are calcium bicarbonate and calcium magnesium bicarbonate types. These wells are screened near the bottom of the surficial aquifer. The absence of substantial proportions of sodium in the waters in this section is an indication that these waters are derived mainly from recharge at the water table along the local flow systems as shown. Any upward leakage from the regional flow system probably is small, possibly because of the tightness of glacial-lacustrine clays that overlie the bedrock (Rosenshein and Hunn, 1968a and 1968b) or the tightness of the shale beds, where present, at the top of the bedrock.

The hydrogeologic framework in section G-G′ (fig. 29) is similar to that of section F-F′. The water table forms a broad mound whose crest is on the south side of Miller Woods. North of the crest of this mound, ground water flows north toward Lake Michigan; south of the crest, flow is toward the Little Calumet River. The ponds in Miller Woods and the Grand Calumet Lagoon are within these local ground-water flow systems.

Unlike section F-F′, however, each well in section G-G′ has a distinct hydrochemical type. The different types of water near the base of the surficial aquifer in this section can be explained in several ways. The calcium bicarbonate water (well 239-65 in table 3) probably is derived from minerals in the surficial aquifer along a local flow path.

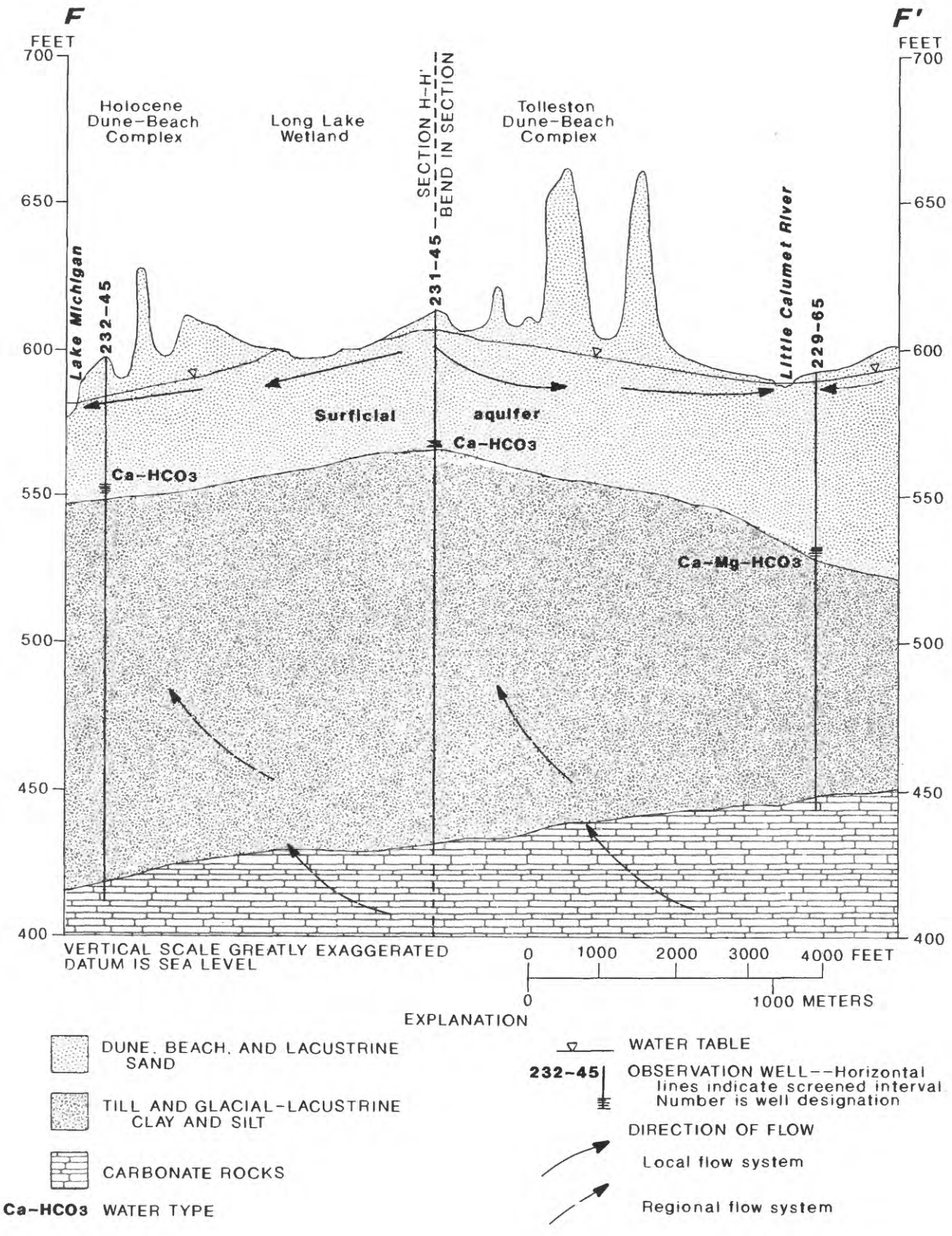


Figure 28. Hydrogeologic section *F-F'*.

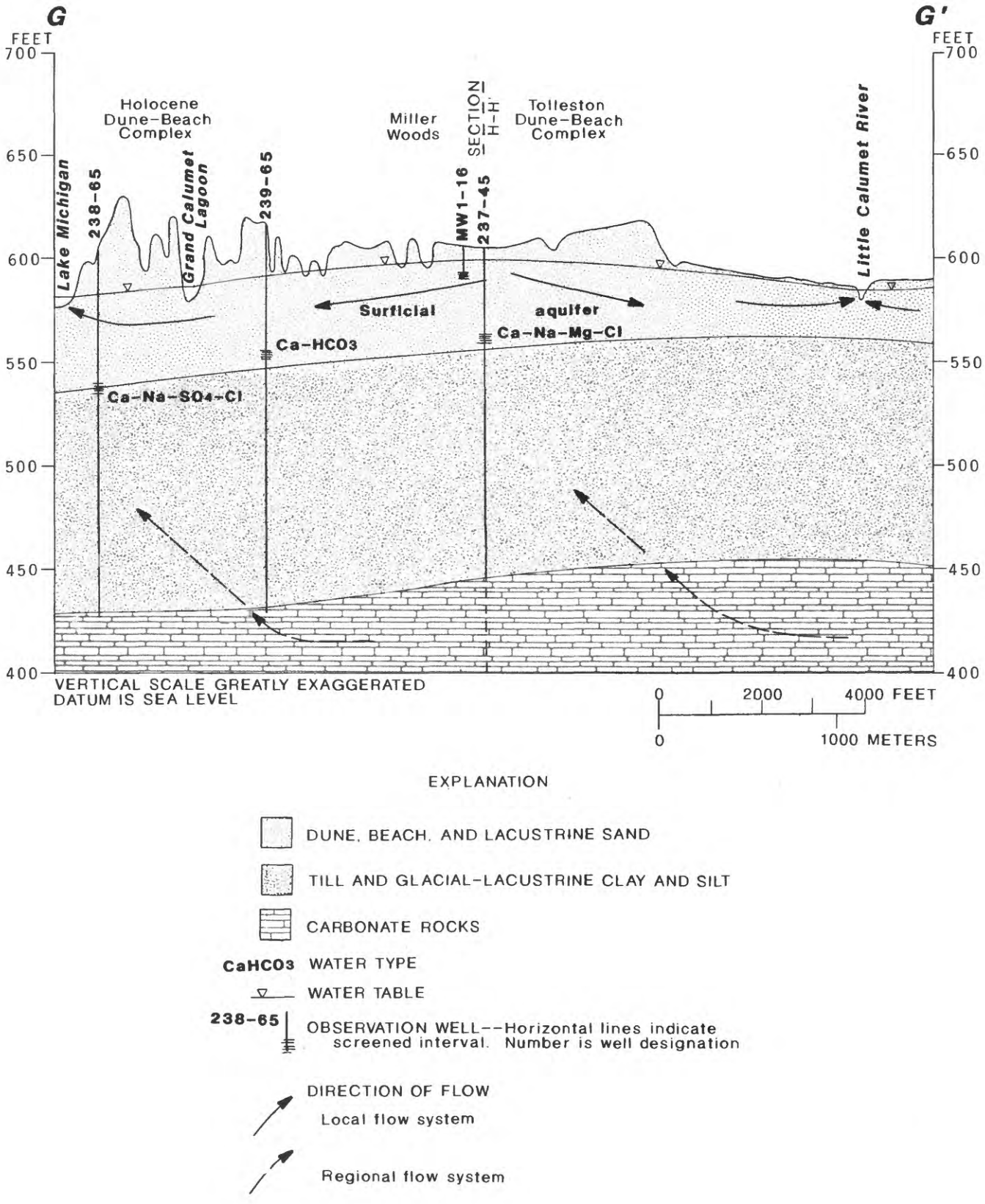


Figure 29. Hydrogeologic section *G–G'*. (Modified from Shedlock and other, 1988, figure 9.)

Origins of the two waters with substantial amounts of sodium and chloride (wells 237-45 and 238-65 in table 3) in the section are not well understood. One explanation is that these waters are influenced by human activities—application of road salt in the case of the calcium sodium magnesium chloride water (well 237-45) and leachate from the nearby industrial-fill area in the case of the calcium sodium sulfate chloride water (well 238-65). These two waters, however, have molar amounts of chloride in excess of sodium. The excess chloride probably should be balanced with calcium, which means that these waters are enriched in calcium chloride. The calcium chloride could be from deicing of roads—a slurry of calcium chloride is used on some of the local highways.

A second explanation, given that these waters are from the base of the surficial aquifer, is that they represent upward leakage of brackish waters from the bedrock. Some of the brines in the nearby Michigan basin are enriched in calcium chloride (Graf and others, 1966). A detailed analysis and discussion of this possibility is beyond the scope of this report; however, on the basis of available data, one cannot conclude that the brackish waters in the western part of the study area are caused entirely by human contamination of the surficial aquifer. More data on the vertical flow regime in the western part of the study area are needed before sound conclusions can be drawn about the origins of these waters.

SUMMARY AND CONCLUSIONS

The hydrology and hydrochemistry of wetlands along the southern shoreline of Lake Michigan are affected by the underlying ground-water system. The majority of wetlands in the study area are in lowlands between and within several major dune-beach complexes. These complexes were deposited in the Pleistocene and Holocene Epochs when the level of ancestral Lake Michigan was higher than it is now. These wetlands and dune-beach complexes are underlain by a complex aquifer system composed of unconsolidated glacial and lacustrine sediments overlying shale and carbonate rocks of Silurian, Devonian, and Mississippian age.

The unconsolidated sediments can be divided into four main aquifers. The dune, beach, and lacustrine sands form a surficial aquifer known locally as the Calumet aquifer. The saturated thickness of this aquifer, which ranges from 0 to more than 80 ft, is greater in the western half of the study area than in the eastern half. Waters from this aquifer in the dune complexes are mostly bicarbonate types containing variable proportions of calcium and magnesium. Waters in the largest interdunal wetland, the Great Marsh, are bicarbonate waters with variable proportions of calcium, magnesium, and sodium, and are more mineralized mixed water types than in the dune complexes.

The glacial and the lacustrine sediments that underlie the surficial aquifer contain three major confined aquifers. A basal sand aquifer is near the bottom of the unconsolidated sediments. This aquifer ranges from 0 to 90 ft in thickness. It is most extensive in the eastern part of the study area. The waters in the basal sand aquifer include bicarbonate types containing variable proportions of sodium, magnesium, calcium and chloride, and a sodium chloride type.

The second confined aquifer, referred to as the subtill aquifer, underlies the Lake Border moraine and extends a variable distance north of the moraine in the subsurface. The aquifer is confined by the till of the Lake Border moraine and underlies the western one-third of the Great Marsh including Cowles Bog. The aquifer ranges from 0 to 60 ft in thickness. Waters in this aquifer are mostly bicarbonate types containing roughly equal proportions of magnesium and calcium.

The third confined aquifer, the Valparaiso aquifer, found only in the southeastern part of the study area, underlies exposed and buried tills of the Valparaiso moraine. This aquifer, which ranges in thickness from 40 to 140 ft in the study area, has a calcium magnesium bicarbonate type of water.

A conceptual model based on the hydrogeologic and hydrochemical data collected in this study show that the wetlands are affected by regional, intermediate, and local ground-water flow systems. The regional flow system is recharged in the Valparaiso moraine, which forms a major upland and surface-drainage divide south of the study area. Water flows down through the moraine into the Valparaiso aquifer and the underlying bedrock, and laterally toward Lake Michigan. Discharge from the regional system probably occurs by upward leakage into the glacial drift near the Lakeshore and into Lake Michigan offshore.

The intermediate flow system is recharged in the Lake Border moraine. This system discharges south into the Little Calumet River and north by upward leakage into the Great Marsh. An uncalibrated cross-sectional digital model produced simulations of the intermediate and the regional flow systems that were consistent with available data on ground-water chemistry, measured heads, and published values for hydraulic conductivities of confined aquifers in and near the study area.

The local flow systems are recharged in the dune-beach complexes and discharge into adjacent interdunal wetlands. The only shallow ground water discharged directly to Lake Michigan is that water north of the water-table divide underlying the shoreline dune-beach complex.

The largest interdunal wetland in the study area, the Great Marsh, is a discharge zone for the local flow systems and probably for the regional and intermediate flow systems. Discharge from the regional and intermediate flow systems is mainly by upward leakage through underlying clay confining layers. This leakage produces mineralized shallow ground and wetland waters found in several interior sections of the Great Marsh. At the raised peat mound in Cowles Bog within the Great Marsh, water from the confined subtill aquifer discharges directly into the sands, marls, and peats of the surficial aquifer through a breach in the clay layer that functions as the upper confining unit for the subtill aquifer. The major ion chemistry and the concentrations of tritium at the mound indicate that upward leakage is a major component of the water budget in Cowles Bog.

The other interdunal wetlands and the small wetlands within the dune-beach complexes occur mainly within the local ground-water flow system. The shallow ground and wetland waters associated with these wetlands are more dilute than those in the Great Marsh and range from calcium bicarbonate to calcium bicarbonate sulfate types. Thus, the chemistry of the water in the wetlands is dependent on the position of the wetland in the ground-water flow regime.

Changes in the water table along profiles through the Great Marsh and the adjacent dune-beach complexes indicate that the dune-wetland margins are the most actively recharged sections of these profiles. Transient water-table mounds were observed in the dunes at the northern margin of the Great Marsh. Although the actual period of flow reversal associated with these mounds is less than a few weeks a year, this phenomenon indicates that recharge is variable in time and space in the dune-wetland complexes and is concentrated near the margins of the wetlands.

The results of this study have led to three general conclusions about hydrogeologic investigations of wetland areas. The first is that an understanding of the hydrogeologic setting of a wetland area is crucial to the understanding of its water balance and hydrochemistry. At Indiana Dunes, the water balance and hydrochemistry of any particular wetland are influenced by the wetland's position in the ground-water flow regime. For wetlands in glacial-lacustrine sediments, a reasonable understanding of the stratigraphy and the sedimentology of these deposits is needed to define accurately the geometry of the aquifer system. In the case of the Great Marsh, water chemistry is strongly affected by the spatial distribution of the basal sand and subtill aquifers. The western half of the Great Marsh receives discharge from the surficial and subtill aquifers, and the composition of shallow ground water represents a mixture of waters from these two aquifers. The eastern half of the Great Marsh receives discharge from the surficial and basal sand aquifers. The composition of shallow ground water in the eastern half of the Great Marsh represents a mixture of waters in the surficial and basal sand aquifers.

A second general conclusion is that hydrologic responses in wetlands are not necessarily uniform in time and space. Different parts of a wetland can alternately respond as either recharge areas or discharge areas under different hydrologic conditions.

The final conclusion is that wetlands are most effectively studied by means of a multidisciplinary approach. The observations and the conclusions of this report are the result of the synthesis of hydrogeologic, sedimentologic, and hydrochemical data. Some investigators cited in this report used ecological and palynological data. Conceptual models in each of these disciplines at the Indiana Dunes were constrained by observations in the other disciplines. These constraints produced models of interactions between ground water and the different types of wetlands that were more detailed and presumably more accurate than could have been developed in each discipline by itself. This type of approach is powerful, not only because of the interpretive constraints but also because of the recognition of wetlands as natural systems that have hydrologic, geologic, and biologic components.

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SUPPLEMENTAL DATA

Table 2. Water-quality analyses of water from wells screened in confined aquifers

[µS/cm, microsiemens per centimeter at 25 degrees Celsius; REDOX, oxidation reduction potential; DEG C, degree Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; $CaCO_3$, calcium carbonate; --, not determined; mV, millivolts; five-digit number in parentheses is WATSTORE (U.S. Geological Survey) parameter code; *, analysis not used in statistical summary in table 6]

Well designation	Station number	Aquifer	Sample date	Specific conductance (µS/cm) (00095)	pH (Standard Units) (00400)	REDOX (Potential Units) (mV) (00090)	Temperature, water (DEG C) (00010)	Oxygen, disolved (mg/L) (00300)	Nitrogen, dissolved (mg/L as N) (00602)
205-65	413739086570502	Valparaiso	04-16-80	493	7.1	132	10.5	0.1	0.02
206-182	413659086573901	Valparaiso	04-16-80	521	7.1	69	11.5	2.2	.35
206-72	413659086573902	Valparaiso	04-16-80	549	7.1	98	11.0	1.4	.30
207-130	413720086584701	Valparaiso	04-17-80	642	7.2	78	11.0	<.1	.24
207-87	413720086584702	Valparaiso	04-17-80	541	7.1	75	10.5	<.1	.29
202-153	414122086544701	Basal sand	04-15-80	613	7.3	–91	12.0	<.1	.60
203-193	414212086555601	Basal sand	04-15-80	640	7.3	93	11.0	.1	.66
241-137	414004086585001	Basal sand	04-16-80	750	7.1	114	11.5	1.4	.49
213-135	414041086592000	Basal sand	04-18-80	904	7.6	100	13.0	<.1	.54
212-213	414057087003000	Basal sand	04-18-80	2,230	8.2	98	14.0	<.1	.97
211-178	413957087002601	Basal sand	04-22-80	940	7.5	118	15.5	<.1	.91
218-141	413907087014401	Basal sand	04-25-80	911	6.9	111	11.5	.1	.43
222-183	413827087040101	Basal sand	04-30-80	1,350	7.5	129	13.0	.4	.57
234-143	413515087145501	Basal sand	04-30-80	751	7.6	--	12.0	.3	.62
243-165	413816087020001	Basal sand	04-30-80	592	7.5	--	11.5	.1	.28
201-205	414014086533601	Basal sand	05-01-80	736	7.8	148	15.0	3.8	.98
204-125	413957086555801	Basal sand	05-01-80	531	7.8	89	14.0	<.1	.67
244-125	413732087105701	Basal sand	05-01-80	510	7.9	--	12.0	--	.44
230-128	413651087110501	Basal sand	05-02-80	1,890	7.2	186	12.5	.1	.83
305-165*	414029087003201	Basal sand	11-08-84	1,020	7.7	--	11.0	--	--
306-212*	414041087003401	Basal sand	03-15-85	1,080	7.6	--	9.0	1.6	--
105-77*	413744087063702	Subtill	10-11-77	855	7.7	--	10.5	4.0	--
224-55*	413732087054700	Subtill	08-28-79	620	7.6	--	11.2	.6	1.9
241-85	414004086585002	Subtill	04-16-80	703	7.4	54	12.0	.2	.76
201-32	414014086533602	Subtill	04-17-80	1,430	7.0	160	11.5	.1	.17
216-49	414057086563700	Subtill	04-22-80	764	7.7	83	15.0	.2	.66
209-78	413910087002400	Subtill	04-25-80	771	7.4	75	11.5	<.1	.47
223-115	413741087043700	Subtill	04-29-80	698	7.4	135	11.5	2.4	.74
220-72	413905087025300	Subtill	04-30-80	710	7.0	69	10.5	.1	.54
243-85	413816087020002	Subtill	04-30-80	623	7.3	--	11.0	.1	.25
204-59	413957086555802	Subtill	05-01-80	1,470	7.0	165	12.5	<.1	.67
222-65	413827087040102	Subtill	05-01-80	755	7.4	187	12.0	.1	.52
210-109	413926086581801	Subtill	05-02-80	1,090	7.3	120	12.5	<.1	1.2
208-72	413812087000800	Subtill	05-02-80	877	7.4	155	13.0	<.1	1.2
219-72	413716087025100	Subtill	05-02-80	826	6.8	180	14.0	2.0	.28
204-59*	413957086555802	Subtill	10-17-80	3,180	7.0	142	12.0	<.1	.6
BR1-500*	413716087283301	Bedrock	06-25-80	930	8.6	--	16.0	--	--
BR2-583*	413716087283306	Bedrock	09-26-80	770	8.7	--	13.5	--	--

Table 2. Water-quality analyses of water from wells screened in confined aquifers--Continued

Well designation	Hardness, total (mg/L as $CaCO_3$) (00900)	Calcium dissolved (mg/L as Ca) (00915)	Magnesium, dissolved (mg/L as Mg) (00925)	Sodium, dissolved (mg/L as Na) (00930)	Potassium, dissolved (mg/L as K) (00935)	Alkalinity, field (mg/L as $CaCO_3$) (00410)	Sulfate, dissolved (mg/L as SO_4) (00940)	Chloride, dissolved (mg/L as Cl) (00940)	Fluoride, dissolved (mg/L as F) (00950)	Bromide, dissolved (mg/L as Br) (71870)
205-65	240	60	21	5.9	1.2	220	19	3.6	0.2	--
206-182	240	59	23	7.9	2.5	262	.4	2.7	.2	--
206-72	280	68	26	4.5	.9	270	32	3.0	.1	--
207-130	270	65	27	22	2.4	280	.8	29	.2	--
207-87	250	61	24	10	2.1	270	1.8	7.4	.2	--
202-153	190	35	26	59	4.5	300	.5	20	.6	--
203-193	170	31	23	72	8.3	306	.9	24	.6	--
241-137	280	58	33	46	4.0	310	1.2	51	.4	--
213-135	280	51	36	84	5.2	230	.7	120	.6	--
212-213	280	54	36	330	7.9	240	2.0	540	.7	--
211-178	310	48	47	81	8.3	500	46	12	.5	--
218-141	460	79	64	25	2.8	480	28	7.3	.4	--
222-183	200	47	20	190	3.6	230	27	280	.9	--
234-143	110	29	9.7	120	1.9	170	55	130	1.1	--
243-165	290	60	35	19	2.4	310	8.4	7.3	.7	--
201-205	260	39	40	54	5.8	370	6.9	23	.7	.2
204-125	260	56	28	12	1.8	280	9.8	4.7	.3	--
244-125	77	20	6.6	78	1.7	230	.9	21	1.3	--
230-128	290	72	26	280	2.9	130	17	500	.8	--
305-165*	130	26	15	160	4.3	359	.2	110	--	--
306-212*	230	41	32	150	6.9	382	<.2	120	--	--
105-77*	260	64	24	58	3.0	210	29	120	.3	--
224-55*	340	81	33	4.2	1.1	285	44	8.2	.1	--
241-85	300	55	39	47	2.8	370	.3	14	.5	--
201-32	710	86	120	33	2.6	530	94	97	.3	--
216-49	180	31	25	88	4.2	200	48	39	.5	.3
209-78	360	62	50	36	4.4	450	1.0	11	.4	--
223-115	270	60	28	44	2.3	280	5.3	62	.5	--
220-72	330	54	47	32	2.8	380	14	16	.6	--
243-85	310	64	37	21	2.3	320	15	7.1	.4	--
204-59	410	74	55	22	2.7	290	160	6.5	.4	--
222-65	330	63	41	32	2.7	310	33	14	.5	--
210-109	470	73	69	70	4.7	430	190	7.5	.8	--
208-72	390	67	53	36	3.3	420	42	13	.5	--
219-72	420	80	54	13	2.0	360	82	5.7	.3	--
204-59*	1,500	190	260	74	6.2	510	1,000	7.9	.5	--
BR1-500*	6	1.5	.6	170	2.6	320	2.3	39	--	.4
BR2-583*	7	1.7	.71	210	2.5	328	2.1	41	6.3	.1

Table 2. Water-quality analyses of water from wells screened in confined aquifers--Continued

Well designation	Silica, dissolved (mg/L as SiO_2) (00955)	Solids, residue at 180 DEG C, dissolved (mg/L) (70300)	Nitrogen, nitrate (NO_2), dissolved (mg/L as N) (00618)	Nitrogen, nitrite (NO_3), dissolved (mg/L as N) (00613)	Nitrogen, NO_2+NO_3, dissolved (mg/L as N) (00631)	Nitrogen, organic, dissolved (mg/L as N) (00607)	Nitrogen, ammonia, dissolved (mg/L as N) (00608)	Nitrogen, ammonia + organic, dissolved (mg/L as N) (00623)	Phosphorous, ortho, dissolved (mg/L as P) (00671)
205-65	15	258	0.01	<0.01	0 .01	<0.01	0.06	0.01	<0.01
206-182	16	277	.01	<.01	.01	.19	.15	.34	.02
206-72	14	332	.01	<.01	.01	.25	.04	.29	<.01
207-130	17	319	.02	<.01	.02	<.01	.26	.22	<.01
207-87	17	287	.02	<.01	.02	.10	.17	.27	.07
202-153	12	348	.02	<.01	.02	.19	.39	.58	.03
203-193	14	393	.02	<.01	.02	.21	.43	.64	.03
241-137	16	387	.12	.02	.14	.33	.02	.35	<.01
213-135	16	516	.01	.01	.02	.51	.01	.52	<.01
212-213	11	1,220	.03	<.01	.03	.35	.59	.94	<.01
211-178	16	502	.18	<.01	.18	.06	.67	.73	<.01
218-141	18	503	<.01	.03	.03	.24	.16	.40	<.01
222-183	12	694	.01	<.01	.01	.07	.49	.56	<.01
234-143	11	411	.01	.01	.02	.26	.34	.60	<.01
243-165	21	337	.14	.01	.15	.09	.04	.13	<.01
201-205	14	410	.03	.02	.05	.48	.45	.93	<.01
204-125	16	292	.11	.01	.12	.51	.04	.55	.09
244-125	9.8	303	<.01	.01	.01	.20	.23	.43	<.01
230-128	11	1,060	.01	.01	.02	.16	.65	.81	.02
305-165*	--	592	--	--	--	--	--	--	--
306-212*	--	591	--	--	--	--	--	--	--
105-77*	7.1	--	--	--	--	--	--	--	--
224-55*	14	--	1.6	.01	1.6	.25	.01	.26	--
241-85	15	378	.02	<.01	.02	.29	.45	.74	.01
201-32	18	822	.01	<.01	.01	.07	.09	.16	.02
216-49	11	278	<.01	<.01	<.01	.03	.63	.66	<.01
209-78	17	463	.04	<.01	.04	.15	.28	.43	.09
223-115	15	394	.10	.01	.11	.47	.16	.63	<.01
220-72	17	361	<.01	<.01	<.01	.22	.32	.54	.02
243-85	16	338	.19	.01	.20	.02	.03	.05	<.01
204-59	15	551	.30	.01	.31	.26	.10	.36	.03
222-65	16	362	.01	.01	.02	.15	.35	.50	.08
210-109	15	721	.05	.02	.07	.47	.63	1.1	.03
208-72	17	472	.48	.02	.50	.43	.29	.72	.02
219-72	18	490	.06	.01	.07	.06	.15	.21	.02
204-59*	22	2,170	.04	<.01	.04	<.01	.61	.61	<.01
BR1-500*	6.6	--	--	--	--	--	--	--	--
BR2-583*	7.4	--	.08	<.01	.08	--	<.01	--	<.01

Table 2. Water-quality analyses of water from wells screened in confined aquifers--Continued

Well designation	Phosphate, ortho, dissolved (mg/L as PO_4) (00660)	Aluminum, dissolved (µg/L as Al) (01106)	Arsenic, dissolved (µg/L as As) (01000)	Beryllium, dissolved (µg/L as Be) (01010)	Boron, dissolved (µg/L as B) (01020)	Cadmium, dissolved (µg/L as Cd) (01025)	Chromium, dissolved (µg/L as Cr) (01030)	Cobalt, dissolved (µg/L as Co) (01035)	Copper, dissolved (µg/L as Cu) (01040)	Iron, dissolved (µg/L as Fe) (01046)
205-65	<0.03	--	--	--	60	--	--	--	--	690
206-182	.06	--	--	--	100	--	--	--	--	1,100
206-72	<.03	--	--	--	30	--	--	--	--	1,200
207-130	<.03	--	--	--	170	--	--	--	--	1,400
207-87	.21	--	--	--	110	--	--	--	--	1,500
202-153	.09	--	--	--	710	--	--	--	--	890
203-193	.09	--	--	--	860	--	--	--	--	520
241-137	<.03	--	--	--	340	--	--	--	--	750
213-135	<.03	--	--	--	630	--	--	--	--	1,400
212-213	<.03	--	--	--	1,800	--	--	--	--	840
211-178	<.03	--	--	--	780	--	--	--	--	720
218-141	<.03	--	--	--	230	--	--	--	--	1,900
222-183	<.03	--	--	--	1,400	--	--	--	--	250
234-143	<.03	--	--	--	1,400	--	--	--	--	20
243-165	<.03	--	--	--	150	--	--	--	--	20
201-205	<.03	10	13	<10	500	3	<10	<3	2	200
204-125	.28	--	--	--	90	--	--	--	--	20
244-125	<.03	--	--	--	750	--	--	--	--	60
230-128	.06	--	--	--	840	--	--	--	--	60
305-165*	--	--	--	--	--	--	--	--	--	--
306-212*	--	--	--	--	--	--	--	--	--	--
105-77*	--	9	<1	--	380	--	--	--	--	80
224-55*	--	--	--	--	40	--	--	--	--	--
241-85	.03	--	--	--	540	--	--	--	--	1,100
201-32	.06	30	17	<10	60	6	10	<3	2	1,900
216-49	<.03	20	<1	--	390	<1	10	--	<1	390
209-78	.28	--	--	--	330	--	--	--	--	340
223-115	<.03	--	--	--	440	--	--	--	--	40
220-72	.06	--	--	--	350	--	--	--	--	930
243-85	<.03	--	--	--	210	--	--	--	--	20
204-59	.09	--	--	--	140	--	--	--	--	270
222-65	.25	--	--	--	380	--	--	--	--	1,100
210-109	.09	--	--	--	820	--	--	--	--	590
208-72	.06	--	--	--	380	--	--	--	--	80
219-72	.06	--	--	--	170	--	--	--	--	1,000
204-59*	<.03	--	--	--	380	--	--	--	--	2,500
BR1-500*	--	100	--	--	--	--	--	--	--	20
BR2-583*	<.03	70	1	--	3,200	2	--	<3	<10	4

Table 2. Water-quality analyses of water from wells screened in confined aquifers--Continued

Well designation	Lead, dissolved (µg/L as Pb) (01049)	Manganese, dissolved (µg/L as Mn) (01056)	Mercury, dissolved (µg/L as Hg) (71890)	Molybdenum, dissolved (µg/L as Mo) (01060)	Nickel, dissolved (µg/L as Ni) (01065)	Selenium, dissolved (µg/L as Se) (01145)	Strontium, dissolved (µg/L as Sr) (01080)	Zinc, dissolved (µg/L as Zn) (01090)	Carbon, organic, dissolved (mg/L as C) (00681)
205-65	--	50	--	--	--	--	--	--	3.1
206-182	--	170	--	--	--	--	--	--	1.1
206-72	--	120	--	--	--	--	--	--	2.6
207-130	--	30	--	--	--	--	--	--	4.4
207-87	--	20	--	--	--	--	--	--	1.6
202-153	--	9	--	--	--	--	--	--	2.0
203-193	--	10	--	--	--	--	--	--	.9
241-137	--	80	--	--	--	--	--	--	4.7
213-135	--	9	--	--	--	--	--	--	1.6
212-213	--	60	--	--	--	--	--	--	1.0
211-78	--	110	--	--	--	--	--	--	4.6
218-141	--	40	--	--	--	--	--	--	1.9
222-183	--	90	--	--	--	--	--	--	2.5
234-143	--	20	--	--	--	--	--	--	5.4
243-165	--	20	--	--	--	--	--	--	4.0
201-205	<.3	30	<.1	8	7	<1	1,700	70	2.8
204-125	--	6	--	--	--	--	--	--	9.5
244-125	--	60	--	--	--	--	--	--	3.8
230-128	--	280	--	--	--	--	--	--	4.5
305-165*	--	--	--	--	--	--	--	--	--
306-212*	--	--	--	--	--	--	--	--	--
105-77*	--	140	--	10	3	--	640	20	8.0
224-55*	--	--	--	--	--	--	--	--	2.6
241-85	--	90	--	--	--	--	--	--	2.5
201-32	<.3	30	.1	<1	1	<1	550	6	7.9
216-49	<.3	30	--	--	--	<1	1,500	40	5.3
209-78	--	130	--	--	--	--	--	--	3.0
223-115	--	110	--	--	--	--	--	--	4.8
220-72	--	30	--	--	--	--	--	--	5.0
243-85	--	10	--	--	--	--	--	--	4.8
204-59	--	80	--	--	--	--	--	--	3.9
222-65	--	30	--	--	--	--	--	--	2.3
210-109	--	160	--	--	--	--	--	--	8.1
208-72	--	110	--	--	--	--	--	--	4.0
219-72									
204-59*	--	--	--	--	--	--	--	--	--
BR1-500*	--	--	--	--	--	--	--	--	--
BR2-583*	<10	2	--	22	--	<1	47	8	--

Table 3. Water-quality analyses of water from wells screened in the surficial aquifer, excluding wells in the Great Marsh screened in sands just below surficial organic sediments

[µs/cm, microsiemens per centimeter at 25 degrees Celsius; REDOX, oxidation reduction potential; DEG C, degree Celsius; mg/L milligrams per liter; µg/L, micrograms per liter; $CaCO_3$, calcium carbonate; --, not determined; ND, not detected; mV, millivolts; five-digit number in parentheses is WATSTORE (U.S. Geological Survey) parameter code; *, analysis not used in statistical summary]

Well designation	Station number	Sample date	Specific conductance (µS/cm) (00095)	pH (Standard Units) (00400)	REDOX (Potential Units) (mV) (00090)	Temperature, water (DEG C) (00010)	Oxygen, dissolved (mg/L) (00300)	Nitrogen, dissolved (mg/L as N) (00602)	Hardness, total (mg/L as $CaCO_3$) (00900)	Calcium, dissolved (mg/L as Ca) (00915)	Magnesium, dissolved (mg/L as Mg) (00925)	Sodium, dissolved (mg/L as Na) (00930)
102-86*	413821087062502	07-30-77	463	8.3	--	13.5	--	--	200	26	33	32
202-26	414122086544702	04-15-80	456	6.8	68	11.5	<.1	1.2	220	60	18	9.1
203-35	414212086555602	04-15-80	359	7.8	60	11.0	<.1	1.0	150	42	12	27
215-35	414045086574500	04-16-80	426	7.4	283	12.0	2.0	1.0	120	34	8.6	33
217-13	414156086570900	04-18-80	140	5.9	269	9.1	.1	.49	47	14	3.0	.8
214-26	414147086581900	04-18-80	559	6.5	252	11.5	1.8	1.3	180	45	17	35
211-25	413957087002602	04-22-80	663	7.5	148	7.5	<.1	.39	280	50	37	27
242-83	413656087091500	04-23-80	419	7.4	76	11.5	.1	.60	150	38	13	27
229-65	413559087113500	04-23-80	277	7.7	44	11.0	.1	.28	140	38	12	11
231-45	413641087122900	04-23-80	496	6.8	104	11.0	.1	1.5	250	63	23	2.1
232-45	413726087123600	04-23-80	645	7.0	84	13.0	<.1	1.4	320	90	22	5.7
233-49	413553087131800	04-23-80	842	7.7	133	12.0	.1	1.3	180	41	19	82
235-45	413629087142600	04-23-80	511	6.9	95	12.5	.1	1.3	240	75	12	6.0
236-45	413622087160300	04-24-80	2,300	6.9	77	11.5	.1	25	440	120	35	240
237-45	413550087163800	04-24-80	3,300	6.5	155	13.0	.2	3.6	930	240	80	250
227-52	413629087062200	04-24-80	469	7.1	85	12.0	.2	.21	220	60	18	6.0
227-24*	413629087062203	04-23-81	1,840	6.1	355	11.0	<.1	.39	300	75	28	190
225-56	413645087051500	04-24-80	429	7.2	118	11.5	.1	.38	210	50	20	5.5
210-31	413926086581802	04-24-80	1,450	6.7	55	11.5	.1	39	350	64	46	70
210-31*	413926086581802	10-16-80	1,400	7.0	119	11.5	<.1	29	350	59	50	68
218-25	413907087014402	04-25-80	360	5.8	250	11.0	.2	.37	140	34	13	3.9
238-65	413705087165500	04-29-80	5,290	7.2	76	11.5	.3	2.7	1,300	370	100	410
238-65*	413705087165500	04-29-81	5,600	7.3	238	13.5	<.1	8.0	1,600	430	120	620
239-65	413634087165300	04-29-80	724	6.7	145	11.5	.1	1.3	320	95	21	5.6
239-65*	413634087165300	10-29-80	636	7.0	126	12.0	.2	1.4	280	81	18	6.3
234-45	413545087145502	04-29-80	508	7.4	108	12.0	.1	.15	240	61	22	5.9
240-61	413552087090800	05-01-80	1,370	7.2	469	14.5	1.2	.86	350	88	31	32
244-65	413732087105702	05-01-80	732	7.1	187	15.0	.1	.96	320	88	25	8.4
230-58	413651087110502	05-02-80	1,230	6.7	139	14.5	.1	1.3	440	120	33	70
230-24*	413651087110503	04-28-81	95	5.9	456	11.0	<.1	2.9	42	13	2.3	3.8
228-53	413637087073100	05-02-80	699	6.7	139	14.0	<.1	.48	320	89	24	13
226-65	413706087040300	05-02-80	1,450	6.8	153	12.5	<.1	1.0	530	140	45	80
212-24*	414057087003003	04-16-81	411	7.2	435	11.0	3.6	.59	240	71	15	.9
275-24*	413756087160500	04-30-81	2,010	7.7	291	12.0	<.1	.86	410	120	27	220
305A-11*	414030087003301	11-08-84	160	5.8	--	13.0	--	--	71	21	4.5	4.3
306-30*	414041087003402	11-08-84	297	7.3	--	12.0	--	--	140	40	10	1.3
322-13*	414037087003301	05-15-86	129	8.2	--	10.5	6.2	--	79	19	7.7	.7

Table 3. Water-quality analyses of water from wells screened in the surficial aquifer, excluding wells in the Great Marsh screened in sands just below surficial organic sediments--Continued

Well designation	Potassium, dissolved (mg/L as K) (00935)	Alkalinity, field (mg/L as $CaCO_3$) (00410)	Sulfate, dissolved (mg/L as SO_4) (00945)	Chloride, dissolved (mg/L as Cl) (00940)	Fluoride, dissolved (mg/L as F) (00950)	Bromide, dissolved (mg/L as Br) (71870)	Silica, dissolved (mg/L as SiO_2) (00955)	Solids, residue at 180 DEG C, dissolved (mg/L) (70300)	Nitrogen, nitrate (NO_2), dissolved (mg/L as N) (00618)	Nitrogen, nitrite (NO_3), dissolved (mg/L as N) (00613)	Nitrogen, NO_2+NO_3, dissolved (mg/L as N) (00631)	Nitrogen, organic, dissolved (mg/L as N) (00607)
102-86*	3.1	220	3.3	14	0.1	--	3.4	--	--	--	--	--
202-26	.5	150	71	7.3	.2	--	21	338	.02	<.01	.02	.68
203-35	1.0	190	3.3	7.3	.3	--	15	248	.02	<.01	.02	.57
215-35	1.1	78	39	44	<.1	.4	5.9	252	.89	.07	.96	.03
217-13	.4	28	9.7	1.1	<.1	--	6.6	40	.03	<.01	.03	.27
214-26	2.8	125	44	60	.1	--	10	358	.21	<.01	.21	.78
211-25	2.1	280	18	30	.3	--	15	375	.08	.03	.11	.22
242-83	1.0	170	42	31	.2	--	13	246	<.01	.02	.02	.32
229-65	.7	130	15	11	.2	--	14	193	.05	.02	.07	.19
231-45	.9	200	43	4.6	.1	--	14	309	.04	.03	.07	.81
232-45	2.0	300	12	12	.1	--	17	407	.01	.03	.04	.51
233-49	4.6	130	62	140	.1	--	8.2	455	.95	.04	.99	.21
235-45	.8	150	82	10	.2	--	18	372	<.01	<.01	<.01	.58
236-45	10	190	79	500	.1	--	11	1,350	.02	.02	.04	23
237-45	5.3	280	170	710	.1	--	18	4,330	.06	.03	.09	1.2
227-52	1.7	170	43	19	.1	--	14	291	<.01	<.01	<.01	.07
227-24*	7.0	112	88	430	<.1	--	9.7	1,070	.28	.01	.29	.08
225-56	1.0	150	58	6.6	.2	--	16	257	.02	.04	.06	.29
210-31	55	520	42	77	.1	--	3.9	706	.01	.03	.04	37
210-31*	72	510	190	66	.1	--	3.8	820	<.01	.02	.02	<.01
218-25	.3	80	50	9.4	.1	--	14	230	<.01	.02	.02	.30
238-65	4.8	290	910	610	.1	.2	17	2,770	.02	.02	.04	.40
238-65*	7.8	472	1,200	820	<.1	--	20	4,030	.5	<.01	.05	3.8
239-65	1.7	310	1.2	11	.1	.2	21	329	.02	.01	.03	.39
239-65*	1.4	362	3.1	10	<.1	.3	28	398	<.01	.01	.01	<.01
234-45	1.2	79	160	6.9	.1	--	8.8	351	.05	.01	.06	.06
240-61	2.3	170	81	120	.2	--	11	525	.69	.01	.70	.13
244-65	1.5	270	35	23	.1	--	12	392	<.01	.01	.01	.38
230-58	2.0	290	120	120	.1	--	11	783	--	.96	.92	.30
230-24*	.7	12	27	5.4	<.1	--	9.1	106	2.0	.02	2.0	.93
228-53	2.1	250	55	24	.2	--	17	424	.09	.03	.12	.30
226-65	3.9	300	73	250	.2	--	17	892	.04	.01	.05	.48
212-24*	.5	208	26	2.0	<.1	--	6.7	258	.44	<.01	.44	.12
275-24*	4.0	310	64	380	.3	--	20	1,110	.03	<.01	.03	.33
305A-11*	1.4	39	33	3.1	--	--	--	116	--	--	--	--
306-30*	.9	124	13	1.0	--	--	--	--	--	--	--	--
322-13*	.3	60	19	1.8	--	--	--	111	--	--	--	--

Table 3. Water-quality analyses of water from wells screened in the surficial aquifer, excluding wells in the Great Marsh screened in sands just below surficial organic sediments--Continued

Well designation	Nitrogen, ammonia, dissolved (mg/L as N) (00608)	Nitrogen, ammonia + organic, dissolved (mg/L as N) (00623)	Phosphorous, ortho, dissolved (mg/L as P) (00671)	Phosphate, ortho, dissolved (mg/L as PO_4) (00660)	Aluminum, dissolved (µg/L as Al) (01106)	Arsenic, dissolved (µg/L as As) (01000)	Barium, dissolved (µg/L as Be) (01010)	Beryllium, dissolved (µg/L as Be) (01010)	Boron, dissolved (µg/L as B) (01020)	Cadmium, dissolved (µg/L as Cd) (01025)	Chromium, dissolved (µg/L as Cr) (01030)	Cobalt, dissolved (µg/L as Co) (01035)
102-86*	--	--	--	--	<100	1	<100	<10	440	ND	ND	ND
202-26	.52	1.2	.08	.25	--	--	--	--	210	--	--	--
203-35	.43	1.0	<.01	<.03	--	--	--	--	310	--	--	--
215-35	.01	.04	<.01	<.03	20	1	--	--	70	5	10	--
217-13	.19	.46	<.01	<.03	--	--	--	--	60	--	--	--
214-26	.32	1.1	.05	.15	--	--	--	--	120	--	--	--
211-25	.06	.28	<.01	<.03	--	--	--	--	160	--	--	--
242-83	.26	.58	<.01	<.03	--	--	--	--	160	--	--	--
229-65	.02	.21	<.01	<.03	--	--	--	--	80	--	--	--
231-45	.59	1.4	<.01	<.03	--	--	--	--	90	--	--	--
232-45	.89	1.4	.04	.12	--	--	--	--	130	--	--	--
233-49	.09	.30	<.01	<.03	--	--	--	--	100	--	--	--
235-45	.72	1.3	.09	.28	--	--	--	--	130	--	--	--
236-45	1.60	25	<.01	<.03	--	--	--	--	180	--	--	--
237-45	2.30	3.5	<.01	<.03	--	--	--	--	290	--	--	--
227-52	.14	.21	<.01	<.03	--	--	--	--	40	--	--	--
227-24*	.02	.10	<.01	--	--	--	--	--	60	--	--	--
225-56	.03	.32	<.01	<.03	--	--	--	--	40	--	--	--
210-31	2.40	39	<.01	<.03	--	--	--	--	720	--	--	--
210-31*	29	29	.01	.03	--	--	--	--	730	--	--	--
218-25	.05	.35	<.01	<.03	--	--	--	--	140	--	--	--
238-65	2.30	2.7	<.01	<.03	10	12	10	10	270	<1	20	<3
238-65*	4.1	7.9	<.01	--	200	67	--	--	520	1	10	--
239-65	.91	1.3	<.01	<.03	10	28	100	<10	150	<1	<10	<3
239-65*	1.4	1.4	.08	.25	<10	89	100	<10	120	1	10	10
234-45	.03	.09	<.01	<.03	--	--	--	--	290	--	--	--
240-61	.03	.16	<.01	<.03	--	--	--	--	70	--	--	--
244-65	.57	.95	<.01	<.03	--	--	--	--	80	--	--	--
230-58	.05	.35	<.01	<.03	--	--	--	--	890	--	--	--
230-24*	<.01	.93	<.01	--	--	--	--	--	40	--	--	--
228-53	.06	.36	<.01	<.03	--	--	--	--	80	--	--	--
226-65	.50	.98	.06	.18	--	--	--	--	240	--	--	--
212-24*	.03	.15	<.01	--	--	--	--	--	40	--	--	--
275-24*	.50	.83	<.01	--	--	--	--	--	200	--	--	--
305A-11*	--	--	--	--	--	--	--	--	--	--	--	--
306-30*	--	--	--	--	--	--	--	--	--	--	--	--
322-13*	--	--	--	--	--	--	--	--	--	--	--	--

Table 3. Water-quality analyses of water from wells screened in the surficial aquifer, excluding wells in the Great Marsh screened in sands just below surficial organic sediments--Continued

Well designation	Copper, dissolved (µg/L as Cu) (01040)	Iron, dissolved (µg/L as Fe) (01046)	Lead, dissolved (µg/L as Pb) (01049)	Manganese, dissolved (µg/L as Mn) (01056)	Mercury, dissolved (µg/L as Hg) (71890)	Molybdenum, dissolved (µg/L as Mo) (01060)	Nickel, dissolved (µg/L as Ni) (01065)	Selenium, dissolved (µg/L as Se) (01145)	Strontium, dissolved (µg/L as Sr) (01080)	Zinc, dissolved (µg/L as Zn) (01090)	Carbon, organic, dissolved (mg/L as C) (00681)
102-86*	ND	50	ND	50	<0.5	2	3	<1	220	ND	2.0
202-26	--	2,000	--	210	--	--	--	--	--	--	18
203-35	--	970	--	220	--	--	--	--	--	--	12
215-35	1	10	<.3	<1	--	--	--	<1	100	8	4.8
217-13	--	860	--	50	--	--	--	--	--	--	8.6
214-26	--	950	--	120	--	--	--	--	--	--	12
211-25	--	650	--	60	--	--	--	--	--	--	4.9
242-83	--	660	--	40	--	--	--	--	--	--	5.4
229-65	--	510	--	40	--	--	--	--	--	--	2.2
231-45	--	8,200	--	350	--	--	--	--	--	--	17
232-45	--	7,100	--	130	--	--	--	--	--	--	8.4
233-49	--	40	--	50	--	--	--	--	--	--	2.5
235-45	--	5,400	--	150	--	--	--	--	--	--	11
236-45	--	8,000	--	240	--	--	--	--	--	--	3.9
237-45	--	4,700	--	870	--	--	--	--	--	--	2.5
227-52	--	2,600	--	190	--	--	--	--	--	--	5.0
227-24*	--	10	--	90	--	--	--	--	--	4,700	1.0
225-56	--	500	--	130	--	--	--	--	--	--	2.6
210-31	--	9,900	--	1,100	--	--	--	--	--	--	27
210-31*	--	1,300	--	1,400	--	--	--	--	--	--	25
218-25	--	710	--	40	--	--	--	--		--	9.6
238-65	1	560	<.3	360	.1	<1	8	<1	1,300	220	13
238-65*	1	13,000	2	240	--	--	--	--	2,000	100	19
239-65	2	2,300	1	370	<.1	<1	3	<1	130	50	7.6
239-65*	2	5,100	10	50	<.1	<1	1	<1	160	20	7.7
234-45	--	20	--	20	--	--	--	--	--	--	5.4
240-61	--	10	--	6	--	--	--	--	--	--	4.6
244-65	--	3,000	--	200	--	--	--	--	--	--	2.9
230-58	--	50	--	270	--	--	--	--	--	--	7.1
230-24*	--	490	--	30	--	--	--	--	--	1,200	12
228-53	--	50	--	40	--	--	--	--	--	--	4.0
226-65	--	3,200	--	340	--	--	--	--	--	--	12
212-24*	--	80	--	5	--	--	--	--	--	970	1.1
275-24*	--	910	--	590	--	--	--	--	--	--	2.8
305A-11*	--	--	--	--	--	--	--	--	--	--	--
306-30*	--	--	--	--	--	--	--	--	--	--	--
322-13*	--	--	--	--	--	--	--	--	--	--	--

Table 4. Water-quality analyses of water from wells in the Great Marsh screened in sands just below surficial organic sediments

[µs/cm, microsiemens per centimeter at 25 degrees Celsius; REDOX, oxidation reduction potential; DEG C, degree Celsius; mg/L milligrams per liter; µg/L, micrograms per liter; $CaCO_3$, calcium carbonate; --, not determined; mV, millivolts; five-digit number in parentheses is WATSTORE (U.S. Geological Survey) parameter code; *, analysis not used in statistical summary in table 6; +, well screened]

Well designation	Station number	Sample date	Specific conductance (µS/cm) (00095)	pH (Standard Units) (00400)	REDOX (Potential Units) (mV) (00090	Temperature, water (DEG C) (00010)	Oxygen, dissolved (mg/L) (00300)	Nitrogen, dissolved (mg/L as N) (00602)	Hardness, total (mg/L as $CaCO_3$) (00900)	Calcium dissolved (mg/L as Ca) (00915)	Magnesium, dissolved (mg/L as Mg) (00925)
GM25-11	414050086590501	04-16-80	860	7.2	170	8.0	<0.1	2.9	350	91	31
GM29-7	414107086574101	04-16-80	403	5.6	190	4.5	<.1	2.5	120	33	8.2
GM21-7	414013087000701	04-17-80	508	6.6	235	9.0	<.1	.78	210	49	22
GM24-7	414036086590601	04-17-80	306	6.1	200	9.5	<.1	.70	88	22	8.0
GM4C-14	413832087053401	04-22-80	768	7.4	260	14.0	<.1	.20	440	91	52
GM45-15	413828087053501	04-22-80	395	7.2	--	13.0	<.1	3.6	410	94	42
GM38-19	413832087052801	04-23-80	741	8.0	120	13.5	<.1	.36	410	79	52
GM39-9	413832087052001	04-23-80	736	7.7	200	9.5	<.1	.54	390	73	51
GM4B-15	413835087053001	04-23-80	732	8.2	130	10.5	<.1	.60	400	75	51
GM44-19	413829087052701	04-23-80	653	7.8	-245	9.5	<.1	.56	320	67	38
GM4A-11	413843087052901	04-24-80	165	5.6	28	6.0	<.1	5.7	100	32	5.0
GM7-11	413842087045201	04-29-80	196	8.1	120	6.0	<.1	1.4	90	22	8.4
GM5-11	413853087052101	04-29-80	290	6.2	230	8.0	<.1	2.1	150	41	12
GM22-7	414029087000801	04-29-80	926	7.1	167	8.0	<.1	2.8	470	150	24
GM2-11	413821087051201	04-29-80	640	7.8	160	7.0	<.1	.31	360	75	43
GM8-7	413900087040801	04-30-80	409	6.9	170	8.5	<.1	.55	200	47	20
GM30-16	414125086574801	04-30-80	351	6.1	180	9.5	<.1	9.1	150	40	11
GM13-7	413937087013901	04-30-80	421	6.8	210	8.5	<.1	.56	160	38	17
GM16-7	413949087014401	04-30-80	462	6.7	205	7.5	<.1	.91	160	39	16
GM1-12	413816087054501	05-01-80	576	7.3	165	10.5	.4	.94	260	57	29
GM46-23*	413831087053701	04-29-81	853	7.1	217	13.5	--	.80	470	96	55
321-5*	414017087002701	03-14-85	943	7.2	--	5.5	1.0	--	210	43	26
+324-4*	414022087003501	03-14-85	1,200	6.3	--	7.5	1.3	--	440	120	33
211-8*	413957087002603	05-15-86	278	6.0	--	12.0	1.2	--	46	13	3.3

Table 4. Water-quality analyses of water from wells in the Great Marsh screened in sands just below surficial organic sediments--Continued

Well designation	Sodium, dissolved (mg/L as Na) (00930)	Potassium, dissolved (mg/L as K) (00935)	Alkalinity, field mg/L as $CaCO_3$ (00410)	Sulfate, dissolved (mg/L as SO_4) (00945)	Chloride, dissolved (mg/L as Cl) (00940)	Fluoride, dissolved (mg/L as F) (00950)	Bromide, dissolved (mg/L as Br) (71870)	Silica, dissolved (mg/L as SiO_2) (00955)	Solids, residue at 180 DEG C, dissolved (mg/L) (70300)	Nitrogen, nitrate (NO_2), dissolved (mg/L as N) (00618)	Nitrogen, nitrite (NO_3), dissolved (mg/L as N) (00613)
GM25-11	49	1.5	410	8.7	43	0.3	--	18	596	0.03	<0.01
GM29-7	29	5.6	30	90	37	<.1	.3	12	274	2.08	.02
GM21-7	23	3.1	180	40	32	.1	--	11	341	.14	<.01
GM24-7	20	.9	36	43	39	.1	--	11	240	.02	<.01
GM4C-14	13	2.6	380	89	8.1	.2	.3	16	493	<.01	.02
GM45-15	8.1	2.6	470	52	3.9	.2	.2	34	491	.03	02
GM38-19	13	2.5	340	86	13	.3	.2	16	477	<.01	<.01
GM39-9	17	2.3	370	58	10	.3	.2	17	465	.02	05
GM4B-15	17	2.7	340	80	11	.3	.3	16	447	<.01	<.01
GM44-19	17	1.1	360	11	11	.4	.2	16	354	--	.03
GM4A-11	2.0	.5	50	53	11	.1	--	14	329	.07	.03
GM7-11	3.9	1.1	56	29	6.3	.2	--	12	173	.16	01
GM5-11	2.3	.2	112	66	6.6	.1	--	16	303	07	.02
GM22-7	31	.8	330	150	31	.2	--	16	697	.05	.01
GM2-11	14	1.8	360	57	6.4	.3	--	14	421	--	.01
GM8-7	6.2	.2	200	11	7.2	.1	--	14	251	<.01	.01
GM30-16	5.3	1.0	160	11	8.4	.1	.2	11	275	<.01	.01
GM13-7	17	.8	150	34	17	.1	--	8.8	232	.13	.01
GM16-7	25	.5	121	58	38	.1	--	11	318	<.01	.01
GM1-12	15	1.2	240	37	23	.1	.2	13	370	.17	.01
GM46-23*	14	2.3	396	94	8.4	.2	--	17	522	--	--
321-5*	100	.6	404	28	24	--	--	--	591	--	--
+324-4*	74	.2	465	48	27	--	--	--	958	--	--
211-8*	37	1.2	58	16	51	--	--	--	188	--	--

Table 4. Water-quality analyses of water from wells in the Great Marsh screened in sands just below surficial organic sediments--Continued

Well designation	Nitrogen, NO_2+NO_3, dissolved (mg/L as N) (00631)	Nitrogen, organic, dissolved (mg/L as N) (00607)	Nitrogen, ammonia, dissolved (mg/L as N) (00608)	Nitrogen, ammonia + organic, dissolved (mg/L as N) (00623)	Phosphorous, ortho, dissolved (mg/L as P) (00671)	Phosphate, ortho, dissolved (mg/L as PO_4) (00660)	Aluminum, dissolved (µg/L as Al) (01106)	Arsenic, dissolved (µg/L as As) (01000)	Boron, dissolved (µg/L as B) (01020)	Cadmium, dissolved (µg/L as Cd) (01025)	Chromium, dissolved (µg/L as Cr) (01030)
GM25-11	0.03	1.5	1.4	2.9	0.01	0.03	--	--	440	--	--
GM29-7	2.1	.32	.03	.35	.07	21	60	2	160	3	10
GM21-7	.14	.62	.02	.64	<.01	<.03	--	--	130	--	--
GM24-7	.02	.52	.16	.68	<.01	<.03	--	--	110	--	--
GM4C-14	.02	.09	.09	.18	.05	.15	10	<1	80	2	20
GM45-15	.05	.20	3.3	3.5	.03	.09	100	<1	120	6	<10
GM38-19	<.01	.17	.19	.36	.01	.03	10	<1	120	3	<10
GM39-9	.07	.29	18	.47	<.01	<.03	10	<1	170	3	<10
GM4B-15	<.01	.37	.23	.60	<.01	<.03	20	<1	180	4	<10
GM44-19	.02	<.01	58	.54	.03	.09	20	1	150	<1	10
GM4A-11	.10	4.1	1.5	5.6	.29	.89	--	--	5	--	--
GM7-11	.17	1.1	.12	1.2	.01	.03	--	--	130	--	--
GM5-11	.09	1.8	.16	2.0	<.01	<.03	--	--	170	--	--
GM22-7	.06	1.8	.93	2.7	.01	.03	--	--	300	--	--
GM2-11	<.01	.14	.17	.31	<.01	<.03	--	--	150	--	--
GM8-7	.01	.39	.15	.54	.04	.12	--	--	70	--	--
GM30-16	.01	2.9	6.2	9.1	.18	.55	100	1	130	5	10
GM13-7	.14	.16	.26	.42	.02	.06	--	--	70	--	--
GM16-7	.01	.75	.15	.90	.08	.25	--	--	120	--	--
GM1-12	.18	.69	.07	.76	<.01	<.03	10	2	50	6	10
GM46-23*	.05	.60	.16	.76	<.01	--	200	1	90	1	20
321-5*	--	--	--	--	--	--	--	--	--	--	--
+324-4*	--	--	--	--	--	--	--	--	--	--	--
211-8*	--	--	--	--	--	--	--	--	--	--	--

Table 4. Water-quality analyses of water from wells in the Great Marsh screened in sands just below surficial organic sediments--Continued

Well designation	Copper, dissolved (µg/L as Cu) (01040)	Iron, dissolved (µg/L as Fe) (01046)	Lead, dissolved (µg/L as Pb) (01049)	Manganese, dissolved (µg/L as Mn) (01056)	Molybdenum, dissolved (µg/L as Mo) (01060)	Nickel, dissolved (µg/L as Ni) (01065)	Selenium, dissolved (µg/L as Se) (01145)	Strontium, dissolved (µg/L as Sr) (01080)	Zinc, dissolved (µg/L as Zn) (01090)	Carbon, organic, dissolved (mg/L as C) (00681)
GM25-11	--	4,400	--	150	--	--	--	--	--	31
GM29-7	1	30	<.3	240	--	--	<1	190	50	7.4
GM21-7	--	2,000	--	50	--	--	--	--	--	16
GM24-7	--	2,300	--	80	--	--	--	--	--	13
GM4C-14	<1	1,900	<.3	90	<1	<1	<1	450	10	5.9
GM45-15	1	5,100	<.3	140	<1	<1	<1	760	5,700	14
GM38-19	<1	2,100	<.3	60	17	<1	<1	940	5	7.5
GM39-9	<1	10	<.3	60	10	<1	<1	970	2,200	3.9
GM4B-15	<1	1,600	<.3	50	17	<1	<1	990	60	2.8
GM44-19	<1	1,100	<.3	60	<1	1	<1	800	2,300	4.1
GM4A-11	--	10	--	120	--	--	--	--	--	82
GM7-11	--	2,300	--	250	--	--	--	--	--	17
GM5-11	--	17,000	--	80	--	--	--	--	--	40
GM22-7	--	7,600	--	700	--	--	--	--	--	39
GM2-11	--	1,000	--	40	--	--	--	--	--	4.7
GM8-7	--	4,000	--	140	--	--	--	--	--	11
GM30-16	1	13,000	<.3	350	--	--	<1	200	30	38
GM13-7	--	4,600	--	210	--	--	--	--	--	8.2
GM16-7	--	3,500	--	180	--	--	--	--	--	14
GM1-12	1	1,500	<.3	60	1	<1	<1	370	<3	5.0
GM46-23*	<1	1,900	1	100	--	--	--	530	40	1.8
321-5*	--	--	--	--	--	--	--	--	--	--
+324-4*	--	--	--	--	--	--	--	--	--	--
211-8*	--	--	--	--	--	--	--	--	--	19

Table 5. Water-quality analyses of surface water in the Great Marsh

[µS/cm, microsiemens per centimeter at 25 degrees Celsius; REDOX, oxidation reduction level; DEG C, degree Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; $CaCO_3$, calcium carbonate; --, not determined; mV, millivolts; five-digit number in parentheses is WATSTORE (U.S. Geological Survey) parameter code]

Site location	Station number	Sample date	Specific conductance (µS/cm) (00095)	pH (Standard Units) (00400)	REDOX (Potential Units) (mV) (00090)	Temperature, water (DEG C) (00010)	Oxygen, dissolved (mg/L) (00300)	Nitrogen, dissolved (mg/L as N) (00602)	Hardness, total (mg/L as $CaCO_3$) (00900)	Calcium, dissolved (mg/L as Ca) (00915)
GM25	414050086590500	04-16-80	286	6.6	460	13.0	11.8	2.3	100	26
GM29	414107086574100	04-16-80	254	6.2	400	10.5	8.4	.69	92	30
GM21	414013087000700	04-17-80	249	6.0	500	11.5	4.6	.91	77	19
GM24	414036086590600	04-17-80	249	5.6	385	12.5	3.6	.43	60	15
GM4C	413832087053400	04-22-80	818	7.1	250	17.0	.1	.81	420	85
GM45	413828087053500	04-23-80	315	7.1	375	9.5	.4	2.1	130	32
GM38	413832087052800	04-23-80	800	7.4	80	12.0	1.0	.71	400	79
GM39	413832087052000	04-23-80	840	7.2	362	17.0	1.4	2.3	430	96
GM4B	413835087053000	04-23-80	720	7.3	50	16.5	.5	.88	350	70
GM44	413829087052700	04-23-80	797	7.2	100	16.0	.5	2.1	380	85
GM4A	413843087052900	04-24-80	113	5.9	300	6.5	2.8	5.2	65	19
GM7	413842087045200	04-29-80	265	6.5	110	7.5	<.1	.52	140	36
GM5	413853087052100	04-29-80	125	5.3	390	11.0	6.6	2.1	51	14
GM22	414029087000800	04-29-80	297	6.8	330	10.0	4.5	1.0	110	26
GM2	413821087051200	04-29-80	204	5.8	335	9.0	1.0	3.9	90	23
GM8	413900087040800	04-30-80	179	6.3	291	10.5	<.1	1.2	84	21
GM30	414125086574800	04-30-80	151	6.3	405	12.0	<.1	3.7	78	21
GM13	413937087013900	04-30-80	198	6.1	415	11.5	.9	1.8	100	24
GM16	413949087014400	04-30-80	306	6.6	320	11.0	6.6	.57	90	22
GM1	413816087054500	05-01-80	478	7.4	339	15.5	15.1	.82	160	38

Table 5. Water-quality analyses of surface water in the Great Marsh--Continued

Site location	Magnesium, dissolved (mg/L as Mg) (00925)	Sodium, dissolved (mg/L as Na) (00930)	Potassium, dissolved (mg/L as K) (00935)	Alkalinity, field (mg/L as $CaCO_3$) (00410)	Sulfate, dissolved (mg/L as SO_4) (00945)	Chloride, dissolved (mg/L as Cl) (00940)	Fluoride, dissolved (mg/L as F) (00950)	Silica, dissolved (mg/L as SiO_2) (00955)	Solids, residue at 180 DEG C, dissolved (mg/L) (70300)	Nitrogen, nitrate, (NO_2) dissolved (mg/L as N) (00618)
GM25	9.2	19	0.9	52	37	28	0.2	4.1	285	0.29
GM29	4.1	11	2.9	25	74	8.8	.1	8.3	197	.02
GM21	7.2	19	2.0	50	35	25	.1	11	177	.13
GM24	5.4	21	1.4	16	39	36	.1	9.9	172	.04
GM4C	50	13	4.6	420	34	11	.3	17	509	<.01
GM45	13	9.5	5.0	131	13	13	.3	6.4	235	.17
GM38	50	15	3.6	340	73	15	.3	17	485	.10
GM39	45	14	2.6	440	49	12	.4	19	546	.13
GM4B	43	17	3.5	320	52	14	.4	14	446	.12
GM44	41	16	2.9	410	5.0	15	4	20	506	.08
GM4A	4.3	3.1	1.4	29	31	9.8	.3	6.0	353	.24
GM7	12	4.2	.5	130	13	3.7	.1	13	190	.07
GM5	4.0	1.7	.6	11	39	3.7	.2	.6	150	.10
GM22	11	18	.3	83	22	26	.2	.1	205	--
GM2	8.0	7.4	1.0	54	42	7.7	.2	11	268	.28
GM8	7.6	2.6	.7	63	27	3.2	.2	8.5	188	.09
GM30	6.3	5.5	2.3	51	16	10	.2	1.1	263	<.01
GM13	9.7	19	.7	56	40	29	.1	11	199	.38
GM16	8.5	22	.3	57	35	32	.1	8.2	193	.05
GM1	16	33	4.6	160	3.5	45	.3	4.6	272	.02

Table 5. Water-quality analyses of surface water in the Great Marsh--Continued

Site location	Nitrogen, nitrite, (NO_3) dissolved (mg/L as N) (00613)	Nitrogen, NO_2+NO_3, dissolved (mg/L as N) (00631)	Nitrogen, organic, dissolved (mg/L as N) (00607)	Nitrogen, ammonia, dissolved (mg/L as N) (00608)	Nitrogen, ammonia + organic, dissolved (mg/L as N) (00623)	Phosphorous, ortho, dissolved (mg/L as P) (00671)	Phosphate, ortho, dissolved (mg/L as PO_4) (00660)	Boron, dissolved (µg/L as B) (01020)	Iron, dissolved (µg/L as Fe) (01046)	Manganese, dissolved (µg/L as Mn) (01056)	Carbon, organic, dissolved (mg/L as C) (00681)
GM25	0 .02	0.31	2.0	0.05	2.0	0.03	0.09	300	760	140	36
GM29	<.01	.02	.66	.01	.67	<.01	<.01	160	130	90	15
GM21	.01	.14	.75	.02	.77	.01	.03	140	170	5	14
GM24	<.01	.04	.34	.05	.39	<.01	<.01	130	120	30	10
GM4C	<.01	<.01	.73	.08	.81	.01	.03	170	240	670	18
GM45	.04	.21	1.8	.11	1.9	<.01	<.01	350	330	800	18
GM38	<.01	.10	.45	.16	.61	<.01	<.01	160	30	130	8.7
GM39	.03	.16	1.8	.29	2.1	<.01	<.01	230	1,100	1,100	31
GM4B	<.01	.12	.65	.11	.76	<.01	<.01	210	10	2	11
GM44	<.01	.08	1.8	.20	2.0	<.01	<.01	220	1,300	750	28
GM4A	.02	.26	4.8	.13	4.9	<.01	<.01	590	7,300	770	90
GM7	<.01	.07	.24	.21	.45	<.01	<.01	50	840	50	4.1
GM5	.01	.11	2.0	.04	2.0	.04	.12	160	1,000	270	25
GM22	.01	<.01	.98	.02	1.0	.03	.09	110	440	20	15
GM2	.02	.30	3.1	.50	3.6	<.01	<.01	280	2,200	110	58
GM8	.01	.10	.99	.11	1.1	.04	.12	150	7,400	280	23
GM30	.02	.02	3.6	.09	3.7	.13	.40	440	2,500	410	79
GM13	.01	.39	1.4	.04	1.4	.01	.03	70	80	110	9.7
GM16	.01	.06	.48	.03	.51	.01	.03	100	390	10	16
GM1	.01	.03	.74	.05	.79	.01	.03	130	370	100	15

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