Geohydrology, Water Levels and Directions of Flow, and Occurrence of Light-Nonaqueous-Phase Liquids on Ground Water in Northwestern Indiana and the Lake Calumet Area of Northeastern Illinois

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PLATE **In pocket**

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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
foot per foot (ft/ft)	0.3048	meter per meter
mile (mi)	1.609	kilometer
acre	4,047	square meter
foot per day (ft/d)[1]	0.3048	meter per day
foot per mile (ft/mi)	0.1894	meter per kilometer
cubic feet per second (ft^3/s)	0.02832	cubic meter per second

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

$$°F = 9/5\ (°C) + 32$$

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 first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

[1]Foot per day is the mathematically reduced term of cubic foot per day per square foot of aquifer cross-sectional area.

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By Robert T. Kay, Richard F. Duwelius, Timothy A. Brown, Frederick A. Micke[1], *and* Carol A. Witt-Smith[1]

Abstract

A study was performed by the U.S. Geological Survey, in cooperation with the U.S. Environmental Protection Agency, to describe the geohydrology and distribution of light-nonaqueous-phase liquids in an industrialized area of northwestern Indiana and northeastern Illinois. The geologic units of concern underlying this area are the carbonates of the Niagaran Series, the Detroit River and Traverse Formations; the Antrim Shale; and sands, silts, and clays of Quaternary age. The hydrologic units of concern are surface water, the Calumet aquifer, the confining unit, and the Silurian-Devonian aquifer.

Water levels collected in June 1992 indicate that the water-table configuration generally is a subdued reflection of topography. Recharge from landfill leachate and ponded water, discharge to sewers, and pumping also affect the water-table configuration. A depression in the potentiometric surface of the Silurian-Devonian aquifer results from pumping. Light-nonaqueous-phase liquids were detected near petroleum handling, industrial and waste-disposal facilities.

Horizontal ground-water velocity at the water table in the confining unit ranged from 4.4×10^{-4} to 1.0×10^{-3} feet per day. Horizontal ground-water velocity in the Calumet and Silurian-Devonian aquifers ranged from 1.0×10^{-2} to 3.4×10^{-1} and from 1.4×10^{-2} to 2.9×10^{-2} feet per day, respectively.

Vertical hydraulic gradients indicate generally downward flow from the Calumet aquifer into the confining unit, then into the Silurian-Devonian aquifer. Calculated vertical ground-water velocity through the weathered and unweathered parts of the confining unit are 3.8×10^{-2} and 1.5×10^{-3} feet per day, respectively.

[1]U.S. Environmental Protection Agency, Region 5, Chicago, Illinois.

INTRODUCTION

In June 1992, the U.S. Geological Survey (USGS), in cooperation with the U.S. Environmental Protection Agency (USEPA), began a study of the geohydrology and distribution of light-nonaqueous-phase liquids (LNAPL's) in an urban and industrial area of northwestern Indiana and northeastern Illinois (fig. 1). Industry in this area includes several steel mills, petroleum refineries, petroleum-tank farms, forging and foundry plants, and chemical manufacturing facilities (fig. 2). In addition, 2 hazardous-waste incinerators, at least 11 sanitary landfills, numerous uncontrolled waste-disposal sites, and about 80 accidental-spill sites are located within this area. Contaminants from these and other sources have leached to ground water and surface water

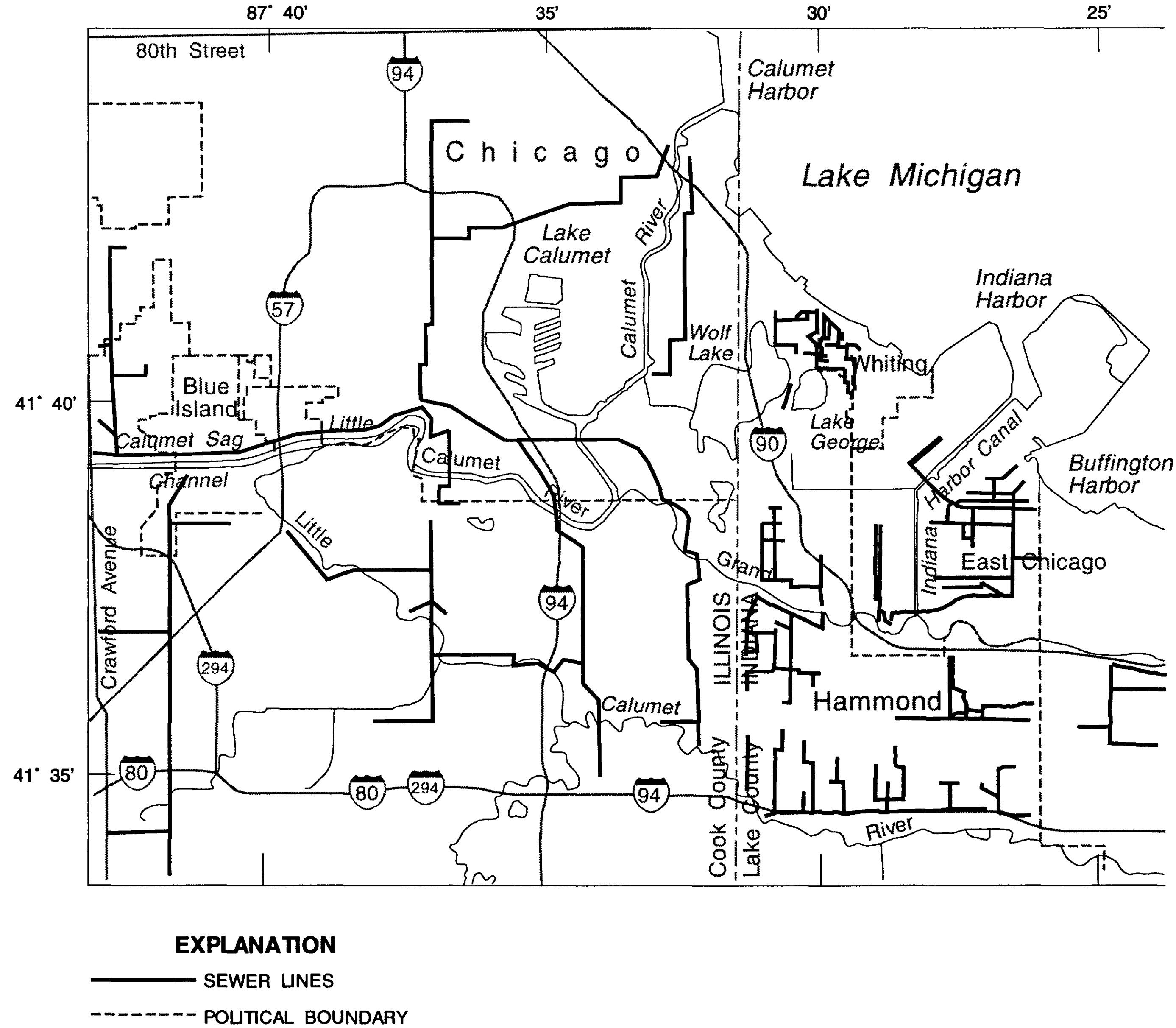


Figure 1. Location of study area, political boundaries, large sewer lines, and surface-water bodies, northwestern Indiana and the Lake Calumet area of northeastern Illinois. (Sewers shown in Indiana are modified from Fenelon and Watson, 1993. Sewers shown in Illinois are modified from Keifer and Associates, 1976.)

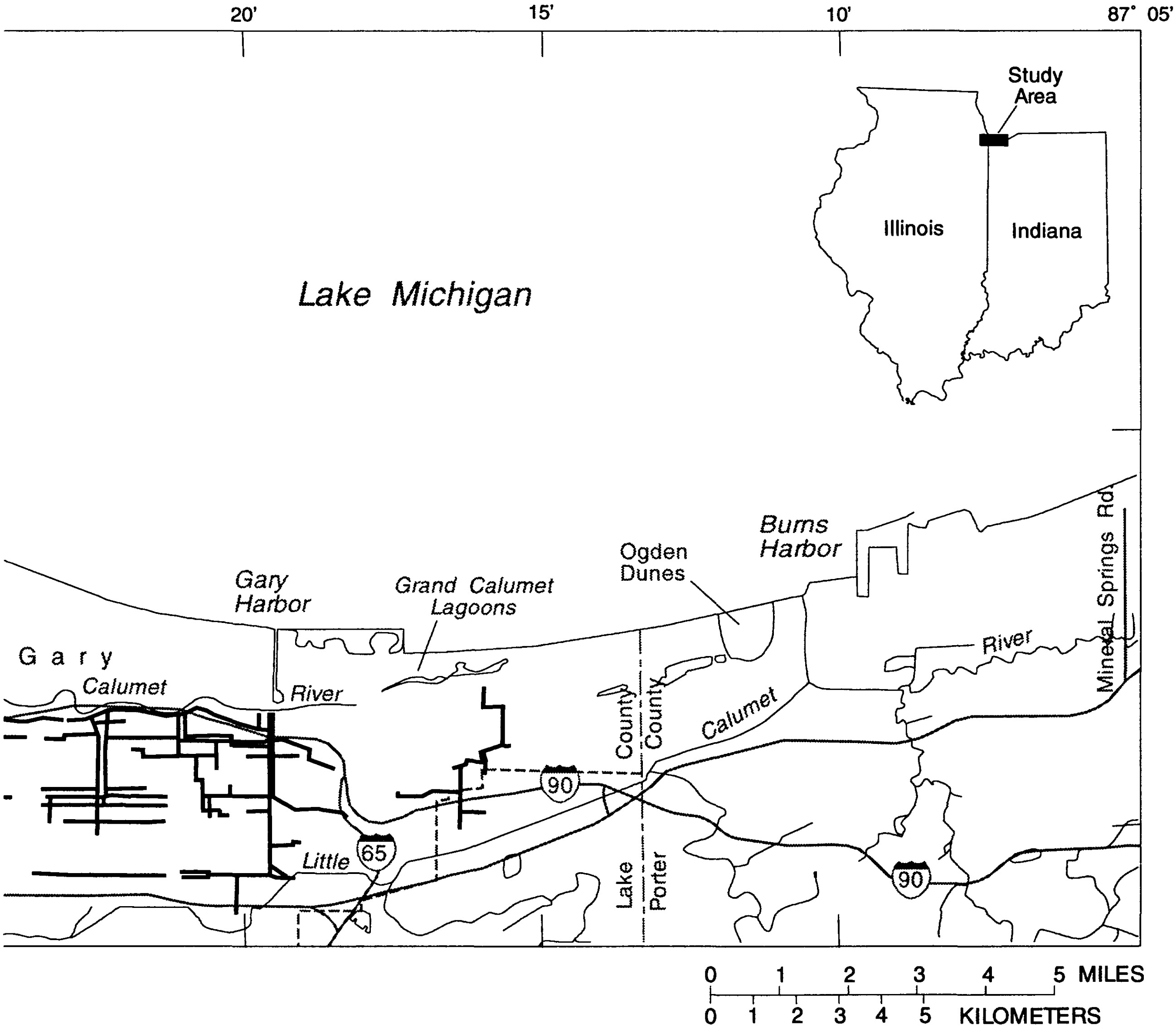


Figure 1. Continued.

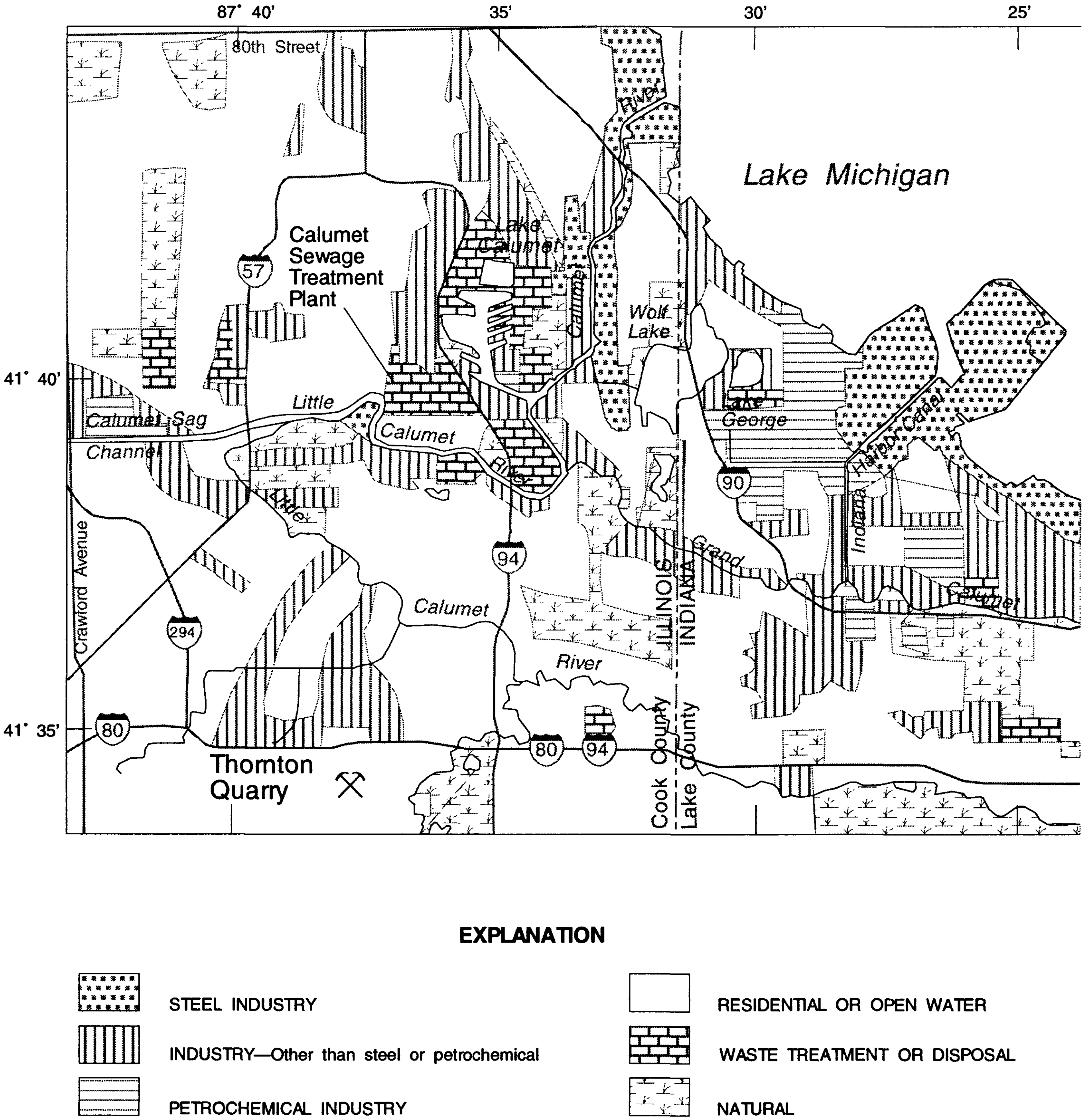


Figure 2. Land use in northwestern Indiana and the Lake Calumet area of northeastern Illinois.

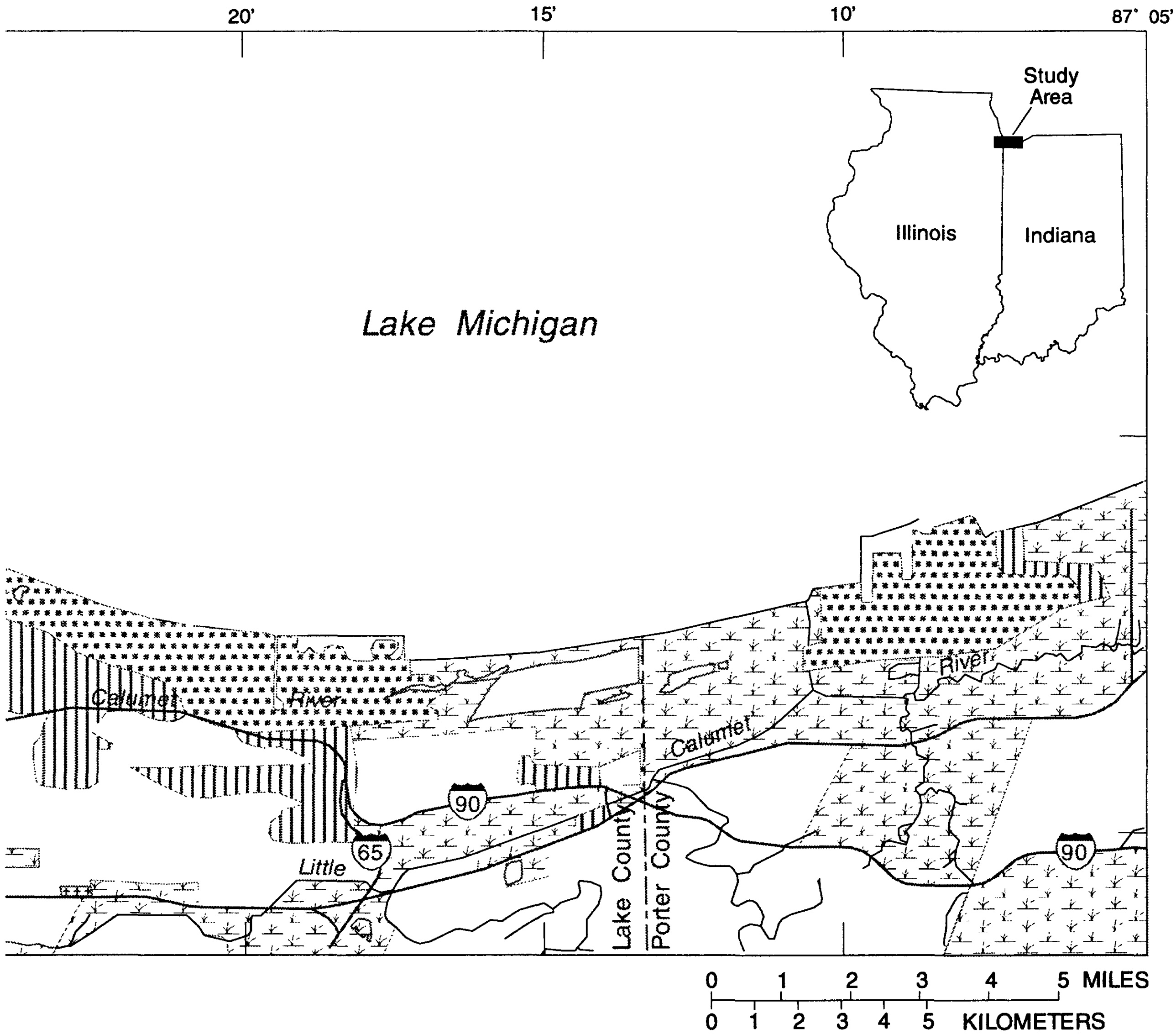


Figure 2. Continued.

(U.S. Department of Health, Education and Welfare, 1965; HydroQual, Inc., 1985; Fenelon and Watson, 1993).

The study was designed to describe the geology and hydrology in this area, determine surface-water-flow directions, determine ground-water-flow directions within and between the shallow hydraulic units, characterize the interaction between surface water and ground water, and to obtain a preliminary estimate of the location and extent of LNAPL's on the water table. This information will be used to identify areas needing additional study.

The study was divided into two major components: compilation and analysis of the existing geologic, hydrologic, and water-quality data; and collection of LNAPL and static water-level measurements during a 2-day synoptic period. Geologic, hydrologic, and water-quality data were compiled and analyzed to assess hydraulic and water-quality conditions and to plan the synoptic water-level survey. Static water-level measurements were collected to determine the directions of flow within and between the hydraulic units and to provide a better understanding of the factors that affect surface-water and ground-water flow. Measurements of LNAPL's in observation wells were collected to obtain a preliminary estimate of the location and extent of LNAPL's.

Purpose and Scope

This report describes the results of an investigation designed to characterize the geohydrology and to determine the location and extent of LNAPL's in an industrialized area in northwestern Indiana and northeastern Illinois. In addition to a description of the geology and hydrology of the study area, the results of an area-wide synoptic water-level survey are presented. The report identifies the direction of surface-water flow, the direction and velocity of vertical and horizontal ground-water flow within the hydraulic units of concern, and the nature of the surface-water and ground-water interaction in the study area during the synoptic water-level survey. The location and thickness of LNAPL's measured on the water table during the synoptic water-level survey also are presented.

Previous Work

Concerns about environmental problems have resulted in several studies of the hydrology and ground-water quality within the study area. These investigations have focused on Lake Calumet in Illinois and the Grand Calumet River near the Indiana Harbor Canal in Indiana (fig. 1). These areas have experienced the most severe environmental degradation.

One of the first investigations to provide a framework under which the environmental effects of industrial and waste-disposal activities could be assessed was a compilation of industrial waste-disposal activities in the Lake Calumet area from 1869 through 1970 (Colten, 1985). It is assumed that the history of industrial-waste disposal in Indiana is similar. Colten divided industrial activity and waste-disposal practices into three phases on the basis of the legal and technological framework within which disposal took place.

The first phase of waste-disposal activities in the Lake Calumet area occurred from 1869 to 1921 and was characterized by the discharge of untreated liquid and particulate wastes to surface-water bodies, primarily the Calumet and Little Calumet Rivers (fig. 1). The liquid wastes contained hundreds of tons of phenols, cyanide, lubricating oils, sulfuric acid, and iron sulfate (Colten, 1985, p. 27, 45, 63). Solid wastes, especially slag and fly ash, typically were dumped onto vacant land and into lakes and wetlands as fill.

The second phase of waste-disposal activity identified by Colten occurred from 1922 to 1940 and was characterized by the opening of the Calumet Sag Channel and construction of the Calumet Sewage Treatment Plant (fig. 2). Opening of the Calumet Sag Channel diverted flow in the Calumet River system from Lake Michigan to the Illinois River system under most hydraulic conditions. This diversion greatly reduced the amount of contamination in Lake Michigan, the principal source of water for industrial and municipal supply in northeastern Illinois and northwestern Indiana. Construction of the Calumet Sewage Treatment Plant resulted in effluent from a few of the industrial facilities receiving some treatment before being discharged to surface water.

The third phase of waste-disposal activities occurred from 1940 to 1970 and was characterized by a shift from disposal of industrial wastes in water to disposal on land. Municipal and construction refuse, as well as industrial waste, was buried in municipal landfills. In addition to slag and ash, which had always been disposed of in this manner, dredge spoil and sludges from wastewater-treatment facilities were dumped into nearby wetlands during this period. An increasing number of industrial facilities also began treating wastewater before releasing the effluent to the rivers.

The shift from water to land disposal of wastes, environmental regulations requiring wastewater treatment, and a decline in industrial activity lessened the effect of waste disposal on the Calumet River system since 1970 (HydroQual, Inc., 1985, p. S–3). However, significant environmental problems associated with surface-water and ground-water degradation still remain.

The disposal of large quantities of municipal and industrial wastes in lakes, wetlands, and on the land surface affects ground-water quality at several industrial and waste-disposal sites, in addition to affecting the viability of the lakes and wetlands. The effect of land disposal is particularly severe at Lake Calumet, where much of the lake area in 1869 had been filled with municipal and industrial waste by 1994 (fig. 3). Crushed and hot-poured slag also has been used as fill to create large areas of "made" land along the shores of Lake Michigan, Wolf Lake, and Lake George.

Colten (1985, appendix A) identified sites of waste disposal and industrial activities in the Lake Calumet area from 1869 to 1970 and evaluated each site for the risk it posed to human health and the environment. It was concluded that a number of these sites had the potential to adversely affect human health and the environment but that additional information was needed to accurately characterize that effect.

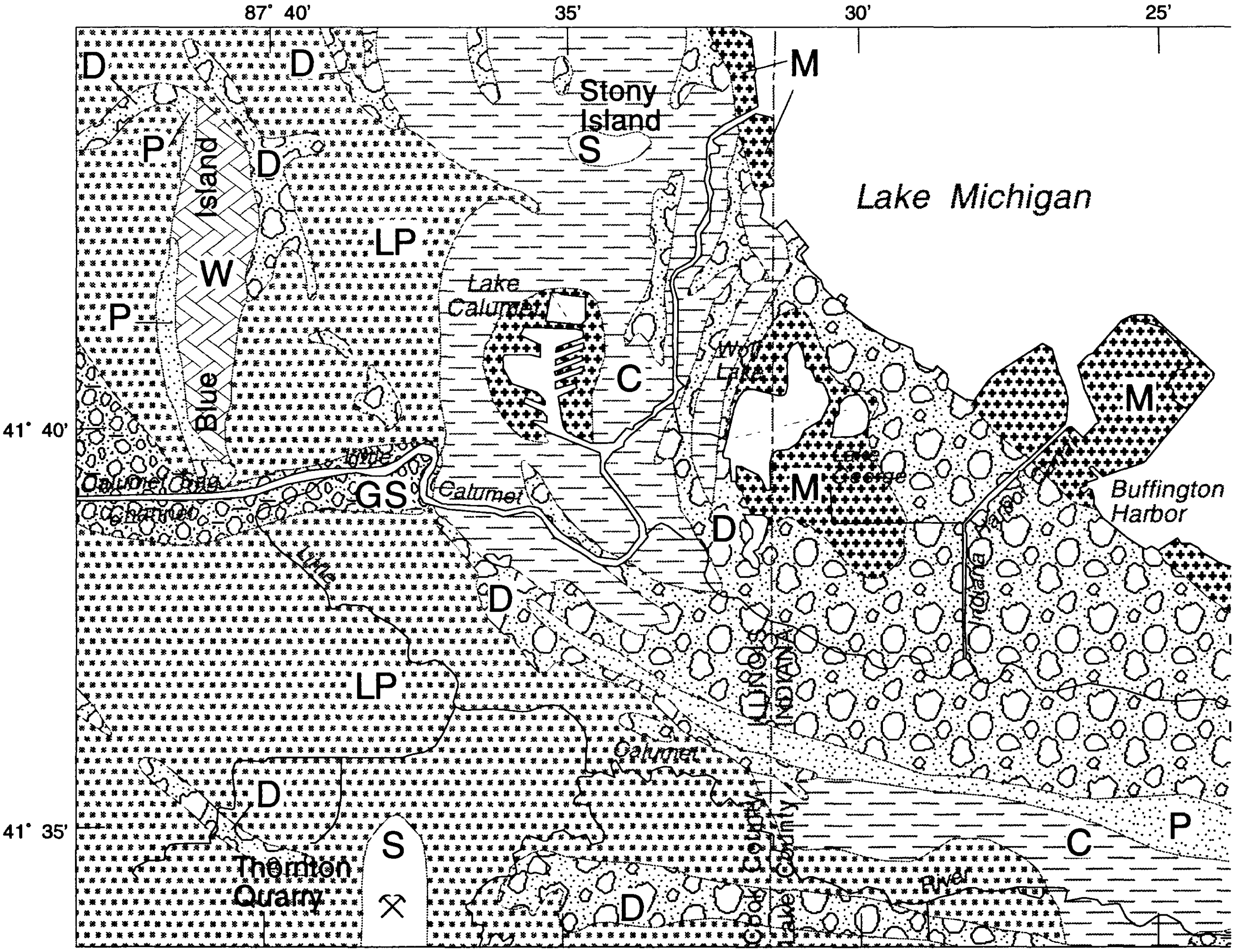
The Illinois Environmental Protection Agency (IEPA) drilled several borings in the Lake Calumet area and analyzed the soils and ground water from the borings for a number of compounds (Illinois Environmental Protection Agency, 1986) to determine the effect of industrial and waste-disposal activities on shallow ground-water quality in the Lake Calumet area. Concentrations of several metals above background levels were detected in some of the soil samples. Several volatile and semivolatile organic compounds were detected in ground-water samples collected at some industrial sites.

Expanding on the work of the IEPA, the Illinois State Water Survey (ISWS) performed a preliminary assessment of the hydrology and ground-water quality in the Lake Calumet area (Cravens and Zahn, 1990). Cravens and Zahn noted that shallow ground-water flow is intrinsically connected to flow in the surface-water bodies but that delineation of the shallow ground-water-flow system was difficult because of the sparse data then available. The report also noted that flow in the uppermost bedrock aquifer is generally toward Lake Michigan, though it has been disrupted by excavations in the bedrock for the Metropolitan Water Reclamation District of Greater Chicago's Tunnel and Reservoir Plan (TARP) storm-drainage tunnels. These tunnels are about 300 ft below the land surface and are used to transport combined-sewer-overflow water to treatment facilities. Analysis of ground-water-quality data collected by the ISWS and a number of government agencies and private organizations led to the conclusion that, although organic compounds and metals were detected in the shallow ground water near many of the industrial and waste-disposal facilities, no evidence of widespread contamination of the shallow ground water in the Lake Calumet area was found. Analysis of the ground-water-quality data also led to the conclusion that the small amounts of contamination detected in the uppermost bedrock aquifer could be attributed to leakage from the surface or shallow ground water to the bedrock aquifer around improperly sealed wells or borings, not to transport through geologic material.

The ISWS is currently (1994) investigating the hydrogeology and ground-water quality in the shallow ground-water-flow system near Lake Calumet and Wolf Lake. High concentrations of metals and volatile organic compounds were detected in ground-water samples collected in several shallow wells during this current study (Cravens and Roadcap, 1991, p. 13, 14; Roadcap and Kelly, 1994, p. 39, 40). Slag fill was assumed to be the source of most of the metals.

A detailed study of the shallow ground-water-flow system in the Indiana part of the study area was done by the USGS in 1985–86 (Watson and others, 1989). The report notes that the water-table configuration in this area mirrors surface topography except near large sewers and pumping centers where local depressions are present. Analysis of surface-water and ground-water levels during this study indicates that ground water typically discharges to the major surface-water bodies and small ditches, though flow reversals are common.

A follow-up study of the hydrology and ground-water quality in the shallow ground-water system in northwestern Indiana was done by the USGS in



EXPLANATION

RECENT

M — MADE AND MODIFIED LAND—Artificial fill and land substantially modified by the removal of unconsolidated deposits. Many small areas not mapped

WISCONSINAN AND RECENT

GS — MUCK OR SILT OVER SAND AND GRAVEL—Outwash sand and gravel overlain in places by thin lacustrine, paludal or alluvial deposits of peat, muck, or clay. Martinsville Formation over outwash facies of Atherton Formation in Indiana, glacial sluiceway in Illinois

P — SAND AND SOME SILT—Dune deposits. Dune facies of Atherton Formation in Indiana, Parkland Sand in Illinois

D — SAND AND GRAVEL—Beach and shoreline deposits in bars, spits, and beaches. Some dune sand. Atherton Formation in Indiana, Dolton Member in Illinois

C — CLAY AND SILT—Lacustrine deposits. Lacustrine facies of Atherton Formation in Indiana, Carmi Member in Illinois

WISCONSINAN

W — TILL—End moraine deposit. Lagro Formation in Indiana, Wadsworth Till in Illinois

LP — TILL—Wave-scoured lake-bottom till. Lagro Formation in Indiana, Wadsworth Till in Illinois

SILURIAN

S — DOLOMITE—Marine deposit. Niagaran Series

Figure 3. Surficial geology, northwestern Indiana and the Lake Calumet area of northeastern Illinois. (From Schneider and Keller, 1970.)

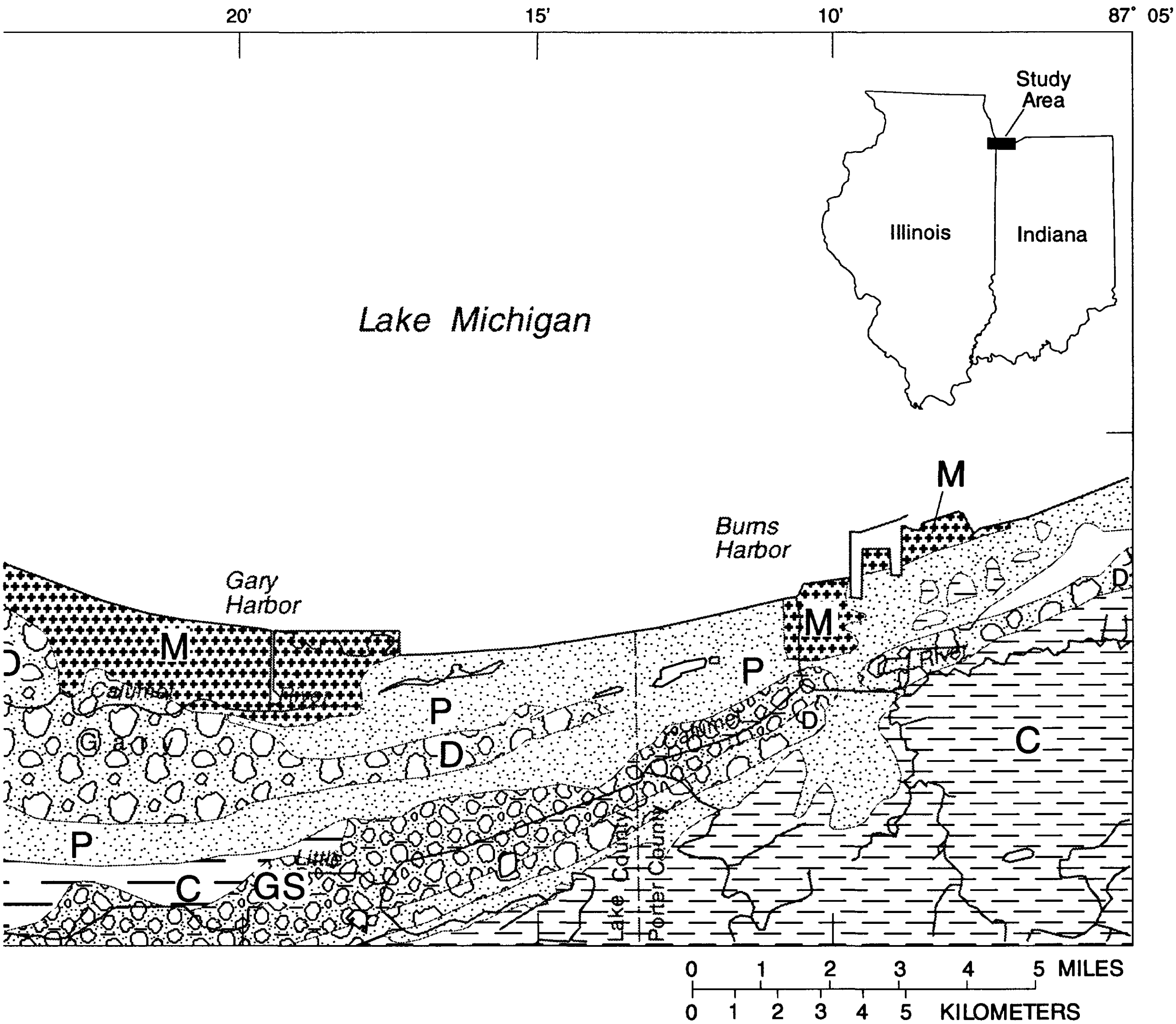


Figure 3. Continued.

1988–89 (Fenelon and Watson, 1993). Ground-water quality is described as being poorest at the steel and petrochemical facilities, moderate near light industrial and commercial areas, and best in residential and park areas. It was estimated that ground water may contribute more than 10 percent of the total chemical load of ammonia, chromium, and cyanide to the Grand Calumet River.

Numerous geotechnical and environmental investigations at specific industrial and waste-disposal sites also have been done. Results indicate environmental problems at several sites, many of which are adjacent. These site-specific investigations generally provide a detailed understanding of the geohydrology at a specific site, but not of the hydrogeologic relation between adjacent sites and between a site and the area as a whole.

Acknowledgments

The authors extend their thanks to the numerous Federal, State, and municipal agencies and corporations that provided hydrogeologic information and (or) access to the data-collection points. In addition, the authors would like to thank those persons from the USEPA, Indiana Department of Environmental Management, and Metcalf and Eddy, Inc., who helped collect the water-level data for this study. Finally, Doug Yeskis of the USEPA and Jeff Miller of Metcalf and Eddy, Inc., are thanked for their assistance in the planning and execution of this study.

DESCRIPTION OF STUDY AREA

The study area is located in the Calumet area of northwestern Indiana and northeastern Illinois and includes parts of Porter and Lake Counties in Indiana and Cook County in Illinois (fig. 1). The study area is bounded by the southern limit of the Little Calumet River and Interstates 80 and 94 to the south, Crawford Avenue to the west, Mineral Springs Road to the east, and 80th Street and Lake Michigan to the north.

Physiography and Climate

The study area is in the Eastern Lake Section of the Central Lowland physiographic province defined by Fenneman (1938). The Indiana part is in the Calumet Lacustrine Plain subdivision of the Northern Moraine and Lake Region defined by the Indiana Geological Survey (IGS) (Malott, 1922, p. 113; Schneider, 1966, p. 50). The Calumet Lacustrine Plain extends westward into Illinois where it is called the Chicago Lake Plain subsection of the Great Lakes Section of the Central Lowland physiographic province as defined by the Illinois State Geological Survey (ISGS) (Leighton and others, 1948, p. 21).

Glacial, lacustrine, paludal, and aeolian processes have produced the physiographic characteristics of this area. Near the end of the last glacial period, glacial ice moved southward along the basin currently occupied by Lake Michigan. The ice stopped just south of the study area, forming the Valparaiso Morainic System (Bretz, 1939, p. 45–59, fig. 37). The glacier receded and advanced north of the Valparaiso Morainic System several times, forming several end moraines in Illinois and Indiana. As the glacier receded to the north, Lake Chicago formed between the glacier and the moraines (Wayne, 1966, p. 36). Lake Chicago and its successors rose and fell repeatedly, producing physiographic features whose locations are controlled, in part, by the location of the shoreline during the fluctuating lake stages.

Erosional and depositional processes associated with the advance and retreat of the glaciers and the fluctuations in lake stage resulted in a generally flat land surface that slopes gently toward Lake Michigan. The flat surface of the lake plain is broken up by a number of low beach ridges, morainal headlands and islands, and a large glacial drainway (fig. 4). Most of the area is swampy and poorly drained under natural conditions, and the location of surface-water bodies is primarily affected by the location of the beach ridges. The land-surface altitude on the flat part of the lake plain ranges from about 590 ft above sea level west of Lake Calumet to about 581 ft above sea level along the shore of Lake Michigan.

The largest of the beach ridges is the Toleston Beach Ridge, which separates the Grand Calumet and Little Calumet Rivers. Rising between 10 and 15 ft above the lake plain, the Toleston Beach Ridge is the most lakeward of the dune and beach complexes produced by shoreline deposition during a period of higher lake stage (Thompson, 1989, p. 711). Numerous smaller sandy ridges, including dunes, spits, and bars, also are present. Many of the ridges that were once present have been leveled or removed by quarrying in the past century. These ridges roughly parallel Lake Michigan.

The most prominent dune deposits in the study area are located at the Indiana Dunes National Lakeshore (IDNL) (fig. 4). Topographic relief at the IDNL varies from near lake level (581 ft above sea level) to as high as 750 ft above sea level. The dune crests are the highest natural features in the study area.

Blue Island is a morainal island near the western edge of the study area (fig. 4). Blue Island trends north-south with a maximum elevation of about 670 ft above sea level.

Stony Island is a bedrock outcrop north of Lake Calumet (fig. 4). About 1 mi long and a quarter of a mile in width, Stony Island is about 20 ft above the lake plain and trends east-west.

The principal outlet for Lake Chicago was through a glacial sluiceway, or outwash channel, between the Toleston Beach Ridge and Blue Island (fig. 4) (Malott, 1922, p. 152; Bretz, 1939, p. 59; Willman, 1971, p. 55), although the lake drained to the east during periods of low lake stage (Fullerton, 1980). Erosion along the sluiceway formed a topographic depression which is the current location of the Calumet Sag Channel.

The climate in this area is classified as temperate continental, with a mean annual temperature of about 10°C and a mean annual precipitation of 35.7 in. (National Oceanic and Atmospheric Administration, 1991, 1992b). More than half of the average annual precipitation falls from April 1 through August 31. Although large variations in precipitation and temperature may occur in any year, summers generally are hot and humid, whereas winters are cold. Lake Michigan has a moderating local effect on temperature.

The National Oceanic and Atmospheric Administration (NOAA) maintained two weather stations in the study area—one at the Gary Regional Airport, and the other at Ogden Dunes, Ind. (fig. 4). From 1951 to 1980, the mean monthly temperature at these stations varied from about –5°C in January to about 23°C in July, and the mean monthly precipitation varied from 1.5 in. in February to 4.0 in. in June. Precipitation at Ogden Dunes was slightly larger than at the Gary airport (National Oceanic and Atmospheric Administration, 1982).

From June 1991 to June 1992, the 12-month period before the start of the synoptic water-level survey, the amount of precipitation measured at a NOAA station at the University of Chicago, about 1 mi north of the northern boundary of the study area, was 13 in. below normal (National Oceanic and Atmospheric Administration, 1991, 1992b). The University of Chicago station was used because the Gary airport and Ogden Dunes stations were not in operation from June 1991 to June 1992.

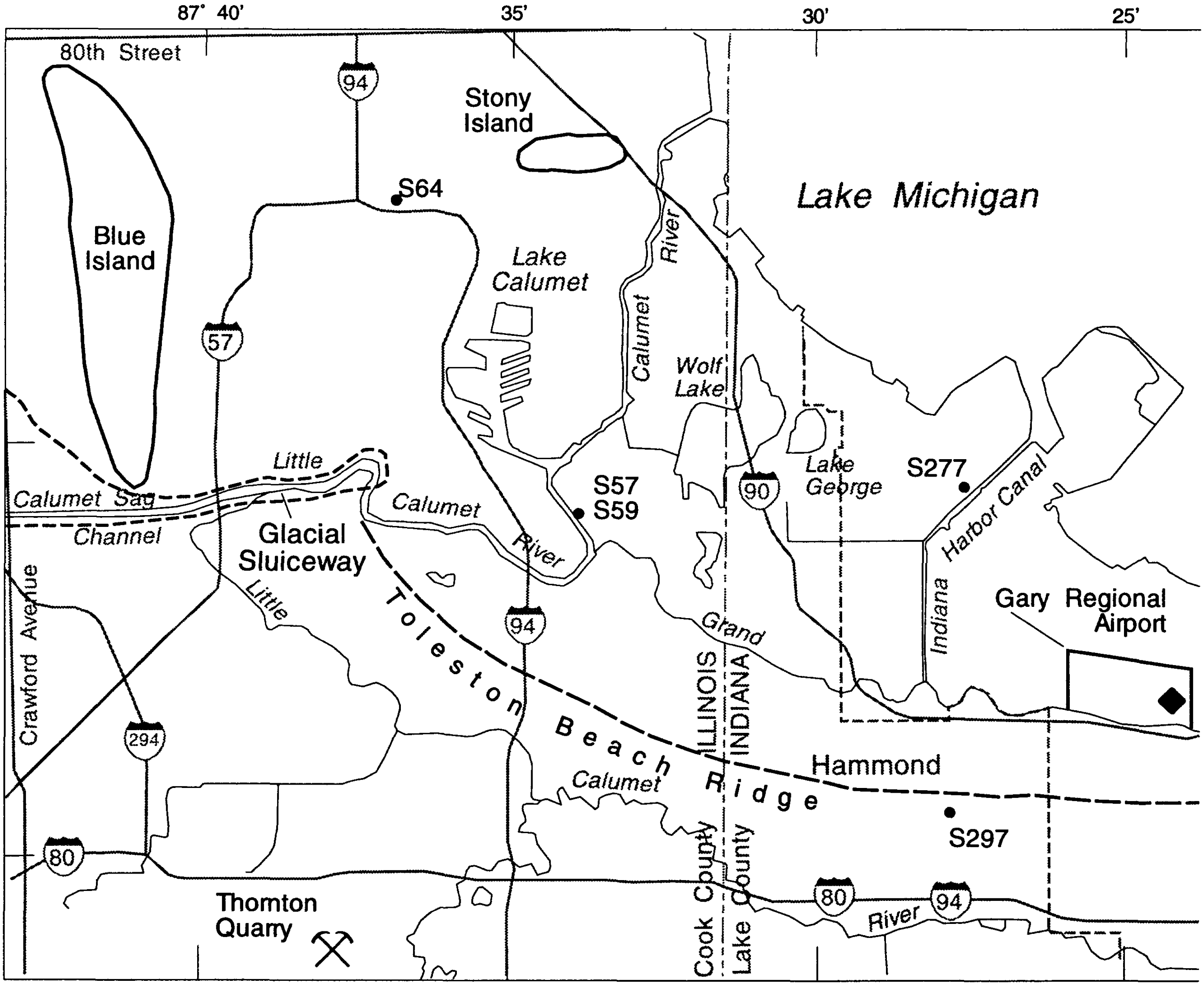
An estimated 70 percent of the average annual precipitation on this area is returned to the atmosphere by evapotranspiration (Mades, 1987, p. 13). Based on this percentage, average annual precipitation available for recharge to ground water is no greater than 10.7 in. More than three-quarters of all evapotranspiration occurs during the growing season (U.S. Geological Survey, 1970, p. 96). During the growing season, evapotranspiration normally exceeds precipitation by about 1 to 2 in. and depletes available soil moisture. During the nongrowing season, precipitation generally exceeds evapotranspiration by about 11 in. and replenishes soil moisture and recharges ground water. The mean annual lake evaporation is 29.5 in. or about 83 percent of the average annual precipitation.

Land Use

Land use in the study area is primarily residential and industrial (fig. 2). Large tracts of open water, natural land, and land for the treatment and disposal of wastes also are present. Much of the land along Lake Michigan and the Calumet River is or was used for steel production. Land used by the petrochemical industry for tank farms and petroleum refining is located south and west of the steel mills in Indiana and at scattered locations along the Grand Calumet River, the Calumet Sag Channel, and Lake Calumet in Illinois. A variety of other industrial activities, including automobile assembly, scrap processing, and chemical manufacturing take place in this area. Several landfills, wastewater-treatment plants, and unregulated waste-disposal facilities are present near Lake Calumet.

GEOHYDROLOGY

The geology and hydrology of the study area have been described by a number of investigators (Bretz, 1939, 1955; Rosenshein and Hunn, 1968;



EXPLANATION

• S64 MONITORING WELL LOCATION AND NAME—Site of well in which background water-level data were collected

◆ WEATHER STATION

Figure 4. Location of important topographic features and selected monitoring wells, northwestern Indiana and the Lake Calumet area of northeastern Illinois.

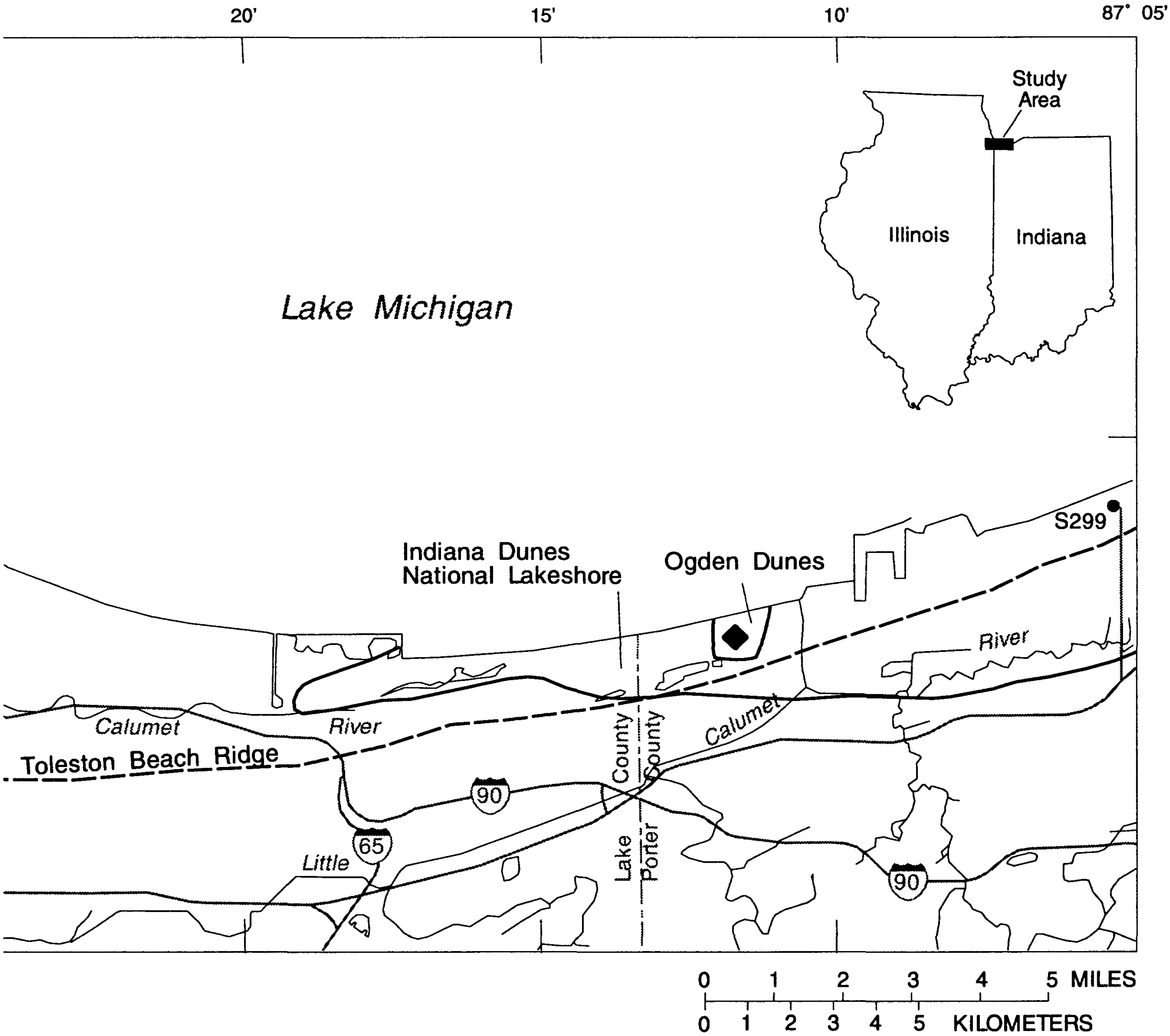


Figure 4. Continued.

Willman, 1971; Hartke and others, 1975; Watson and others, 1989; Cravens and Zahn, 1990). Their descriptions, in combination with analysis of lithologic and hydrologic data compiled during this and previous studies, form the basis for the discussion of the geology and hydrology.

Geology

The geologic deposits of concern to this investigation are bedrock deposits of Silurian and Devonian age and unconsolidated deposits of Quaternary age. The stratigraphic nomenclature used in this report is that of the ISGS (Willman and Frye, 1970, p. 70–75; Willman and others, 1975, p. 100–104) and the IGS (Shaver and others, 1970, 1986). Their usage does not necessarily follow the usage of the USGS.

Bedrock Deposits

The bedrock in this area is comprised primarily of dolomite, limestone, and shale. The bedrock strata are essentially horizontal, except in the northeastern part of the study area where the bedrock strata dip slightly toward the northeast.

The oldest bedrock deposits of concern to this investigation are Silurian dolomites and limestones of the Niagaran Series. The Niagaran carbonates are up to 300 ft thick in the study area and are present at the bedrock surface in Illinois and western Indiana (fig. 5). These deposits are known as the Wabash Formation in Indiana (Shaver and others, 1986, p. 162) and the Racine Dolomite in Illinois (Willman, 1971, p. 29–30).

The Niagaran carbonates are characterized by large reefs, two of which are present at the land surface at Stony Island and Thornton Quarry (fig. 3). The reefs are composed of a vuggy dolomite with traces of argillaceous material or sand grains. A solid petroleum residue called asphaltum is present in some of the vugs in the reefs (Willman, 1971, p. 30). Beds on the flanks of the reefs commonly dip radially away from the massive to irregularly bedded reef core. Away from the reefs, the Niagaran deposits consist of dense, cherty, argillaceous dolomite and limestone with localized lenses of green shale.

The Niagaran carbonates contain an irregularly distributed network of vertical fractures with a major trend at N. 47° W. and a minor trend at about N. 57° E. (Zeizel and others, 1962; Foote, 1982). Fractures are generally more abundant near the bedrock surface, where the bedrock is more weathered, and decrease in number with depth as the rock becomes more competent (Suter and others, 1959, p. 9). The reef deposits tend to have fewer fractures than the interreef deposits.

In addition to fractures, several vertical faults have been identified in the bedrock in Illinois (fig. 5). Most of these faults are oriented northwest to southeast and are 2–3 mi long. Faulting has offset the bedrock strata as much as 30 ft, but displacement does not extend upward into the unconsolidated materials (Keifer and Associates, 1976, p. 27–36). The extent of faulting in Indiana is unknown.

Lower to middle Devonian deposits of the Detroit River and Traverse Formations unconformably overlie the Niagaran Series in parts of Indiana (fig. 5). The Detroit River Formation varies from a light colored, fine-grained, sandy dolomite near the base of the formation to a gray to dark brown dolomite and limestone with thin to massive beds of gypsum and anhydrite in the upper part of the deposit (Shaver and others, 1986, p. 35–37). The Traverse Formation unconformably overlies the Detroit River Formation. The Traverse Formation consists of brown to gray, fine-to-coarse grained limestone to dolomitic limestone (Shaver and others, 1986, p. 156). Both formations thicken toward the northeast.

The Upper Devonian Antrim Shale is the youngest bedrock unit in the study area and unconformably overlies the Traverse Formation in Porter County (fig. 5). The Antrim Shale consists of brown to black, noncalcareous shale with gray calcareous shale or limestone in the lower part of the formation (Shaver and others, 1986, p. 5).

The bedrock surface, based on lithologic logs compiled from throughout the study area, has more than 175 ft of relief (fig. 6). Bedrock highs are present at Stony Island and Thornton Quarry. Bedrock lows are present near Burns Harbor, Gary Harbor, the Indiana Harbor Canal, and immediately east of Lake Calumet. Bedrock highs at Stony Island and Thornton Quarry are attributed to the greater resistance of the reef deposits in these areas to erosion (Bretz, 1939, p. 66). The bedrock valleys may mark the paths of preglacial drainage that flowed north and east from a surface-water divide (Bretz, 1939, p. 92)

Unconsolidated Deposits

Most of the unconsolidated sediments were originally deposited by glaciers or were deposited as lake-bottom and near-shore deposits of Lake Chicago and its successors (Willman, 1971, p. 38–51; Hartke and others, 1975, p. 7). Glacial and lacustrine processes resulted in the deposition of three types of materials: glacial till, lacustrine silt and clay, and fluvial and aeolian sand. Small amounts of muck, peat, and fine gravel were deposited in localized areas (fig. 3). The total thickness of the unconsolidated sediments ranges from less than 1 ft in the vicinity of Thornton Quarry to over 225 ft east of Burns Harbor (figs. 7 and 8).

In most of the area, the bedrock is overlain by dense, lenticular bodies of poorly sorted gravel, sand, and silt. These deposits are informally called the Lemont Drift in Illinois (Cravens and Zahn, 1990, p. 15). The exact age of these deposits is unknown, but they appear to have been eroded and weathered before being covered by sediments during subsequent glacial advances.

The Lemont Drift and similar deposits in Indiana are overlain by a gray clayey till. The till is very hard and tends to become denser and more consolidated with depth, probably because of compression by the ice sheets during the glacial advances. This till is known as the Wadsworth Till Member of the Wedron Formation in Illinois (Willman, 1971, p. 46) and composes part of the Lagro Formation in Indiana (Shaver and others, 1970, p. 87–88). The Wadsworth Till Member is present at the land surface at Blue Island (fig. 3).

The Wadsworth Till Member is overlain by sand, silt, and clay deposits known as the Equality Formation in Illinois (Willman, 1971, p. 49) and the Atherton Formation in Indiana (Shaver and others, 1970, p. 7). These deposits are the surficial geologic unit in most of the study area (fig. 3). The Wadsworth-Equality boundary represents a transition from deposition dominated by glacial processes to deposition dominated by lacustrine processes.

The Equality Formation is subdivided by the ISGS into the Carmi and Dolton Members. The Carmi Member is equivalent to the lacustrine facies of the Atherton Formation (Schneider and Keller, 1970; Willman, 1971, pl. 1). The Dolton Member is equivalent to the beach and shoreline deposits of the Atherton Formation (Schneider and Keller, 1970; Willman, 1971, pl. 1). These units grade laterally into each other and are superimposed in some areas.

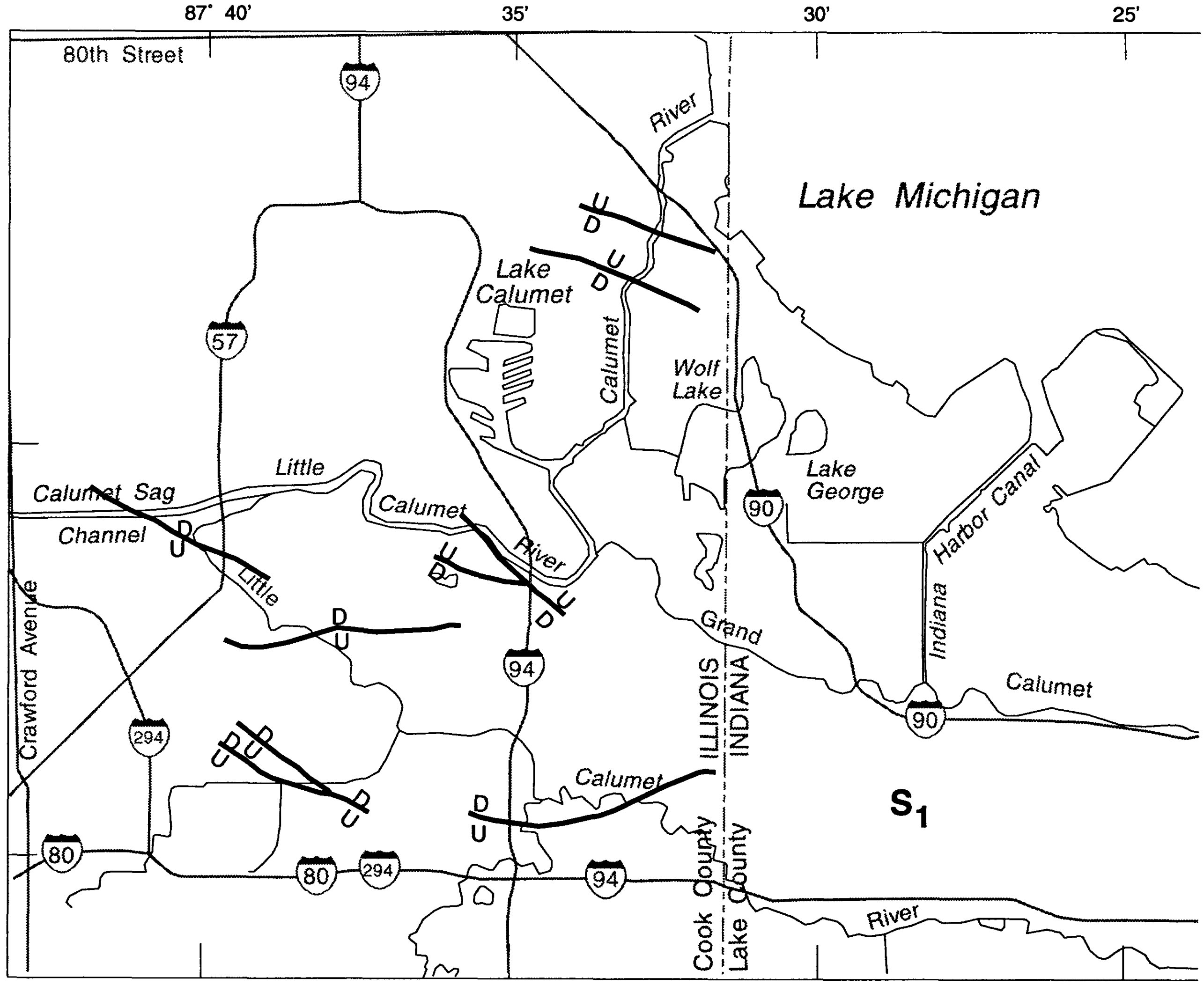
The Carmi Member is comprised predominantly of silt and clay with localized peat beds. These are generally well bedded or laminated lake deposits and are at the land surface in much of the area around Lake Calumet and parts of the Little Calumet River (fig. 3). The Carmi Member underlies the Dolton Member near the confluence of the Calumet, Grand Calumet, and Little Calumet Rivers (Woodward-Clyde Consultants, 1984, fig. E–3) and in most of the Indiana part of the study area (Watson and others, 1989, p. 18).

The Dolton Member is predominantly sand but contains thin, discontinuous beds of muck and peat as well as pebbly sand and gravel. These sands consist of shore and shallow-water lake deposits, commonly found in ridges defining the former locations of spits and beaches. The Dolton Member is at the land surface in much of the area east of the Calumet River and at sporadic locations west of Lake Calumet (fig. 3). The Dolton Member underlies the Carmi Member in much of the area from the State line to the eastern shore of Lake Calumet and along parts of the Little Calumet River (compare fig. 3 and fig. 8).

The Parkland Sand is a well sorted, medium-grained sand that was blown from the glacial outwash and beach deposits into dunes and sheet-like deposits around the dunes (Willman, 1971, p. 50). The Parkland Sand is found along the Toleston Beach Ridge, the western flank of Blue Island, and at the Indiana Dunes National Lakeshore (figs. 3, 4). The Parkland Sand is equivalent to the dune facies of the Atherton Formation in Indiana (Shaver and others, 1970, p. 7).

The glacial sluiceway eroded into, and in some areas through, the till along the path of the Calumet Sag Channel and was filled with fluvial sand and gravel deposits (fig. 3). These sands and gravels have a maximum thickness of about 25 ft (fig. 8). Glacial outwash deposits of sand and gravel also are along the path of the Little Calumet River in parts of Indiana (fig. 3). Outwash and sluiceway deposits are part of the Martinsville Formation described by Shaver and others (1970, p. 107).

With the exception of the area mapped as Wadsworth Till at Blue Island, which was never submerged, the top of the Wadsworth Till Member was reworked by wave erosion throughout the study area (fig. 3) (Willman, 1971, pl. 1; Watson and others, 1989, p. 18). Though deposition from wave erosion was minimal, the upper surface of the



EXPLANATION

DEVONIAN

D_2 ANTRIM SHALE—Brown to black and gray shale with limestone in lower part

D_1 TRAVERSE AND DETROIT RIVER FORMATIONS—Predominately limestone and dolomite

SILURIAN

S_1 NIAGARAN SERIES—Predominately dolomite

U / D FAULT—Approximately located. U indicates upthrown side. D indicates downthrown side. No fault data available for Indiana

Figure 5. Bedrock geology, northwestern Indiana and the Lake Calumet area of northeastern Illinois. (Modified from Schneider and Keller, 1970.)

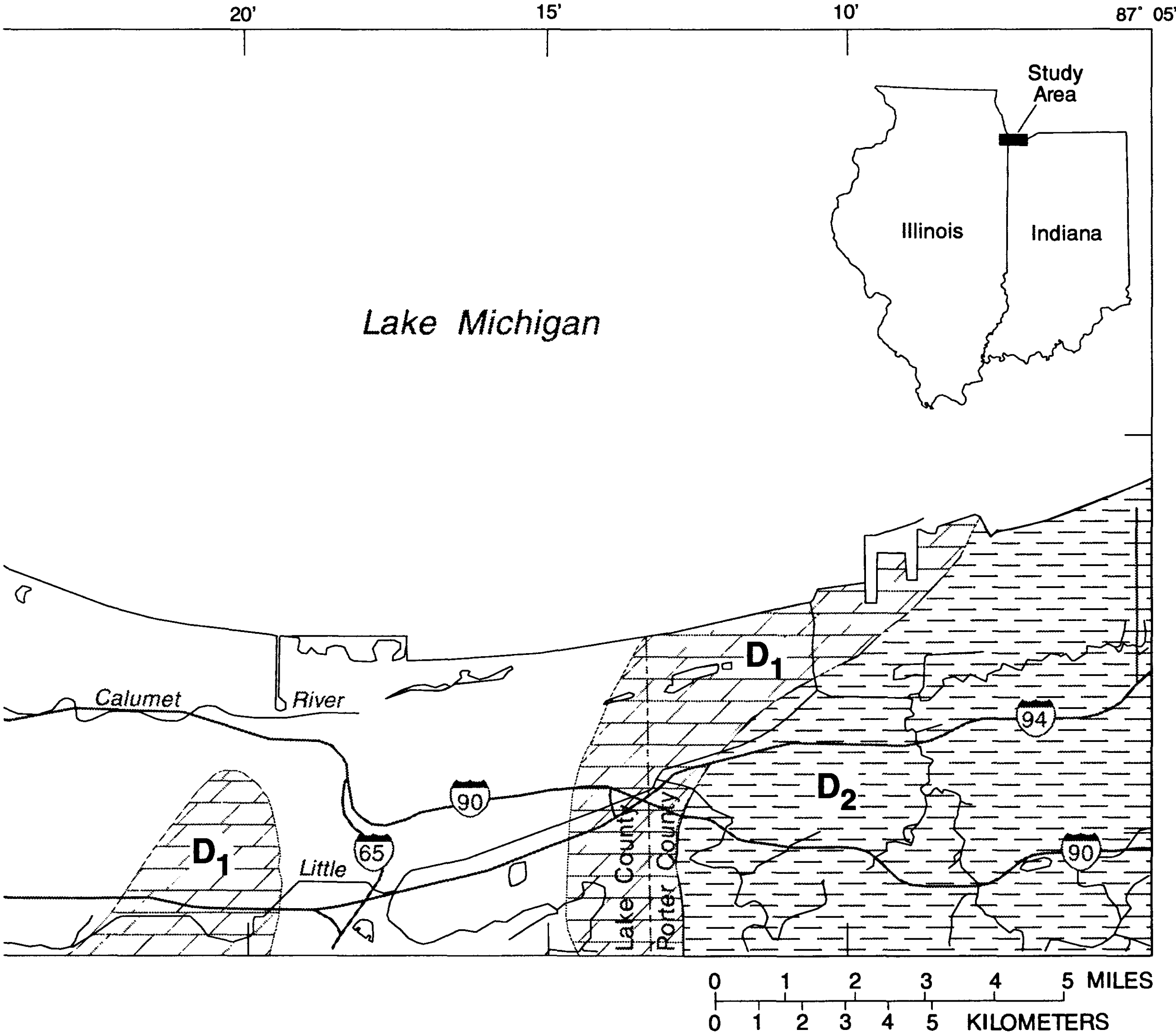
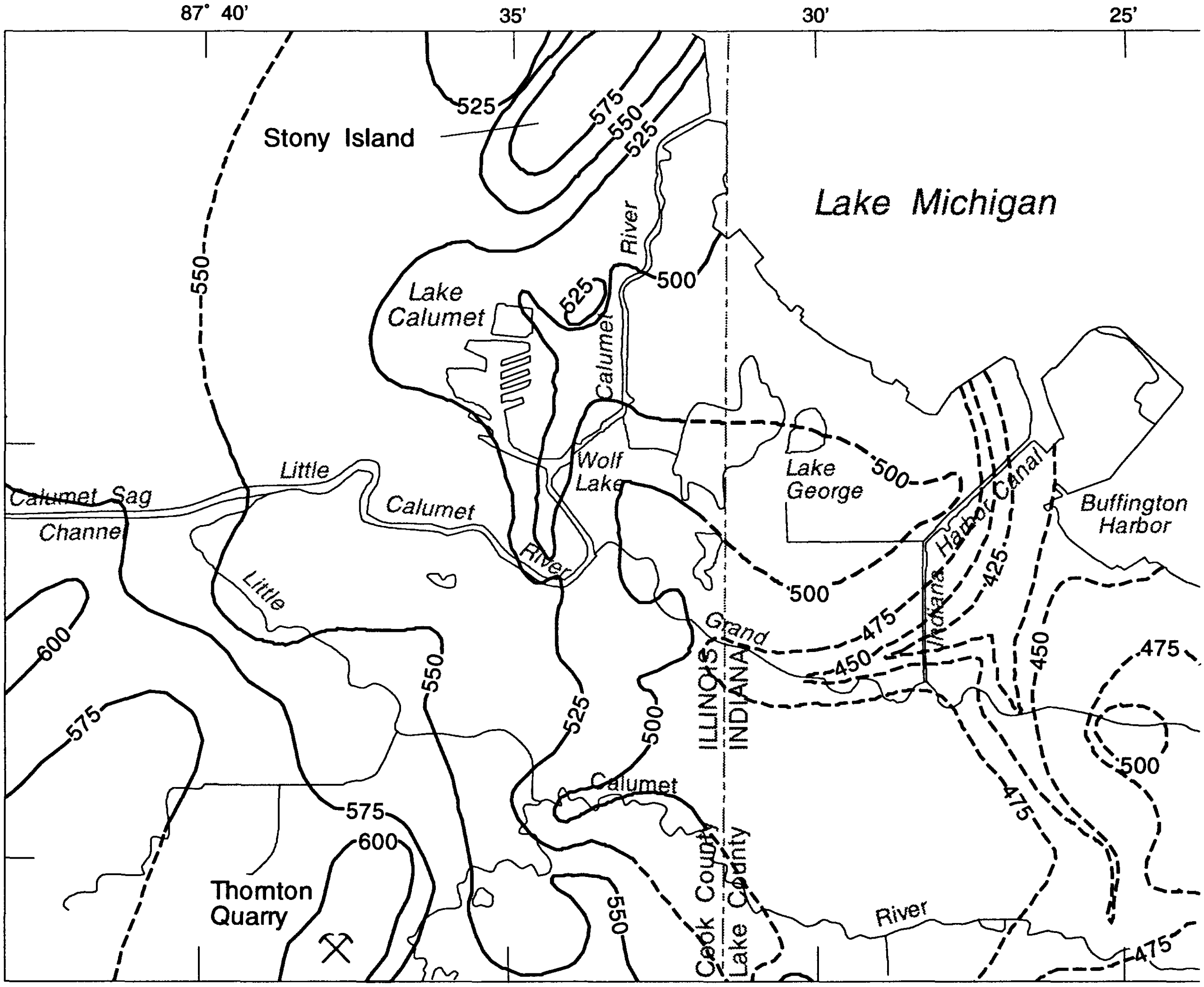


Figure 5. Continued.



EXPLANATION

—450— BEDROCK-SURFACE CONTOUR—
Shows altitude of bedrock surface.
Dashed where approximate.
Contour interval 25 feet.
Datum is sea level

Figure 6. Bedrock surface, northwestern Indiana and the Lake Calumet area of northeastern Illinois.

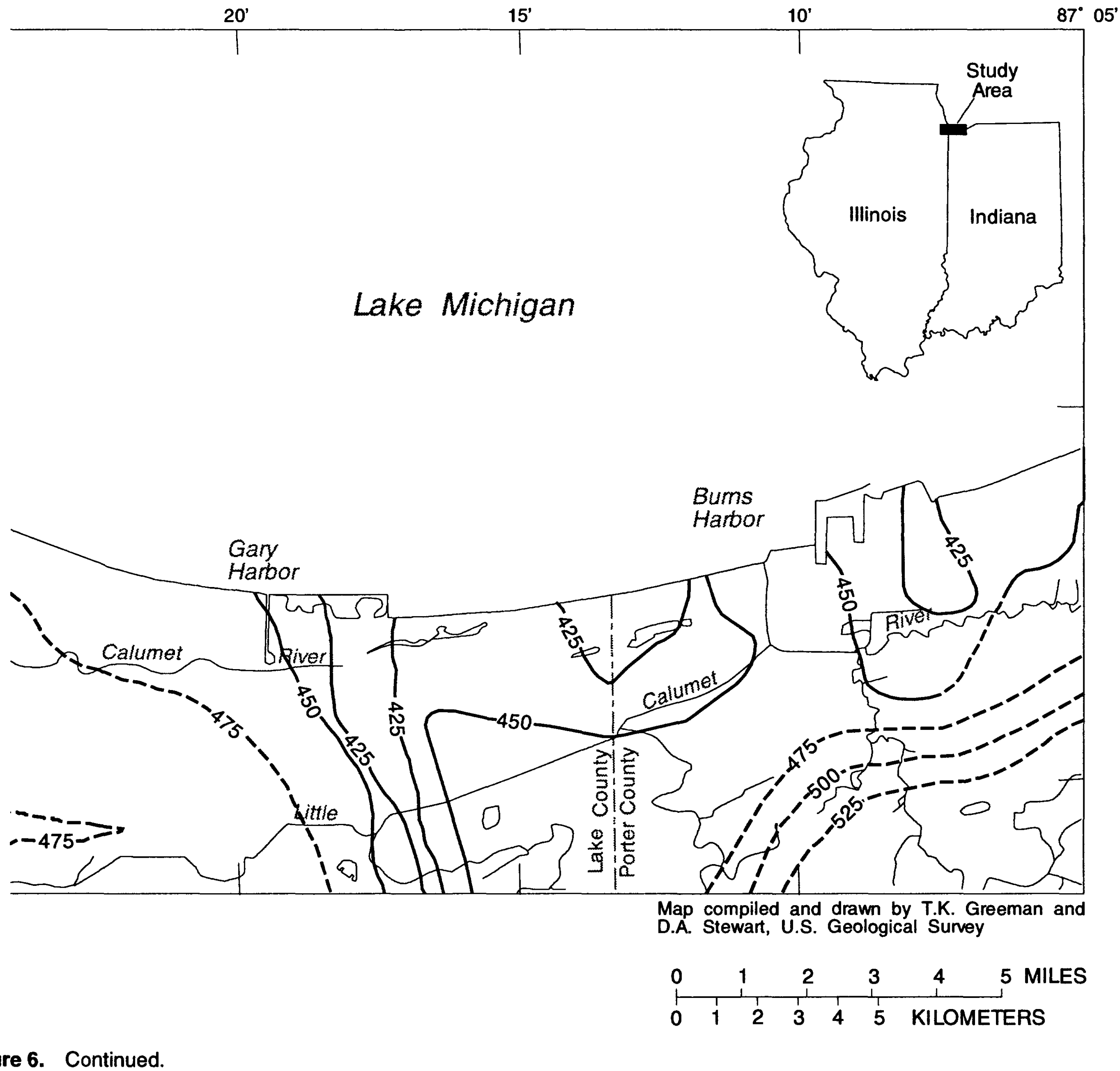
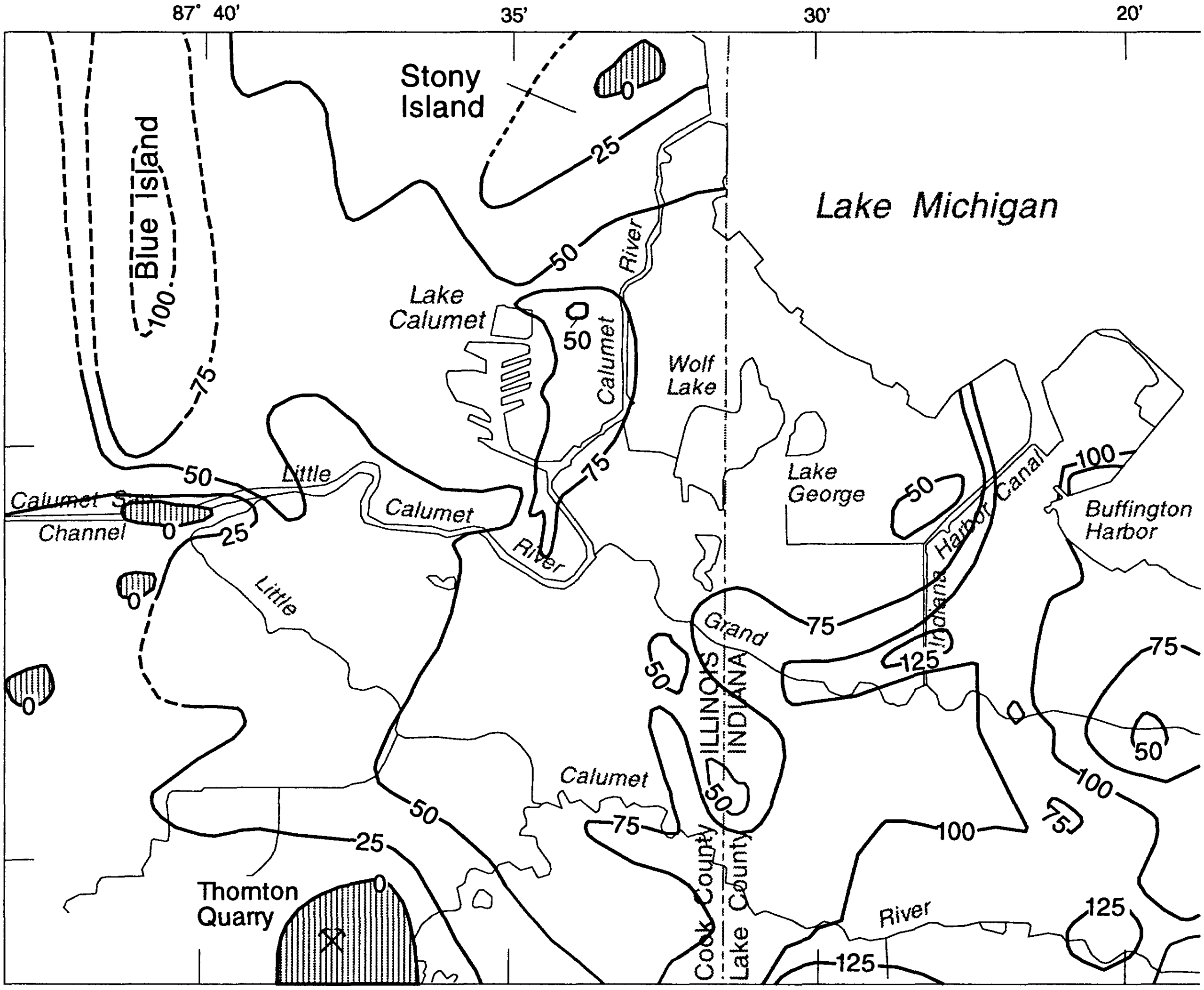


Figure 6. Continued.



EXPLANATION

SILT AND CLAY ABSENT

—50— LINE OF EQUAL THICKNESS—Shows thickness of silt and clay deposits. Dashed where approximate. Interval 25 feet

Figure 7. Thickness of fine-grained unconsolidated deposits, northwestern Indiana and the Lake Calumet area of northeastern Illinois.

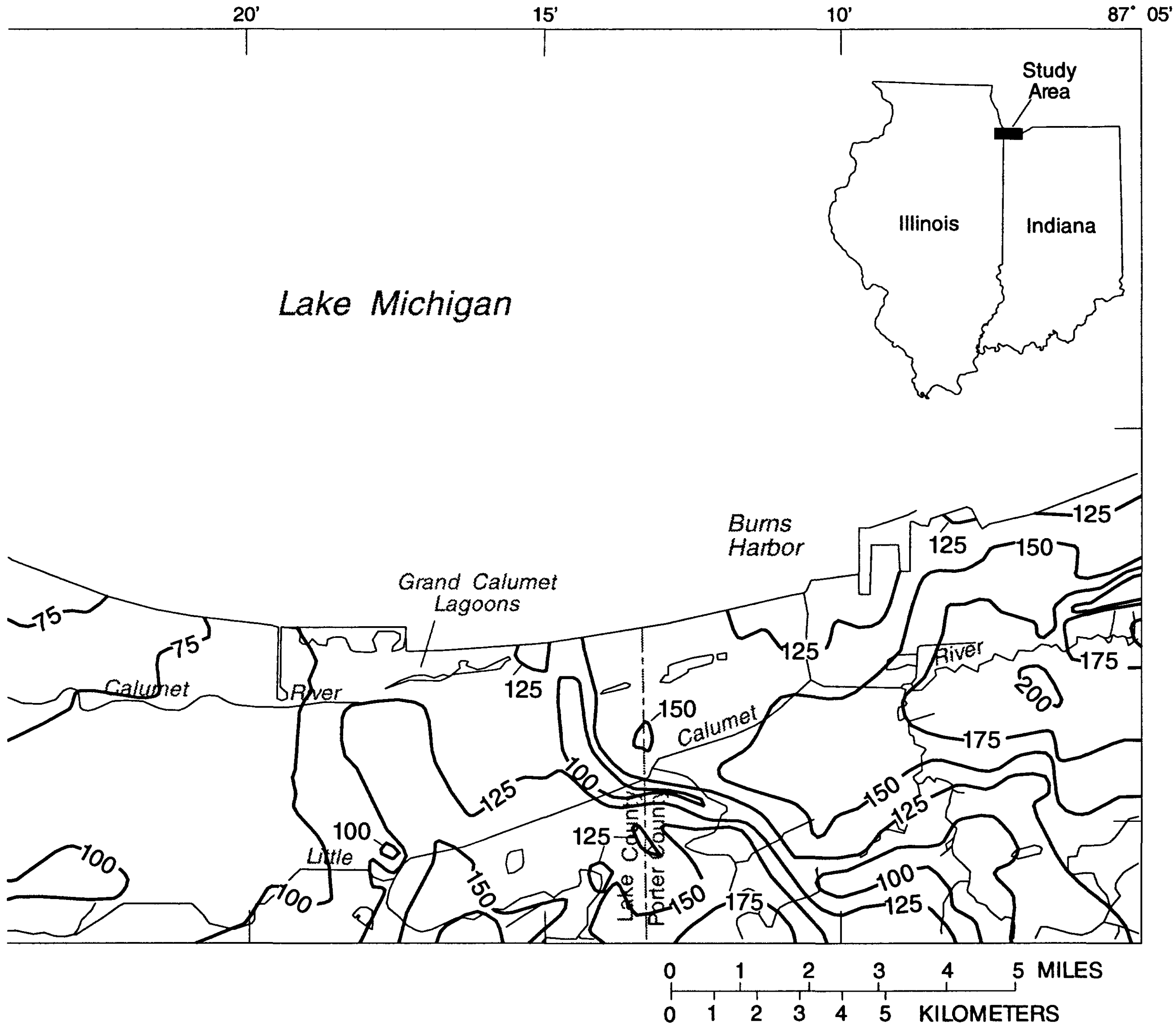
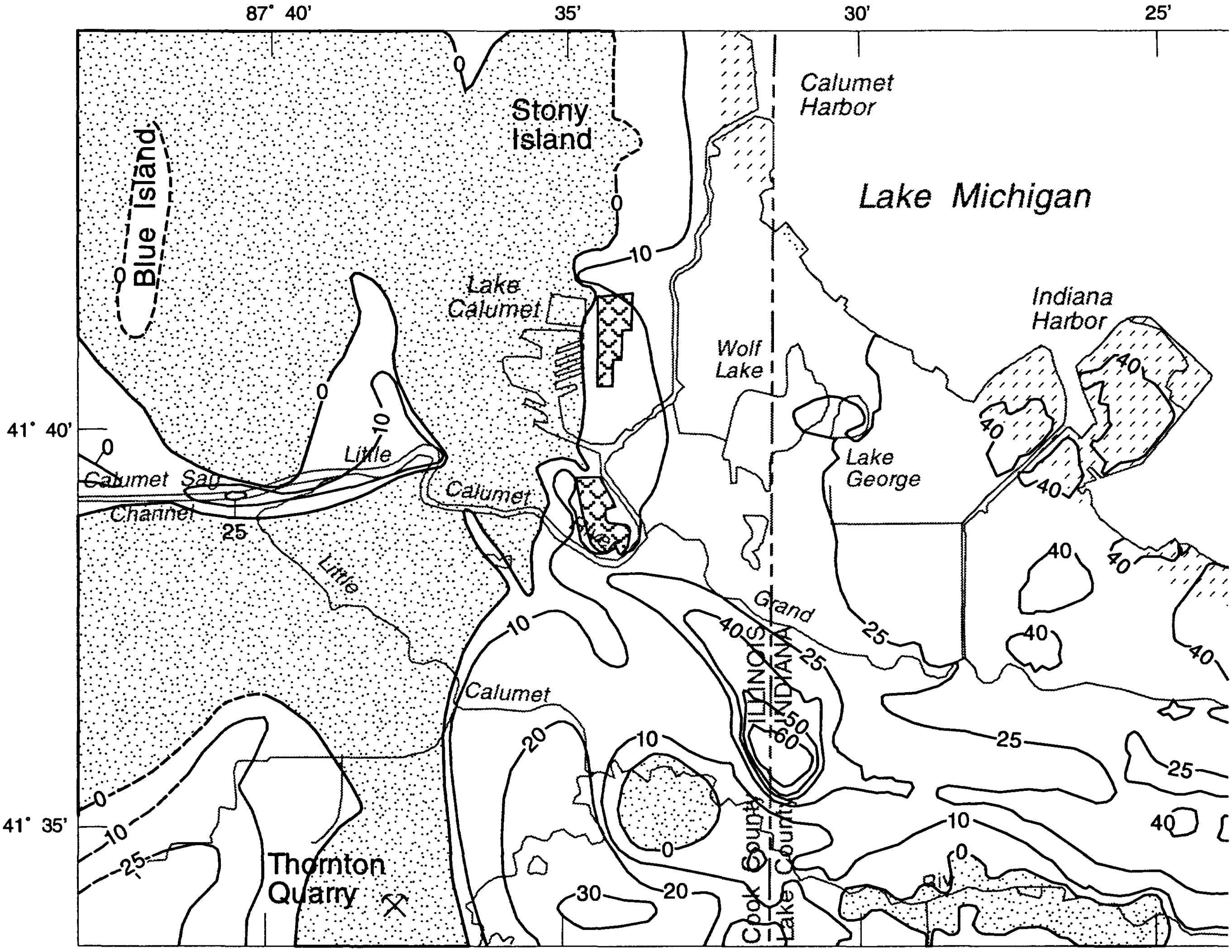


Figure 7. Continued.



EXPLANATION

SAND ABSENT WITHIN 20 FEET OF LAND SURFACE

SAND INTERSPERSED WITH FILL

SAND ORIGINALLY PRESENT BUT REMOVED BY QUARRYING

—25— LINE OF EQUAL THICKNESS—Shows thickness of sand deposits where the top is within 20 feet of the land surface. Dashed where approximate. Interval, in feet, is variable

Figure 8. Thickness of sand deposits, northwestern Indiana and the Lake Calumet area of northeastern Illinois.

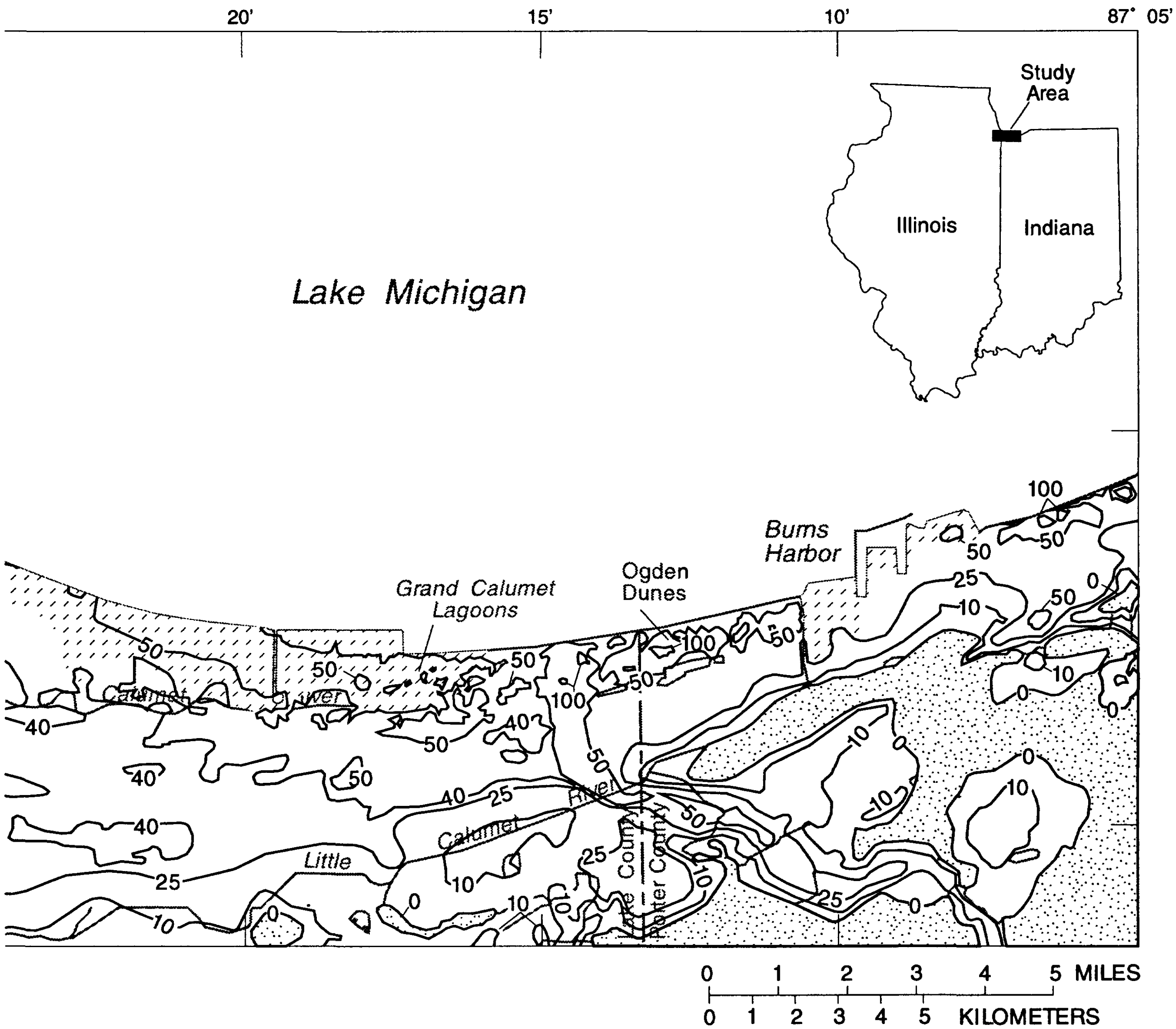


Figure 8. Continued.

Wadsworth Till Member was modified. Those areas where the Wadsworth Till Member was submerged and not covered by subsequent sediment deposition are mapped as wave-scoured lake-bottom till (fig. 3), hereafter referred to as the Lake-Plain deposits. Equality Formation deposits are common in the area of the Lake-Plain deposits.

The Lemont Drift, Wadsworth Till Member, Carmi Member (where not underlain by sand), and Lake-Plain deposits constitute a continuous layer of fine-grained unconsolidated material overlying the bedrock in almost all of the study area. These fine-grained deposits are absent near Stony Island, Thornton Quarry, and the Calumet Sag Channel and are over 200 ft thick near the eastern edge of the study area (fig. 7). The Lemont Drift and the Wadsworth Till Member constitute most of the fine-grained material. The Carmi Member typically is less than 15 ft thick (Land and Lakes Co., 1988, p. 14).

The thickness of the fine-grained unconsolidated deposits in Illinois was measured directly from drillers' logs. Because of the scarcity of data points in Indiana, the elevations of the top of the bedrock and the top of the fine-grained deposits, obtained from drillers' logs, were digitized into the ARC/INFO[2] geographic information system. A set of adjacent nonoverlapping triangles, referred to as a triangulated irregular network (TIN), was computed from the digital contour data. This TIN structure formed a digital surface interpolated from the contour lines. The TIN was then converted into a lattice coverage representing 30 by 30 meter pixels. Applying map algebra, the bedrock-surface lattice was subtracted from the surface of the fine-grained deposit lattice to determine the thickness of the fine-grained unconsolidated deposits. A coverage containing the contour lines was created directly from the resultant lattice coverage. This coverage was joined in ARCEDIT (a module of ARC/INFO) to the digitized contour coverage created for Illinois. Additional smoothing of the contours was done interactively in ARCEDIT. This method does not account for the thin sand deposits directly overlying the bedrock and within the fine-grained deposits, resulting in a slight overestimation of the thickness of the fine-grained deposits in Indiana.

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[2]Use of the brand names ARC/INFO and ARCEDIT in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

In those parts of the study area where the fine-grained deposits are within a few feet of the land surface, the upper part of this unit typically is weathered. The weathered zone is characterized by an extensive network of open vertical fractures, macropores, soil joints, and root channels (Ecology and Environment, Inc., 1990, p. 4–17). The size and number of the weathering features decrease with depth. These features are virtually absent below about 30 ft (Ecology and Environment, Inc., 1990, p. 4–17).

In most of the area east of Lake Calumet, the fine-grained deposits are overlain by sands of the Equality Formation, the Parkland Sand, or the glacial sluiceway. Fill deposits consisting of sand are present locally along the western shore of Lake Calumet but are too discontinuous to be mapped at the scale shown in figure 8. Continuous fill deposits consisting primarily of sand and slag are present along the shore of Lake Michigan in much of the study area (fig. 3). These continuous fill deposits are mapped in figure 8 as if they were composed entirely of sand. The thickness of the sand deposits generally increases from west to east, ranging from 0 ft in most of Illinois west of Lake Calumet to about 100 ft along Lake Michigan east of the Grand Calumet Lagoons (fig. 8). In the extreme eastern part of the study area, two sand lenses are separated by a silty-clay layer.

The map of sand thickness (fig. 8) was prepared in the same way as the map of the thickness of fine-grained unconsolidated deposits. The thickness of the sand deposits in Illinois was measured directly from drillers' logs. Because of the scarcity of data points and the large changes in surface topography at the dunes in Indiana, digital line graph hypsography data were used to create a TIN representing land surface. The TIN surface was then converted into a lattice coverage. The procedure for determining the sand thickness was the same as that used to determine the thickness of the fine-grained unconsolidated deposits. The lattice representing the surface of the fine-grained unconsolidated deposits was subtracted from the land-surface lattice. The contour coverage was created directly from the resultant lattice coverage and joined to the digitized contour coverage of the sand thickness for Illinois. Additional smoothing of the contours was done interactively in ARCEDIT. Values of sand thickness presented in figure 8 do not account for the presence of fill interspersed with the sand along Lake Michigan, resulting in an overestimation of the actual thickness of the sand in these areas.

The surficial and bedrock deposits have been extensively altered by human activities in this area. Substantial volumes of material have been removed during quarrying, tunneling, and excavating for buildings and landfills (fig. 7). The surficial geology also has been modified by the deposition of large amounts of fill including sand, silt, slag, dredging spoil, and municipal wastes (fig. 3). These activities have combined to disrupt the spatial continuity and homogeneity of the deposits and to modify the surface topography.

Hydrology

The four hydrologic units of concern to this study are surface-water bodies, the unconsolidated sand aquifer, the unconsolidated silt and clay confining unit, and the carbonate aquifer. These are the units most affected by industrial and waste-disposal activities.

Surface Water

Lake Michigan, the second largest of the Great Lakes, is the dominant influence on surface-water and ground-water hydrology in the study area. From 1903 to 1991, the stage of Lake Michigan at Calumet Harbor ranged from 576.9 to 582.3 ft above sea level (National Oceanic and Atmospheric Administration, written commun., 1992). Water in Lake Michigan usually flows from east to west (Fitzpatrick and Bhowmik, 1990, p. 15).

Lake Calumet, at approximately 780 acres, is the second largest surface-water body in the study area. The lake occupies a depression in the postglacial topographic surface. Lake Calumet is currently divided into a number of basins by slag deposits (fig. 9). The northernmost basin is hydraulically isolated from the southern basins. The southern basins are interconnected by openings in the causeways separating the basins. Slag and other materials have been used to fill in wetlands surrounding Lake Calumet and to build several piers out into the lake.

Water is delivered to Lake Calumet by manmade drainage channels and storm sewers; no natural drainage is currently known to exist (Ross and others, 1988, p. 47). The major inflow to the lake from surface drainage is through Pullman Creek, a drainage channel on the west side of the lake (fig. 9). A drainage channel at the northeastern corner of the lake and two storm-sewer outfalls also have been identified by Ross and others (1988).

Wolf Lake and Lake George, approximately 770 and 130 acres in size, respectively, occupy shallow depressions between a series of sandy ridges. Wolf Lake is currently divided by slag deposits into an eastern, a central, and a western basin (fig. 9). Each of these basins has a different water level and is divided by slag deposits into a number of smaller, interconnected basins. Slag and other materials have been used to fill in parts of Wolf Lake, Lake George, and some of the surrounding wetlands.

Wolf Lake was once connected to Lake Michigan by a channel, now blocked, extending from the northern part of Wolf Lake. Water is currently delivered to Wolf Lake through manmade drainage channels and industrial discharge. Most of the discharge is from industries along the northern arm of the lake. The discharged water is originally pumped from Lake Michigan. A shallow drainage ditch on the western shore of Wolf Lake connects the lake to the Calumet River.

Lake George does not receive surface-water flow under most conditions. During periods of high water, however, Lake George may connect to the Indiana Harbor Canal through a series of ditches extending south from the lake.

In addition to the large lakes, numerous small lakes, ponds, and wetlands are present in this area. The smaller lakes generally occupy depressions on the lake plain or pits created by mining of sand and clay. Many of the smaller lakes and wetlands also have been modified by dredging and disposal of fill materials.

The Grand Calumet, Little Calumet, and Calumet Rivers and the Calumet Sag Channel are the principal rivers in the study area (fig. 9). The natural gradient and direction of flow in these rivers has been substantially altered by human activities. Prior to about 1810, the Little Calumet and Grand Calumet Rivers were two reaches of the same river, referred to as the Grand Konomick River (Moore, 1959, p. 10). At that time, the Grand Konomick River, fed by a number of smaller streams that drained from the moraines to the south, meandered along the southern edge of the nearly flat lake plain between the

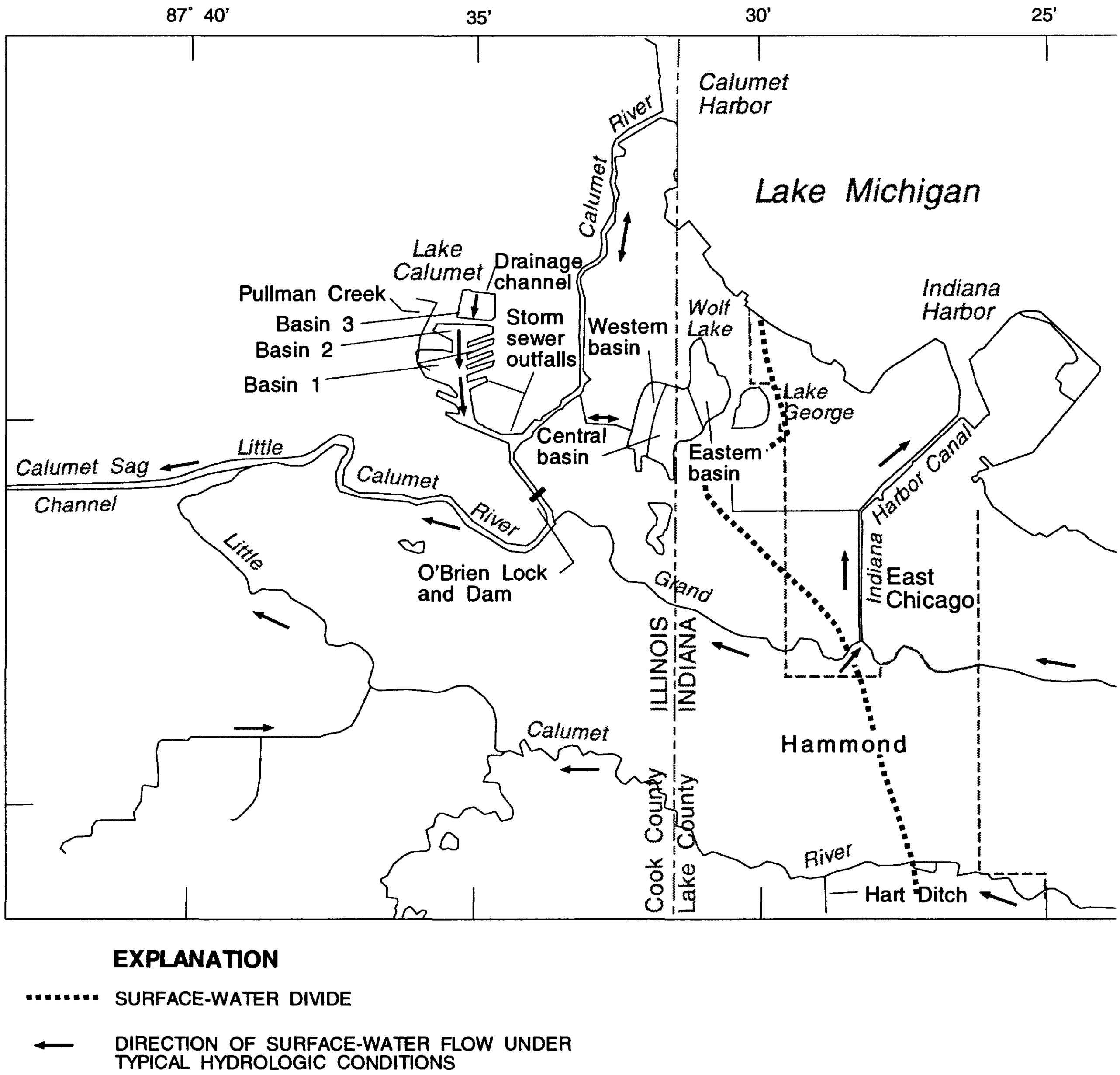


Figure 9. Typical directions of surface-water flow, northwestern Indiana and the Lake Calumet area of northeastern Illinois. (Modified from U.S. Department of Health, Education, and Welfare, 1965, fig. V-1.)

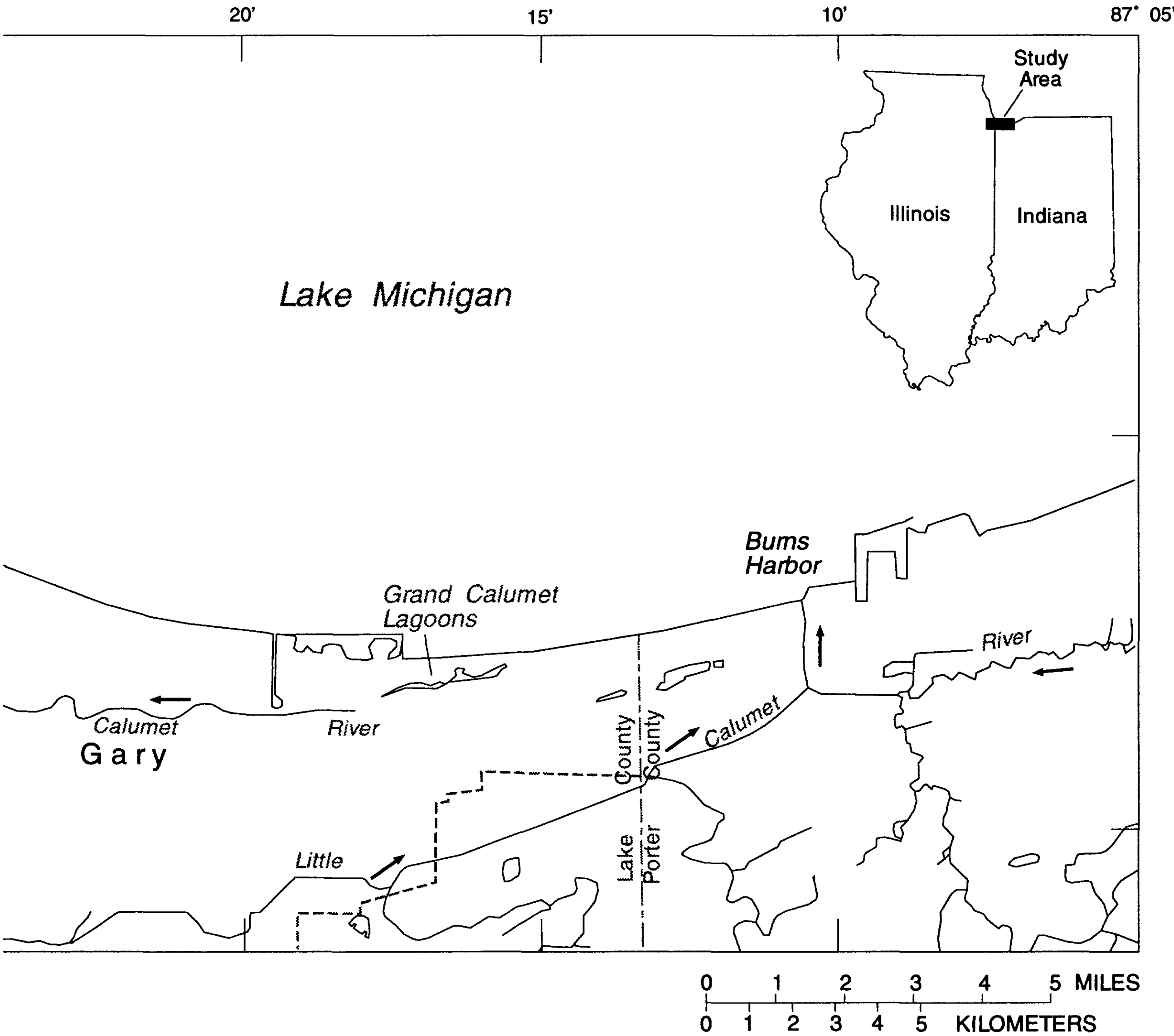


Figure 9. Continued.

dunes and beach ridges along the path of the Little Calumet River. Flowing westward from Indiana into Illinois, the river reversed course in a topographic depression between the Toleston Beach Ridge and the moraine at Blue Island, which was presumably formed by erosion along the path of the glacial sluiceway. Flowing eastward into Indiana, the river followed the approximate path of the Grand Calumet River and discharged into Lake Michigan near what are now the Grand Calumet Lagoons (Cook and Jackson, 1978, p. 24) (fig. 9). Sometime between about 1809 and 1820, a small channel opened between the elbow in the Calumet River south of Lake Calumet and the Grand Konomick River. This created two rivers: the Little Calumet River, which flowed west from Indiana and discharged to Lake Michigan through the Calumet River; and the Grand Calumet River, which continued to flow to the east and discharge to Lake Michigan near the Grand Calumet Lagoons (Moore, 1959, p. 10). The diversion of water from the Grand Calumet River reduced its current enough that at some time between 1840 and 1845, beach and dune deposits had blocked the mouth of this channel, preventing flow into Lake Michigan (Moore, 1959, p. 11). Under these conditions, the Grand Calumet and Little Calumet Rivers both originated in Indiana and flowed westward into Illinois meeting the newly extended Calumet River and discharging into Lake Michigan.

The Indiana Harbor Canal was constructed from 1901 to 1906 to connect the Grand Calumet River to Lake Michigan at East Chicago. This canal provided an additional outlet for flow to Lake Michigan and created a surface-water divide on the Grand Calumet River at the Hammond Treatment Plant near the East Chicago–Hammond boundary (U.S. Department of Health, Education and Welfare, 1965, p. 57; G.S. Roadcap, Illinois State Water Survey, oral commun., 1994) (fig. 9). Under typical flow conditions, water in the Grand Calumet River between the divide and the Indiana Harbor Canal flows east to the canal. At the canal, this water mixes with water from the eastern part of the study area and discharges into Lake Michigan. West of the divide, flow is toward the Calumet River.

The Calumet Sag Channel was opened in 1922 to connect the Calumet River system with the Illinois River system (Moore, 1959, p. 13). This diverted flow in the Calumet River from Lake Michigan to the Calumet Sag Channel under most flow conditions. The reversal of flow of the Calumet River also resulted in a diversion of flow in the Little Calumet River and the western part of the Grand Calumet River to the Calumet Sag Channel (fig. 9).

Burns Harbor was constructed from 1924 to 1926 (Cook and Jackson, 1978, p. 63). This project included dredging a portion of the Little Calumet River to connect the eastern part of the river to Lake Michigan. This construction created a surface-water divide on the Little Calumet River caused by high points in the riverbed west of Gary and east of Hart Ditch (U.S. Department of Health, Education and Welfare, 1965, p. 57) (fig. 9). Under normal flow conditions, flow in the Little Calumet River east of this divide is toward Burns Harbor and Lake Michigan, whereas flow west of this divide is toward the Calumet Sag Channel.

The O'Brien Lock and Dam was constructed in 1968 to control flow between Lake Michigan and the Calumet Sag Channel. The O'Brien Lock and Dam is kept closed except during floods or to transmit barge traffic. Under typical conditions, the Calumet River flows from Lake Michigan toward the Calumet Sag Channel when the lock is open (fig. 9). Flow in the Calumet River north of the lock and dam is usually toward Lake Michigan when the lock is closed. Flow in the Calumet River south of the lock and dam is usually toward the Calumet Sag Channel when the lock is closed.

The previous discussion describes drainage patterns and flow directions during typical conditions. The locations of the flow divides on the Calumet River system can vary over several miles, and the directions of surface-water flow can be reversed depending on the stage of Lake Michigan—whether the O'Brien Lock and Dam is open or closed; the intensity, duration, and location of rainfall; and the location and volume of discharges to the streams (Fitzpatrick and Bhowmik, 1990, p. 13).

A decline in the stage of Lake Michigan by as little as 0.5 ft can produce a hydraulic gradient capable of shifting the location of the surface-water divides on the Little Calumet and Grand Calumet Rivers to the west and reversing flow in the Calumet River (U.S. Department of Health, Education and Welfare, 1965, p. 60). Conversely, a rise in lake level could increase the amount of flow from Lake Michigan into the Calumet River and shift the surface-water divides on the Grand Calumet and Little Calumet Rivers to the east. Local variations in the level of Lake Michigan of 0.5 to 1.0 ft can be caused by wind or barometric-pressure effects.

Because the Calumet Sag Channel is unable to transmit high volumes of flow, relatively large hydraulic heads can form in that part of the Calumet River system flowing toward the Illinois River during heavy rains. This may result in a westward shift in the surface-water divides on the Little Calumet and Grand Calumet Rivers. In extreme cases, the O'Brien Lock and Dam will be opened and water west of the divides will flow toward the Calumet River and Lake Michigan. Flow reversals on the Calumet River caused by opening of the O'Brien Lock and Dam are infrequent events that take place for short periods of time (U.S. Department of Health, Education and Welfare, 1965, p. 60–63; Fitzpatrick and Bhowmik, 1990, p. 14).

Ground Water

The aquifers of interest in this study are the surficial sand aquifer, hereafter referred to as the Calumet aquifer, and the carbonate aquifer, hereafter referred to as the Silurian-Devonian aquifer. The aquifers are separated by a confining unit composed primarily of till.

Calumet Aquifer

The surficial sands of the Dolton Member of the Equality Formation, the Parkland Sand, and the glacial sluiceway, as well as the permeable fill deposits constitute the Calumet aquifer (Hartke and others, 1975, p. 25). Thin layers of peat, muck, and organic-rich clay may be present in the Calumet aquifer, functioning as localized semiconfining units. These semiconfining units have minimal effect on overall flow in the aquifer.

The Calumet aquifer is under unconfined conditions and is continuous through most of the area east of Lake Calumet but is present only in scattered locations west of Lake Calumet (fig. 8). The saturated thickness of the Calumet aquifer ranges from 0 to about 70 ft and generally thickens to the east. Though not extensively pumped, records indicate that several wells drilled for commercial, industrial, irrigation, and drinking-water uses are open to the Calumet aquifer. It is unknown how many of these wells are currently in use.

The Calumet aquifer is recharged by direct infiltration from precipitation and is the primary pathway for lateral ground-water flow in the unconsolidated deposits (Watson and others, 1989, p. 30–31; Cravens and Zahn, 1990, p. 29–30). Ground water in the Calumet aquifer generally flows from topographic highs toward topographic lows. Localized changes in this pattern are a result of vertical barriers to ground-water flow; ground-water recharge from landfill leachate and ponded water; and ground-water discharge to sewer lines, small ditches, and pumping centers at quarries, underpasses, and sites of ground-water remediation.

Discharge from the Calumet aquifer is primarily to area rivers, lakes, and wetlands. Evapotranspiration also constitutes a major portion of the total discharge during spring and summer months (Rosenshein and Hunn, 1968, p. 30). Some water flows from the Calumet aquifer into the underlying confining unit.

The position of the water table in the Calumet aquifer ranges from near land surface along the Lake Michigan shoreline to more than 100 ft beneath the highest dunes. The depth to water in most of the study area is less than 15 ft (appendix 1). Lowering of the water table in parts of the Calumet aquifer as a result of ditching and draining the wetlands may have decreased the rate of recharge by dewatering the upper part of the aquifer (Rosenshein and Hunn, 1968, p. 30). Urbanization also alters recharge by covering large areas with buildings and pavement, and by construction of storm sewers to drain excess water.

The Calumet aquifer is in good hydraulic connection with the surface-water bodies, except in the areas where sheet piles have been installed for bank stability. Water levels in most of the Calumet aquifer near the surface-water bodies rise and fall within moments of changes in river or lake stage (Lee Watson, U.S. Geological Survey, oral commun., 1992).

Slug tests were performed in 26 wells open to the Calumet aquifer during this study to determine the horizontal hydraulic conductivity of the aquifer, which is necessary to estimate ground-water velocity (table 1). Slug testing also was used to determine the spatial trends in horizontal hydraulic conductivity. Slug tests consisted of inserting a solid cylinder below the water surface in the well, then measuring the water-level decline over time using a pressure transducer (falling-head test), followed by removing the

Table 1. Horizontal hydraulic conductivities calculated from slug-test data, northwestern Indiana and the Lake Calumet area of northeastern Illinois

[WTCA, water table in the Calumet aquifer; BCA, base of the Calumet aquifer; WTCU, water table in the confining unit; MCU, middle of the confining unit; SD, Silurian-Devonian aquifer. Well locations noted in appendix 1]

Well number	Horizontal hydraulic conductivity (feet per day)	Hydrologic unit
S52	8.3×10^{1}	WTCA
S54	4.2×10^{0}	WTCA
S57	3.4×10^{0}	WTCA
S60	4.3×10^{0}	WTCA
S61	2.1×10^{0}	WTCA
S63	1.3×10^{1}	WTCA
S66	3.6×10^{2}	WTCA
S69	1.0×10^{1}	WTCA
S70	2.8×10^{1}	WTCA
S71	1.1×10^{1}	WTCA
S72	1.2×10^{1}	WTCA
S73	9.8×10^{1}	WTCA
S74	4.5×10^{1}	WTCA
S75	5.9×10^{0}	WTCA
S76	8.9×10^{0}	WTCA
S77	8.6×10^{0}	WTCA
S260	3.0×10^{1}	WTCA
S264	1.2×10^{1}	WTCA
S272	2.4×10^{1}	WTCA
S273	2.1×10^{1}	WTCA
S284	2.0×10^{1}	WTCA
S290	2.2×10^{1}	WTCA
S293	1.7×10^{1}	WTCA
S259	6.2×10^{0}	BCA
S285	2.2×10^{1}	BCA
S292	4.8×10^{0}	BCA
S49	5.4×10^{-2}	WTCU
S64	1.5×10^{-2}	WTCU
S50	1.4×10^{-3}	MCU
S55	4.2×10^{-3}	MCU
S58	5.6×10^{-3}	MCU
S67	8.7×10^{-4}	MCU
S53	2.0×10^{-1}	SD
S59	1.5×10^{-1}	SD
S62	3.3×10^{-2}	SD
S65	4.4×10^{-1}	SD
S68	6.2×10^{-2}	SD

cylinder from the well and measuring the water-level rise over time (rising-head test). Results of the rising-head tests and the falling-head tests were similar.

Slug-test data were analyzed using the technique of Bouwer and Rice (1976). This technique was developed for use in aquifers under unconfined conditions with wells that fully or partially penetrate the aquifer and assumes the following conditions:

1. The water-level change in the vicinity of the well is negligible.
2. Flow above the water table can be ignored; flow is only through the saturated zones.
3. Head losses as the water enters the well are negligible.
4. The hydraulic unit is homogeneous and isotropic.

These conditions are met or approximated in each of the hydraulic units tested.

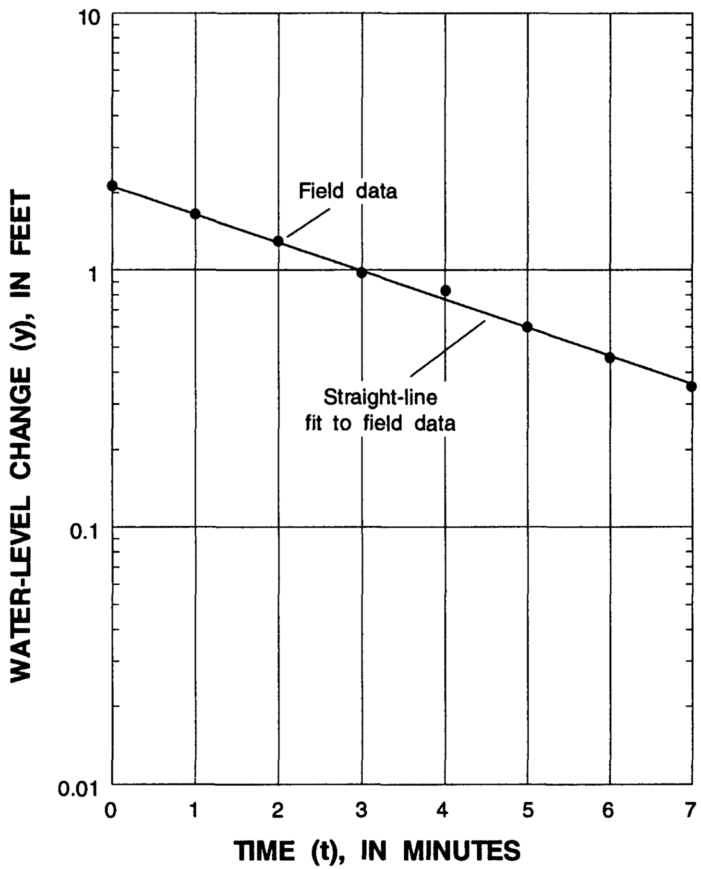
When analyzing the slug-test data, it was assumed that

1. the radius of the casing is equal to the radius of the inner casing if the water-level altitude measured before the start of the test was above the top of the screened interval of the well. If this was not the case, the radius of the casing was computed applying the technique described by Bouwer and Rice (1976, p. 424);
2. the value of the length of the well through which water enters the aquifer is equal to the length of the screened interval of the well if the water-level altitude measured before the start of the test was above the top of the well screen. If this was not the case, the value is equal to the distance from the bottom of the well screen to the water level measured before the start of the test; and
3. the borehole radius is equal to the nominal outside diameter of the auger or drill bit used to drill the well.

These assumptions greatly simplify the analysis of the slug-test data and should not result in a significant error in the calculated horizontal hydraulic conductivities.

Although most of the slug tests resulted in clearly defined trends in water level with time that were easily analyzed (fig. 10), slug-test data from some of the wells did not show a linear decline in water level with time, complicating the data analysis. Where possible, these anomalous data were analyzed in accordance with the recommendations of Bouwer (1989) to obtain the value most representative of the horizontal hydraulic conductivity of the hydraulic unit tested.

The horizontal hydraulic conductivity calculated from slug tests in the Calumet aquifer for this study (table 1) and studies done by other investigators ranged from 6.5×10^{-1} to 3.6×10^{2} ft/d. Most values were between 2.1×10^{0} and 3.0×10^{1} ft/d (Baker/TSA,



EXPLANATION

$$K = \frac{r_c^2 \, ln\left(\frac{R_e}{r_w}\right)}{2L} \; \frac{1}{t} \, ln\left(\frac{y_o}{y_t}\right) = 0.44 \text{ ft/d}$$

$$ln\left(\frac{R_e}{r_w}\right) = \left[\left(\frac{1.1}{ln\left(\frac{H}{r_w}\right)}\right) + \left(\frac{A + \frac{B\,ln\left(D - H\right)}{r_w}}{\frac{L}{r_w}}\right)\right]^{-1}$$

$r_c = 0.083$ ft

$r_w = 0.17$ ft

$L = 10.0$ ft

$t = 6.94 \times 10^{-4}$ days

$y_o = 2.10$ ft

$y_t = 1.60$ ft

$H = 59.0$ ft

$D = 232$ ft

$A = 3.5$

$B = 0.30$

EXPLANATION OF SYMBOLS

K = Horizontal hydraulic conductivity, in feet per day (ft/d)

r_c = Effective radius of the well casing, in feet (ft)

r_w = Effective radius of the borehole, in feet (ft)

L = Length of the portion of the well through which water enters, in feet (ft)

t = Time since beginning of test, in days (d)

y_o = Water level at start of test, in feet (ft)

y_t = Water level some time during the test, in feet (ft)

R_e = Effective radius of the aquifer, in feet (ft)

H = Height of the water table above the bottom of the well, in feet (ft)

D = Saturated thickness of the aquifer, in feet (ft)

A = Aquifer coefficient related to L/r_w (dimensionless)

B = Aquifer coefficient related to L/r_w (dimensionless)

Figure 10. Water-level change as a function of time during slug testing, well S65, rising-head phase.

1984; Geosciences Research Associates, Inc., 1987 and 1988; Warzyn Engineering, Inc., 1987; Cravens and Roadcap, 1991, p. 10; Kenneth Gelting, Waste Management of Illinois, written commun., 1993; G.S. Roadcap, Illinois State Water Survey, oral commun; 1993: Richard Leonard, U.S. Army Corps of Engineers, written commun., 1993).

Horizontal-hydraulic-conductivity values obtained during this and other studies from slug-test analysis are in only fair agreement with the values obtained by Rosenshein and Hunn (1968, p. 29) from specific-capacity tests throughout Lake County. Rosenshein and Hunn reported a range of horizontal hydraulic conductivity of about 8.0×10^0 to 1.3×10^2 ft/d, and an average value of 6.0×10^1 ft/d. This value is about double the most common values calculated from the slug-test data collected in this and other studies. Differences in the values can be attributed to differences in the method of analysis, the volume of aquifer tested, and the locations where testing was done.

The slug-test data indicate that the horizontal hydraulic conductivity of the Calumet aquifer, where it is composed of fill deposits, is highly variable. Horizontal-hydraulic-conductivity values calculated from slug tests in 30 wells open to typical fill deposits (including clay, sand, silt, slag, and construction debris) at one of the piers in Lake Calumet varied from 3.7×10^{-4} to 8.2×10^1 ft/d with a median value of 5.3×10^{-1} ft/d (Lisa Grassel, Waste Management of North America, Inc., written commun., 1992). These values vary over five orders of magnitude, indicating that the fill deposits are highly heterogeneous. This indicates that ground-water flow through the fill will not be uniform. Flow will be primarily through the permeable parts of the fill, which are typically coarse grained, fractured, and (or) poorly consolidated.

In addition to variations in the hydraulic properties of the fill, variations in the hydraulic properties of the entire Calumet aquifer also exist. These variations can be related to differences between the hydraulic properties of the sand and the fill and differences in the thickness and composition of the sand deposits. The largest horizontal-hydraulic-conductivity value calculated from the slug tests in the Calumet aquifer was 3.6×10^2 ft/d (table 1). This value was calculated at a well (S66) open to the fill deposits and is about an order of magnitude greater than the typical value for the Calumet aquifer where flow is through the sand. Results from the pier in Lake Calumet and station S66 indicate that the median horizontal hydraulic conductivity of the fill deposits can be substantially less than the typical value of the sand deposits, but the largest conductivity values in the fill deposits exceed the largest values in the sand deposits.

The horizontal hydraulic conductivity of the Calumet aquifer generally decreases to the west (fig. 11). Near Lake Michigan in Illinois, conductivity values calculated at three wells open to the Calumet aquifer exceeded 8.0×10^1 ft/d. Horizontal-hydraulic-conductivity values in much of the area east of Lake George are greater than or equal to 2.0×10^1 ft/d, whereas values north and south of this area are usually from 1.0×10^0 to 1.4×10^1 ft/d. Except for the highly conductive area along Lake Michigan and small areas along the southwestern part of Wolf Lake and the northeastern corner of Lake Calumet, the horizontal hydraulic conductivity of the Calumet aquifer west of Lake George is less than 2.0×10^1 ft/d and is typically less than 1.0×10^1 ft/d. Hydraulic-conductivity values near the eastern shore, and south of, Lake Calumet are usually less than 1.0×10^0 ft/d. This decrease in hydraulic conductivity coincides with a decrease in the thickness of the Calumet aquifer (fig. 8). It also coincides with a decrease in the size of the sand grains composing the aquifer and an increase in the percentage of silt and clay in the aquifer, which was observed during drilling operations (Jeff Miller, Metcalf and Eddy, Inc., oral commun., 1992).

The horizontal hydraulic conductivity of the Calumet aquifer decreases with depth at a site in northwest Gary, Ind. (Geosciences Research Associates, Inc., 1988, p. 4–25), and shows no significant change with depth at a second site in southwest Gary (Geosciences Research Associates, Inc., 1987, p. 4–26). Where the horizontal hydraulic conductivity decreased with depth, the percentage of silt and clay in the aquifer increased with depth (Geosciences Research Associates, Inc., 1988, p. 4–25), suggesting that they are related.

Confining Unit

The confining unit is composed of the Antrim Shale, the silt and clay tills of the Lemont Drift and the Wadsworth Till, the silt and clay lacustrine deposits of the Carmi Member of the Equality Formation, and the fine-grained fill deposits. The confining unit separates the Calumet and the Silurian-

Devonian aquifers in most of the study area. In the eastern part of the study area, a sand aquifer is present within the confining unit (Shedlock and others, 1994, p. 16).

The water table is located in the confining unit in most of the area west of Lake Calumet, where the surficial deposits are predominately fine grained. The confining unit is more than 200 ft thick in Porter County and is thin or absent near Stony Island, Thornton Quarry, and in isolated areas south of Blue Island (fig. 7). Except for small areas northeast of Stony Island and south of Blue Island, the confining unit underlies the Calumet aquifer restricting flow between the Calumet aquifer and the underlying Silurian-Devonian aquifer.

The confining unit is recharged by the Calumet aquifer and by infiltration from precipitation where the Calumet aquifer is absent. Discharge from the confining unit is primarily to the Silurian-Devonian aquifer and to rivers, lakes, and wetlands. Where the Calumet aquifer is absent, evapotranspiration constitutes a major part of the discharge during spring and summer months (Rosenshein and Hunn, 1968, p. 30). The depth of the water table in the confining unit ranges from near land surface around Lake Calumet to about 27 ft below land surface near some of the landfills (appendix 1).

Vertical and horizontal flow in the confining unit is increased by a network of fractures, root channels, macropores, and soil joints in the weathered part of the unit. This weathered zone is typically about 30 ft thick (Ecology and Environment, Inc., 1990, p. 4–15) and appears to be restricted to areas where the Calumet aquifer is less than about 5 ft thick (Woodward-Clyde Consultants, 1984, p. V–13). Though fractures are present in the deeper, unweathered parts of the confining unit, their size and number are greatly reduced and other forms of secondary permeability are absent. Vertical flow through both the weathered and unweathered parts of the confining unit is considerably greater than lateral flow (Cravens and Zahn, 1990, p. 37–38).

Laboratory tests of soil-moisture content of the confining unit were performed on saturated samples collected from more than 50 boreholes at 10 facilities in Illinois. The reported soil-moisture content ranged from 8 to 37 percent and decreased with depth at almost every borehole. The moisture content of the upper part of the confining unit is typically about 20 percent. The moisture content of the lower part of the confining unit is typically about 15 percent. The soil-moisture content of a saturated deposit is equivalent to its porosity (Freeze and Cherry, 1979, p. 39).

Horizontal-hydraulic-conductivity values were calculated from slug tests done in 42 wells open to the confining unit during this and previous investigations. These values ranged from 1.7×10^{-5} to 5.5×10^{-1} ft/d (Geosciences Research Associates, Inc., 1987 and 1988; Ecology and Environment, Inc., 1990, p. 4–37; Eldridge Engineering Assoc., 1990; Cravens and Roadcap, 1991, p. 10; G.S. Roadcap, Illinois State Water Survey, oral commun., 1993; Richard Leonard, U.S. Army Corps of Engineers, written commun., 1993; Lisa Grassel, Waste Management of North America, Inc., written commun., 1993; Luci Alteiri, Land and Lakes Co., written commun., 1993). Slug tests were done in 24 wells open to the weathered zone and 18 wells open to the unweathered zone. The median horizontal hydraulic conductivity of the weathered part of the confining unit was calculated to be 5.8×10^{-2} ft/d, whereas the median value for the unweathered part of the confining unit was calculated to be 2.8×10^{-3} ft/d.

The horizontal hydraulic conductivity within 30 ft of the water table is substantially less where the water table is in the confining unit than where the water table is in the Calumet aquifer (fig. 11). East of Lake Calumet, where the water table is primarily in the Calumet aquifer, horizontal-hydraulic-conductivity values almost always exceed 1.0×10^{0} ft/d. West of Lake Calumet, where the water table is primarily in the confining unit, values are usually between 1.0×10^{-2} and 7.5×10^{-1} ft/d.

Rosenshein (1963, p. 22) estimated an average vertical hydraulic conductivity of 4.0×10^{-4} ft/d for the confining unit in Lake County. Permeameter tests at three sites near Lake Calumet and two sites in Gary indicate a range of vertical hydraulic conductivity from 3.7×10^{-6} to 1.6×10^{-3} ft/d (Geosciences Research Associates, Inc., 1987 and 1988; Roy F. Weston Consultants, 1989, p. 5–15; Kenneth Gelting, Waste Management of Illinois, written commun., 1993). The confining unit does not appear to be weathered at these sites. Permeameter tests from these sites do not indicate a correlation between vertical hydraulic conductivity and depth or stratigraphy within the

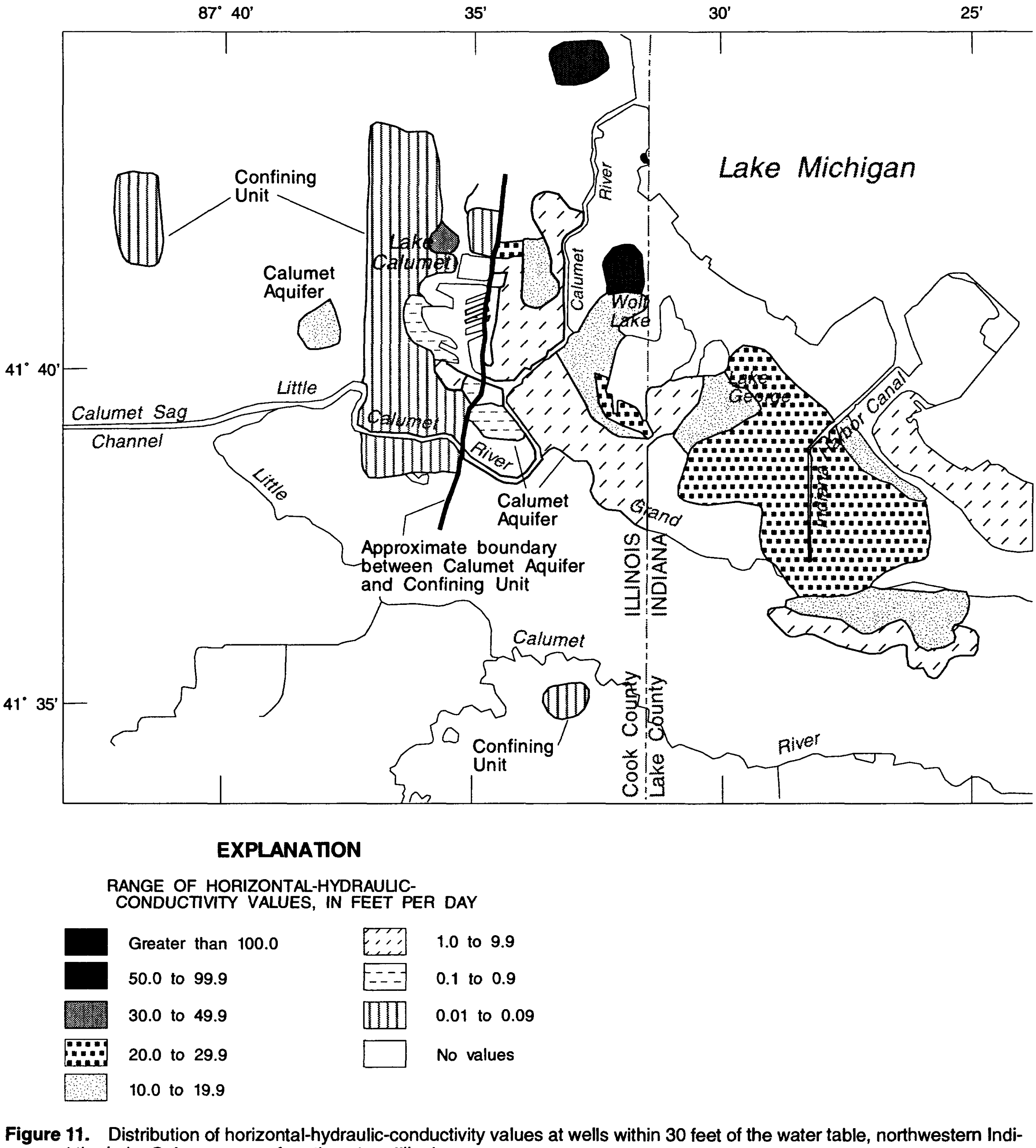


Figure 11. Distribution of horizontal-hydraulic-conductivity values at wells within 30 feet of the water table, northwestern Indiana and the Lake Calumet area of northeastern Illinois.

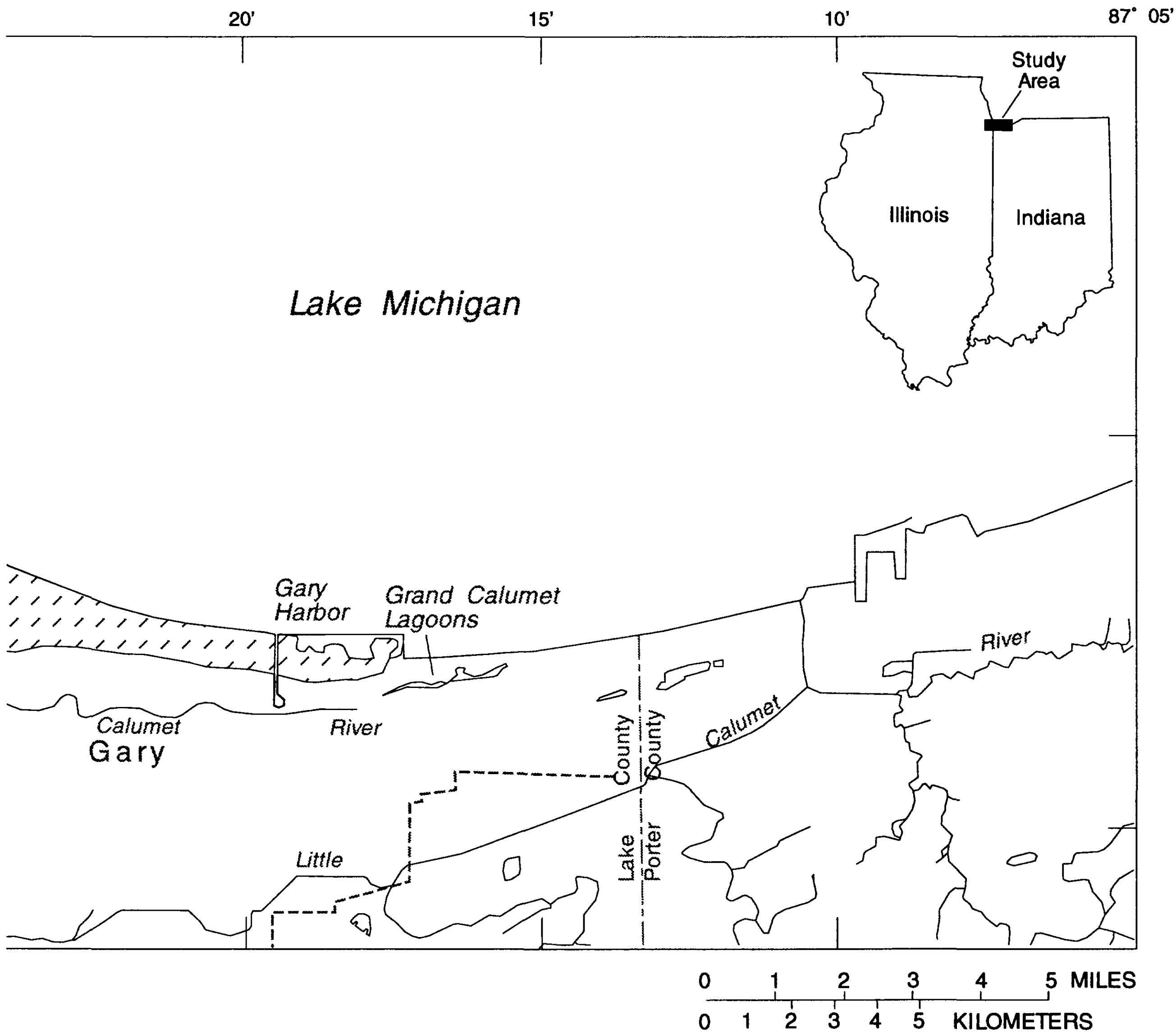


Figure 11. Continued.

confining unit. It is probable, however, that the vertical hydraulic conductivity is greatest where the confining unit is weathered.

Silurian-Devonian Aquifer

The dolomite and limestone of the Racine, Detroit River, and Traverse Formations compose the Silurian-Devonian aquifer. This aquifer is unconfined at Stony Island and Thornton Quarry. Northeast of Stony Island and south of Blue Island the confining unit is absent and the Silurian-Devonian aquifer is in direct hydraulic connection with the Calumet aquifer (fig. 7). In the rest of the study area, the aquifer is semiconfined. The Silurian-Devonian aquifer is pumped for commercial and industrial supply and serves as a source of drinking water in the study area. The aquifer is pumped more extensively in Illinois than in Indiana.

The Silurian-Devonian aquifer in the study area is recharged primarily by vertical flow through the confining unit. However, recharge to the Silurian-Devonian aquifer through the till in any area is less than 1 percent of the total flow through the aquifer beneath that area (Land and Lakes Co., 1988, p. 27). Where the confining unit is absent, recharge is from the Calumet aquifer or direct infiltration from precipitation.

Lateral ground-water flow in the Silurian-Devonian aquifer is generally toward Lake Michigan, though there is localized flow toward excavations in the bedrock and pumping centers (Cravens and Zahn, 1990, p. 30, 34). Movement of ground water within the Silurian-Devonian aquifer is primarily through an interconnected network of joints, fissures, faults, bedding plane openings, and solution cavities in the bedrock. Very little ground water flows through the rock matrix. With the exception of the extensive network of vertical faults in Illinois, most of the openings in the bedrock are irregularly distributed both vertically and horizontally but tend to be more abundant near the top of the bedrock (Suter and others, 1959, p. 9).

Discharge from the Silurian-Devonian aquifer is primarily to pumping, including dewatering centers for the Tunnel and Reservoir Plan (TARP) (Cravens and Zahn, 1990, p. 30–35). Some ground water may discharge from the Silurian-Devonian aquifer to Lake Michigan through the confining unit and the Calumet aquifer in the eastern quarter of the study area (Watson and others, 1989, p. 18). Rosenshein (1963) showed that local recharge to the Silurian-Devonian aquifer through the confining unit would increase as water levels in the aquifer were lowered by pumping.

Horizontal-hydraulic-conductivity values calculated from 25 slug tests in wells open to the upper few feet of Silurian-Devonian aquifer ranged from 2.0×10^{-2} to 1.1×10^{0} ft/d (Woodward-Clyde Consultants, 1984, p. V-18; Geosciences Research Associates, Inc., 1987; Ecology and Environment, Inc., 1990, p. 4–37; Eldridge Engineering Assoc., 1990; Luci Alteiri, Land and Lakes Co., written commun., 1993). The median value was calculated to be 1.6×10^{-1} ft/d. No trends were identified in the areal distribution of horizontal hydraulic conductivity in the Silurian-Devonian aquifer.

Median horizontal-hydraulic-conductivity values calculated from the slug tests are somewhat larger than the median value of 6.2×10^{-2} ft/d calculated from water-pressure tests in deep boreholes drilled for the TARP (Harza Engineering Co., 1972). This is consistent with the analysis of Hartke and others (1975, p. 30), who noted that horizontal-hydraulic-conductivity values are generally larger in the upper 200 ft of the aquifer because of weathering, fracturing, and development of limited karst solution features. Differences in the method of testing and the volume of aquifer tested by each method also may account for the differences in the values.

WATER LEVELS AND DIRECTIONS OF FLOW

Water levels were measured in 523 wells and at 34 surface-water stations during a synoptic water-level survey on June 23–25, 1992 (appendix 1). Water levels were not measured during this period in seven of the wells listed in the appendix because of equipment problems or lack of accessibility during the survey. All but two water levels were measured between 0700 hours on June 23 and 1530 hours on June 24. Ground-water levels were measured at wells open to the Calumet aquifer, the confining unit, and the Silurian-Devonian aquifer. Surface-water levels were measured from established reference marks on bridges and culverts and at six USGS streamflow-gaging stations.

Most water levels were measured with steel tapes. Successive measurements were made until at least two measurements agreed within 0.01 ft.

Measurements were made with electric tapes if obstructions in the well prevented a steel-tape measurement or if LNAPL's were detected in the well. Measurements of LNAPL thickness were made with an oil-water interface tape. Corrections were made to account for the effects of LNAPL's on ground-water levels (Farr and others, 1990, p. 50).

All steel tapes and electric tapes were calibrated at one well open to the water table and a second well open to the Silurian-Devonian aquifer. All measurements agreed to within 0.03 ft. These differences are minor compared to the differences in the water-level altitudes in the wells at different sites and no corrections for tape measurements were necessary.

Inspection of ground-water levels in well S297 (USGS observation well 413559087270301) from July 1986 to September 1992 shows that the water-level altitude in well S297 ranged from 586.8 to 591.9 ft above sea level (Stewart and others, 1993, p. 316) and averaged 589.6 ft above sea level. Well S297 is open to the Calumet aquifer in Indiana (fig. 4). Water levels in well S297 averaged 588.4 ft above sea level during the synoptic survey, indicating that water levels in the Calumet aquifer at this time may be slightly lower than normal (fig. 12). The lower ground-water levels probably resulted from below normal amounts of recharge from precipitation in the months prior to the synoptic survey.

Water levels in well S297 from June 15–29, 1992, indicate that the synoptic survey began on the fifth day of a period of slowly declining ground-water levels in the Calumet aquifer. The water level in well S297 declined 0.30 ft during the synoptic period.

Water levels were monitored continuously during the synoptic survey at two other wells in Indiana (wells S299 and S277) (figs. 4, 13) and three wells in Illinois (wells S64, S57, and S59) (figs. 4, 14) to determine the timing and magnitude of background water-level changes. Wells S299, S277, and S57 are open to the Calumet aquifer. Wells S59 and S64 are open to the Silurian-Devonian aquifer and the confining unit, respectively. Total changes in water levels in these wells ranged from 0.04 to 0.30 ft. These changes are minor compared to the differences in water levels in the wells at different sites, and it is assumed that no corrections for background fluctuations in water level were necessary.

In addition to ground-water levels, the stage of Lake Michigan at Calumet Harbor (fig. 15) was monitored by NOAA, who provided daily mean water-level altitudes. The total change in the stage of Lake Michigan at Calumet Harbor during the synoptic survey was 0.19 ft. This change in stage is probably too small to produce significant changes in surface-water elevation or ground-water altitudes, and no corrections for changes in lake stage were made.

The results of the synoptic water-level survey depict hydrologic conditions during June 23–25, 1992. Seasonal variations in water levels cannot be accounted for and the conditions during this survey may not be completely representative of conditions during periods of heavy precipitation, large fluctuations in the stage of Lake Michigan, or changes in the amount and location of pumping from the aquifers.

Surface Water

Surface-water-flow directions during the synoptic survey were consistent with the typical hydrologic conditions described during previous investigations (compare fig. 9 and fig. 15). The O'Brien Lock and Dam was closed during the synoptic period except to transmit barge traffic. Though 2.02 in. of rainfall was measured at the University of Chicago on June 18, 1992 (National Oceanic and Atmospheric Administration, 1992b, p. 8), the effects of the rainfall on water levels appear to have dissipated by the start of the survey. The stage of Lake Michigan did not change significantly during the survey.

The surface-water elevation of Lake Michigan was measured at Gary Harbor (SW-21) and at Calumet Harbor (SW-1). The surface-water elevation at both stations was 580.1 ft above sea level (fig. 15). The data are inadequate to identify the flow direction in Lake Michigan.

Water levels were measured at two sites in the eastern and western basins of Wolf Lake (fig. 15). The water-level altitude at the western shore of Wolf Lake was 582.1 ft above sea level; the water-level altitude at the eastern shore was 583.0 ft above sea level. This suggests the potential for flow from east to west between the basins of Wolf Lake.

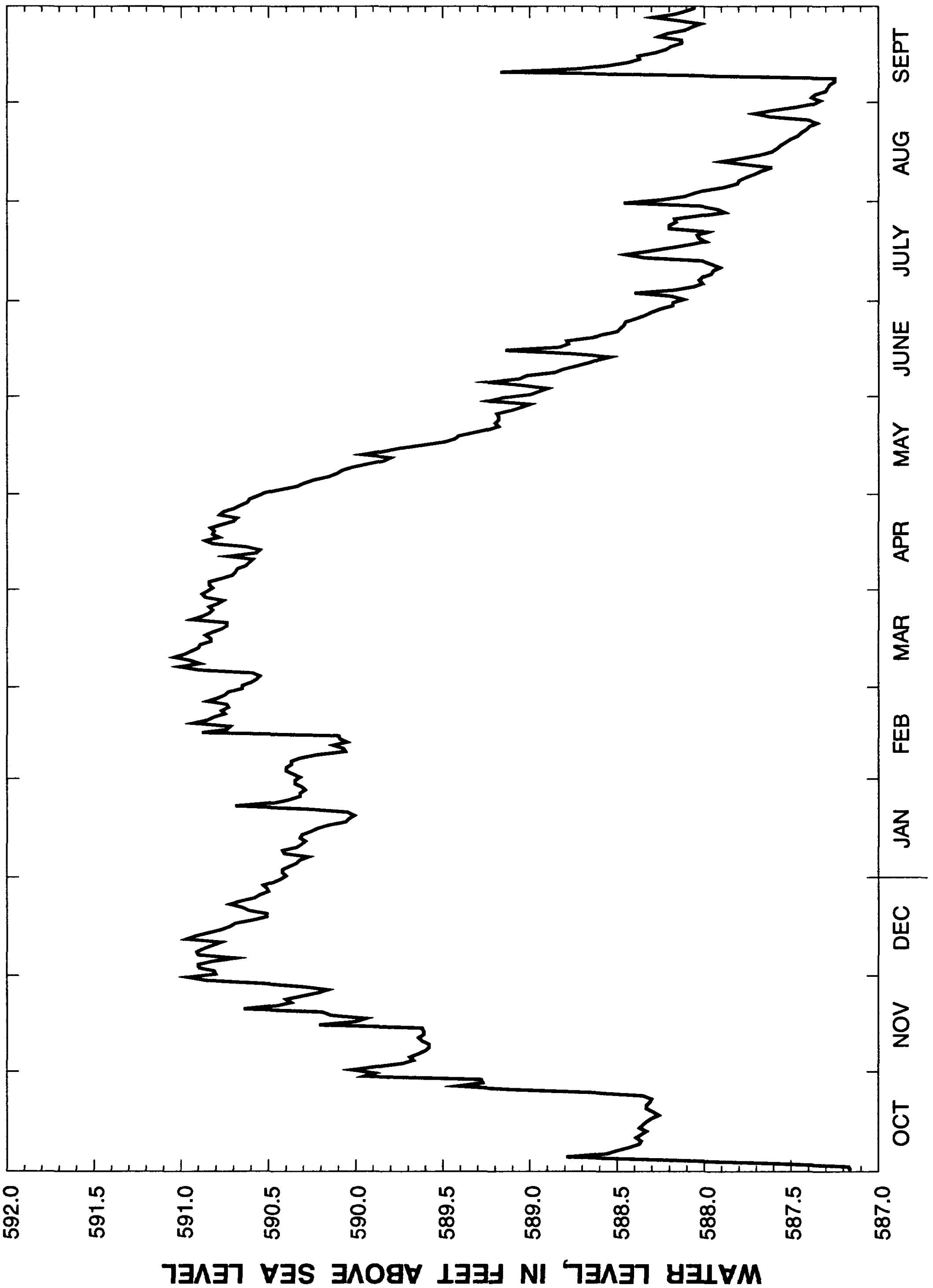


Figure 12. Water-level trends in well S297, northwestern Indiana and the Lake Calumet area of northeastern Illinois, Oct. 1, 1991–Sept. 30, 1992.

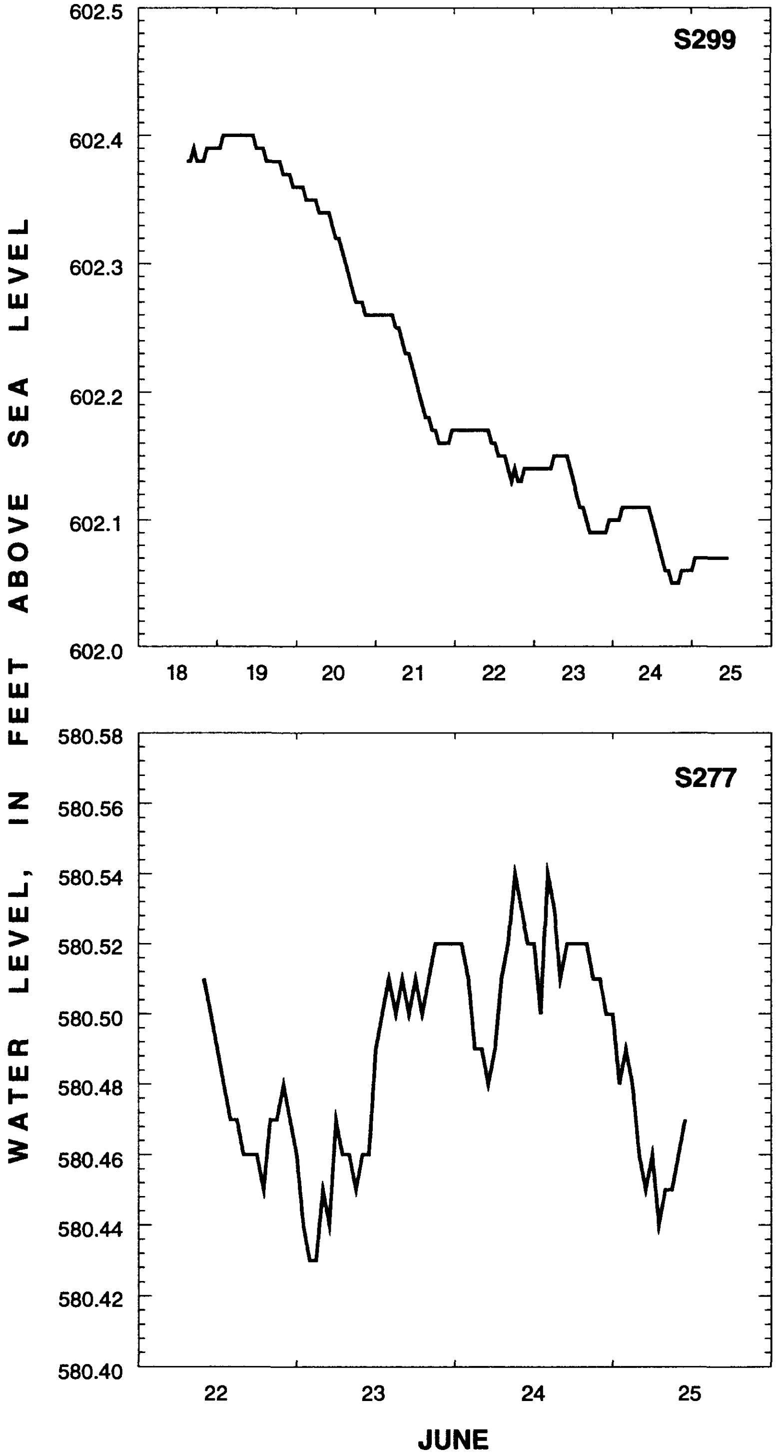


Figure 13. Water-level trends in wells S299 and S277, northwestern Indiana and the Lake Calumet area of northeastern Illinois, June 18–25, 1992.

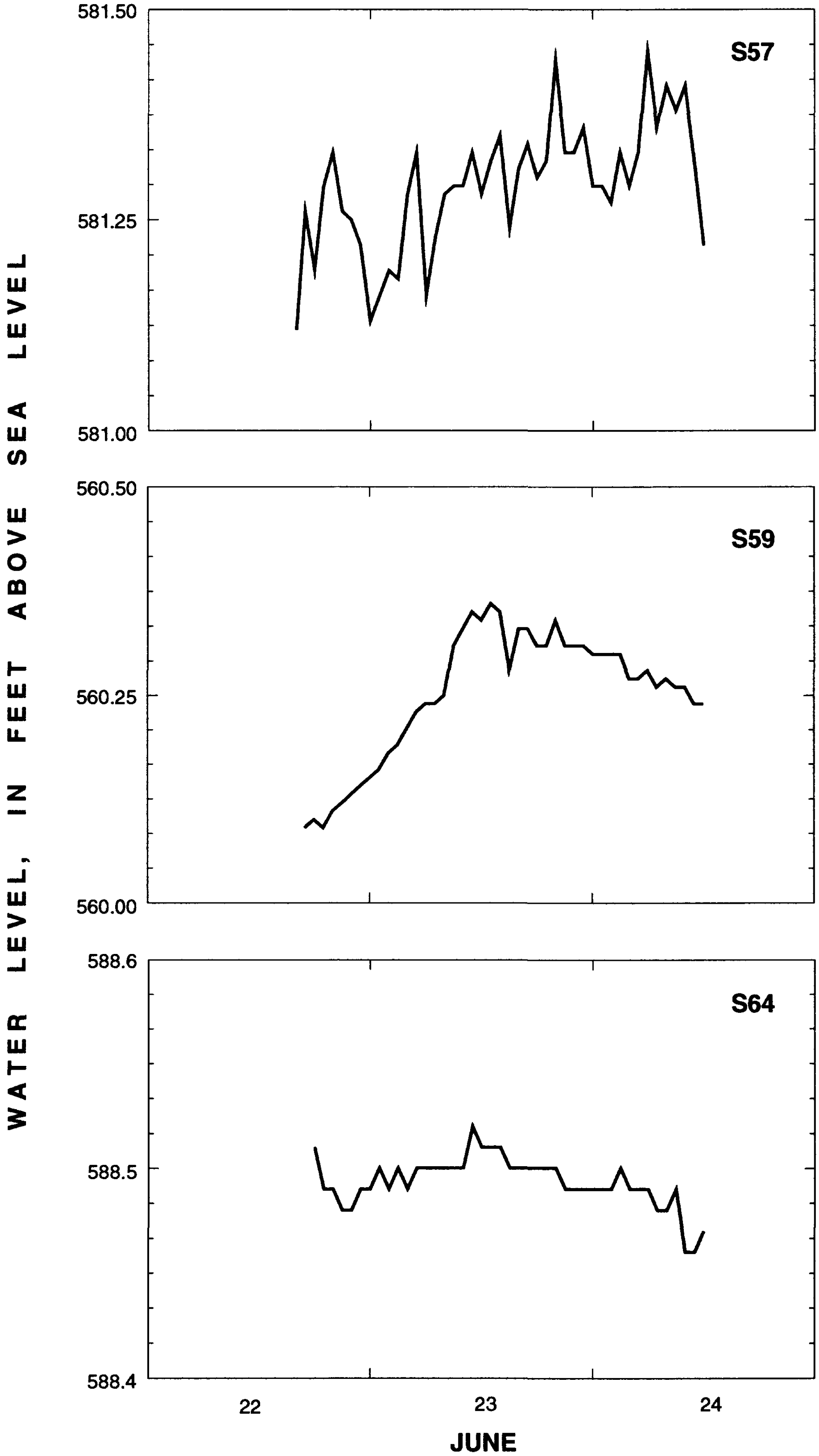


Figure 14. Water-level trends in wells S57, S59, and S64, northwestern Indiana and the Lake Calumet area of northeastern Illinois, June 22–24, 1992.

The surface-water elevation (591.8 ft above sea level) measured on the Little Calumet River near Hart Ditch at station SW-30 is substantially higher than at any of the nearby stations, indicating a flow divide near this site (fig. 15). East of the divide, the Little Calumet River flows toward Burns Harbor and Lake Michigan. West of the divide, the Little Calumet River flows toward the Calumet Sag Channel.

The Grand Calumet River flows westward from its source near the Grand Calumet Lagoons into the Indiana Harbor Canal and Lake Michigan (fig. 15). Though it is likely that there is some eastward flow between station SW-14 and the inlet to the Indiana Harbor Canal, the water levels indicate that westward flow of the Grand Calumet River continues to its confluence with the Little Calumet River. Flow in the Little Calumet River south of the O'Brien Lock and Dam and west of the confluence with the Grand Calumet River is westward to the Calumet Sag Channel.

Surface-water levels at the Calumet River indicate a high in the vicinity of station SW-3 (fig. 15). This high water level appears to be caused by surface-water discharge from Wolf Lake to the Calumet River at the drainage ditch near station SW-3. North of station SW-3, flow of the Calumet River is toward Lake Michigan. South of station SW-3, flow is toward Lake Calumet.

Several surface-water-level measurements (stations SW-7 and SW-8 on the Little Calumet River, station SW-6 on the Calumet Sag Channel) indicate different flow directions than those shown by the arrows in figure 15. The apparent discrepancies are probably the result of measurement errors caused by wind blowing the steel tape during measurement or by water-level changes associated with wind effects, stream turbulence, or obstructions in the channel (Sauer and Meyer, 1992, p. 14 and 16).

Surface-water gradients were determined by dividing the change in water level between two stations by the measured distance along the stream between the stations. Gradients for the Grand Calumet and Calumet Rivers averaged 0.4 ft/mi. Gradients for the Little Calumet River were generally the largest and averaged 0.7 ft/mi. Gradients for the Indiana Harbor Canal were small, with an average value of about 0.2 ft/mi. No gradient could be calculated for the Calumet Sag Channel because only one data point was available.

Discharge readings were made at stations SW-24 and SW-31 on the Little Calumet River and at station SW-12 on the Grand Calumet River. During June 23–25, 1992, daily mean discharge of the Little Calumet River was 37 ft^3/s at station SW-24 and 10 ft^3/s at station SW-31 (Stewart and others, 1993, p. 203 and 243). Daily mean discharge of the Grand Calumet River averaged 18 ft^3/s at station SW-12 (Stewart and others, 1993, p. 244).

Ground Water

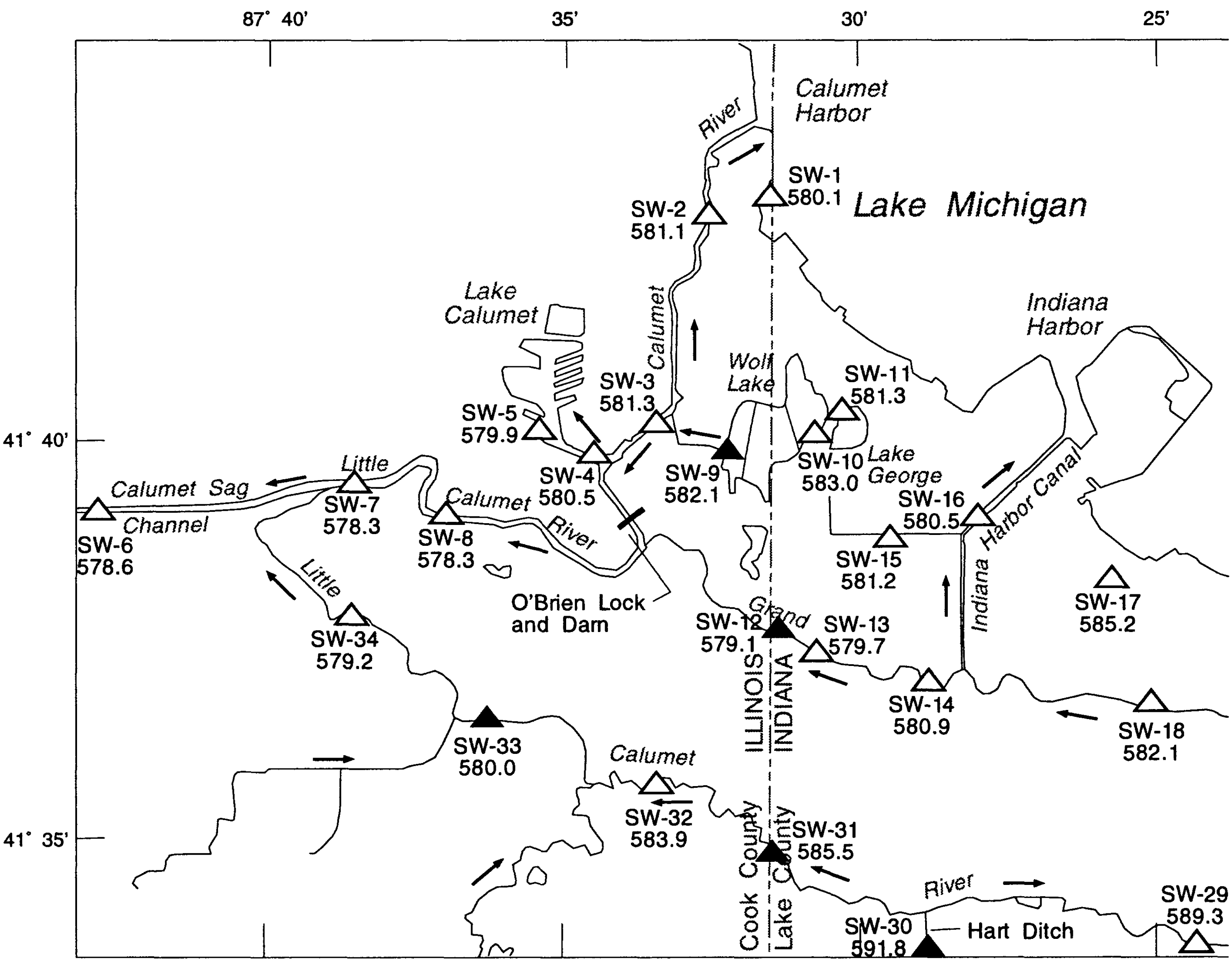
The configuration of the water table and the potentiometric surface of the top of the Silurian-Devonian aquifer were plotted to define the horizontal direction of ground-water flow in these units and to identify the factors that control ground-water levels.

Water Table

The water-table configuration generally follows surface topography where topographic relief is significant (compare fig. 4 and pl. 1). In those parts of the study area where the surface topography is relatively flat (particularly between the Calumet River, the Grand Calumet River, Lake Michigan, and the Indiana Harbor Canal), the water-table configuration is more complex. This is consistent with the results of the water-table mapping done in Indiana during previous studies (Watson and others, 1989, p. 32–33).

Plotting the water-table configuration is complicated by the lack of ground-water-level data in some parts of the study area. The well coverage between the western shore of Lake Calumet and the eastern edge of the study area is sufficient to provide a detailed depiction of the water-table configuration at the scale presented on plate 1. Data points are scarce or absent, however, in most of the area south of the Little Calumet River and west of Lake Calumet. It is possible that the water-table configuration in these areas is more complex than is shown on plate 1.

A long (approximately 5 mi) north-south trending ground-water divide, defined as a ridge in the water table from which ground water moves away in both directions normal to the ridge line, is present along the topographic ridge at Blue Island (pl. 1). Ground-water flow west of the divide is directed south and west toward the Calumet Sag Channel. Flow east of the divide is directed south and east toward the Little Calumet River and Lake Calumet.



EXPLANATION

DIRECTION OF SURFACE-WATER FLOW

SW-15 581.2 SURFACE-WATER-LEVEL MEASUREMENT SITE AND DESIGNATION—Number is water-level elevation, in feet above sea level

SW-31 585.5 CONTINUOUS MONITORING SITE AND DESIGNATION—Number is water-level altitude, in feet above sea level

Figure 15. Direction of surface-water flow, northwestern Indiana and the Lake Calumet area of northeastern Illinois, June 23–25, 1992.

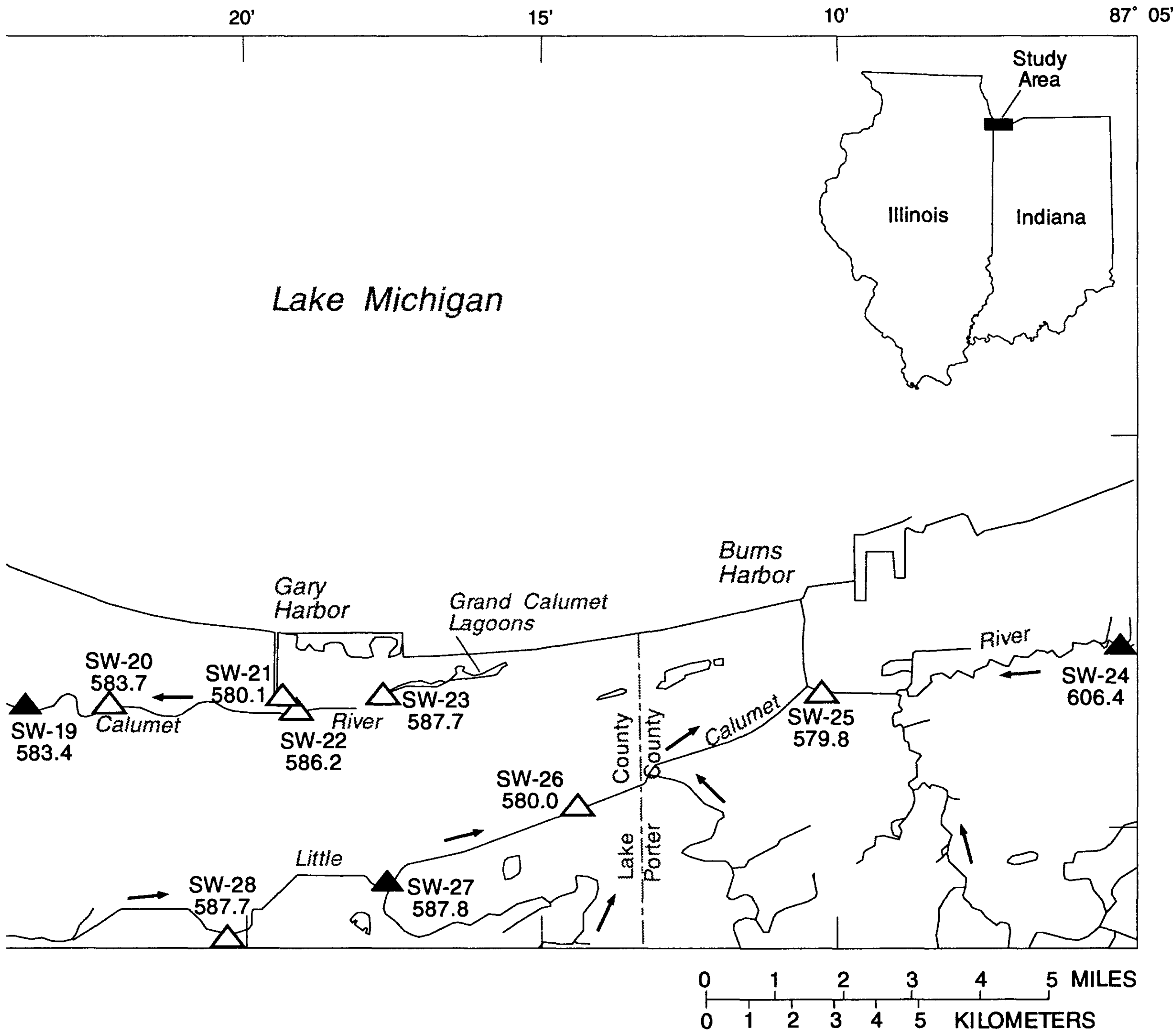


Figure 15. Continued.

An east-west trending ground-water divide is present beneath the topographic high associated with the Toleston Beach Ridge (pl. 1). The western extent of the divide is at the bend in the Little Calumet River near the Calumet Sag Channel. The divide extends eastward beyond Gary Harbor and the Grand Calumet Lagoons to the vicinity of Burns Harbor. North of the divide, ground water flows northward to the Little Calumet River, the Grand Calumet River, or Lake Michigan. South of the divide, ground water flows toward the Little Calumet River.

A small east-west trending ground-water divide is present between the Grand Calumet River and Lake Michigan east of the Indiana Harbor Canal. North of the divide, ground water flows northward to Lake Michigan. South of the divide, ground water flows southward toward the Grand Calumet River.

An elongated, east-west trending ground-water divide was identified between Gary Harbor and the Grand Calumet Lagoons. Ground water flows radially away from this high toward Lake Michigan, the Grand Calumet River, Gary Harbor, and the western lagoon. Near the eastern lagoon, ground water flows northward toward Lake Michigan.

A fourth east-west trending ground-water divide is present in the northern edge of the study area. This divide is associated with the topographic high at Stony Island. Flow from Stony Island is toward Lake Calumet and Lake Michigan.

In addition to the ground-water divides, several ground-water mounds, defined as a raised area in the water table resulting from ground-water recharge, have been identified in the study area. The largest water-table mound is the north-south trending mound along the western shore of Lake Calumet. Ground-water flow east of the mound is toward Lake Calumet. Along the northwestern part of the mound, flow is toward the west, changing toward the east away from the mound. Southwest of the mound, ground water flows toward the Little Calumet River. The mound is a local feature partially caused by enhanced recharge to ground water from ponded water at some of the industrial facilities in this area. The current well network is inadequate to fully define the extent of water-table mounding in this area, but results from a previous investigation do not indicate enhanced recharge to ground water from ponds at the Calumet Sewage Treatment Plant (Ecology and Environment, Inc., 1990, p. 4–29).

A second north-south trending ground-water mound is present between Lake Calumet and the Calumet River. This mound appears to be the result of additional recharge to ground water from one or more of the landfills in this area. Flow in the vicinity of this mound is toward Lake Calumet or the Calumet River.

Several small ground-water mounds are associated with the piers in Lake Calumet. The height and location of the mounds at these piers is controlled by enhanced recharge of ponded water to ground water.

Several depressions in the water-table surface were identified throughout the study area. Most of these are between the Calumet River, the Grand Calumet River, Lake Michigan, and the Indiana Harbor Canal. Most of the depressions in this and other areas appear to result from ground-water drainage into sewer lines (Watson and others, 1989, p. 30) (compare pl. 1 and fig. 1).

Three areas display depressions in the water table that cannot be attributed to ground-water drainage to sewer lines. Two of these are in the bend of the Little Calumet River immediately west of the confluence with the Grand Calumet River (pl. 1). The eastern depression is caused by drainage to, and pumping from, an excavation at the southern edge of the landfill at this site. The western depression may be caused by water-level measurements in monitoring wells where water levels had not returned to equilibrium after dedicated sampling pumps were removed. Water levels in these wells are not entirely representative of actual conditions. The actual water-table altitude at this depression is likely to be higher than shown on plate 1. The third area where the water table is depressed is northwest of the Indiana Harbor Canal and east of Lake George. The water-table configuration in this area is affected primarily by pumping associated with ground-water remediation efforts and dewatering at highway underpasses. Drainage to sewer lines also has some affect on the water-table configuration. In this area, ground water flows toward Lake Michigan, the Indiana Harbor Canal, pumping centers, and sewers.

Silurian-Devonian Aquifer

Identifying the direction of ground-water flow in the Silurian-Devonian aquifer is complicated by the lack of ground-water-level data. Most of the wells open to this aquifer for environmental investigations are in the Lake Calumet area. Only four wells open to the Silurian-Devonian aquifer, none of which were located in the eastern third of the study area, could be measured in Indiana. The wells drilled for environmental investigations are open only to the top few feet of the aquifer. The wells drilled for the TARP are located over a large area of Illinois but are open to the aquifer over tens or hundreds of feet (S135 to S152 in appendix 1). Because of the long open intervals, water levels from the TARP wells are considerably lower than water levels in the shallower monitoring wells in the same area, indicating downward flow within the aquifer. Only the water levels from the wells open to the top 20 ft of the Silurian-Devonian aquifer are discussed because water-level altitudes from the shallow and deep wells represent different parts of the flow system and should not be compared.

The potentiometric surface of the top of the Silurian-Devonian aquifer is highest at the bedrock high near Stony Island (fig. 16). A second water-level high associated with the bedrock high north-northeast of Thornton Quarry is inferred. These areas are separated by a depression near the confluence of the Little Calumet and Grand Calumet Rivers. This depression appears to be centered at a drop shaft open to the aquifer that was being dewatered by pumping. Pumping at the drop shaft ceased shortly after the synoptic survey. It is unclear if the potentiometric surface shown in figure 16 is representative of current conditions. Ground-water pumping from the Silurian-Devonian and underlying aquifers at industrial facilities along the Calumet River and Lake Calumet also may have some effect on the potentiometric surface. The depression in the potentiometric surface around Thornton Quarry is attributed to excavation and pumping at the quarry.

Surface-Water and Ground-Water Interactions

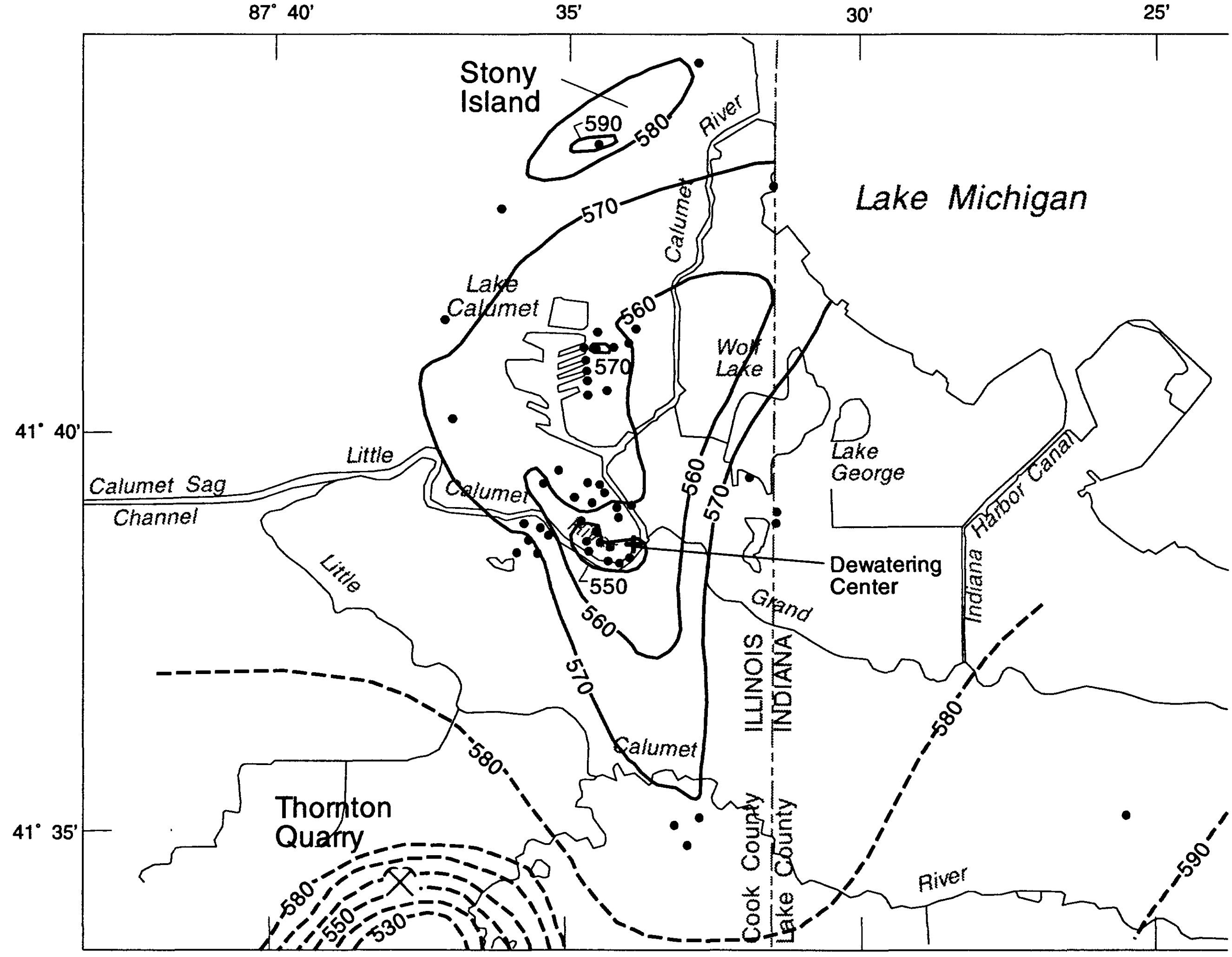
Comparison of surface-water and ground-water levels indicates complex interactions between surface water and ground water. Ground-water contours indicate that the general direction of ground-water flow, which is perpendicular to the potentiometric contours, is toward the major surface-water bodies (pl. 1). However, ground-water levels in wells nearest surface-water stations indicate the potential for surface-water recharge to ground water in parts of the study area.

Interpretation of the interaction between surface water and ground water is further complicated by sheet piles driven through the Calumet aquifer. Gary Harbor is lined with sheet piles that extend east from the mouth of the harbor approximately 1.5 mi into Lake Michigan and then south to the shoreline. Sheet piles also are present along long reaches of the Calumet River, Lake Calumet, the Indiana Harbor Canal, and Lake Michigan. The sheet piles form a barrier to the flow of surface water and ground water, forcing water to move under the wall or through cracks, holes, and joints in the sheet piles. As a consequence of the lack of area through which discharge can occur, large gradients can be built up between ground water and surface water. Such gradients are evident around Gary Harbor (pl. 1). Although the large hydraulic gradient indicates the potential for substantial flow from ground water to surface water, the lack of a flow pathway may (or may not) prevent this flow.

The surface-water elevation of Lake Michigan measured at station SW-1 in Calumet Harbor and station SW-21 in Gary Harbor was 580.1 ft above sea level. It is assumed, therefore, that the lake level throughout the study area is about 580.1 ft above sea level. Ground-water levels in wells nearest Lake Michigan exceeded the lake levels except in one well near the State line in Indiana. This indicates the potential for ground-water discharge to Lake Michigan in virtually all of the study area. Sheet pilings along Lake Michigan at several of the steel-manufacturing facilities restrict ground-water flow to the lake.

The surface-water elevation measured at station SW-4 is assumed to approximate the level of Lake Calumet (fig. 15). This is lower than the ground-water altitude in the wells around the lake, indicating the potential for ground-water discharge to Lake Calumet. Sheet piling along the southwestern corner of Lake Calumet near station SW-5 indicates that the higher ground-water levels in this area are caused by a restriction of flow behind the sheet piles. It is unclear how much ground water is discharging to the lake in this area.

Surface-water/ground-water interaction at Wolf Lake is affected by lake level, which is affected by industrial discharge to the lake, and ground-water levels, which are affected by drainage to sewer lines. The surface-water elevation at station SW-10 is from 0.2 to 0.8 ft higher than the ground-water altitude in nearby wells (fig. 15). This indicates the potential



EXPLANATION

—550— POTENTIOMETRIC CONTOUR—Shows altitude at which water level would have stood in tightly cased wells. Dashed where approximate. Contour interval 10 feet. Datum is sea level

• WELL LOCATION

Figure 16. Potentiometric surface of the Silurian-Devonian aquifer, northwestern Indiana and the Lake Calumet area of northeastern Illinois, June 23–25, 1992.

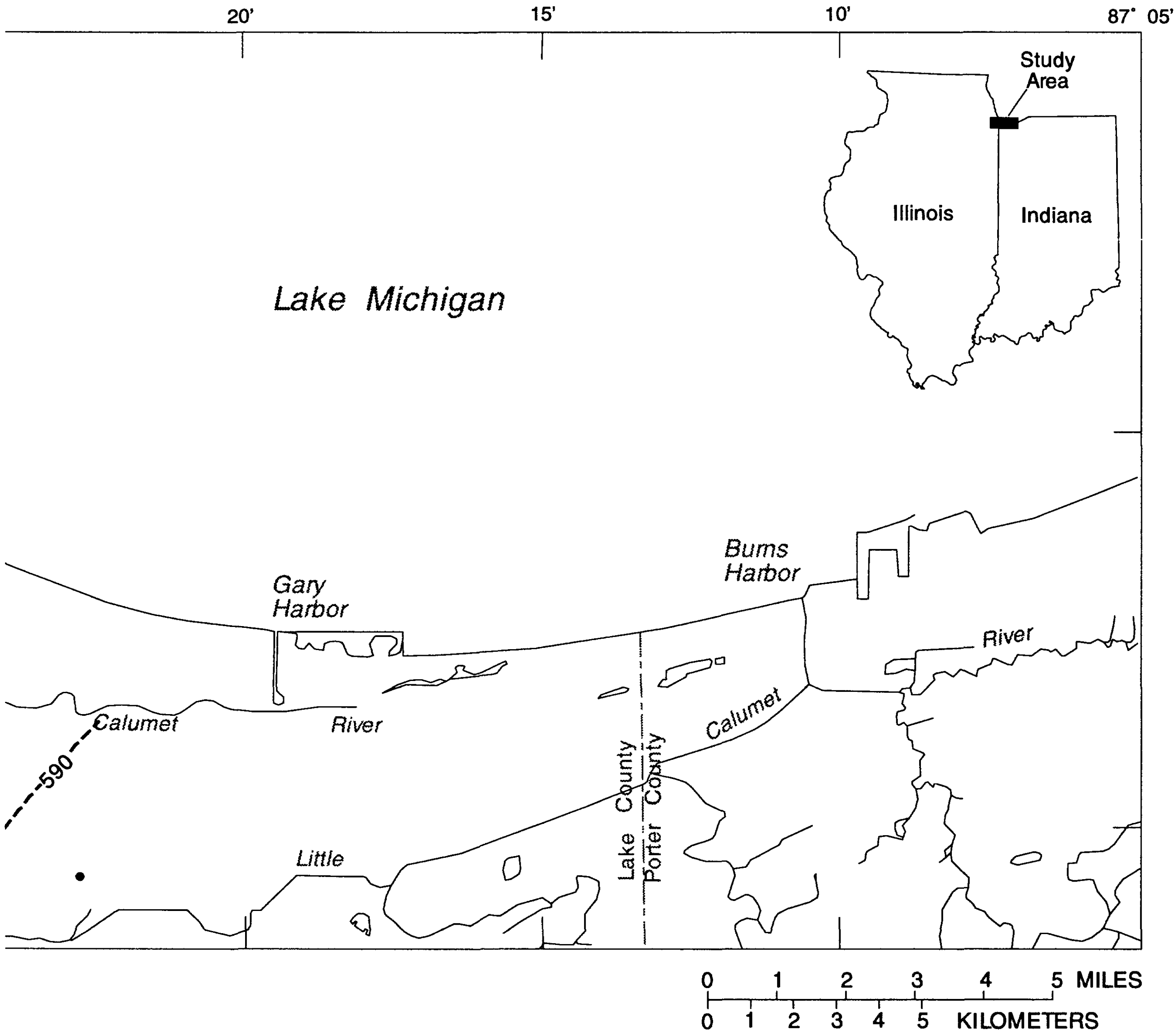


Figure 16. Continued.

for surface-water discharge to ground water in most of the eastern basin. The eastern basin is the site of industrial discharge, and several large sewers are near this area (fig. 1). The surface-water elevation in the western basin at station SW-9 is about 0.9 ft lower than the ground-water altitude in a well about 300 ft west of the station, about 0.5 ft higher than the ground-water altitude in a well next to the lake about 1,400 ft south of the station, and about 0.3 ft lower than the ground-water altitude in a well next to the lake along the southern tip of the western basin. This indicates the potential for ground-water discharge to surface water in the west-central and southeastern parts of Wolf Lake and surface-water recharge to ground water along the southwestern part of the lake. Ground-water levels exceed surface-water levels in the north-western part of the basin (G.S. Roadcap, Illinois State Water Survey, written commun., 1994). No industrial discharge or large sewers are present near the western basin, but small sewers are present in the residential areas southwest of the lake (fig. 2).

The measured surface-water elevations on the Calumet River at station SW-4 were from 0.11 to 1.0 ft higher than ground-water levels in nearby wells. This indicates the potential for the river to recharge the Calumet aquifer in this area. The surface-water elevation of the Calumet River at station SW-2 was about 0.50 ft lower than ground-water levels in nearby wells. This indicates the potential for discharge from ground water to surface water in this area. Sheet piling is present near station SW-2, indicating that the higher ground-water levels are caused by a restriction of flow behind the sheet piles. It is unclear how much ground water is discharging to the river near station SW-2.

Wells are present near stations SW-12, SW-13, SW-19, and SW-20 on the Grand Calumet River (fig. 15). Ground-water levels exceeded surface-water levels at each of these stations, indicating the potential for ground-water discharge to the Grand Calumet River over its entire reach.

Ground-water levels near the Calumet Sag Channel at station SW-6 are lower than surface-water levels, indicating the potential of water from the Calumet Sag Channel to discharge to ground water in this area. The low ground-water levels in this area appear to be caused by drainage to sewer lines (compare pl. 1 and fig. 1).

The surface-water elevation of the Little Calumet River east of station SW-8 (fig. 15) exceeds ground-water altitudes in the area of the depression in the water table near the confluence of the Little Calumet and the Grand Calumet Rivers (pl. 1). Water from the Little Calumet River has the potential to discharge to ground water in this area. No wells are located near stations SW-24 through SW-34 on the Little Calumet River. The available data indicate that ground water will discharge to the Little Calumet River along this reach.

Horizontal Hydraulic Gradients and Ground-Water Velocities

Horizontal hydraulic gradients at the water table and at the top of the Silurian-Devonian aquifer were calculated with water levels measured during the synoptic survey. Horizontal hydraulic gradients were calculated by dividing the change in the altitude of the water table or the potentiometric surface of the Silurian-Devonian aquifer along two points parallel to the direction of ground-water flow by the horizontal distance between those points.

The calculated horizontal hydraulic gradient of the water table along nine transects along lines of flow in Illinois ranged from 1.2×10^{-3} to 4.4×10^{-3} ft/ft (fig. 17, table 2). These values do not vary substantially with location or changes in lithology.

The calculated horizontal hydraulic gradient along five lines of flow at the water table in Indiana ranged from 7.8×10^{-4} to 5.1×10^{-3} ft/ft (fig. 17, table 2). The transects cross the ground-water divides so two values were calculated for each transect.

The calculated horizontal hydraulic gradient of the potentiometric surface of the Silurian-Devonian aquifer along five transects in Illinois and Indiana ranged from 8.8×10^{-4} to 1.8×10^{-3} ft/ft (fig. 18, table 3). Gradients increase toward the pumping center in the dolomite aquifer north of the confluence of the Grand Calumet and Little Calumet Rivers.

Horizontal hydraulic gradients calculated from water levels collected during the synoptic survey generally are less than those calculated during the site-specific investigations. This is probably because of the unusually small amount of precipitation in the months prior to the synoptic survey and the larger

Table 2. Calculated horizontal hydraulic gradient and ground-water velocity at the water table along transects, northwestern Indiana and the Lake Calumet area of northeastern Illinois

Transect (see fig. 17)	Horizontal hydraulic gradient (foot per foot)	Porosity (percent)	Horizontal hydraulic conductivity (feet per day)	Horizontal ground-water velocity (feet per day)
		Flow line primarily through confining unit		
A-A'	3.1×10^{-3}	20	5.8×10^{-2}	9.0×10^{-4}
B-B'	3.1×10^{-3}	20	5.8×10^{-2}	9.0×10^{-4}
C-C'	3.6×10^{-3}	20	5.8×10^{-2}	1.0×10^{-3}
H-H'	1.5×10^{-3}	20	5.8×10^{-2}	4.4×10^{-4}
		Flow line primarily through Calumet aquifer		
X-D'	4.4×10^{-3}	30	1.5×10^{0}	2.2×10^{-2}
X-E'	2.0×10^{-3}	30	1.5×10^{0}	1.0×10^{-2}
X-F'	2.6×10^{-3}	30	1.5×10^{0}	1.3×10^{-2}
G-G'	3.9×10^{-3}	30	5.0×10^{0}	6.5×10^{-2}
G-G"	3.2×10^{-3}	30	5.0×10^{0}	5.3×10^{-2}
I-I'	1.2×10^{-3}	30	5.0×10^{0}	2.0×10^{-2}
J-J'	1.6×10^{-3}	30	2.0×10^{1}	1.1×10^{-1}
J-J"	1.8×10^{-3}	30	2.0×10^{1}	1.2×10^{-1}
K-K'	9.4×10^{-4}	30	1.0×10^{1}	3.1×10^{-2}
K-K"	1.6×10^{-3}	30	5.0×10^{0}	2.7×10^{-2}
L-L'	2.7×10^{-3}	30	2.0×10^{1}	1.8×10^{-1}
L-L"	1.6×10^{-3}	30	2.0×10^{1}	1.1×10^{-1}
M-M'	5.1×10^{-3}	30	2.0×10^{1}	3.4×10^{-1}
M-M"	3.0×10^{-3}	30	2.0×10^{1}	2.0×10^{-1}
N-N'	7.8×10^{-4}	30	2.0×10^{1}	5.2×10^{-2}
N-N"	3.6×10^{-3}	30	2.0×10^{1}	2.4×10^{-1}

distances over which the horizontal hydraulic gradients were calculated.

Average linear ground-water velocity (V) at the water table along the lines of transect was calculated by solving the equation

$$V = (K \times I)/n, \qquad (1)$$

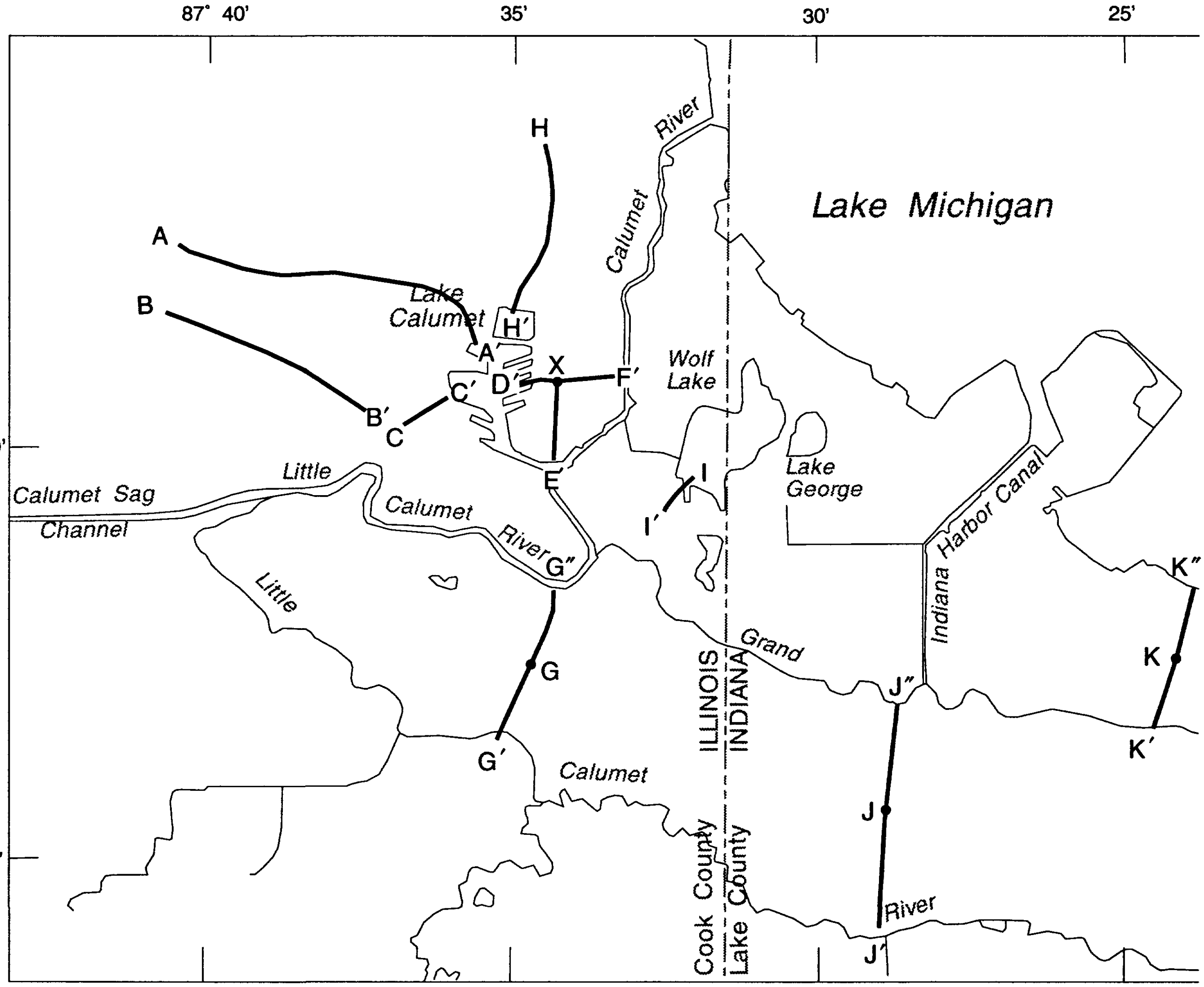
where

K is the horizontal hydraulic conductivity, in feet per day;
I is the horizontal hydraulic gradient, in foot per foot; and
n is the effective porosity, in percent.

Ground-water velocities near the water table in the confining unit were calculated using the median horizontal-hydraulic-conductivity values obtained from the slug tests, the horizontal hydraulic gradient along a transect, and a representative value for effective porosity (table 2). Use of a mean horizontal hydraulic conductivity for the calculation of ground-water velocity will result in an estimate of the velocity through a typical section of the confining unit. Larger or smaller ground-water velocities are likely locally.

The effective porosity of the Calumet aquifer is assumed to be 30 percent (Freeze and Cherry, 1979, p. 37). The horizontal hydraulic conductivity of the aquifer is variable along the lines of transect (figs. 11, 17) so approximate values were used (table 2). Where no data were available in Indiana, the horizontal hydraulic conductivity was assumed to be 2.0×10^{1} ft/d. Where no data were available in Illinois, a value of 5.0×10^{0} ft/d was assumed. Applying these values, the calculated ground-water velocity through the Calumet aquifer along the lines of transect ranges from about 1.0×10^{-2} to 3.4×10^{-1} ft/d.

The effective porosity of the confining unit at the water table is about 20 percent, whereas the median horizontal hydraulic conductivity in the confining unit at the water table was calculated to be 5.8×10^{-2} ft/d. Applying these values, the ground-water velocity at the water table in the confining unit



EXPLANATION

J ——— J′ J ——— J″ X ——— F′	TRANSECTS— Ground-water flow is toward the prime letter designation. For example, flow is from J to J', from J to J", and from X to F'

Figure 17. Location of transects where horizontal hydraulic gradients along the water table were calculated, northwestern Indiana and the Lake Calumet area of northeastern Illinois, June 23–25, 1992.

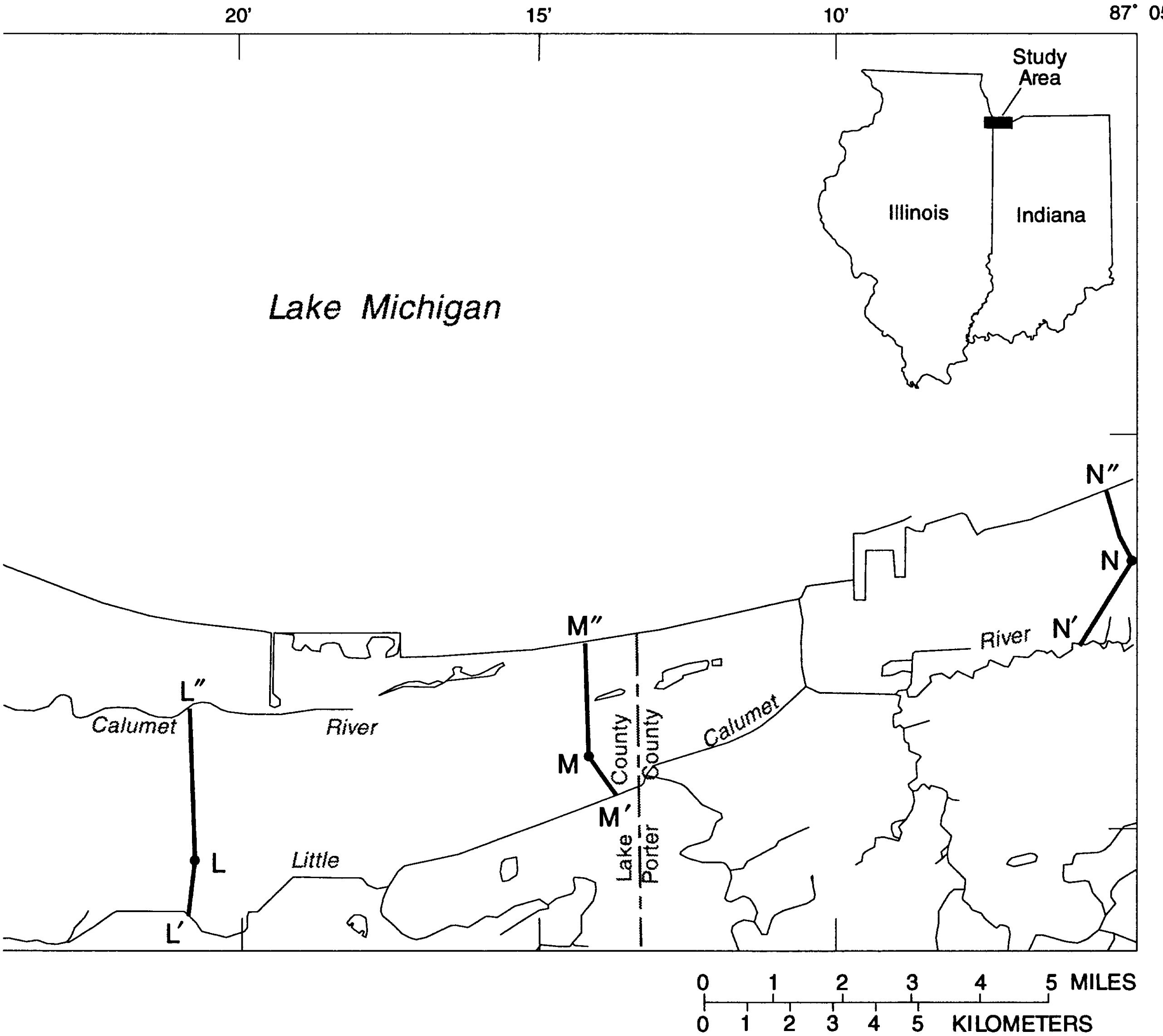
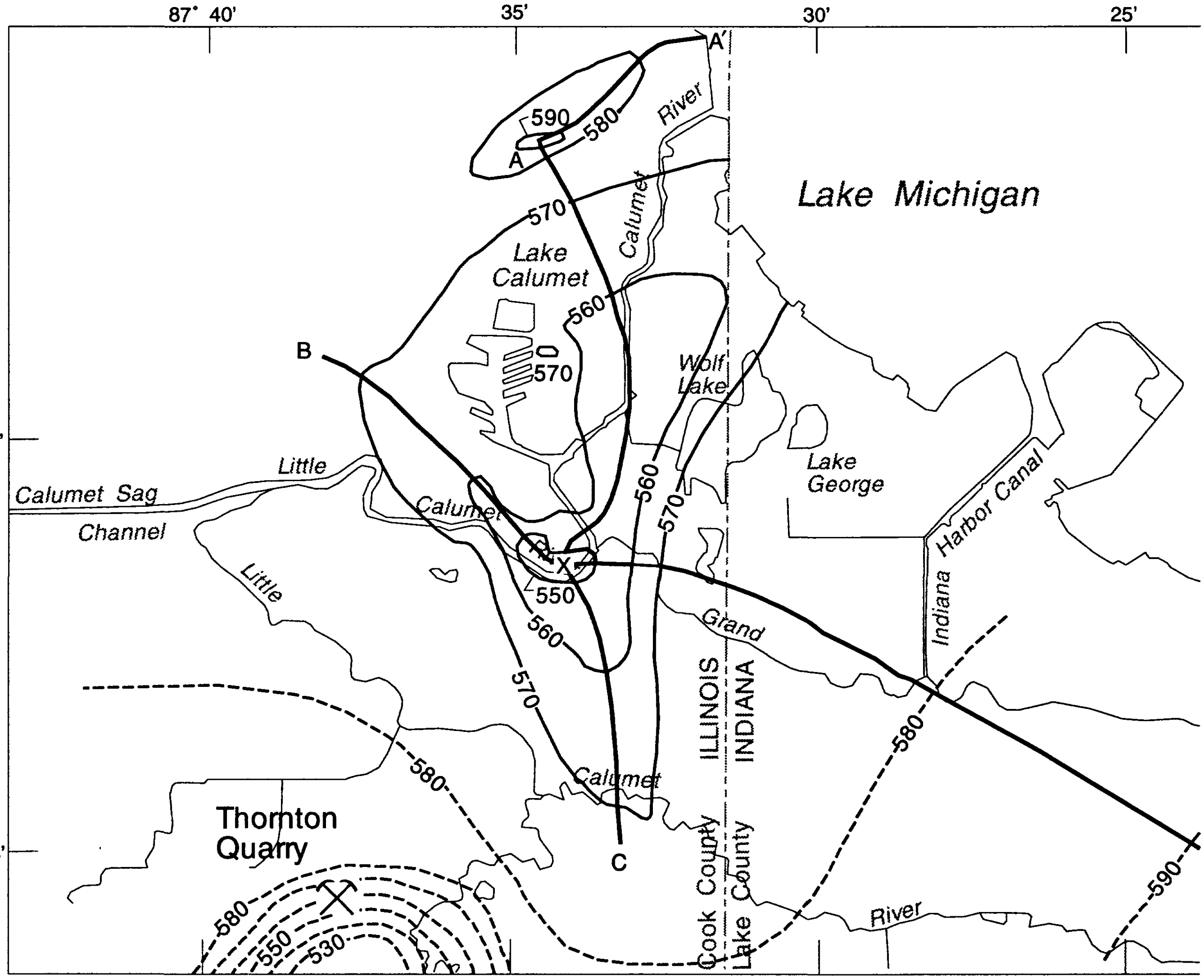


Figure 17. Continued.



EXPLANATION

—550— POTENTIOMETRIC CONTOUR—Shows altitude at which water level would have stood in tightly cased wells. Dashed where approximate. Contour interval 10 feet. Datum is sea level

A——A' TRANSECTS—
A——X Ground-water flow is toward the prime letter designation and toward "X". For example, flow is from A to A' and from A to X

Figure 18. Location of transects where horizontal hydraulic gradients in the Silurian-Devonian aquifer were calculated, northwestern Indiana and the Lake Calumet area of northeastern Illinois, June 23–25, 1992.

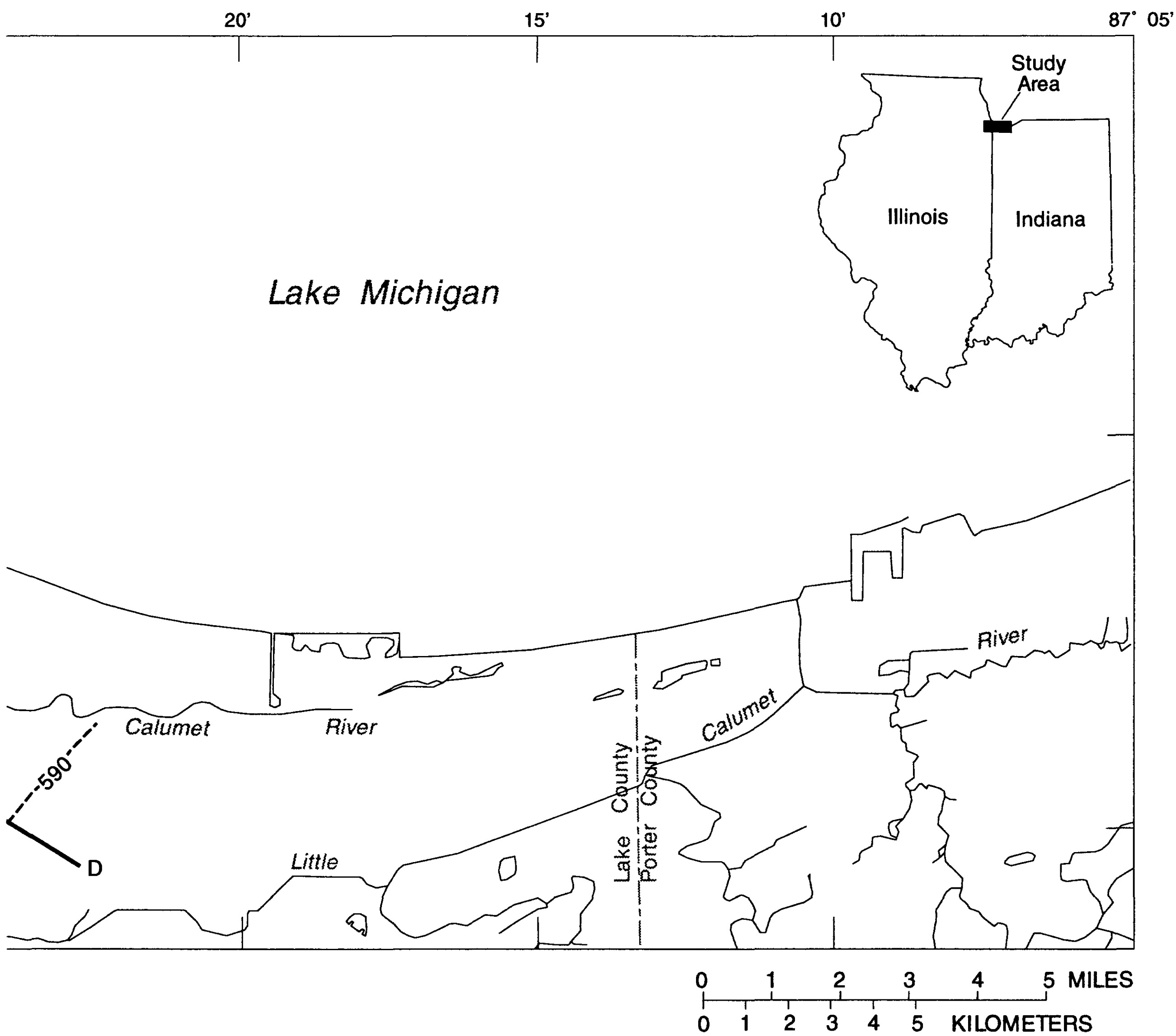


Figure 18. Continued.

Table 3. Calculated horizontal hydraulic gradient and ground-water velocity in the Silurian-Devonian aquifer along transects, northwestern Indiana and the Lake Calumet area of northeastern Illinois

Transect (see fig. 18)	Horizontal hydraulic gradient (foot per foot)	Porosity (percent)	Horizontal hydraulic conductivity (feet per day)	Horizontal ground-water velocity (feet per day)
A-A'	1.5×10^{-3}	1	1.6×10^{-1}	2.4×10^{-2}
A-X	1.8×10^{-3}	1	1.6×10^{-1}	2.9×10^{-2}
B-X	1.3×10^{-3}	1	1.6×10^{-1}	2.1×10^{-2}
C-X	1.3×10^{-3}	1	1.6×10^{-1}	2.1×10^{-2}
D-X	8.8×10^{-4}	1	1.6×10^{-1}	1.4×10^{-2}

along the lines of transect ranged from 4.4×10^{-4} to 1.0×10^{-3} ft/d (table 2).

The effective porosity of the Silurian-Devonian aquifer is estimated to be about 1 percent based on typical porosity values of dolomite deposits (Freeze and Cherry, 1979, p. 375). The median horizontal hydraulic conductivity, as determined from the 24 slug tests performed by the USGS and other investigators, is 1.6×10^{-1} ft/d. Using these values, the average linear ground-water velocity through the upper part of the Silurian-Devonian aquifer along the lines of transect is calculated to range from 1.4×10^{-2} to 2.9×10^{-2} ft/d (table 3).

Vertical Hydraulic Gradients and Ground-Water Velocities

The vertical hydraulic gradient is the difference in the altitude of the water levels in wells in the same location but open to different depths divided by the vertical distance separating the midpoints of the saturated open interval of the wells. If the water-level altitude in the shallow well is higher than that in an adjacent deeper well, the vertical hydraulic gradient is downward and water has the potential for downward flow. If the water-level altitude in the shallow well is lower than in the deep well, the vertical hydraulic gradient is upward and water has the potential for upward flow. As a convention, upward gradients are positive and downward gradients are negative.

Vertical hydraulic gradients between four hydraulic horizons—the water table and the base of the Calumet aquifer, the water table and the confining unit, the confining unit and the top of the Silurian-Devonian aquifer, and the water table and the top of the Silurian-Devonian aquifer—were calculated to determine the vertical direction of ground-water flow (table 4). Because the water level in well S67 had not recovered from well development during the synoptic survey, the vertical hydraulic gradient at the S66/S67/S68 well cluster was calculated using water-level measurements collected on October 27, 1992. It is assumed that measured water levels in all well clusters at which vertical hydraulic gradients were calculated are representative of hydrostatic conditions.

Forty-three sites have wells open to different depths in the Calumet aquifer. Differences between water levels within well clusters ranged from 0 to 3.9 ft (appendix 1). Vertical hydraulic gradients were calculated for the 30 well clusters with differences in water-level altitude greater than 0.02 ft. Assuming an uncertainty of 0.01 ft for each measurement, water-level differences of 0.02 ft or less are considered indicative of horizontal flow.

Of the 30 well clusters in the Calumet aquifer where vertical flow was identified, downward gradients were measured at 14 well clusters and upward gradients were measured at 16 well clusters (table 4). Downward gradients range from -9.7×10^{-4} to -1.3×10^{-1} ft/ft and average -2.1×10^{-2} ft/ft. Upward gradients range from 1.2×10^{-3} to 3.3×10^{-1} ft/ft and average 3.6×10^{-2} ft/ft.

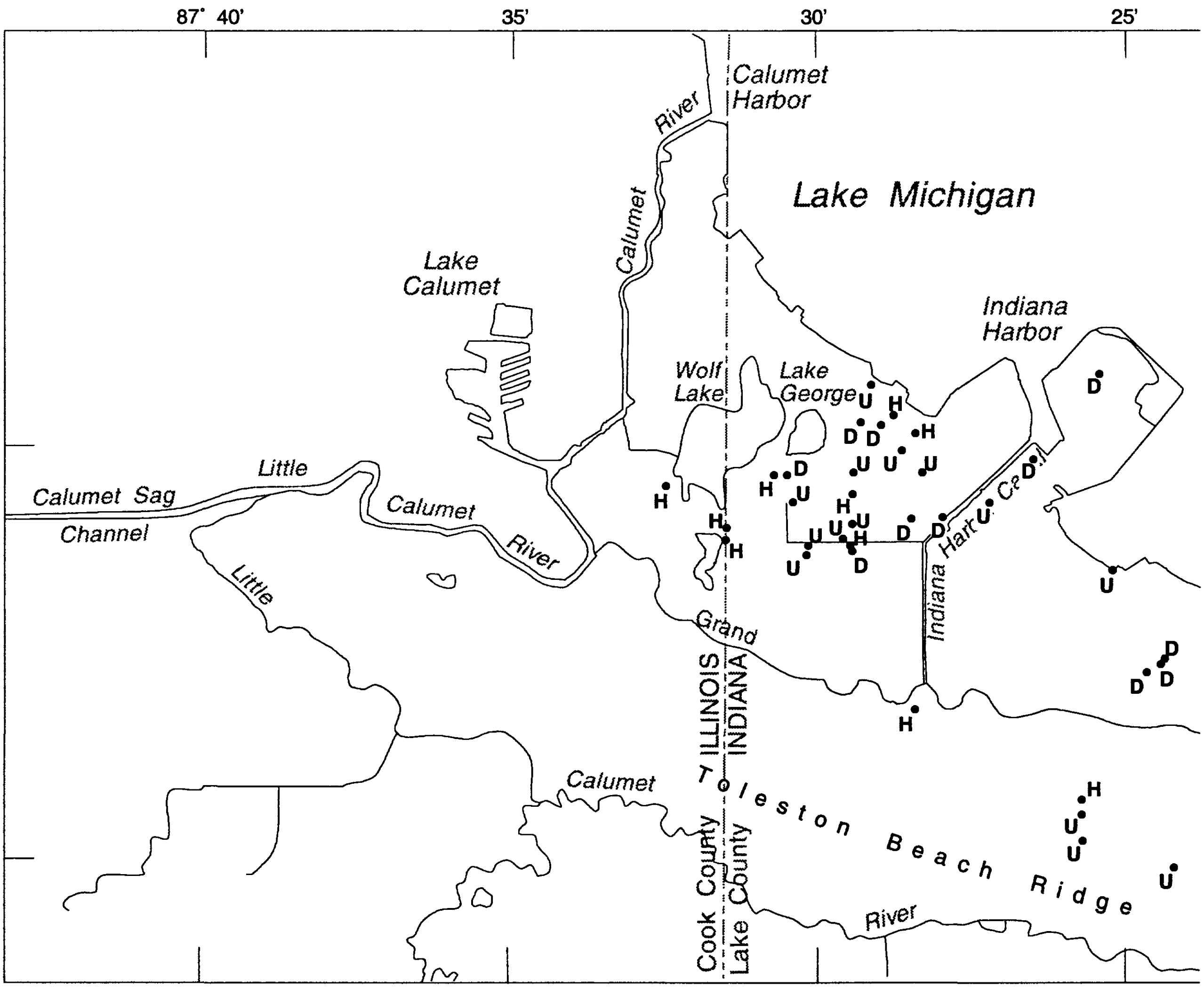
No clear pattern to the direction of vertical hydraulic gradients in the Calumet aquifer is evident. Downward gradients are present along ground-water divides south of Burns Harbor, on the peninsula east of Indiana Harbor, and between the Grand Calumet River, the Indiana Harbor Canal, Gary Harbor, and Lake Michigan (compare pl. 1 and fig. 19). Upward gradients are present at several well clusters along the ground-water divide at the Toleston Beach Ridge. Vertical gradients are absent, indicating horizontal

Table 4. Calculated vertical hydraulic gradient at selected points, northwestern Indiana and the Lake Calumet area of northeastern Illinois

[–, Denotes that the altitude of the water level in the deep well in the well cluster is lower than in the shallow well, indicating the potential for downward movement; Well locations noted in appendix 1]

Well number	Calculated vertical hydraulic gradient (foot per foot)
Water Table in Calumet Aquifer/Base of Calumet Aquifer	
S259/S260	3.3×10^{-1}
S269/S270	4.0×10^{-2}
S275/S276	-3.0×10^{-3}
S338/S339	-2.3×10^{-2}
S343/S344	-4.2×10^{-3}
S347/S348	1.9×10^{-3}
S350/S351	1.2×10^{-3}
S353/S354	-2.6×10^{-3}
S356/S357	4.7×10^{-2}
S358/S359	8.1×10^{-3}
S361/S362	4.8×10^{-3}
S363/S364	-4.7×10^{-3}
S367/S368	5.0×10^{-3}
S372/S373	-3.2×10^{-2}
S374/S375	5.2×10^{-3}
S376/S377	3.7×10^{-3}
S401/S402	2.3×10^{-3}
S431/S432	1.0×10^{-1}
S435/S436	-6.4×10^{-3}
S439/S440	-9.7×10^{-4}
S447/S448	1.8×10^{-3}
S451/S452	2.4×10^{-2}
S454/S455	-1.9×10^{-2}
S456/S457	-3.3×10^{-3}
S458/S459	-6.7×10^{-3}
S460/S461	-1.3×10^{-2}
S463/S464	-4.0×10^{-2}
S466/S467	-1.3×10^{-1}
S472/S473	3.3×10^{-3}
S490/S491	3.8×10^{-3}
Water Table/Middle of Confining Unit	
S09/S10	-1.8×10^{-1}
S27/S28	-6.0×10^{-2}
S49/S50	-8.0×10^{-2}
S54/S55	-1.0×10^{-1}
S57/S58	-1.4×10^{-1}
[1]S66/S67	-4.0×10^{-2}
S198/S199	-3.4×10^{-1}
S201/S202	-1.2×10^{-1}
S201/S203	5.0×10^{-2}
S205/S206	4.9×10^{-1}
S207/S208	-1.1×10^{-1}
S209/S210	-9.0×10^{-2}
S211/S212	-1.9×10^{-1}
S213/S214	-2.4×10^{-1}
Base of Calumet Aquifer/Middle of Confining Unit	
S339/S340	-2.0×10^{-1}
S351/S352	-1.3×10^{-2}
S432/S433	-3.9×10^{-2}
S436/S437	-1.5×10^{-1}
S440/S441	1.8×10^{-2}
Middle of Confining Unit/Top of Silurian Aquifer	
S10/S11	-2.6×10^{-1}
S28/S29	-1.4×10^{0}
S33/S34	-5.9×10^{-1}
S36/S37	-9.0×10^{-1}
S58/S59	-4.0×10^{-1}
[1]S67/S68	-5.6×10^{-1}
S199/S200	1.3×10^{-1}
S202/S204	-2.0×10^{-1}
S203/S204	-2.8×10^{-1}
Water Table/Silurian Aquifer	
S01/S02	-1.7×10^{-1}
S03/S04	-5.0×10^{-1}
S06/S07	-5.7×10^{-1}
S09/S11	-2.2×10^{-1}
S12/S13	-3.9×10^{-1}
S21/S22	-6.1×10^{-1}
S23/S24	-6.6×10^{-1}
S25/S26	-6.1×10^{-1}
S27/S29	-6.2×10^{-1}
S30/S31	-5.5×10^{-1}
S52/S53	2.2×10^{-2}
S57/S59	-3.7×10^{-1}
S61/S62	-1.7×10^{-1}
S64/S65	-3.6×10^{-1}
S66/S68	-2.9×10^{-1}
S96/S97	-4.7×10^{-1}
S98/S99	-2.5×10^{-1}
S100/S101	-3.6×10^{-1}
S103/S104	-2.6×10^{-1}
S106/S107	-2.8×10^{-1}
S108/S109	-2.0×10^{-1}
S116/S117	-3.0×10^{-1}
S118/S119	-3.5×10^{-1}
S121/S122	-3.5×10^{-1}
S184/S185	-2.0×10^{-1}
S186/S187	-4.3×10^{-1}
S188/S189	-2.0×10^{-1}
S190/S191	-3.7×10^{-1}
S192/S193	-3.3×10^{-1}
S198/S200	-7.7×10^{-2}
S201/S204	-2.2×10^{-1}
S239/S240	-3.2×10^{-1}
S380/S381	-1.1×10^{-1}
S383/S385	-1.8×10^{-1}
S447/S449	-2.6×10^{-2}
S451/S453	-1.5×10^{-1}

[1]Measurement made 10/27/92.



EXPLANATION

• U VERTICAL HYDRAULIC GRADIENTS IN CALUMET AQUIFER—
U, denotes upward gradient;
D, denotes downward gradient;
H, denotes vertical gradient absent

Figure 19. Direction of vertical hydraulic gradient within the Calumet aquifer, northwestern Indiana and the Lake Calumet area of northeastern Illinois, June 23–25, 1992.

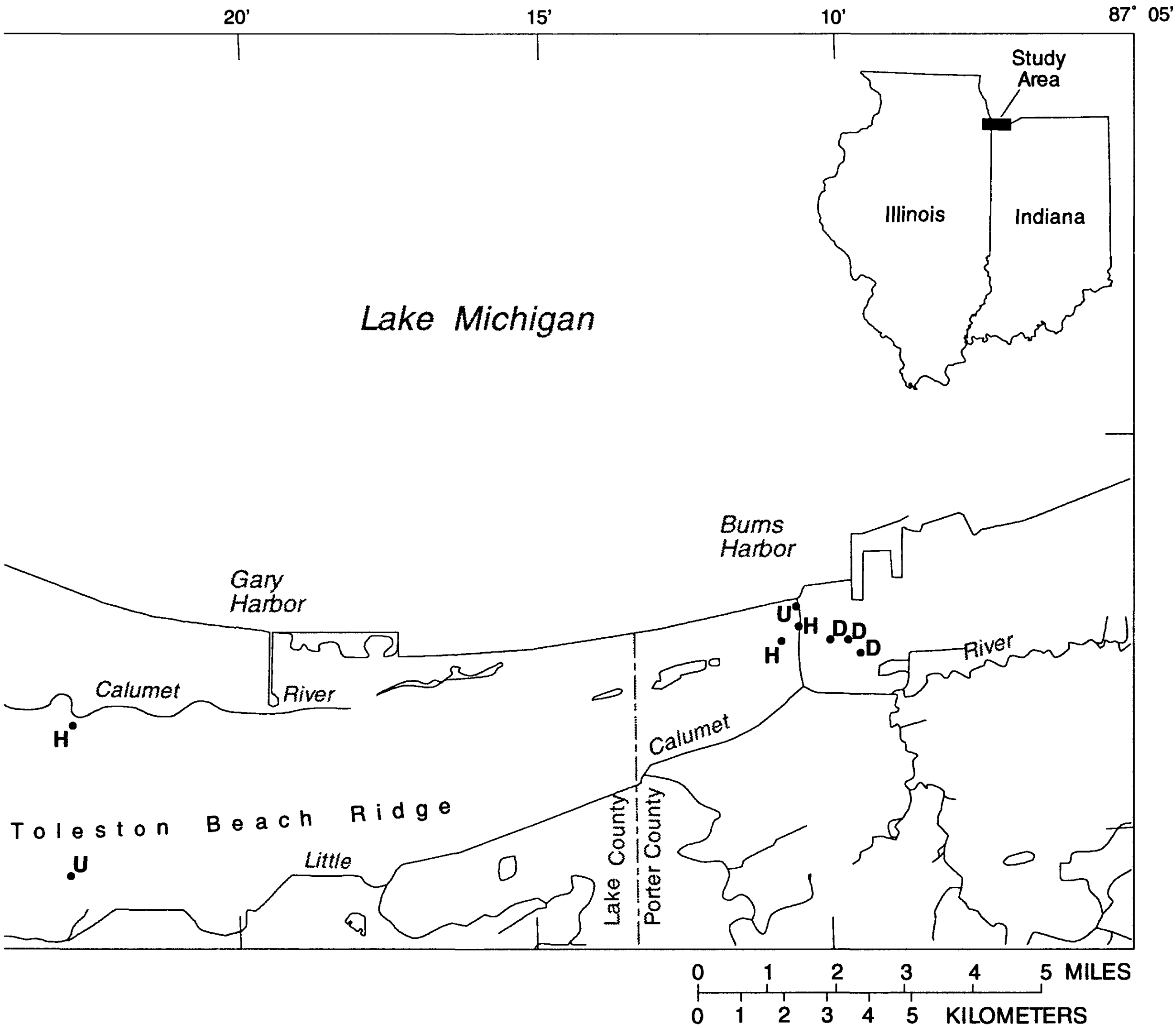


Figure 19. Continued.

flow, at several well clusters near the Grand Calumet River, Burns Harbor, Wolf Lake, and parts of Lake Michigan. Flow in the area between Lake George, Lake Michigan, and the Indiana Harbor Canal is primarily upward or horizontal. Vertical flow in the Calumet aquifer appears to be affected primarily by pumping and drainage to sewers.

Vertical hydraulic gradients were directed downward at 16 of the 19 well clusters where one well is open to either the water table or the base of the Calumet aquifer and a second well is open to the middle of the confining unit (table 4). This indicates the potential for flow from the water table or the base of the Calumet aquifer down into the confining unit in most of the study area. Differences in water levels within wells open to the water table or the base of the Calumet aquifer and the middle of the confining unit at a cluster range from 0.23 to 11.86 ft (appendix 1). Downward vertical hydraulic gradients average -1.3×10^{-1} ft/ft, whereas upward gradients average 1.9×10^{-1} ft/ft.

Vertical hydraulic gradients between the confining unit and the Silurian-Devonian aquifer were directed downward at eight of the nine well clusters measured (table 4). This indicates the potential for ground water to flow from the confining unit down to the Silurian-Devonian aquifer in most of the area where data are present. Differences in water levels within well clusters open to the confining unit and the Silurian-Devonian aquifer ranged from 5.98 to 29.39 ft. Downward gradients average -5.7×10^{-1} ft/ft. The value of the one upward gradient was 1.3×10^{-1} ft/ft.

Vertical hydraulic gradients between the water table and the top of the Silurian-Devonian aquifer were directed downward at 35 of the 36 well clusters measured (table 4). This indicates the potential for ground-water flow from the water table down to the Silurian-Devonian aquifer except in the area east of Stony Island where flow is from the Silurian-Devonian aquifer to the water table. Differences in water levels within well clusters open to these units ranged from 1.52 to 37.44 ft (appendix 1). The average of the downward gradients was -3.3×10^{-1} ft/ft. The value of the one upward gradient was 2.2×10^{-2} ft/ft.

The average downward vertical hydraulic gradient between the water table or the base of the Calumet aquifer and the middle of the confining unit is -1.3×10^{-1} ft/ft. This value is substantially lower than the average gradient between the water table and the Silurian-Devonian aquifer (-3.3×10^{-1} ft/ft). Both of these gradients are less than the average gradient between the middle of the confining unit and the top of the Silurian-Devonian aquifer (-5.7×10^{-1} ft/ft). These trends are independent of the presence or absence of the Calumet aquifer. These trends indicate that the vertical hydraulic conductivity of the Calumet aquifer and the weathered part of the confining unit are both greater than that of the unweathered part of the confining unit.

The vertical ground-water velocity can be calculated by solving equation 1 if vertical hydraulic conductivity is substituted for horizontal hydraulic conductivity and vertical hydraulic gradient is substituted for horizontal hydraulic gradient. The vertical and horizontal hydraulic conductivity of the unweathered part of the confining unit are approximately equal (Keros Cartwright, Illinois State Geological Survey, oral commun., 1994). Where vertical fractures are present, as in the weathered part of the confining unit, vertical hydraulic conductivity typically exceeds horizontal hydraulic conductivity. It is assumed that the median vertical hydraulic conductivity of the weathered part of the confining unit is equal to the median horizontal-hydraulic-conductivity value of 5.8×10^{-2} ft/d. The actual value is likely to be larger. Laboratory tests of soil-moisture content show that the porosity of the weathered part of the confining unit typically is about 20 percent. Applying the average of the vertical hydraulic gradients between the water table and the middle of the confining unit (-1.3×10^{-1} ft/ft), the vertical ground-water velocity through the weathered part of the confining unit is conservatively estimated to be 3.8×10^{-2} ft/d. This is more than 30 times greater than the horizontal ground-water velocity in the weathered part of the confining unit, indicating that vertical flow will greatly exceed horizontal flow.

In the unweathered parts of the confining unit, the mean vertical hydraulic conductivity is assumed to be 4.0×10^{-4} ft/d (Rosenshein, 1963, p. 22). The porosity of the confining unit at depth is about 15 percent. If the average of the downward vertical hydraulic gradients between the middle of the confining unit and the top of the Silurian-Devonian aquifer (-5.7×10^{-1} ft/ft) is used, the vertical ground-water velocity through the unweathered part of the confining unit is calculated to be 1.5×10^{-3} ft/d. Vertical flow through the unweathered part of the confining unit is likely to exceed horizontal flow.

OCCURRENCE OF LIGHT-NONAQUEOUS-PHASE LIQUIDS ON GROUND WATER

LNAPL's were detected in several wells near the petrochemical facilities in Indiana, particularly north and east of Lake George (table 5; figs. 2 and 20). The measured thickness of LNAPL's in the vicinity of the petrochemical facilities ranged from a thin film to more than 10 ft. Measurements indicate that, although not ubiquitous, LNAPL's are present in a large part of the petrochemical land-use area.

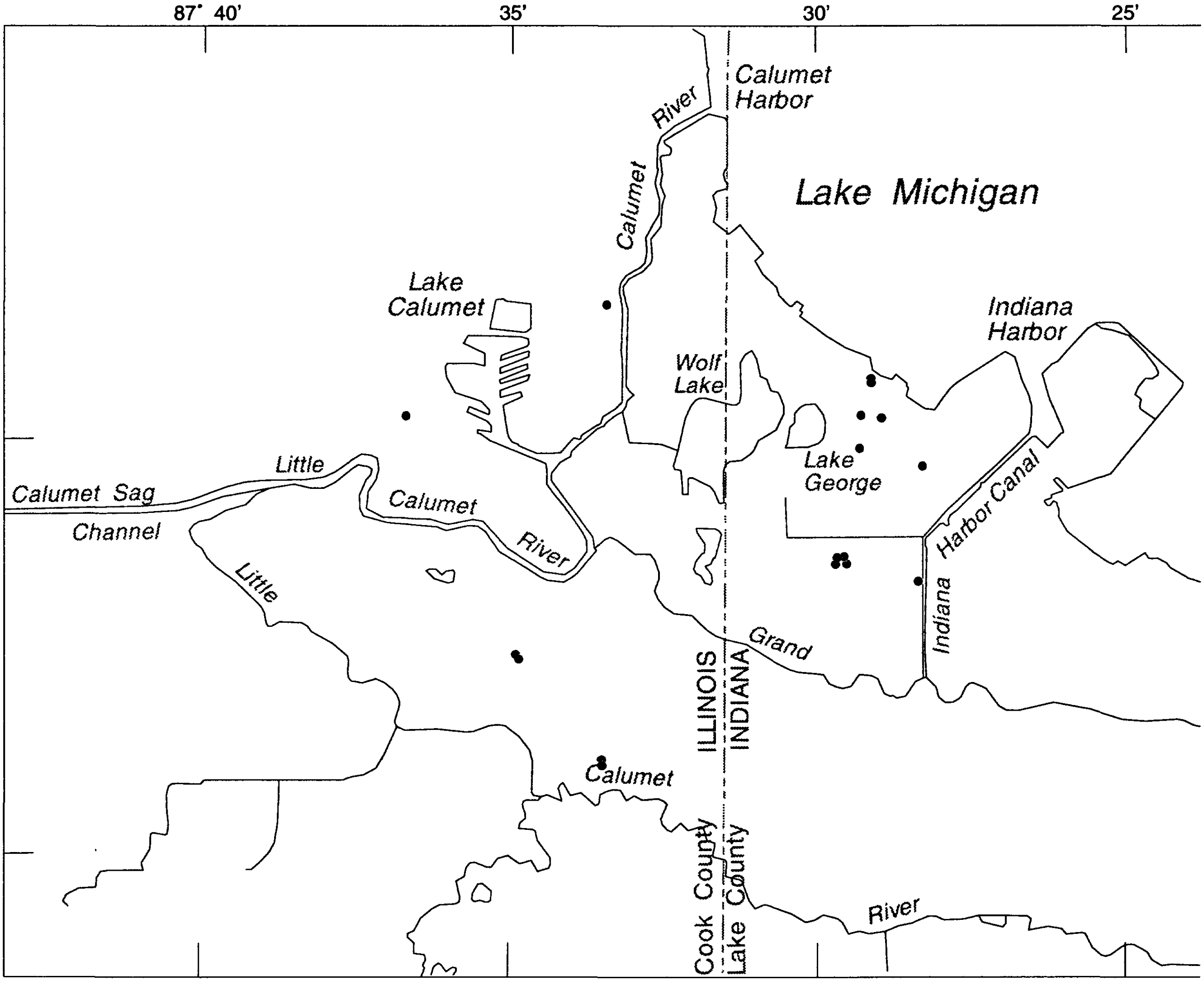
LNAPL's were detected in wells at several gas stations and at a few industrial or waste-disposal facilities in Illinois and Indiana (table 5). The measured thickness of LNAPL's in these wells ranged from a thin film to greater than 10.0 ft. No LNAPL's were detected in any well that was not near a refinery, gas station, industrial facility, or waste-disposal facility, which indicates that LNAPL's are not likely to be present on ground water beneath residential areas that are not near such facilities.

The measured thickness of LNAPL's in a well is affected by the location of the oil-water interface in relation to the well screen. The LNAPL's may have been present at some shallow wells but were not detected because the water level in the well was above the screened interval. This could result in an underestimation of the location and thickness of LNAPL's in the study area. If the oil-water interface at a well is located within the well screen and a capillary fringe is present above the water table, LNAPL's may move laterally into the monitoring well. The weight of the LNAPL's will depress the surface of the water in the well below that of the actual water table (Fetter, 1993, p. 225). This results in an increase in the LNAPL thickness and a decrease in the water-level altitude in the well that is not representative of conditions outside of the well bore. It is possible that the measured thickness of LNAPL's in some of the wells is greater than is actually present in the aquifer. It is also possible that the actual water-table altitude near some of these wells is higher than was determined from the water-level measurement.

Table 5. Light-nonaqueous-phase-liquid (LNAPL) thickness, northwestern Indiana and the Lake Calumet area of northeastern Illinois, June 23–24, 1992

[--, measurement not taken; >, greater than; well locations noted in appendix 1]

Well number	Latitude/ Longitude	Measured depth to LNAPL (feet)	Measured depth to water (feet)	LNAPL thickness (feet)
S162	414138/873326	10.02	10.52	0.50
S233	413602/873330	--	5.71	film
S234	413601/873330	--	4.00	film
S235	413721/873452	--	9.42	film
S236	413720/873451	--	9.40	film
S237	414016/873640	4.39	5.36	.97
S269	414044/872908	7.48	7.75	.27
S270	414043/872908	8.97	9.06	.09
S338	414017/872918	9.65	>20.34	>10.69
S343	414015/872858	9.14	9.19	.05
S349	413953/872919	15.44	17.69	2.25
S350	413940/872818	13.07	14.75	1.68
S416	413606/872338	--	7.95	film
S428	413816/872822	--	--	film
S478	413831/872938	--	7.54	film
S481	413832/872937	7.57	7.58	.01
S482	413832/872936	--	7.18	film
S486	413832/872935	7.47	7.48	.01



EXPLANATION

● WELL LOCATION

Figure 20. Location of wells where light-nonaqueous-phase liquids were detected, northwestern Indiana and the Lake Calumet area of northeastern Illinois, June 23–25, 1992.

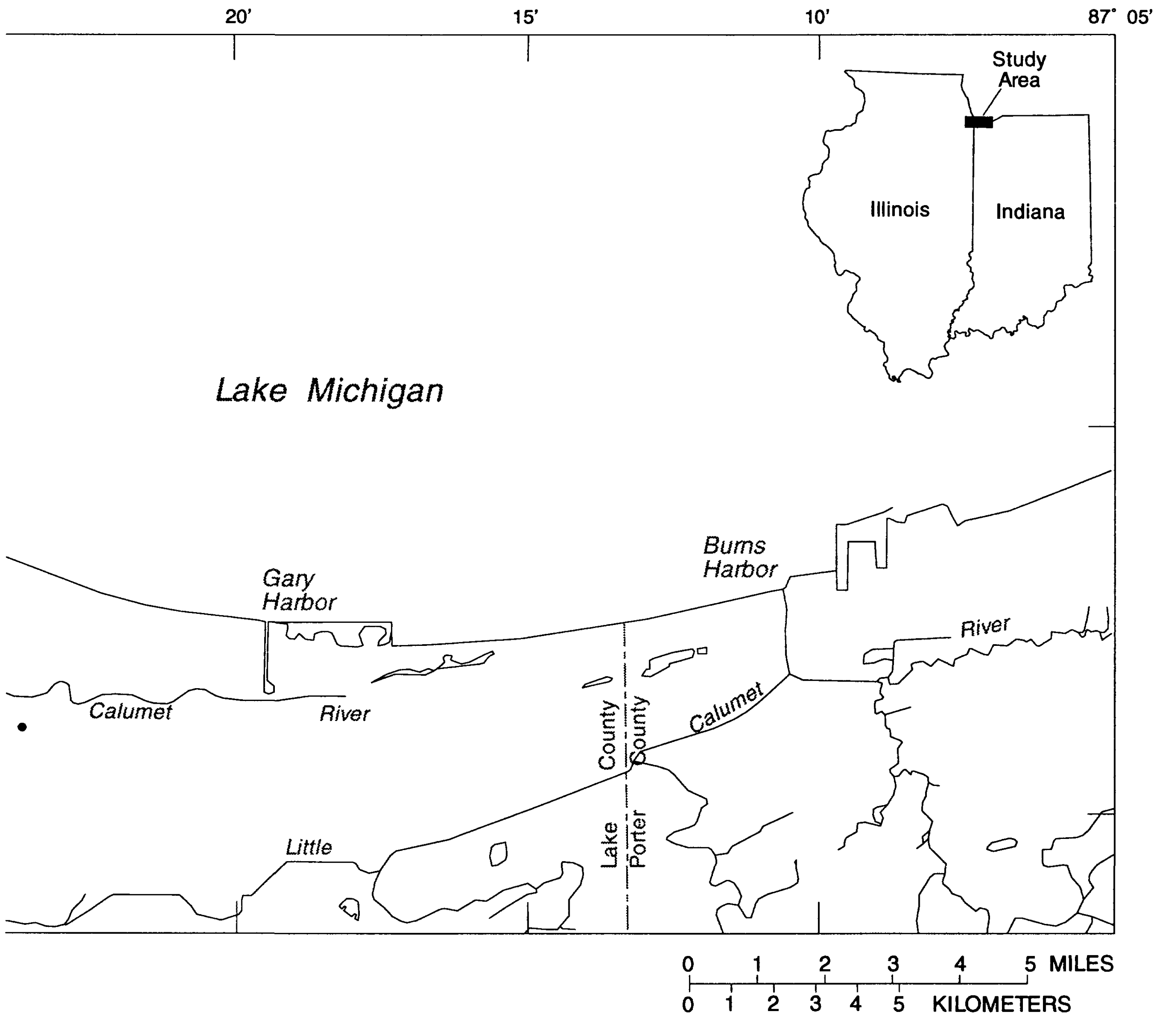


Figure 20. Continued.

The extent of the LNAPL's at the refineries and industrial and waste-disposal facilities has not been completely defined in this study, in part because permission to measure LNAPL's could not be obtained at a number of facilities and in a number of wells where LNAPL's were known or suspected to be present. Furthermore, no monitoring wells were available at a number of industrial facilities where LNAPL's may be present. The extent of LNAPL's in the study area determined during this survey should be considered as a minimum.

SUMMARY AND CONCLUSIONS

In June 1992, the U.S. Geological Survey, in cooperation with the U.S. Environmental Protection Agency, began a study of the hydrogeology and distribution of light-nonaqueous-phase liquids (LNAPL's) in a heavily industrialized area of northwestern Indiana and northeastern Illinois. The study was designed to describe the geology and hydrology in the area, determine the direction of surface-water and ground-water flow, characterize the interaction between surface water and ground water, and to obtain a preliminary estimate of the location and extent of LNAPL's on the water table.

The bedrock geologic deposits of concern are Silurian dolomites of the Niagaran Series, lower to middle Devonian limestones and dolomites of the Detroit River and Traverse Formations, and the upper Devonian Antrim Shale. The Silurian deposits are at the bedrock surface in the western half of the study area. The Detroit River and Traverse Formations are at the bedrock surface in the central part of the study area. The Antrim Shale is at the bedrock surface in the eastern edge of the study area.

The bedrock deposits are overlain by unconsolidated silt and clay tills. The tills are at the land surface in most of the area west of Lake Calumet. Sand deposits overlie the tills and are at the land surface in most of the area east of the Calumet River. Thin silt and clay lacustrine deposits overlie the tills or the sands and are at the land surface around Lake Calumet and parts of the Little Calumet River.

The four hydrologic units of concern are surface-water bodies, the Calumet aquifer, the confining unit, and the Silurian-Devonian aquifer. The most important surface-water bodies are Lake Michigan, Lake Calumet, Wolf Lake, Lake George, the Calumet River, the Grand Calumet River, the Little Calumet River, and the Calumet Sag Channel. The Calumet aquifer is composed primarily of sand deposits. The confining unit is composed primarily of silt and clay tills and lacustrine deposits. The Silurian-Devonian aquifer is composed of Silurian and Devonian carbonate deposits.

The Calumet aquifer is unconfined and continuous through most of the area east of Lake Calumet but is only present in scattered locations west of Lake Calumet. The horizontal hydraulic conductivity of the Calumet aquifer ranges from 6.5×10^{-1} to 3.6×10^{2} ft/d and generally decreases to the west.

The water table is located in the confining unit in much of the area west of Lake Calumet where the Calumet aquifer is absent. The upper part of the confining unit is typically weathered where the Calumet aquifer is thin or absent. The confining unit underlies the Calumet aquifer in most of the remainder of the study area. The horizontal hydraulic conductivity of the confining unit ranges from 1.7×10^{-5} to 5.5×10^{-1} ft/d. The horizontal hydraulic conductivity of the weathered part of the confining unit is larger than that of the unweathered part of the confining unit.

The Silurian-Devonian aquifer is confined except at Stony Island and Thornton Quarry, where the water table is in the dolomite, and northeast of Stony Island and south of Blue Island, where the confining unit is absent and the aquifer is in direct hydraulic connection with the Calumet aquifer. The horizontal hydraulic conductivity of the Silurian-Devonian aquifer ranges from 2.0×10^{-2} to 1.1×10^{0} ft/d.

Water levels were measured in 523 wells and at 34 surface-water stations during a synoptic water-level survey on June 23–25, 1992. The water-table configuration on June 23–25, 1992, generally followed topography. Ground-water divides were along topographic highs at Blue Island, Stony Island, and the Toleston Beach Ridge. Ground-water mounds were present southwest of Lake Calumet, between Lake Calumet and the Calumet River, and between the Indiana Harbor Canal, the Grand Calumet River, Lake Michigan, and Gary Harbor. Recharge to ground water from landfill leachate and ponded water affected the location of the ground-water mounds.

Several depressions in the water-table surface were also identified. The depressions in most of these areas appear to be caused by ground-water drainage into sewer lines and excavations and pumping from shallow wells.

The potentiometric surface of the top of the Silurian-Devonian aquifer shows two highs separated by a depression. The northern high point is associated with the bedrock high at Stony Island. The southern high point is associated with the bedrock high at Thornton Quarry. The deepest part of the depression in the potentiometric surface of the Silurian-Devonian aquifer coincides with the location of a drop shaft open to the aquifer, which was being dewatered by pumping.

Comparison of surface-water and ground-water levels indicates a complex interaction between surface water and ground water. The general direction of ground-water flow inferred from plots of ground-water contours is toward the major surface-water bodies, but surface water may be discharging to ground water in several areas.

The horizontal hydraulic gradient at the water table along several transects range from 7.8×10^{-4} to 5.1×10^{-3} ft/ft. These values do not vary substantially with changes in location or lithology.

The horizontal hydraulic gradient of the potentiometric surface of the Silurian-Devonian aquifer along several transects range from 8.8×10^{-4} to 1.8×10^{-3} ft/ft. These values show no significant variation with changes in lithology but tend to increase near the pumping center located near the confluence of the Grand Calumet and Little Calumet Rivers.

The average linear horizontal ground-water velocity in the Calumet aquifer ranged from 1.0×10^{-2} to 3.4×10^{-1} ft/d. The horizontal linear ground-water velocity through the silt and clay deposits at the water table ranged from 4.4×10^{-4} to 1.0×10^{-3} ft/d. The ground-water velocity through the upper part of the Silurian-Devonian aquifer ranged from 1.4×10^{-2} to 2.9×10^{-2} ft/d.

Vertical hydraulic gradients within the Calumet aquifer indicate complex vertical flow. Vertical hydraulic gradients indicate the potential for downward flow from the Calumet aquifer to the confining unit and from the confining unit to the Silurian-Devonian aquifer over most of the study area. The vertical ground-water velocity through the weathered part of the confining unit is calculated to be 3.8×10^{-2} ft/d. The vertical ground-water velocity through the unweathered part of the confining unit is calculated to be 1.5×10^{-3} ft/d.

Light-nonaqueous-phase liquids were detected in several wells near the petrochemical facilities in Indiana and at several gas stations and a few industrial or waste-disposal facilities in Illinois and Indiana. No LNAPL's were detected in any well that was not near a refinery, gas station, industrial facility, or waste-disposal facility.

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APPENDIX

APPENDIX 1. SUMMARY OF INFORMATION AND DATA COLLECTED DURING THE SYNOPTIC SURVEY OF WELLS AND SURFACE-WATER STATIONS IN NORTHWESTERN INDIANA AND THE LAKE CALUMET AREA OF NORTHEASTERN ILLINOIS, JUNE 23–25, 1992

[USGS, U.S. Geological Survey; ID, identification; e, estimated; *, denotes water-level altitude corrected for light-nonaqueous-phase liquid displacement; >, greater than; <, less than]

Geologic unit: D, Dolomite; M, Manmade land; UC, Unconsolidated deposit, coarse grained; UF, Unconsolidated deposit, fine grained

Hydrologic unit: BCA, Base of Calumet aquifer; BCU, Bottom of confining unit; CA, Calumet aquifer; CSA, Confined sand aquifer; CU, Confining unit; MCA, Middle of Calumet aquifer; MCU, Middle of confining unit; SD, Silurian-Devonian aquifer; TCU, Top of confining unit; WTCA, Water table, Calumet aquifer; WRCU, Water table, confining unit; WTSD, Water table, Silurian-Devonian aquifer

Water-level altitude: NT, Measurement not taken

Organic vapor reading: B, Background value; NT, Measurement not taken

Well number	Well name	Latitude/ Longitude	USGS Site ID number	Land-surface altitude (feet above sea level)	Measuring point altitude (feet above sea level)	Screen interval (feet below land surface)	Geologic unit	Hydrologic unit	Water-level altitude (feet above sea level)	Organic vapor reading (parts per million in air)
S01	G14S	413727/873424	413927087342401	588	590.20	18- 19	UC	WTCA	580.44	NT
S02	A14D	413927/873424	413927087342402	588	591.09	94-104	D	SD	566.61	NT
S03	G204	413832/873430	413832087343001	593	594.08	13- 17	UC	WTCA	583.63	NT
S04	A03D	413832/873429	413832087342901	592	596.51	80- 90	D	SD	549.33	NT
S05	G10S	413451/872934	413451087293401	587	589.94	3- 8	UC	WTCA	NT	NT
S06	G12S	413928/873511	413928087351101	585	586.03	9- 10	UC	WTCA	583.00	NT
S07	G12DR	413928/873510	413928087351001	586	586.13	42- 52	D	SD	561.48	NT
S08	G13SR	413928/873434	413928087343401	588	591.53	3- 8	UC	WTCA	NT	NT
S09	G15S	413918/873418	413918087341801	586	587.77	18- 19	UC	WTCA	579.80	NT
S10	G233	413918/873418	413918087341803	586	589.27	50- 60	UF	MCU	573.47	NT
S11	G15DR	413918/873418	413918087341802	586	588.55	93- 98	D	SD	563.27	NT
S12	G16D	413907/873409	413907087340902	585	588.44	72- 82	D	SD	558.40	NT
S13	G16S	413907/873409	413907087340901	586	588.06	15- 16	UC	WTCA	582.49	NT
S14	G32D	413845/873439	413845087343901	591	593.49	65- 75	D	SD	542.32	NT
S15	G39D	413856/873444	413856087344401	590	592.56	73- 83	D	SD	554.77	NT
S16	G44D	413825/873357	413824087335702	586	589.32	70- 80	D	SD	542.07	NT
S17	G44T	413825/873357	413824087335701	586	589.57	40- 45	UF	MCU	569.48	NT
S18	G104	413838/873345	413838087334501	589	590.14	37- 40	UF	MCU	567.42	NT
S19	G105	413838/873354	413838087335401	591	593.91	37- 40	UF	MCU	567.42	NT
S20	G106	413838/873438	413838087343801	593	596.00	62- 72	UF	BCU	542.93	NT

Well number	Well name	Latitude/ Longitude	USGS Site ID number	Land-surface altitude (feet above sea level)	Measuring point altitude (feet above sea level)	Screen interval (feet below land surface)	Geologic unit	Hydrologic unit	Water-level altitude (feet above sea level)	Organic vapor reading (parts per million in air)
S21	MW201	413835/873438	413835087343801	588	589.62	7- 11	UC	WTCA	583.12	NT
S22	MW202	413835/873438	413835087343802	588	590.14	59- 68	D	SD	545.68	NT
S23	G205	413822/873405	413822087340501	592	593.50	10- 14	UC	WTCA	580.63	NT
S24	G206	413822/873405	413822087340502	591	593.21	65- 75	D	SD	544.82	NT
S25	G209	413829/873439	413829087343901	587	589.40	10- 14	UC	WTCA	578.48	NT
S26	G210	413829/873439	413829087343902	587	589.58	63- 73	D	SD	546.28	NT
S27	G217	413822/873421	413822087342101	584	587.45	3- 8	UC	WTCA	577.45	NT
S28	R252	413822/873422	413822087342203	588	590.65	33- 43	UF	MCU	575.44	NT
S29	G216	413822/873421	413822087342102	584	586.43	56- 62	D	SD	546.05	NT
S30	G221	413827/873418	413827087341801	586	588.53	5- 10	UC	WTCA	584.16	NT
S31	G220	413827/873418	413827087341802	588	588.14	69- 78	D	SD	547.70	NT
S32	G231	413908/873453	413908087345301	589	591.69	46- 56	UF	MCU	583.16	NT
S33	G232	413928/873435	413928087343501	591	593.75	50- 60	UF	MCU	581.68	NT
S34	R13D	413928/873434	413928087343401	589	590.94	74- 84	D	SD	567.45	NT
S35	G234	413907/873435	413907087343501	588	590.10	50- 60	UF	MCU	563.40	NT
S36	G235	413912/873456	413912087345601	590	592.64	43- 53	UF	MCU	591.60	NT
S37	R23D	413913/873457	413913087345701	587	590.10	68- 78	D	SD	569.08	NT
S38	G251	413824/873411	413824087341101	587	588.80	35- 45	UF	MCU	573.84	NT
S39	P4E	413856/873425	413856087342501	595	598.13	17- 22	UC	WTCA	584.09	NT
S40	P6W	413909/873435	413909087343501	588	591.35	10- 15	UC	WTCA	584.35	NT
S41	P7W	413900/873443	413900087344301	590	592.45	5- 10	UC	WTCA	584.49	NT
S42	R251	413824/873411	413824087341101	584	588.80	35- 45	UF	MCU	572.82	NT
S43	1	413915/874151	413915087415101	596	597.55	14- 24	UC	WTCA	576.61	B
S44	2	413918/874237	413918087423701	596	597.30	8- 18	UC	WTCA	587.67	0.3
S45	3	413922/874322	413922087432201	593	595.01	19- 29	UC	WTCA	579.73	1.3
S46	SE	413841/873555	413841087355501	591	594.46	30- 40	UF	WTCU	581.41	B
S47	NE	413852/873554	413852087355401	593	594.25	30- 40	UF	WTCU	578.71	15.0
S48	NW	413434/873032	413434087303201	596	599.43	30- 40	UF	WTCU	580.25	B
S49	BH1S	414238/874011	414238087401101	667	667.25	5- 15	UF	WTCU	659.40	B
S50	BH1D	414238/874011	414238087401102	665	665.47	75- 90	UF	MCU	654.00	B
S51	BH2	414140/874219	414140087421901	626	626.13	10- 20	UF	WTCU	609.74	B
S52	BH4S	414442/873257	414442087325701	585	586.26	8- 13	UC	WTCA	579.21	B
S53	BH4D	414442/873257	414442087325702	587	586.97	23- 33	D	SD	579.62	B
S54	BH5S	413919/873230	413919087323001	584	583.98	10- 15	UC	WTCA	578.94	B
S55	BH5D	413919/873230	413919087323002	584	583.54	45- 55	UF	MCU	575.27	B

Well number	Well name	Latitude/ Longitude	USGS Site ID number	Land-surface altitude (feet above sea level)	Measuring point altitude (feet above sea level)	Screen interval (feet below land surface)	Geologic unit	Hydrologic unit	Water-level altitude (feet above sea level)	Organic vapor reading (parts per million in air)
S56	BH6	414340/873432	414340087343201	602	603.15	11- 21	D	WTSD	599.07	B
S57	BH7S	413910/873358	413910087335801	588	586.90	7- 17	UC	WTCA	581.20	B
S58	BH7I	413910/873358	413910087335802	588	587.05	19- 29	UF	MCU	580.11	B
S59	BH7D	413910/873358	413910087335803	588	587.06	69- 79	D	SD	560.23	B
S60	BH8	413932/873131	413932087313101	584	586.85	15- 30	UC	WTCA	582.58	B
S61	BH9S	413929/873158	413929087315801	584	587.84	13- 23	UC	WTCA	582.40	B
S62	BH9D	413929/873158	413929087315802	585	587.63	83- 93	D	SD	570.81	B
S63	BH11	413952/873259	413952087325901	585	585.16	18- 28	UC	WTCA	581.24	B
S64	BH16S	414250/873624	414250087362401	596	599.11	28- 38	UF	WTCU	588.39	B
S65	BH16D	414250/873624	414250087362402	596	599.72	68- 78	D	SD	575.63	B
S66	BH18S	414315/873131	414315087313101	591	594.13	8- 18	M	WTCA	581.46	B
S67	BH18I	414316/873131	414316087313102	592	594.35	35- 45	UF	MCU	555.39	B
S68	BH18D	414316/873131	414316087313103	592	595.35	58- 68	D	SD	568.23	B
S69	BH21	413832/873236	413832087323601	586	588.20	3- 13	UC	WTCA	580.15	B
S70	BH22	413948/873218	413948087321801	586	588.82	13- 23	UC	WTCA	582.99	B
S71	BH23	414038/873805	414038087380501	624	624.37	8- 18	UC	WTCA	609.26	B
S72	BH24	414113/873222	414113087322201	587	589.33	6- 16	UC	WTCA	579.41	B
S73	BH25	414151/873202	414151087320201	586	590.10	6- 16	UC	WTCA	579.63	B
S74	BH28	414156/873317	414156087331701	585	Unknown	7- 17	UC	WTCA	NT	NT
S75	BH31	413947/873025	413947087302501	600	Unknown	18- 28	UC	WTCA	NT	NT
S76	BH32	414141/873437	414141087343701	586	Unknown	8- 18	UC	WTCA	NT	NT
S77	BH33	414034/873147	414034087314701	587	Unknown	13- 23	UC	WTCA	NT	NT
S78	IC	413511/873003	413511087300302	590	590.00	53- 58	D	SD	559.08	NT
S79	IT	414217/873350	414217087335001	585	585.00	79- 84	D	SD	566.20	NT
S80	IP	414132/873659	414132087365901	591	591.00	72- 77	D	SD	573.62	NT
S81	I1	413938/873507	413938087350701	586	585.90	7- 11	UF	WTCU	584.53	NT
S82	I2	413944/873525	413944087352501	587	587.63	5- 15	UF	WTCU	583.50	NT
S83	I3	413958/873536	413958087353601	584	584.49	3- 13	UF	WTCU	580.93	NT
S84	I6	414016/873542	414016087354201	584	584.68	3- 8	UF	WTCU	582.36	NT
S85	I8	414037/873604	414037087360401	583	583.67	9- 14	UF	WTCU	581.74	NT
S86	I9	414104/873604	414104087360401	585	585.60	6- 11	UF	WTCU	581.83	NT
S87	I10	414037/873607	414037087360701	585	585.41	5- 10	UF	WTCU	583.21	NT
S88	I12	414138/873548	414138087354801	585	585.13	5- 10	UF	WTCU	580.27	NT
S89	I13	414210/873525	414210087352501	587	587.21	4- 14	UF	WTCU	583.71	NT
S90	I14	413950/873430	413950087343001	589	589.14	10- 15	UC	WTCA	580.36	NT

Well number	Well name	Latitude/ Longitude	USGS Site ID number	Land-surface altitude (feet above sea level)	Measuring point altitude (feet above sea level)	Screen interval (feet below land surface)	Geologic unit	Hydrologic unit	Water-level altitude (feet above sea level)	Organic vapor reading (parts per million in air)
S91	I15	414011/873430	414011087343001	589	589.38	10- 15	UC	WTCA	584.19	NT
S92	I16	414023/873430	414023087343001	587	587.46	9- 14	UC	WTCA	584.20	NT
S93	I20	414025/873323	414025087334301	591	590.09	10- 15	UC	WTCA	581.14	NT
S94	I21	413932/873338	413932087333801	590	589.89	7- 12	UC	WTCA	582.50	NT
S95	11S	413855/873536	413855087353601	597	599.52	20- 25	UF	WTCU	577.51	B
S96	12S	413848/873520	413848087352001	585	587.06	21- 26	UC	WTCA	578.00	B
S97	12D	413848/873520	413848087352002	585	587.01	50- 55	D	SD	565.66	B
S98	17S	413852/873550	413852087355001	597	600.60	21- 26	UF	WTCU	571.90	B
S99	17D	413852/873550	413852087355002	597	599.82	50- 55	D	SD	565.34	B
S100	18S	413853/873526	413853087352601	601	603.69	23- 28	UF	WTCU	576.14	B
S101	18D	413853/873526	413853087352602	601	604.09	57- 62	D	SD	564.94	4.0
S102	14S	413839/873528	413839087352801	588	590.90	25- 30	UF	WTCU	582.02	B
S103	15S	413828/873551	413828087355101	592	594.10	25- 30	UF	WTCU	583.65	B
S104	15D	413828/873551	413828087355102	590	594.30	47- 57	D	SD	578.22	B
S105	16S	414050/873430	414050087343001	591	593.10	14- 19	UF	WTCU	584.53	B
S106	19S	413840/873539	413840087353901	588	591.30	13- 18	UF	WTCU	582.90	B
S107	19D	413840/873539	413840087353902	588	591.20	53- 58	D	SD	573.52	B
S108	101S	413839/873551	413839087355101	588	593.40	14- 19	UF	WTCU	579.04	B
S109	105S	413828/873529	413828087352901	585	588.70	8- 15	UF	WTCU	580.55	B
S110	105D	413828/873529	413828087352902	585	589.60	53- 58	D	SD	572.74	B
S111	W4	414103/873608	414103087360801	586	588.79	1- 10	UF	WTCU	580.49	B
S112	W5	414058/873608	414058087360801	588	589.71	2- 12	UF	WTCU	584.23	B
S113	W6	414050/873608	414050087360801	587	589.48	4- 15	UF	WTCU	582.75	B
S114	1A	414057/873634	414057087363401	592	594.38	5- 15	UF	WTCU	587.90	B
S115	7	414044/873608	414044087360801	589	591.38	5- 15	UF	WTCU	584.51	B
S116	G11S	413510/873259	413510087325001	598	601.38	8- 16	UF	WTCU	595.52	B
S117	G11D	413510/873259	413510087325002	600	602.94	94- 96	D	SD	595.52	B
S118	G13S	413511/873321	413511087332101	598	601.10	9- 19	UF	WTCU	594.96	B
S119	G13D	413511/873321	413511087332102	598	601.10	84- 87	D	SD	571.36	B
S120	G15S	413510/873309	413510087330901	600	603.98	18- 23	UF	WTCU	594.56	B
S121	G16S	413458/873300	413458087330001	600	603.35	17- 22	UF	WTCU	595.81	B
S122	G16D	413458/873300	413458087330002	600	603.23	86- 91	D	SD	571.47	B
S123	G17S	413505/873258	413505087325801	601	604.40	17- 22	UF	WTCU	597.06	B
S124	G18S	413501/873313	413501087331301	599	602.00	13- 18	UF	WTCU	597.00	B
S125	R15S	413510/873309	413501087330901	601	603.00	14- 19	UF	WTCU	593.86	B

Well number	Well name	Latitude/ Longitude	USGS Site ID number	Land-surface altitude (feet above sea level)	Measuring point altitude (feet above sea level)	Screen interval (feet below land surface)	Geologic unit	Hydrologic unit	Water-level altitude (feet above sea level)	Organic vapor reading (parts per million in air)
S126	MW1	414301/873138	414301087313801	595	597.04	11- 21	M	WTCA	581.35	NT
S127	MW3	414302/873136	414302087313601	596	597.98	13- 23	M	WTCA	581.30	NT
S128	MW4	414302/873136	414302087313601	594	596.06	11- 21	M	WTCA	581.27	NT
S129	MW5	414303/873135	414303087313501	594	595.85	10- 20	M	WTCA	581.33	NT
S130	MW6	414301/873138	414301087313801	592	594.00	9- 19	M	WTCA	581.22	NT
S131	L1	414018/873413	414018087341302	595	599.00	16- 21	UC	WTCA	585.95	NT
S132	L2	413955/873425	413955087342502	591	595.00	11- 17	UC	WTCA	582.75	NT
S133	L3	413950/873408	413950087340802	592	596.00	13- 18	UC	WTCA	580.20	NT
S134	L4	414010/873353	414010087335302	592	596.00	14- 19	UC	WTCA	581.22	NT
S135	W1	414216/873459	414216087345902	596	596.10	85-119	D	SD	568.15	NT
S136	W2	414144/873438	414144087343802	590	590.30	107-167	D	SD	564.38	NT
S137	W3	414143/873516	414143087351602	588	588.70	91-149	D	SD	567.44	NT
S138	W4	414208/873525	414208087352502	591	591.30	91-126	D	SD	534.39	NT
S139	OC1	413907/874251	413907087425102	599	599.48	57-251	D	SD	558.61	NT
S140	OC2	413907/874210	413907087421002	604	604.68	68-267	D	SD	558.63	NT
S141	OC3	413909/874046	413909087404602	594	593.98	47-266	D	SD	427.42	NT
S142	QC5	413633/873704	413633087370402	596	595.98	275-329	D	SD	418.36	NT
S143	QC7	413721/873706	413721087370602	597	600.80	283-335	D	SD	434.53	NT
S144	QC10	413807/873228	413807087322802	588	589.23	250-303	D	SD	548.07	NT
S145	QC11	413838/873259	413838087325902	584	586.68	255-308	D	SD	526.67	NT
S146	QC12	413839/873331	413839087333102	581	583.68	258-326	D	SD	507.18	NT
S147	QC13	413829/873439	413829087343902	572	574.98	267-335	D	SD	522.64	NT
S148	QC14	413929/873552	413929087355202	580	583.28	275-343	D	SD	509.18	NT
S149	QC15	413830/873635	413830087363502	605	607.70	284-352	D	SD	528.50	NT
S150	QC16	414253/872711	414253087271102	594	596.36	261-300	D	SD	371.66	NT
S151	QC17	413551/873842	413551087384202	600	603.35	262-310	D	SD	553.12	NT
S152	QC18	413548/873749	413548087374902	594	597.38	269-318	D	SD	540.40	NT
S153	WP1	413937/873219	413937087321901	584	586.95	15- 20	UC	BCA	581.62	NT
S154	WP2	413937/873219	413937087321902	584	586.88	9- 12	UC	MCA	581.62	NT
S155	WP3	413937/873219	413937087321903	584	587.33	2- 7	UC	WTCA	581.61	NT
S156	WP4	413937/873221	413937087322101	584	588.04	3- 18	UC	WTCA	581.33	NT
S157	WP5	413938/873220	413938087322001	584	587.16	15- 18	UC	WTCA	581.47	NT
S158	MW1	414209/873322	414209087332201	587	590.03	3- 13	UC	WTCA	581.60	B
S159	MW2	414157/873316	414157087331601	593	595.23	10- 20	UC	WTCA	583.45	B
S160	MW3	414150/873330	414150087333001	590	590.78	6- 16	UC	WTCA	581.87	B

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S161	MW4	414145/873328	414145087332801	590	592.56	9- 19	UC	WTCA	581.52	B
S162	MW5	414138/873326	414138087332601	591	592.95	7- 17	UC	WTCA	*582.86	5.0
S163	G101A	414048/873506	414048087350601	589	591.08	10- 15	M	WTCA	581.08	B
S164	G110	414054/873451	414054087345101	592	593.67	10- 15	M	WTCA	586.89	B
S165	G120S	414054/873451	414054087345101	591	593.84	13- 18	M	WTCA	585.58	B
S166	G121S	414056/873450	414056087345001	592	593.89	13- 18	M	WTCA	584.99	.1
S167	G123S	414055/873445	414055087344501	591	594.13	13- 18	M	WTCA	587.11	B
S168	G124S	414053/873446	414053087344601	591	593.28	13- 18	M	WTCA	582.75	B
S169	G305	414058/873442	414058087344201	589	591.36	4- 14	M	WTCA	581.97	B
S170	G307	414100/873435	414100087343501	588	590.64	4- 14	M	WTCA	584.18	.2
S171	P322	414056/873442	414056087344201	589	591.51	3- 8	M	WTCA	587.05	50.0
S172	P323	414058/873437	414058087343701	589	591.37	8- 12	M	WTCA	585.80	B
S173	P329	414054/873443	414054087344301	590	592.28	15- 20	M	WTCA	584.16	B
S174	P334	414051/873435	414051087345501	589	592.44	6- 11	M	WTCA	586.34	.2
S175	G342	414048/873441	414048087344101	590	592.36	10- 15	M	WTCA	580.37	B
S176	G343	414050/873435	414050087343501	589	591.85	5- 15	M	WTCA	586.13	B
S177	G348	414047/873440	414057087344001	590	592.91	6- 11	M	WTCA	584.96	B
S178	G349	414048/873441	414048087344101	591	593.39	6- 11	M	WTCA	585.35	B
S179	B17S	414105/873411	414105087341101	590	590.55	4- 14	UC	WTCA	582.73	NT
S180	G122	414113/873403	414113087340301	586	588.99	6- 16	UC	WTCA	582.95	NT
S181	SS1D	414121/873353	414121087335302	586	588.54	95-111	D	SD	556.24	NT
S182	SS2D	414117/873433	414117087343302	582	582.96	70-100	D	SD	564.41	NT
S183	ST3S	414142/873433	414142087343301	586	587.45	2- 12	UF	WTCU	582.83	NT
S184	ST1S	414106/873355	414106087335501	584	586.77	2- 11	UC	WTCA	580.77	NT
S185	ST1D	414106/873355	414106087335502	588	588.75	98-115	D	SD	562.23	NT
S186	ST2S	414139/873352	414139087335201	586	586.60	5- 15	UC	WTCA	583.56	NT
S187	ST2D	414139/873352	414139087335202	583	586.54	39- 61	D	SD	568.56	NT
S188	ST4S	414104/873431	414104087343101	588	591.39	10- 15	UC	WTCA	580.10	NT
S189	ST4D	414104/873431	414104087343102	590	590.91	80-103	D	SD	565.04	NT
S190	GA1S	414050/873413	414050087341301	596	598.75	14- 24	UC	WTCA	591.78	B
S191	GA1D	414050/873413	414050087341302	596	598.95	90-100	D	SD	566.09	B
S192	GA4S	414025/873412	414025087341201	597	599.37	9- 19	UC	WTCA	587.56	15.0
S193	GA4D	414025/873412	414025087341202	596	599.28	85- 95	D	SD	564.38	B
S194	G13D	414025/873430	414025087343002	589	594.54	78- 84	D	SD	566.24	B
S195	G14S	414026/873430	414026087343001	589	594.45	5- 15	UC	WTCA	584.85	B

Well number	Well name	Latitude/ Longitude	USGS Site ID number	Land-surface altitude (feet above sea level)	Measuring point altitude (feet above sea level)	Screen interval (feet below land surface)	Geologic unit	Hydrologic unit	Water-level altitude (feet above sea level)	Organic vapor reading (parts per million in air)
S196	G15D	413531/873051	413531087305102	588	590.49	76- 81	D	SD	565.94	B
S197	G16S	413531/873051	413531087305101	588	590.94	6- 16	UC	WTCA	586.05	B
S198	G11S	414103/873431	414103087343101	589	589.80	12- 17	UC	WTCA	580.49	B
S199	G11D	414103/873431	414103087343101	589	590.52	50- 53	UF	MCU	568.63	B
S200	G11B	414103/873431	414103087343102	588	591.02	94- 99	D	SD	574.32	B
S201	G13S	414103/873408	414103087340801	593	594.76	14- 20	UC	WTCA	584.94	NT
S202	G13D	414103/873408	414103087340801	593	594.44	20- 25	UF	TCU	584.34	NT
S203	G23D	414104/873409	414104087340401	591	592.87	39- 44	UF	MCU	586.07	NT
S204	G13B	414103/873408	414103087340802	591	593.13	107-113	D	SD	567.69	NT
S205	G15S	414104/873418	414104087341801	592	593.91	15- 20	UC	WTCA	583.83	NT
S206	G15D	414104/873418	414104087341801	593	594.86	38- 43	UC	MCU	593.50	NT
S207	G19S	414103/873355	414103087335501	592	593.79	14- 19	UC	WTCA	584.65	B
S208	G19D	414103/873355	414103087335501	591	593.54	38- 48	UF	MCU	582.02	B
S209	G20S	414050/873351	414050087335101	589	590.53	11- 16	UC	WTCA	582.31	B
S210	G20D	414050/873351	414050087335101	588	590.13	35- 40	UF	MCU	580.38	B
S211	G21S	414044/873351	414044087335101	590	592.49	11- 16	UC	WTCA	584.88	NT
S212	G21D	414044/873351	414044087335101	592	592.73	45- 50	UF	MCU	578.91	NT
S213	G22S	414044/873408	414044087340801	594	595.66	16- 21	UC	WTCA	591.61	B
S214	G22D	414044/873408	414044087340801	595	595.70	38- 43	UF	MCU	586.74	B
S215	R105	414054/873431	414054087343101	592	593.15	15- 19	UF	WTCU	586.37	B
S216	G105B	414050/873430	414050087343002	591	593.31	92- 97	D	SD	567.52	B
S217	G108	414044/873359	414044087335901	588	589.27	18- 23	UC	WTCA	584.51	B
S218	G130B	414049/873410	414049087341002	597	599.62	111-117	D	SD	567.06	B
S219	MW1	414109/874051	414109087405101	644	644.10	2- 12	UF	WTCU	640.45	12.0
S220	MW2	414105/874050	414105087405001	644	644.27	2- 12	UF	WTCU	640.82	6.2
S221	MW5	414101/874313	414101087431301	598	598.06	2- 12	UF	WTCU	593.60	5.0
S222	MW2	414101/874313	414101087431301	599	599.68	3- 13	UF	WTCU	592.30	2.0
S223	MW8	414332/874316	414332087431601	621	620.90	5- 25	UF	WTCU	617.41	B
S224	MW9	414432/874316	414432087431601	621	620.91	5- 15	UF	WTCU	615.95	B
S225	MW103	414410/873653	414410087355301	588	588.39	Unknown	Unknown	Unknown	583.18	B
S226	MW101	414410/873653	414410087355301	588	587.50	Unknown	Unknown	Unknown	582.73	B
S227	TB	414439/873307	414439087330701	588	588.14	Unknown	Unknown	Unknown	581.96	7.5
S228	TA	414440/873306	414440087330601	589	588.64	Unknown	Unknown	Unknown	581.59	2.5
S229	MW6	414208/873133	414208087313301	589	589.13	4- 8	UC	WTCA	580.06	B
S230	MW10	414209/873134	414209087313401	589	588.98	4- 8	UC	WTCA	580.13	B

Well number	Well name	Latitude/ Longitude	USGS Site ID number	Land-surface altitude (feet above sea level)	Measuring point altitude (feet above sea level)	Screen interval (feet below land surface)	Geologic unit	Hydrologic unit	Water-level altitude (feet above sea level)	Organic vapor reading (parts per million in air)
S231	MW04	413748/873330	413748087333001	585	585.41	3- 13	UC	WTCA	579.51	B
S232	MW13	413748/873332	413748087333201	586	585.73	2- 23	UC	WTCA	580.45	50.0
S233	MW01A	413602/873330	413602087333001	602	602.38	3- 13	UC	WTCA	596.67	13.0
S234	MW03	413601/873330	413601087333001	601	601.77	2- 12	UF	WTCU	597.77	4.0
S235	TA	413721/873452	413721087345201	606	606.10	7- 17	UC	WTCA	596.68	B
S236	TB	413720/873451	413720087345101	605	605.54	7- 17	UC	WTCA	596.14	1.5
S237	G102	414016/873640	414016087364001	596	597.96	3- 8	UF	WTCU	*595.42	>20
S238	G104	414015/873645	414015087364501	595	596.21	7- 12	UF	WTCU	591.82	NT
S239	FILO9	414018/873647	414018087364701	584	587.21	15- 30	UF	WTCU	582.01	NT
S240	FILO10	414018/873647	414018087364702	586	587.44	71- 81	D	SD	567.79	NT
S241	FILO12	414028/873644	414028087364401	593	595.90	5- 19	UF	WTCU	589.62	1.0
S242	A-1	413647/871919	413647087191901	604	605.46	18- 21	M	WTCA	586.04	NT
S243	A-2	413706/871818	413706087181800	603	604.71	34- 39	UC	MCA	586.73	NT
S244	A-3	413631/871820	413631087182000	590	590.90	3- 6	M	WTCA	588.31	NT
S245	A-4	413630/871821	413630087182100	603	605.70	18- 23	UC	MCA	588.55	NT
S246	A-5	413629/871921	413629087192102	601	603.34	18- 21	UC	WTCA	586.35	NT
S247	A-6	413706/871701	413706087170101	589	589.66	4- 7	UC	WTCA	584.94	NT
S248	A-10	413626/871919	413626087191901	590	591.39	12- 15	UC	WTCA	585.90	NT
S249	A-15	413617/871912	413617087191201	591	592.11	2- 5	UC	WTCA	589.51	NT
S250	A-20	413503/871935	413503087193501	614	616.15	21- 24	UC	WTCA	595.96	NT
S251	B-1	413637/872343	413637087234301	585	585.76	9- 12	UC	WTCA	584.90	NT
S252	B-2	413752/872235	413752087223500	608	610.61	43- 48	UC	MCA	579.88	NT
S253	B-3	413633/872220	413633087222000	594	595.97	18- 23	UC	MCA	584.40	NT
S254	B-5	413632/872340	413632087234001	589	590.43	7- 10	UC	WTCA	584.36	NT
S255	B-7	413617/872252	413617087225202	596	596.71	8- 11	UC	WTCA	586.87	NT
S256	B-8	413617/872252	413617087225201	596	598.82	32- 37	UC	BCA	586.89	NT
S257	B-10	413544/872337	413544087233700	607	608.80	17- 20	UC	WTCA	592.81	NT
S258	C-1	413830/872600	413830087260000	587	588.85	4- 7	UC	WTCA	582.13	NT
S259	C-4	413828/872513	413828087251302	589	591.76	8- 13	UC	WTCA	580.24	NT
S260	C-3	413828/872513	413828087251301	589	591.81	25- 28	UC	MCA	580.22	NT
S261	C-5	413655/872752	413655087275202	585	586.43	2- 5	UC	WTCA	582.99	NT
S262	C-12	413650/872620	413650087262000	584	587.36	13- 18	UC	MCA	582.00	NT
S263	C-15	413650/872748	413650087274802	583	585.58	1- 9	UC	WTCA	581.72	NT
S264	C-18	413607/872522	413607087252200	595	594.96	17- 22	UC	BCA	590.92	NT
S265	C-19	413617/872620	413617087262001	592	593.29	2- 5	UC	WTCA	589.47	NT

Well number	Well name	Latitude/ Longitude	USGS Site ID number	Land-surface altitude (feet above sea level)	Measuring point altitude (feet above sea level)	Screen intervai (feet below land surface)	Geologic unit	Hydrologic unit	Water-level altitude (feet above sea level)	Organic vapor reading (parts per million in air)
S266	C-20	413557/872839	413557087283901	593	595.41	3- 6	UC	WTCA	592.62	NT
S267	C-25	413527/872543	413527087254301	599	600.33	2- 5	UC	WTCA	595.71	NT
S268	D-1	414052/872912	414052087291201	590	591.72	8- 11	UC	WTCA	581.34	NT
S269	D-5	414044/872908	414044087290801	588	589.99	2- 7	UC	WTCA	*582.47	NT
S270	D-10	414043/872908	414043087290802	588	591.43	7- 10	UC	WTCA	*582.55	NT
S271	D-11	414043/872908	414043087290801	588	590.79	17- 22	UC	MCA	582.54	NT
S272	D-20	413941/872900	413941087290000	588	590.31	6- 9	UC	WTCA	583.22	NT
S273	D-21	413941/872926	413941087292600	584	587.21	13- 18	UC	MCA	580.23	NT
S274	D-25	413909/872803	413804087291102	588	590.56	5- 8	UC	WTCA	582.15	NT
S275	D-30	413907/872758	413758087290702	586	587.53	6- 9	UC	WTCA	580.86	NT
S276	D-31	413907/872758	413907087275901	586	588.72	12- 17	UC	MCA	580.83	NT
S277	D-35	413906/872757	413757087290601	586	589.86	4- 7	UC	WTCA	580.56	NT
S278	D-40	413835/872851	413835087245101	584	586.17	4- 7	UC	WTCA	580.63	NT
S279	D-45	413812/872702	413812087270201	586	587.67	6- 9	UC	WTCA	580.63	NT
S280	D-50	413800/872854	413800087285401	585	587.74	9- 12	UC	WTCA	577.52	NT
S281	D-55	413758/872814	413758087281401	585	588.94	5- 8	UC	WTCA	580.46	NT
S282	D-60	413758/872810	413758087281001	587	589.97	5- 8	UC	WTCA	581.28	NT
S283	D-66	413654/872740	413654087274000	587	590.41	17- 22	UC	MCA	581.25	NT
S284	D-67	413647/872825	413647087282502	589	589.16	4- 7	UC	WTCA	583.88	NT
S285	D-68	413647/872825	413647087282501	589	590.82	18- 23	UC	MCA	583.86	NT
S286	D-70	413515/872914	413515087291401	603	604.66	6- 9	UC	WTCA	599.01	NT
S287	D-75	413435/872919	413435087291901	601	603.09	5- 8	UC	WTCA	595.95	NT
S288	E-1	413844/873104	413844087310401	582	583.53	5- 8	UC	WTCA	578.80	NT
S289	E-2	414105/872939	414105087293900	585	586.23	3- 6	UC	WTCA	580.92	NT
S290	E-3	414013/873033	414013087303300	585	587.98	8- 13	UC	MCA	582.18	NT
S291	E-5	413810/873052	413810087305201	587	588.16	9- 12	UC	WTCA	581.05	NT
S293	E-6	413938/873043	413938087304301	586	589.40	17- 22	UC	BCA	583.62	NT
S292	E-7	413938/873043	413938087304302	586	588.11	2- 5	UC	WTCA	583.60	NT
S294	E-10	413722/873041	413722087304101	586	587.42	6- 9	UC	WTCA	581.20	NT
S295	E-15	413720/873042	413720087304201	584	587.05	6- 9	UC	WTCA	580.86	NT
S296	E-20	413627/873105	413627087310500	592	594.03	5- 8	UC	WTCA	587.45	NT
S297	LK-13	4135590872703	413559087270301	592	595.41	18- 23	UC	BCA	588.51	NT
S298	24	413817/870513	413817087051301	609	610.63	7- 10	UC	WTCA	606.52	NT
S299	25	413842/870512	413842087051201	605	608.30	11- 14	UC	WTCA	602.12	NT
S300	26	413831/870713	413831087071301	611	614.47	20- 23	UC	WTCA	596.96	NT

Well number	Well name	Latitude/ Longitude	USGS Site ID number	Land-surface altitude (feet above sea level)	Measuring point altitude (feet above sea level)	Screen interval (feet below land surface)	Geologic unit	Hydrologic unit	Water-level altitude (feet above sea level)	Organic vapor reading (parts per million in air)
S301	27	413840/870711	413840087071101	606	608.94	22- 25	UC	WTCA	589.18	NT
S302	102	413821/870625	413821087062502	620	621.66	81- 84	UC	CSA	602.34	NT
S303	105	413744/870635	413744087063702	609	610.37	71- 76	UC	CSA	603.08	NT
S304	106	413744/870635	413744087063701	610	610.87	20- 25	UC	MCA	602.56	NT
S305	225	413645/870518	413645087051500	638	637.63	47- 52	UC	BCA	623.21	NT
S306	228	413643/870736	413637087073100	635	634.30	43- 48	UC	BCA	612.12	NT
S307	230-24	413701/871109	413651087110503	611	611.09	24- 27	UC	MCA	595.71	NT
S308	230-58	413701/871109	413651087110502	611	610.56	50- 55	UC	BCA	593.29	NT
S309	230-128	413701/871109	413651087110501	611	610.72	114-119	UC	CSA	593.35	NT
S310	232	413730/871230	413726087123600	597	596.42	38- 43	UC	BCA	584.74	NT
S311	234-142	413547/871458	413545087145501	613	612.47	130-135	UC	CSA	603.75	NT
S312	235-45	413628/871449	413629087142600	606	605.51	37- 42	UC	BCA	601.37	NT
S313	237-45	413549/871638	413550087163800	608	607.88	34- 39	UC	BCA	600.18	NT
S314	238	413705/871655	413705087165500	604	607.08	58- 63	UC	BCA	584.90	NT
S315	242	413708/870923	413656087091500	600	603.20	75- 80	UC	CSA	596.00	NT
S316	244-65	413738/871059	413732087105702	629	631.52	57- 62	UC	BCA	585.63	NT
S317	244-125	413738/871059	413732087105701	629	631.38	115-120	UC	CSA	584.95	NT
S318	D-2A	413838/870645	413838087064502	608	609.67	13- 16	UC	WTCA	596.52	NT
S319	D-4A	413843/870628	413843087062802	605	607.92	10- 13	UC	WTCA	597.45	NT
S320	D-5A	413836/870610	413836087061002	607	610.15	10- 13	UC	WTCA	604.80	NT
S321	D-6A	413847/870556	413847087055602	605	606.65	10- 13	UC	WTCA	599.55	NT
S322	G-1	413821/870709	413821087070901	626	627.41	40- 45	UC	BCA	600.68	NT
S323	G-4	413821/870650	413821087065001	621	624.17	21- 26	UC	MCA	602.54	NT
S324	G-4A	413821/870650	413821087065003	622	624.71	32- 35	UC	MCA	599.95	NT
S325	MW-1	413603/871645	413603087164501	603	604.83	6- 9	UC	WTCA	600.43	NT
S326	MW-2	413618/871646	413618087164601	601	603.25	3- 6	UC	WTCA	599.03	NT
S327	MW-5	413632/871613	413622087161301	603	604.22	4- 7	UC	WTCA	599.08	NT
S328	MW-10	413702/871622	413702087162201	594	594.63	6- 9	UC	WTCA	588.78	NT
S329	W-1A	413625/871318	413625087132001	606	607.98	6- 9	UC	WTCA	603.07	NT
S330	W-2	413602/871427	413602087142701	608	611.30	11- 14	UC	WTCA	603.12	NT
S331	W-3Dune	413609/871427	413609087142802	606	607.70	7- 10	UC	WTCA	601.64	NT
S332	W-3West	413609/871427	413609087142801	604	607.30	6- 9	UC	WTCA	601.76	NT
S333	W-4	413554/871427	413554087142701	609	611.00	6- 9	UC	WTCA	605.08	NT
S334	W-5	413605/871403	413605087140301	606	607.10	6- 9	UC	WTCA	602.64	NT
S335	W-6	413601/871503	413601087150301	604	604.91	2- 5	UC	WTCA	601.17	NT

Well number	Well name	Latitude/ Longitude	USGS Site ID number	Land-surface altitude (feet above sea level)	Measuring point altitude (feet above sea level)	Screen interval (feet below land surface)	Geologic unit	Hydrologic unit	Water-level altitude (feet above sea level)	Organic vapor reading (parts per million in air)
S336	W-7	413622/871427	413622087142701	604	607.01	6- 9	UC	WTCA	599.80	NT
S337	W-9	413702/871320	413702087132001	597	597.98	3- 6	UC	WTCA	597.14	NT
S338	122A	414017/872918	NA	588	590.81	2- 17	UC	WTCA	*581.16	NT
S339	122B	414017/872918	NA	588	590.48	23- 33	UC	BCA	580.78	NT
S340	122C	414017/872918	NA	588	590.15	43- 48	UF	CU	577.50	NT
S341	127A	414022/872846	NA	589	591.51	3- 19	UC	WTCA	585.18	NT
S342	127B	414022/872846	NA	590	591.78	27- 37	UC	BCA	585.20	NT
S343	128A	414015/872858	NA	594	595.27	3- 18	UC	WTCA	*586.12	NT
S344	128B	414015/872858	NA	594	596.22	30- 40	UC	BCA	586.03	NT
S345	130A	414009/872827	NA	589	591.67	2- 18	UC	WTCA	584.76	NT
S346	130B	414009/872825	NA	589	591.70	28- 38	UC	BCA	584.76	NT
S347	131A	413957/872837	NA	592	594.23	3- 18	UC	WTCA	586.60	NT
S348	131B	413957/872838	NA	592	594.31	28- 38	UC	MCA	586.64	NT
S349	132A	413953/872919	NA	586	588.14	3- 18	UC	WTCA	*572.36	NT
S350	133A	413940/872818	NA	592	593.80	3- 18	UC	WTCA	*579.94	NT
S351	133B	413940/872818	NA	592	594.13	30- 40	UC	BCA	580.18	NT
S352	133C	413940/872818	NA	592	594.10	50- 55	UF	CU	579.95	NT
S353	136A	413906/872829	NA	586	587.95	1- 17	UC	WTCA	579.10	NT
S354	136B	413906/872829	NA	586	588.26	26- 36	UC	BCA	579.05	NT
S355	S41	413930/872956	NA	588	590.47	6- 22	UC	WTCA	585.21	NT
S356	S53A	413940/872925	NA	586	588.82	4- 19	UC	WTCA	580.44	NT
S357	S53B	413940/872925	NA	586	588.81	29- 34	UC	BCA	581.19	NT
S358	S54A	413918/873024	NA	588	590.35	3- 18	UC	WTCA	582.12	NT
S359	S54B	413918/873024	NA	588	590.37	26- 31	UC	BCA	582.23	NT
S360	S56B	413854/873024	NA	590	593.14	26- 31	UC	BCA	580.52	NT
S361	S57A	413851/872935	NA	585	587.04	2- 17	UC	WTCA	580.99	NT
S362	S57B	413851/872935	NA	585	586.75	25- 30	UC	BCA	581.06	NT
S363	S59A	413938/873030	NA	585	587.73	1- 16	UC	WTCA	582.28	NT
S364	S59B	413938/873030	NA	585	587.60	24- 29	UC	BCA	582.21	NT
S365	S63A	413924/872926	NA	587	589.27	1- 16	UC	WTCA	584.59	NT
S366	S63B	413924/872926	NA	587	589.04	27- 32	UC	BCA	584.60	NT
S367	S67A	413902/872926	NA	588	590.57	Unknown	UCe	WTCAe	583.47	NT
S368	S67B	413902/872926	NA	588	590.04	Unknown	UCe	BCAe	583.53	NT
S369	S76B	413911/872959	NA	593	595.78	31- 37	UC	BCA	585.55	NT
S370	S92A	413846/872928	NA	585	586.82	2- 18	UC	WTCA	581.18	NT

Well number	Well name	Latitude/ Longitude	USGS Site ID number	Land-surface altitude (feet above sea level)	Measuring point altitude (feet above sea level)	Screen interval (feet below land surface)	Geologic unit	Hydrologic unit	Water-level altitude (feet above sea level)	Organic vapor reading (parts per million in air)
S371	S92B	413846/872928	NA	585	586.57	26- 31	UC	BCA	581.19	NT
S372	S93A	413842/872926	NA	586	588.81	2- 18	UC	WTCA	581.91	NT
S373	S93B	413842/872926	NA	587	588.76	26- 31	UC	BCA	581.49	NT
S374	S96A	413846/873009	NA	584	586.52	2- 18	UC	WTCA	580.28	NT
S375	S96B	413846/873009	NA	584	586.45	22- 27	UC	BCA	580.34	NT
S376	S97A	413839/873011	NA	584	586.36	2- 18	UC	WTCA	581.50	NT
S377	S97B	413839/873011	NA	584	586.34	21- 26	UC	BCA	581.54	NT
S378	1	413859/872840	NA	587	588.41	10-20e	UCe	WTCAe	579.37	0
S379	2	413854/872841	NA	589	589.22	10-20e	UCe	WTCAe	580.74	0
S380	MW-2	413859/873129	NA	587	587.51	4- 15	UC	WTCA	581.77	0
S381	MW-1	413859/873129	NA	587	587.26	69- 80	D	SD	574.58	0
S382	MW-3	413859/873129	NA	585	587.42	13- 24	UC	MCA	581.79	0
S383	MW-8	413850/873130	NA	587	590.33	4- 15	UC	WTCA	584.29	10
S384	MW-9	413850/873130	NA	587	590.02	15- 26	UC	BCA	584.29	0
S385	MW-22	413850/873130	NA	587	591.74	39- 50	D	SD	577.61	0
S386	1	413743/872611	NA	587	588.95	Unknown	UCe	CA	585.17	0
S387	2	413705/872603	NA	587	587.43	Unknown	UCe	CA	581.80	0
S388	3	413740/872705	NA	587	589.22	Unknown	UCe	CA	582.84	0
S389	MW-5	413650/872703	NA	588	590.13	16- 31	UC	MCA	581.43	NT
S390	MW-10	413720/872701	NA	588	590.47	18- 33	UC	MCA	584.38	NT
S391	MW-18	413850/872913	NA	586	586.21	Unknown	UCe	CA	583.33	NT
S392	MW-30	413915/872918	NA	586	586.05	Unknown	UCe	CA	583.87	NT
S393	MW-33	413915/872852	NA	588	588.63	Unknown	UCe	CA	581.77	NT
S394	MW-34	413833/872922	NA	586	585.83	Unknown	UCe	CA	581.57	NT
S395	MW-35	413841/872905	NA	586	586.26	Unknown	UCe	CA	581.84	NT
S396	P-24	413846/872905	NA	585	584.86	Unknown	UCe	CA	580.47	NT
S397	MW-1	414026/872955	NA	584	586.37	5- 29	UC	WTCA	580.03	NT
S398	MW-2A	414021/872951	NA	584	585.71	Unknown	UCe	CA	581.15	NT
S399	MW-3	414021/872942	NA	583	583.76	4- 28	UC	WTCA	580.46	NT
S400	MW-5	414018/872951	NA	581	582.26	9- 24	UC	WTCA	581.16	NT
S401	GM-4A	413451/872413	NA	611	612.97	4- 14	UC	WTCA	604.46	NT
S402	GM-4B	413451/872413	NA	610	612.93	30- 35	UC	BCA	604.51	NT
S403	MW-1	413510/872421	NA	604	606.50	8- 18	UC	WTCA	593.50	NT
S404	MW-4	413451/872421	NA	609	611.91	6- 16	UC	WTCA	604.01	0
S405	2M	413629/872420	NA	586	588.60	Unknown	UCe	CA	585.78	0

Well number	Well name	Latitude/ Longitude	USGS Site ID number	Land-surface altitude (feet above sea level)	Measuring point altitude (feet above sea level)	Screen interval (feet below land surface)	Geologic unit	Hydrologic unit	Water-level altitude (feet above sea level)	Organic vapor reading (parts per million in air)
S406	3E	413630/872427	NA	586	586.26	Unknown	UCe	CA	583.39	0
S407	3M	413630/872428	NA	586	586.80	Unknown	UCe	CA	583.35	0
S408	3W	413630/872428	NA	586	586.42	Unknown	UCe	CA	583.30	0
S409	5E	413634/872428	NA	586	585.56	Unknown	UCe	CA	583.43	0
S410	5W	413634/872428	NA	586	585.72	Unknown	UCe	CA	583.81	0
S411	6M	413632/872408	NA	586	586.46	Unknown	UCe	CA	583.53	0
S412	7E	413633/872412	NA	586	586.60	Unknown	UCe	CA	583.90	0
S413	7M	413633/872412	NA	586	586.48	Unknown	UCe	CA	583.89	0
S414	100	413822/872645	NA	588	587.62	Unknown	UCe	WTCAe	580.21	0
S415	105	413822/872646	NA	588	587.73	Unknown	UCe	WTCAe	580.08	5
S416	2	413606/872338	NA	595	594.98	Unknown	UCe	WTCAe	587.03	10
S417	3	413606/872339	NA	595	594.04	Unknown	UCe	WTCAe	586.61	75
S418	MW-8	413553/871026	NA	637	636.29	Unknown	UCe	WTCAe	614.53	0.8
S419	MW-12	413553/871024	NA	637	635.81	Unknown	UCe	CA	614.15	0
S420	OW-3	413434/871047	NA	638	637.84	Unknown	UCe	WTCAe	628.66	0
S421	OW-6	413433/871046	NA	638	637.24	Unknown	UCe	WTCAe	628.64	0
S422	W-1	413807/872820	NA	587	589.30	Unknown	UCe	CA	581.03	0
S423	W-2	413817/872818	NA	585	587.04	Unknown	UCe	CA	580.57	0
S424	W-3	413816/872820	NA	585	586.34	Unknown	UCe	CA	580.95	3
S425	W-4	413820/872824	NA	586	588.09	Unknown	UCe	CA	581.70	0
S426	W-5	413819/872819	NA	585	587.36	Unknown	UCe	CA	580.79	0
S427	W-6	413817/872831	NA	586	588.28	Unknown	UCe	CA	581.11	0
S428	W-7	[1]413816/872822	NA	588	589.54	Unknown	UCe	CA	NT[2]	3
S429	CGA3	413722/872513	NA	590	591.87	Unknown	UCe	CA	585.09	NT
S430	CGA4	413719/872519	NA	591	592.83	Unknown	UCe	CA	584.88	NT
S431	MW-1A	413918/872713	NA	592	594.10	2- 13	UC	WTCA	581.90	0
S432	MW-1B	413918/872713	NA	592	593.24	22- 42	UC-UF	BCA	583.90	0
S433	MW-1C	413918/872713	NA	592	594.31	53- 63	UF	MCU	582.89	0
S434	MW-1D	413918/872713	NA	592	593.81	95-105	UF	BCU	578.72	0
S435	MW-6C	413950/872630	NA	597	598.60	10- 20	UC	WTCA	585.52	0
S436	MW-6D	413950/872630	NA	597	598.67	44- 54	UC-UF	BCA	585.31	0
S437	MW-6E	413950/872630	NA	595	596.41	73- 83	UF	MCU	580.59	0
S438	MW-6F	413950/872630	NA	595	596.66	124-134	UF	BCU	577.75	0
S439	MW-22A	414052/872526	NA	597	597.96	5- 20	UC	WTCA	585.70	0
S440	MW-22B	414052/872526	NA	597	598.07	40- 55	UC-UF	BCA	585.67	0

Well number	Well name	Latitude/ Longitude	USGS Site ID number	Land-surface altitude (feet above sea level)	Measuring point altitude (feet above sea level)	Screen interval (feet below land surface)	Geologic unit	Hydrologic unit	Water-level altitude (feet above sea level)	Organic vapor reading (parts per million in air)
S441	MW-22C	414052/872526	NA	597	598.11	70- 80	UF	MCU	586.17	0
S442	MW-22D	414052/872526	NA	597	597.82	118-128	UF	BCU	584.48	0
S443	P-5B	413919/872620	NA	590	589.25	?- 15	UC	WTCA	582.29	0
S444	P-13	414020/872554	NA	596	596.72	?- 20	UC	WTCA	585.28	0
S445	P-14A	413947/872508	NA	594	595.63	9- 19	UC	WTCA	580.89	0
S446	P-24	414104/872527	NA	597	598.94	?- 17	UC	WTCA	588.26	0
S447	MW-1	413423/872255	NA	607	610.39	6- 16	UC	WTCA	599.90	0
S448	MW-2	413423/872254	NA	607	610.25	24- 34	UC	BCA	599.93	0
S449	MW-16	413423/872255	NA	606	609.67	133-138	D	SD	596.61	0
S450	MW-25	413405/872236	NA	594	595.06	Unknown	UCe	CA	590.24	0
S451	E-10	413511/872540	NA	609	611.21	5- 10	UC	WTCA	603.34	0
S452	E-30	413511/872540	NA	609	610.83	23- 28	UC	BCA	603.80	0
S453	E-200	413511/872540	NA	609	610.63	147-152	D	SD	582.40	0
S454	F-10	413720/872426	NA	595	597.60	6- 11	UC	WTCA	588.07	NT
S455	F-30	413720/872426	NA	595	597.64	41- 46	UC	BCA	587.43	NT
S456	J-10	413724/872422	NA	601	603.37	17- 22	UC	WTCA	588.46	NT
S457	J-30	413724/872422	NA	601	602.22	47- 52	UC	BCA	588.36	NT
S458	K-10	413714/872440	NA	589	592.61	3- 8	UC	WTCA	586.01	0
S459	K-30	413714/872440	NA	589	592.07	36- 42	UC	BCA	585.79	0
S460	MW-G6A	413722/871006	NA	606	607.30	12- 22	UC	WTCA	592.42	0
S461	MW-G6C	413722/871006	NA	606	607.23	40- 50	UC	BCA	592.07	0
S462	MW-G6I	413722/871006	NA	606	607.07	76- 86	UC	CSA	591.95	0
S463	MW-G8A	413722/870948	NA	607	608.89	10- 20	UC	WTCA	597.08	0
S464	MW-G8C	413722/870948	NA	608	609.38	39- 49	UC	CSA	595.96	0
S465	MW-G8I	413722/870948	NA	608	609.02	68- 78	UC	CSA	595.34	0
S466	MW-G12A	413712/870935	NA	606	607.49	9- 19	UC	WTCA	599.41	0
S467	MW-G12C	413712/870935	NA	607	608.33	39- 49	UC	CSA	595.53	0
S468	MW-G12I	413712/870935	NA	607	607.89	81- 91	UC	CSA	595.25	0
S469	MW-L2A	413732/871038	NA	609	610.39	36- 46	UC	MCA	581.59	0
S470	MW-L2B	413732/871038	NA	609	610.26	62- 72	UC	CSA	581.60	0
S471	MW-L2C	413732/871038	NA	609	610.51	96-106	UC	CSA	581.55	0
S472	MW-L4A	413747/871041	NA	620	621.13	37- 47	UC	MCA	581.00	0
S473	MW-L4B	413747/871041	NA	621	621.55	49- 59	UC	CSA	581.03	0
S474	MW-L4C	413747/871041	NA	620	621.14	85- 95	UC	CSA	581.03	0
S475	MW-L5A	413721/871055	NA	605	605.83	15- 25	UC	WTCA	587.97	0

Well number	Well name	Latitude/ Longitude	USGS Site ID number	Land-surface altitude (feet above sea level)	Measuring point altitude (feet above sea level)	Screen interval (feet below land surface)	Geologic unit	Hydrologic unit	Water-level altitude (feet above sea level)	Organic vapor reading (parts per million in air)
S476	MW-L5B	413721/871055	NA	605	605.84	23- 33	UC	MCA	587.97	0
S477	MW-L5C	413721/871055	NA	605	605.90	69- 79	UC	CSA	587.88	0
S478	MW-1	413831/872938	NA	585	590.36	Unknown	UCe	CA	582.84	4
S479	MW-2	413834/872938	NA	585	589.54	Unknown	UCe	CA	582.64	0
S480	MW-3	413834/872934	NA	585	589.64	Unknown	UCe	CA	582.71	0
S481	MW-4	413832/872937	NA	585	590.42	Unknown	UCe	CA	582.85	0
S482	MW-5	413832/872936	NA	585	589.98	Unknown	UCe	CA	582.81	0
S483	MW-6	413832/872938	NA	586	590.94	Unknown	UCe	CA	582.78	0
S484	MW-7	413833/872936	NA	585	590.35	Unknown	UCe	CA	582.75	0
S485	MW-8	413830/872938	NA	585	590.64	Unknown	UCe	CA	582.90	0
S486	MW-9	413832/872935	NA	585	590.42	Unknown	UCe	CA	582.95	0
S487	MW-10	413831/872936	NA	585	589.90	Unknown	UCe	CA	582.83	0
S488	W-11S	413541/872543	NA	601	603.27	3- 13	UC	WTCA	595.04	0
S489	W-12D	413541/872543	NA	601	602.66	16- 26	UC	MCA	595.03	0
S490	W-51S	413530/872543	NA	601	602.83	2- 12	UC	WTCA	597.38	0
S491	W-52D	413530/872543	NA	601	602.73	18- 28	UC	MCA	597.44	0
S492	MW-2	413809/870619	NA	610	609.86	5- 10	UC	WTCA	604.39	0
S493	MW-4	413809/871621	NA	610	609.62	5- 15	UC	WTCA	603.30	20
S494	MW-4D	413809/871621	NA	610	609.29	30- 35	UC	MCA	599.11	0
S495	OW-1	413809/870624	NA	610	610.31	5- 15	UC	WTCA	604.09	0
S496	BH-12	413620/872044	413620087204401	601	600.62	10- 20	UC	WTCA	588.15	NT
S497	BH-13	413548/872040	413548087204001	603	602.92	9- 19	UC	WTCA	591.98	NT
S498	BH-14	413445/872047	413445087204701	610	609.45	9- 19	UC	WTCA	603.60	NT
S499	BH-15	414120/873047	414120087304701	585	584.56	10- 15	UC	WTCA	582.80	NT
S500	BH-17	413706/871507	413706087150701	599	599.00	10- 20	UC	WTCA	587.03	NT
S501	BH-19	413516/872223	413516087222301	602	601.56	10- 20	UC	WTCA	590.70	NT
S502	BH-20	413615/872013	413615087201301	600	599.48	14- 24	UC	WTCA	587.17	0
S503	MW-1	414146/873043	NA	591	590.41	Unknown	UCe	WTCAe	579.18	0
S504	HWD2-5	413707/871726	NA	623	623.81	70- 90	UC	BCA	584.46	0
S505	HWD2-6	413706/871813	NA	607	609.22	50- 70	UC	BCA	585.39	0
S506	HWD2-7	413636/871751	NA	599	600.76	30- 50	UC	BCA	591.51	0
S507	HWD5-4	413810/872405	NA	592	594.08	11- 47	UC	CA	583.26	0
S508	HWD5-5R	413813/872355	NA	592	594.62	?- 47	UC	CA	581.65	0
S509	HWT2-2	413750/872300	NA	602	603.81	16- 61	UC	CA	583.75	0
S510	HWT2-4	413747/872251	NA	605	606.80	20- 65	UC	CA	583.21	0

Well number	Well name	Latitude/ Longitude	USGS Site ID number	Land-surface altitude (feet above sea level)	Measuring point altitude (feet above sea level)	Screen interval (feet below land surface)	Geologic unit	Hydrologic unit	Water-level altitude (feet above sea level)	Organic vapor reading (parts per million in air)
S511	HWT2-8	413758/872257	NA	588	589.68	30- 50	UC	CA	581.74	0
S512	HWT2-9	413752/872234	NA	608	609.36	50- 70	UC	CA	580.07	0
S513	HWT2-12S	413739/872251	NA	600	602.20	14- 29	UC	CA	584.95	NT
S514	HWT2-10	413730/872316	NA	589	591.25	24- 44	UC	CA	586.61	0
S515	HWT2-11S	413743/872302	NA	604	605.64	15- 30	UC	CA	584.61	NT
S516	HWT13-1	413736/872233	NA	601	602.57	24- 60	UC	CA	585.65	0
S517	HWT13-4	413741/872228	NA	602	603.75	26- 62	UC	CA	581.83	0
S518	HWT14-1	413725/872250	NA	591	592.74	13- 49	UC	CA	584.21	0
S519	HWT14-4	413729/872244	NA	591	592.07	?- 48	UC	CA	586.32	0
S520	HWT14-5	413721/872254	NA	589	590.79	27- 47	UC	BCA	584.33	0
S521	P-1	413649/871722	NA	601	603.10	19- 29	UC	MCA	587.66	0
S522	P-2	413658/871731	NA	615	616.36	30- 40	UC	MCA	586.93	0
S523	P-3	413650/871744	NA	615	616.98	29- 39	UC	MCA	588.55	0
S524	P-4	413743/872238	NA	602	603.85	25- 35	UC	MCA	582.24	0
S525	P-6	413744/872250	NA	605	606.92	20- 30	UC	MCA	584.26	0
S526	P-11	413736/871722	NA	596	596.94	15- 25	UC	WTCA	585.13	0
S527	P-12	413725/872241	NA	593	594.80	10- 20	UC	WTCA	585.10	0
S528	P-14	413751/872404	NA	590	592.23	10- 20	UC	WTCA	585.49	0
S529	P-16	413801/872353	NA	595	597.09	15- 25	UC	WTCA	583.20	0
S530	G-6	413821/870625	413821087062501	619	620.87	5.4- 10.4	UC	WTCA	<608.6	NT

Station number	Location	Latitude/Longitude	USGS site ID number	Measuring point altitude (feet above sea level)	Surface-water altitude (feet above sea level)
SW-1	Calumet Harbor	414302/873133	NA	580.45	580.1
SW-2	Calumet River at 106th Street	414210/873247	NA	607.66	581.1
SW-3	Calumet River at Torrence Avenue	414010/873338	NA	607.66	581.3
SW-4	Lake Calumet at Stony Island Avenue	413950/873432	NA	584.66	580.5
SW-5	Lake Calumet west	413957/873521	NA	584.41	579.9
SW-6	Calumet Sag Channel at Crawford Avenue	413904/874301	NA	613.59	578.6
SW-7	Little Calumet River at Halsted Avenue, Calumet Park	413921/873825	05536366	614.60	578.3
SW-8	Little Calumet River at Indiana Avenue	413900/873700	NA	601.16	578.3
SW-9	West side Wolf Lake	413953/873222	D4D9250	580.45	582.1
SW-10	Wolf Lake at Hammond	414016/873038	NA	584.55	583.0
SW-11	Lake George at Hammond	414022/873019	NA	584.27	581.3
SW-12	Grand Calumet River at Hohman Avenue	413728/872310	05536350	575.00	579.1
SW-13	Grand Calumet River at Calumet Avenue	413714/873032	NA	584.69	579.7
SW-14	Grand Calumet River at Indianapolis Boulevard	413651/872850	NA	595.39	580.9
SW-15	Lake Mary at Hammond	413841/872937	NA	582.46	581.2
SW-16	Indiana Harbor Canal at East Chicago	413904/872757	NA	581.22	580.5
SW-17	Unnamed Lake near Buffington Harbor	413809/872532	NA	586.30	585.2
SW-18	Grand Calumet River at Gary Regional Airport	413640/872513	NA	585.04	582.1
SW-19	Grand Calumet River at US 12	413629/872339	04092677	580.00	583.4
SW-20	Grand Calumet River at Bridge Street	413632/872219	NA	600.02	583.7
SW-21	Gary Harbor	413632/871925	NA	589.23	580.1
SW-22	Grand Calumet River near Broadway Street	413627/871920	NA	589.99	586.2
SW-23	Calumet Lagoons at Gary	413645/871733	NA	588.15	587.7
SW-24	Little Calumet River at Porter	413718/870513	04094000	603.48	606.4
SW-25	Little Calumet River at State Road 249	413644/871025	NA	604.45	579.8
SW-26	Little Calumet River at State Road 51	413513/871425	NA	603.09	580.0
SW-27	Little Calumet River at Gary	413419/871613	04093200	580.00	587.8
SW-28	Little Calumet River at Broadway Street	413339/872012	NA	603.27	587.7
SW-29	Little Calumet River at Colfax Street	413350/872447	NA	601.91	589.3
SW-30	Hart Ditch near Munster	413340/872850	05536190	591.27	591.8
SW-31	Little Calumet River at Munster	413407/873118	05536195	580.72	585.5
SW-32	Little Calumet River at Torrence Avenue	413538/873318	NA	605.64	583.9
SW-33	Little Calumet River at Cottage Grove Avenue	413625/873552	05536290	575.00	580.0
SW-34	Little Calumet River at Halsted Avenue, Harvey	413745/873825	NA	601.18	579.2

[1]Latitude/longitude determined by TRC Environmental Corporation by use of global positioning.
[2]Viscous oil found in well, did not allow measurement of water level.