Water-Table and Aquifer-Susceptibility Maps of Calumet County, Wisconsin

Madeline B. Gotkowitz and Stephen J. Gaffield
2006
Miscellaneous Map 56

INTRODUCTION

The Calumet County Board of Supervisors sponsored the Calumet County Groundwater Project to provide information pertinent to protecting the quality of groundwater resources in the county. These maps and figures are products of this project; they are based upon our compilation and analysis of geologic and hydrologic data. The maps illustrate significant characteristics of the regional groundwater flow system and its susceptibility to contamination from human activities. The information presented here indicates that large parts of the groundwater system in Calumet County currently used for drinking-water supplies are moderately or highly susceptible to contamination, underscoring the need for sound planning to maintain a safe drinking-water supply.

THE GROUNDWATER SYSTEM

The *water cycle* is a continuous cycling of water through the Earth's atmosphere, oceans, glaciers, lakes, rivers, soil, and rock (fig. 1). Precipitation that reaches the land surface can flow downhill as overland runoff, evaporate, transpire through plants, or infiltrate the ground. Water that infiltrates the ground percolates through pore spaces and cracks, or *fractures*, in soil and rock. Where these pores and fractures are completely filled with water, the material is *saturated*.

The *water table* is the surface formed by the top of the saturated zone, where hydraulic pressure in the pores is equal to atmospheric pressure. *Groundwater* is the water contained in the saturated zone beneath the water table. Above the water table, where pores and fractures are filled completely with air or with some air and some water, is the *unsaturated zone*. The amount of precipitation that infiltrates the soil and reaches the saturated zone is an important factor in determining the elevation of the water table, which fluctuates seasonally and from one year to another.

In Calumet County, 29 to 32 inches of precipitation fall on the ground surface during an average year. Approximately 70 to 75 percent of this amount cycles back to the atmosphere by evaporation and transpiration by plants (Hindall and Borman, 1974). The remainder either flows as runoff on the land surface to streams and lakes or infiltrates through soil or rock to the water table, where it *recharges* the groundwater system. Many factors, such as topography, vegetation, rainfall intensity, and soil and rock type, affect the amount of precipitation that reaches the groundwater system. For example, in areas where the land surface is covered extensively by pavement (such as parking lots and roadways), stormwater runoff to surface water is increased and groundwater recharge is decreased.

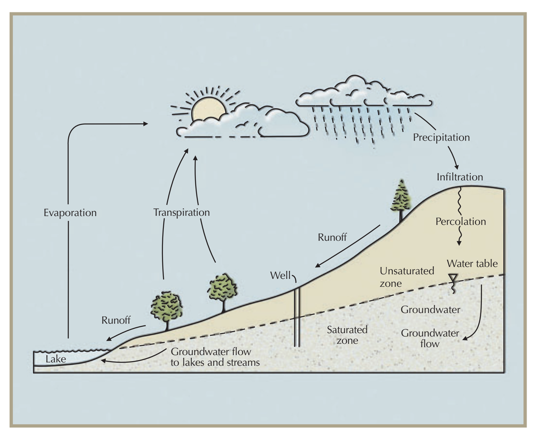


Figure 1. *The water cycle (modified from Dunne and Leopold, 1978).*

Groundwater flow and discharge

An *aquifer* is geologic material (such as sand and gravel deposits or a bedrock layer) that is saturated and yields water to wells. *Hydraulic conductivity* is a measure of an aquifer's ability to transmit groundwater; it is dependent on the nature of the material through which the water is flowing. Large pores or fractures can hold more water than small ones, but for water to flow effectively within an aquifer, these pores or fractures must be connected. An *aquitard* is a rock or sediment layer consisting of low conductivity material (such as shale or clay) that restricts the flow of groundwater and yields very little water to wells. *Confined* aquifers underlie aquitards; *unconfined* aquifers are at, or close to, the ground surface. The *potentiometric surface* represents the water pressure in a confined aquifer; that is, the elevation to which water will rise in wells completed in that aquifer. The water in wells completed in an unconfined aquifer will rise to the elevation of the water table.

Each contour line on the water-table elevation map (shown right) connects points of equal water-table elevation. The natural direction of groundwater flow is in response to gravity, from areas of higher water-table elevation to lower water-table elevation, generally perpendicular to lines of equal water-table elevation. Arrows on the map indicate the general direction of shallow groundwater flow across the county, from high to low water-table elevation.

Groundwater flows through aquifers from recharge to discharge areas. The uplands, where the water-table elevation is higher, tend to be areas where water infiltrates the ground and recharges groundwater. In Wisconsin and other parts of the Midwest, surface-water bodies such as lowland streams, lakes, and wetlands are typically areas of groundwater discharge. Such discharge occurs when the nearby water-table elevation is higher than the elevation of the surface-water body, and groundwater flows into the surface water. Most rivers and streams have some water flowing in them even during extended periods of drought because they are fed by groundwater.

An example of flow from recharge to discharge areas can be seen on the map along the ridge northeast of Brothertown. There, the elevation of the water table is approximately 1,000 ft. Arrows on the map illustrate that shallow groundwater flows to the west, where groundwater discharges to Lake Winnebago, which has an elevation of 747 ft. The arrows on the water-table elevation map show that shallow groundwater also flows from the ridgetop to the east, discharging to Stony Brook and the South Branch of the Manitowoc River.

Springs are natural points of groundwater discharge. In western Calumet County, shallow groundwater discharging through fractures in the dolomite feeds the many springs found along the Niagara Escarpment (a steep bluff formed by the exposed edge, or *outcrop*, of Silurian dolomite).

Water wells are manmade points of groundwater discharge. Pumping lowers the water level in a well, inducing flow to the well from the surrounding aquifer. Pumping can cause a drop in the level of the water table, called a *cone of depression*, around the well. The relatively low volume of groundwater that is currently withdrawn from shallow wells in Calumet County does not cause cones of depression large enough to be seen at the scale of this water-table map. However, pumping from deep wells results in a cone of depression in the potentiometric surface of the sandstone aquifer in Calumet County, as discussed in the next section, *Geology and groundwater availability*.

A *surface-water divide* is a line of separation, commonly along a ridge or tract of high ground, that divides surface waters that flow naturally into one basin from those that flow naturally into a different basin. The major surface-water divides in Calumet County are shown on the water-table map. These divides separate the basins of Lake Winnebago, the lower Fox River, the Manitowoc River, and the Sheboygan River.

A *groundwater divide* is similar to a surface-water divide; it is an imaginary line along the highest elevations of the water table. Shallow groundwater flows away from groundwater divides, toward groundwater discharge areas. Groundwater divides do not necessarily coincide with surface-water divides, although the major groundwater divides in Calumet County are along or relatively close to surface-water divides. The locations of groundwater divides on this map are approximate and may change as the water table rises and falls in response to periods of rainfall and drought. Significant amounts of groundwater pumping from wells drilled near divides may also cause a divide to shift.

The groundwater divides in Calumet County can be used to identify the areas in which shallow groundwater flows toward particular stream systems. For example, in northern Calumet County, groundwater flows toward the lower Fox River and its tributaries. In western Calumet County, a groundwater divide separates the area where groundwater flows toward Lake Winnebago from the area where flow is toward the Manitowoc River and its tributaries, including the Killsnake River, Stony Brook, and the North and South Branches of the Manitowoc River. In the southeastern part of the county, the divide indicates the area where groundwater flows toward the Sheboygan River.

Geology and groundwater availability

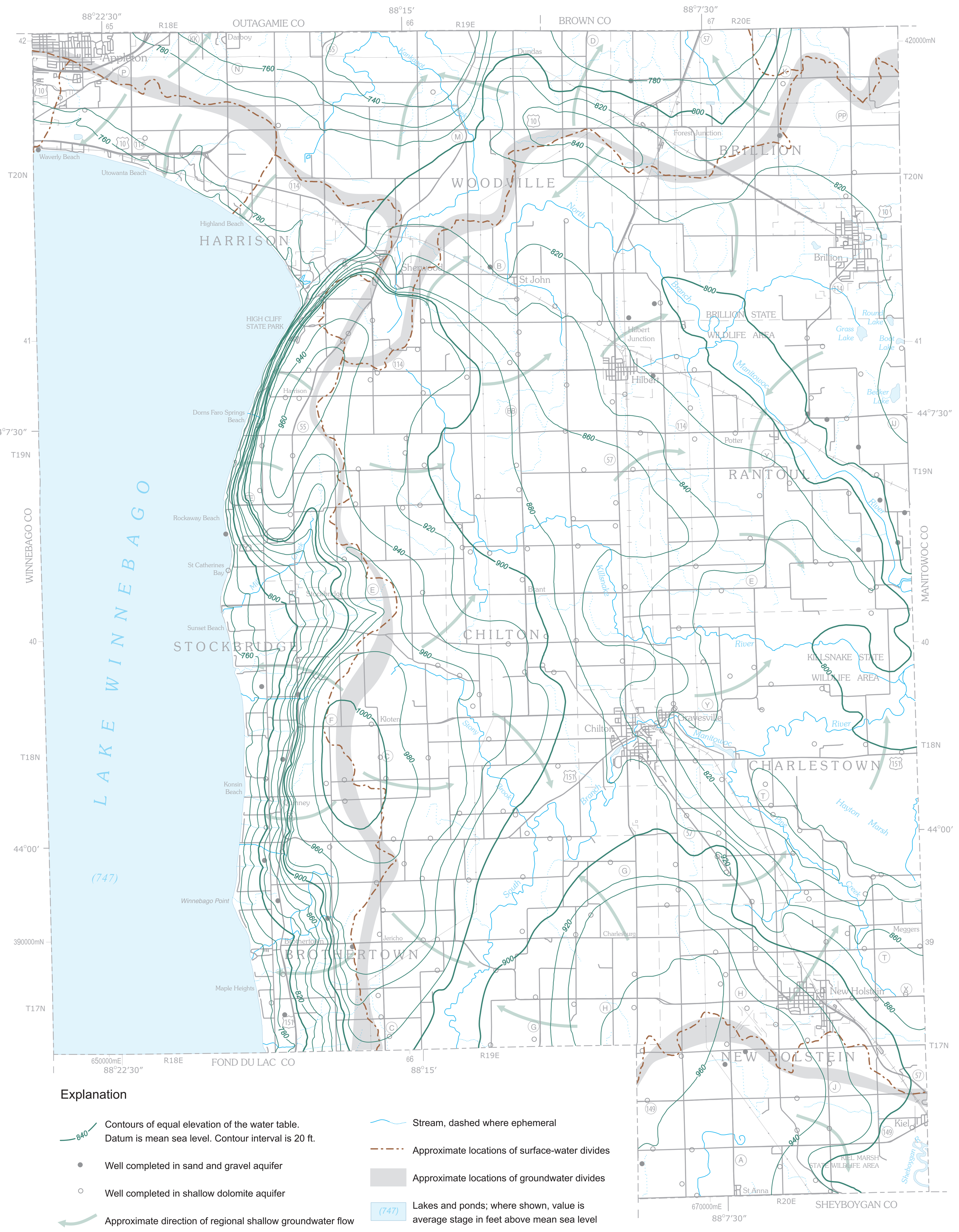
The nature and extent of various geologic materials determine the types and thicknesses of aquifers and aquitards in Calumet County. The uppermost geologic material consists of glacially deposited sediment that overlies bedrock, although in much of central and southern Calumet County, the glacial deposits are very thin or absent, and the bedrock is close to the ground surface (fig. 2B). Across most of the county, Silurian dolomite forms the uppermost bedrock (fig. 3); shale of the Maquoketa Formation is the uppermost bedrock where the Silurian dolomite is absent to the north and west. In the northwest corner of the county, where the Silurian dolomite and Maquoketa shale are absent, the dolomite of the Sinnipee Group forms the uppermost bedrock. The thicknesses and depths of these units vary across the county, as illustrated in the cross sections shown in figure 2. The layers of bedrock dip to the east, toward Lake Michigan, and are truncated to the west.

The units of hydrogeologic significance in Calumet County are as follows:

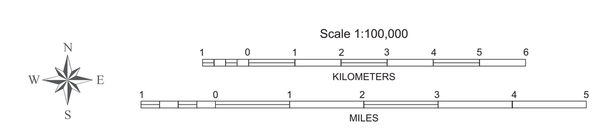
- ***Sand and gravel aquifer.*** In Calumet County, the glacial sediment is predominantly fine grained, consisting of clayey silt and clayey, silty sand mixed with gravel and larger rock fragments. Lacustrine silt and clay (sediment deposited in lakes that were formed during the glacial period) and peat are at or near the land surface in many lowland areas (B.J. Socha, 2004, written communication).

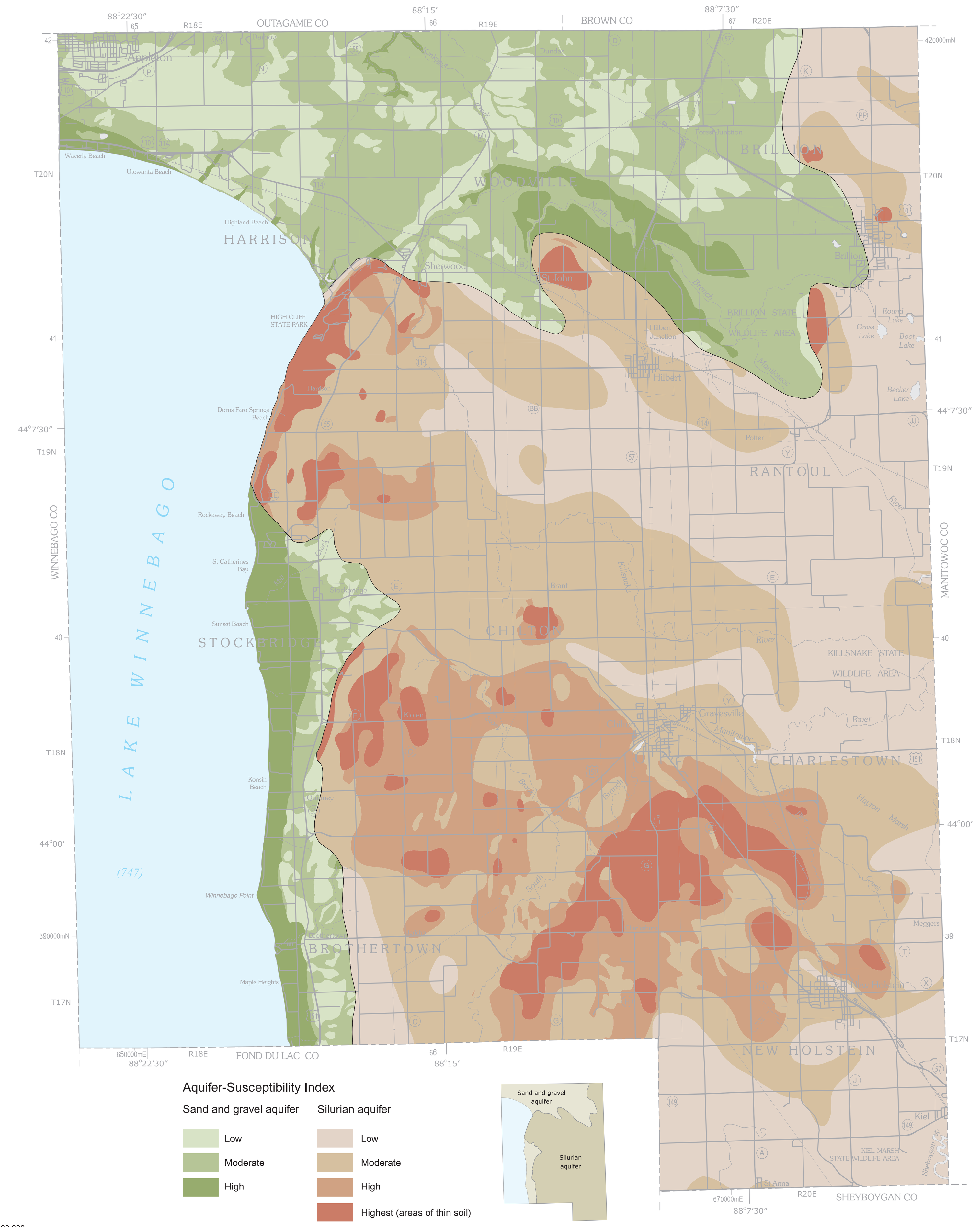
  Deposits of sand and gravel lie within these fine-grained materials in many areas of Calumet County. Sand and gravel deposits typically have well connected pore spaces that have high hydraulic conductivity; these materials make prolific aquifers that readily yield water to wells. In parts of the county, the lenses of sand and gravel are generally small and discontinuous. However, in areas of northern and western Calumet County, such lenses are sufficiently thick and permeable to constitute the uppermost aquifer, and many domestic wells are completed in them.

  In other areas of Calumet County, the glacial deposits consist of clay that has low hydraulic conductivity. Although the clay may be saturated, groundwater flows through it at very slow rates (as little as 1 inch per year). These clay deposits form an aquitard that does not readily yield water to wells and restricts the flow of groundwater to underlying bedrock.



Water-table elevation map of Calumet County, Wisconsin





Susceptibility map of the uppermost aquifers in Calumet County, Wisconsin

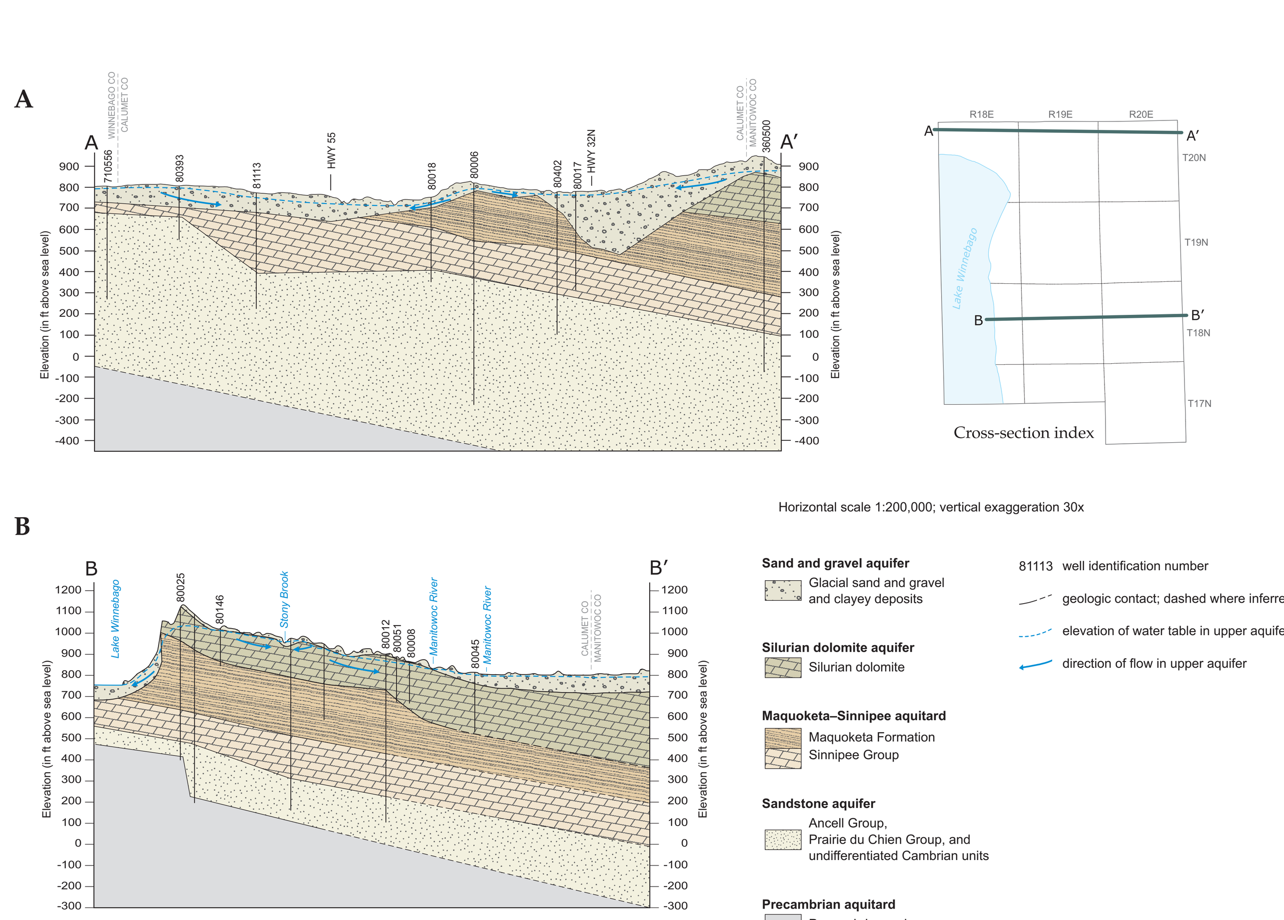


Figure 2. *Hydrogeologic cross sections in northern (A) and central (B) Calumet County.*

- ***Silurian dolomite aquifer.*** The Silurian dolomite is the uppermost bedrock aquifer where it is present in Calumet County (fig. 3), and many wells are completed in this aquifer. In general, dolomite has low hydraulic conductivity except where it is fractured. Where these fractures are extensive and well connected, they provide a conduit for groundwater flow. Fractured dolomite transmits water easily and rapidly (at rates up to tens of feet per day), and well yields may be high where wells intersect fractures. However, where there are only a few poorly connected fractures, dolomite transmits little water and yields small volumes of groundwater. In northeastern Wisconsin, the Silurian dolomite is characterized by zones of laterally extensive horizontal fractures that have high hydraulic conductivity. Between these more permeable zones are layers of finer-grained dolomite that have much lower hydraulic conductivity (Muldoon and others, 2001).

  "Karst" is a type of landscape typified by springs, caves, and other dissolution features, such as fractures. Karst features tend to form in dolomite and limestone because groundwater readily dissolves these types of rock. In Calumet County, karst features can be seen where the Silurian dolomite is at or near the ground surface. Prominent examples include the many springs on the Niagara Escarpment and the bedrock caves and fractures visible at the Ledge View Nature Center near Chilton. Although the Silurian dolomite is a prolific aquifer supplying water to many residents and businesses in Calumet County, shallow aquifers in karst terrain, such as the Silurian, are among the most susceptible aquifers to contamination.

- ***Maquoketa–Sinnipee aquitard.*** The Maquoketa Formation and Sinnipee Group underlie the Silurian dolomite across most of the county (fig. 2) and compose a regionally extensive aquitard. These units consist of low hydraulic conductivity shale and dolomite layers that restrict the vertical flow of groundwater and generally yield little water to wells.

- ***Sandstone aquifer.*** A series of permeable sedimentary bedrock units (the Ordovician Ancell and Prairie du Chien Groups and various Cambrian units) forms a sandstone aquifer underlying the Maquoketa–Sinnipee aquitard. As shown in figure 2, this aquifer is encountered at depths ranging from 100 to 800 feet below ground surface across the county. Groundwater can travel at rates up to several feet per day through porous sandstone aquifers, and the sandstone and dolomite layers that constitute this aquifer yield large volumes of groundwater to wells. Detailed investigations of the hydrogeology of northeastern Wisconsin (Krohelski, 1986; Conlon, 1998) identified regionally extensive layers of silty, shaley dolomite that function as aquitards within the more permeable sedimentary units of the sandstone aquifer. However, the data available for Calumet County are not sufficient to delineate the thickness and extent of these low hydraulic conductivity layers in the county.

- ***Precambrian aquitard.*** Relatively impermeable Precambrian rock underlies the sandstone aquifer and forms an aquitard that is a lower boundary to the groundwater system.

Groundwater pumping from wells in northern Winnebago and Calumet Counties and southern Outagamie and Brown Counties affects groundwater levels in the sandstone aquifer in Calumet County. As shown in figure 4, groundwater withdrawals across the region cause a cone of depression in the potentiometric surface of this aquifer. Water levels reported in wells open to the sandstone aquifer, results of regional groundwater flow modeling (Conlon, 1998), and an interpretation of the potentiometric surface in Fond du Lac County (K.R. Bradbury, 2003, written communication) were considered in constructing the map of the potentiometric surface. The uncertainty associated with this map is high because recent water-level data from deep wells in Calumet County are scarce, and the potentiometric surface changes as the large volume of pumping from the aquifer continues. Data collected from a monitoring well in northern Calumet County demonstrate that the rate of decline of the potentiometric surface in the sandstone aquifer in this area is approximately 2.5 feet per year (fig. 5).

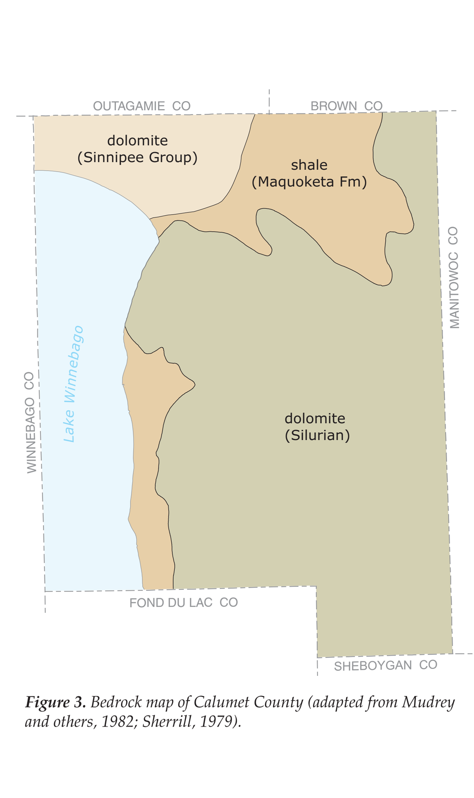


Figure 3. *Bedrock map of Calumet County (adapted from Mudrey and others, 1982; Sherrill, 1979).*

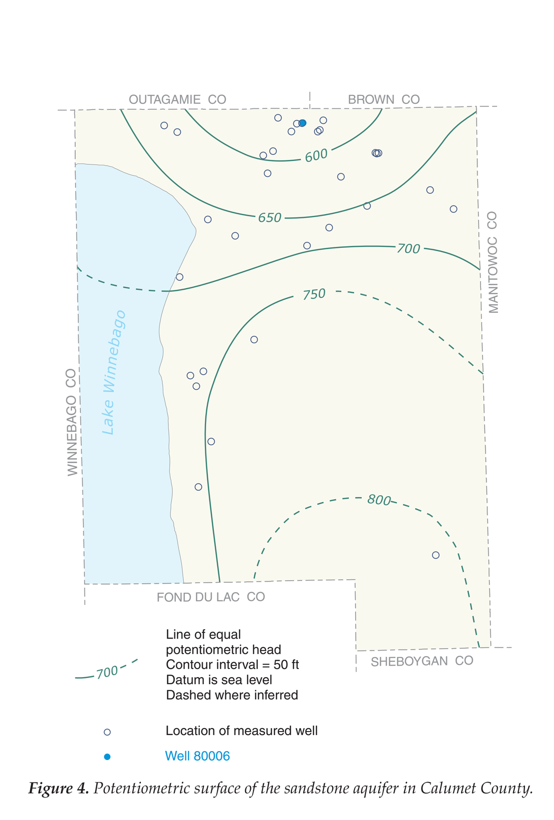


Figure 4. *Potentiometric surface of the sandstone aquifer in Calumet County.*

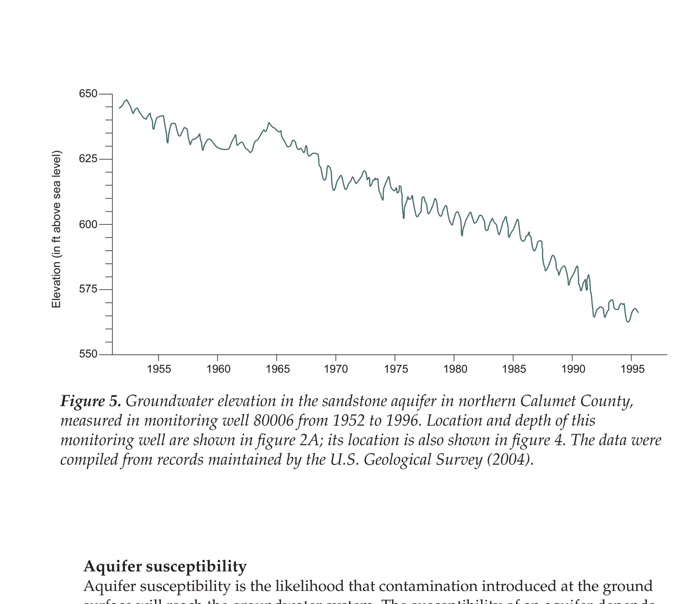


Figure 5. *Groundwater elevation in the sandstone aquifer in northern Calumet County, measured in monitoring well 80006 from 1952 to 1996. Location and depth of this monitoring well are shown in figure 2A; its location is also shown in figure 4. The data were compiled from records maintained by the U.S. Geological Survey (2004).*

Data compilation and interpretation

We estimated groundwater elevations from the elevations of surface-water features such as streams, lakes, and wetlands and from the depths to water recorded on 250 Wisconsin Department of Natural Resources well constructor's reports. U.S. Geological Survey digital data for hydrography (derived from U.S. Geological Survey, 2001), topographic quadrangles (7.5-minute series; U.S. Geological Survey, 1996–97), and the National Elevation Dataset (U.S. Geological Survey, 2001) were used as aids in estimating these elevations and contouring the data.

The reported location of each well used in making the water-table map is indicated with a symbol representing the type of geologic material in which the well was completed. This information can be used to determine where the sand and gravel aquifer is present in sufficient thickness to supply groundwater to wells and where the Silurian dolomite aquifer is more typically used for water supply. In some areas of the county, some wells are completed in the sand and gravel aquifer and others are completed in the underlying Silurian dolomite aquifer. In areas such as this (for example, along the North Branch of the Manitowoc River), the water-table map shows wells completed in the sand and gravel aquifer because water levels in these wells are more likely to reflect water-table conditions.

The accuracy of the map varies throughout the study area, increasing near surface-water bodies and where there is a greater density of wells. The water-table elevations shown on this map are approximate; water levels may vary due to seasonal fluctuations in recharge. The groundwater flow directions shown on this map are not, however, typically affected by seasonal variations in recharge.

The use of water levels recorded on well constructor's reports to create this map may also be a source of inaccuracy. Water-supply wells are not ideal measuring points for determining the water-table elevation because most of these wells are open to the aquifer over long intervals that extend far below the top of the saturated zone. This well design provides a good measurement of depth to groundwater in low-lying areas where groundwater flow is predominantly horizontal. At higher elevations and in areas of steep terrain, groundwater flow may have a significant vertical component. In such areas, the water level measured in a well may be lower than the water-table elevation. For this reason, it is difficult to determine accurately the water-table elevation on ridgetops.

This map is intended for use at the scale of publication (1:100,000). It is a regional interpretation of the water table and may not be sufficient for use at site-specific scales. Information used from the well constructor's reports was not field verified.

CONTAMINATION OF GROUNDWATER

Because groundwater originates from precipitation that percolates down from the land surface, any water-soluble material or liquid that meets the percolating water has the potential to be transported to the uppermost aquifer. Common groundwater pollutants include constituents of gasoline and other fuels from surface spills or underground storage tanks. Nitrogen and herbicides from agricultural sources, residential septic systems, or lawn-care products may also affect groundwater quality.

The unsaturated zone can serve as a natural filter for potential contaminants through a variety of physical, chemical, and biological processes. In general, thick deposits of fine-grained materials (such as clays) are best able to reduce and/or slow the transport of contaminants. Aquifers that do not have overlying aquitards (that is, unconfined aquifers) are particularly susceptible to groundwater contamination. Other settings in which aquifers are highly vulnerable to contamination include regions of coarse, sandy soils where the water table is shallow and regions where very porous or fractured bedrock is close to the ground surface.

Once a contaminant reaches the water table, it has the potential to move with groundwater and discharge to wells or surface-water bodies far from the source of contamination. Groundwater contamination that occurs today may not become evident for several years because groundwater can move as slowly as an inch per year though thick, clayey deposits. In contrast, because groundwater flow rates may be extremely rapid in fractured rock, contaminant transport from the ground surface to a water well completed in fractured rock (such as the Silurian dolomite in Calumet County) can occur as quickly as weeks to months.

The processes of dilution, adsorption onto fine-grained particles, and chemical or biological breakdown can reduce groundwater contamination in the saturated zone. However, once contaminated, groundwater remediation is a difficult engineering challenge that is usually expensive and can take many decades to complete. Preventing contamination is a more cost-effective approach to preserving groundwater quality than remediation.

Naturally occurring constituents, such as iron, sulfate, and chloride, represent another class of compounds affecting groundwater quality. These compounds originate in rocks and minerals, and they dissolve in the groundwater. In western Calumet County, concentrations of naturally occurring sulfate in groundwater from the sandstone aquifer are as high as 900 parts per million (Ryling, 1961). Although sulfate in drinking water is not considered a risk to human health, high levels of sulfate in well water may be unpalatable to well users.

Aquifer susceptibility

Aquifer susceptibility is the likelihood that contamination introduced at the ground surface will reach the groundwater system. The susceptibility of an aquifer depends on many factors. Some of these factors are intrinsic to the natural setting, such as the type and thickness of soil and geologic material overlying the aquifer, the depth to the water table, and the type of sediment or rock that makes up the aquifer. For example, aquifers that are overlain by a thick deposit of clay are much less vulnerable to contamination than an aquifer consisting of fractured dolomite rock overlain by a thin layer of sandy soil. Properties that affect aquifer susceptibility are not typically uniform over the lateral extent of an aquifer, and areas within an aquifer may have differing degrees of susceptibility to contamination.

Other factors that influence aquifer susceptibility, such as the type of contaminant present and the location of the contamination relative to groundwater flow directions, are independent of the natural system. These properties may change over time. For instance, an increase in the rate of pumping from a well can alter groundwater flow paths, potentially drawing contamination in a new direction or increasing its rate of migration within the subsurface. Sources of contamination are also likely to vary over time as land use and development alter the landscape.

All groundwater resources are to some degree susceptible to contamination, but it can be useful to categorize the vulnerability of one aquifer in relation to another or to compare the vulnerability of areas within an aquifer. The susceptibility of an aquifer to contamination cannot be directly measured; scientists or water-resource managers estimate aquifer susceptibility from information about the various factors that contribute to it. The Wisconsin Department of Natural Resources (1987) developed a statewide map that characterizes groundwater susceptibility across regions with differing geologic and hydrogeologic conditions.

We developed the aquifer-susceptibility map for Calumet County (shown above) to help identify areas that are particularly vulnerable to groundwater contamination in relation to other areas of the county. Local officials, concerned citizens, and other interested parties may make use of the map to inform their discussions about land use, drinking-water quality, and natural resource planning in Calumet County. For example, if a land-use activity that has the potential to release contaminants is proposed within an area of high groundwater susceptibility, a higher level of planning, safeguards, and monitoring may be useful.

We compiled this aquifer-susceptibility map from maps of physical characteristics, or factors, that are intrinsic to the natural groundwater system. Those who make use of the map may decide that other local conditions or features warrant a place in their discussions of a particular site or land-use activity. For example, factors that can be considered on a case-by-case basis include the location of existing contaminant sources, locations of water-supply wells and their wellhead-protection areas, the natural (background) quality of the groundwater, and an existing or planned groundwater-quality-monitoring strategy.

Physical factors, such as geology and depth to the water table, vary from location to location. This regional-scale map cannot capture all of the local variability in the natural system; site-specific conditions may differ from the conditions depicted at the regional scale. This map is intended for use at the scale of publication (1:100,000) and may not be sufficient for use at site-specific scales. An additional caution related to the use of this map is that aquifer susceptibility cannot be directly measured; it is estimated from parameters such as depth to bedrock and depth to groundwater. Therefore, assigning rankings of low, moderate, and high susceptibility is a subjective process and is ultimately a matter of professional judgment. The National Research Council (1993) presented a thorough discussion of issues related to groundwater-susceptibility assessments.

Construction and interpretation of the aquifer-susceptibility map

We constructed an aquifer-susceptibility map for the uppermost aquifers in the county; we did not construct a susceptibility map for the sandstone aquifer because it is well protected from land-use activities by the Maquoketa–Sinnipee aquitard. We considered the sand and gravel aquifer to be the uppermost aquifer where the Silurian dolomite aquifer is absent because most domestic water wells in these areas are completed in sand and gravel seams within the glacial deposits. We considered the Silurian dolomite aquifer the uppermost aquifer everywhere this dolomite is present in the county because most wells in this area are completed in the dolomite. However, in a few areas of the county some domestic wells are completed in glacial deposits overlying the Silurian dolomite (for example, along the North Branch of the Manitowoc River). In these areas, we mapped the susceptibility of the Silurian aquifer, rather than the overlying sand and gravel deposits, because many wells are completed in the dolomite. The extent of each aquifer shown on the susceptibility map is based on our interpretation of available well construction reports and geologic logs and the map of the Silurian aquifer presented by Sherrill (1979).

Susceptibility of the sand and gravel aquifer

We considered two factors in determining the susceptibility of the sand and gravel aquifer to contamination: the type of glacial deposits present (based on mapping by B.J. Socha, 2004, written communication) and the depth to the water table (derived from the water-table map). These factors are significant because fine-grained material (such as silt or clay) at the ground surface tends to reduce and/or slow the transport of contaminants through the subsurface. The depth to the water table is important because the greater the distance from the land surface to the water table, the longer the amount of time available for contaminants to degrade within the unsaturated zone. Areas of this aquifer mapped as having high susceptibility consist of relatively permeable deposits and shallow depths to groundwater. In areas mapped as having low susceptibility, the sand and gravel aquifer lies beneath finer-grained materials and the water table is deeper.

The thickness of the deposits overlying an aquifer is also a factor that affects the rate of contaminant transport to the aquifer. However, in Calumet County, some wells constructed in the sand and gravel aquifer are completed in shallow sand seams and some are completed deeper within the deposits. In making this map, we did not consider the thickness of deposits overlying the sand or gravel because it is specific to each well and could not be mapped reliably for the purposes of this project.

In determining the sand and gravel aquifer susceptibility, we assigned the two factors an equal amount of importance. A grid of 10 meter by 10 meter cells was overlaid on the county map. Each cell was assigned a value of 1 to 5, with 5 being the most vulnerable, for each of the two categories. The values were summed for each cell; the higher scores indicated greater aquifer susceptibility. The edges of the resulting grid of susceptibility rankings were smoothed so that the regions of aquifer susceptibility were mapped at a level of detail similar to the level of accuracy of the inputs to this assessment.

Susceptibility of the Silurian dolomite aquifer

The susceptibility of the Silurian aquifer reflects the potential for rapid contaminant transport from the ground surface to wells through fractures in the dolomite. To construct the map of this aquifer, we considered two factors: the thickness of deposits overlying the Silurian dolomite and the type of glacial deposits overlying the aquifer (mapped by B.J. Socha, 2004, written communication). Areas that have low aquifer susceptibility have a thick layer of fine-grained deposits overlying the Silurian dolomite. Relatively permeable sediments at the ground surface and shallow depths to bedrock characterize areas where the dolomite aquifer is mapped as having high susceptibility. An additional category shown for this aquifer includes areas where the depth to the dolomite is less than 5 feet. In these areas, groundwater in the dolomite aquifer is extremely vulnerable to contamination because little soil or sediment buffers the aquifer from contaminants applied at the ground surface. These areas of shallow bedrock were identified from the SSURGO database of soils information (Natural Resources Conservation Service, 1998–2004).

The depth to groundwater was not considered in constructing the susceptibility of this aquifer because of the extensive fractures present within the Silurian dolomite. Fractures provide a direct and rapid pathway for contaminants to reach saturated bedrock. Natural attenuation of contaminants, which typically occurs in unsaturated materials above the water table, may not take place where fractures provide a pathway for rapid contaminant migration.

In contrast to our determination of the susceptibility of the sand and gravel aquifer, we did not assign equal weight to the two factors considered in determining the susceptibility of the Silurian aquifer. For this aquifer, the thickness of materials overlying the dolomite in each 10 meter by 10 meter cell was given twice as much significance as the type of material overlying it. The thickness of the overlying deposits is a crucial factor in this setting because it provides a buffer between contaminant transport from the ground surface to the very rapid travel times that occur once contamination reaches a fractured rock aquifer. Assigning this factor twice the weight results in a greater extent of the aquifer mapped with higher susceptibility. The type of material overlying the Silurian dolomite does not vary significantly across this region; it is primarily clayey silt or clayey, silty sand. This relative lack of variation suggests that the *type* of surficial material will not result in large spatial variations in the susceptibility of the dolomite aquifer, but the *thickness* of these materials, which does vary significantly across the region, will have a greater impact on aquifer susceptibility.

ACKNOWLEDGMENTS

The Calumet County Board of Supervisors and the Wisconsin Department of Natural Resources Bureau of Drinking Water and Groundwater funded this work. Danielle Cassidy and Kurt K. Zeiler compiled data for the project. Ken Pabich of the Calumet County Land Information Office, Eugene McLeod of Calumet County Land and Water Conservation Department, Kenneth R. Bradbury and John W. Attig of the Wisconsin Geological and Natural History Survey, and Jeffrey Helmuth of the Wisconsin Department of Natural Resources reviewed these maps and text. We thank them for their thorough assessments and suggestions, which helped us to significantly improve these products.

SOURCES OF INFORMATION

Conlon, T.D., 1998, Hydrogeology and simulation of groundwater flow in the sandstone aquifer, northeastern Wisconsin: U.S. Geological Survey Water Resources Investigations Report 97-4096, 60 p.

Dunne, Thomas, and Leopold, L.B., 1978, *Water in Environmental Planning:* W.H. Freeman and Company, 818 p.

Hindall, S.M., and Borman, R.G., 1974, Water resources of Wisconsin, Lower Wisconsin River Basin: U.S. Geological Survey Hydrologic Investigations Atlas HA-479, scale 1:1,000,000.

Krohelski, J.T., 1986, Hydrogeology and ground-water use and quality, Brown County, Wisconsin: Wisconsin Geological and Natural History Survey Information Circular 57, 42 p.

Mudrey, M.G., Jr., Brown, B.A., and Greenberg, J.K., 1982, Bedrock geology map of Wisconsin: Wisconsin Geological and Natural History Survey, scale 1:1,000,000.

Muldoon, M.A., Simo, J.A., and Bradbury, K.R., 2001, Correlation of hydraulic conductivity with stratigraphy in a fractured-dolomite aquifer, northeastern Wisconsin, USA: *Hydrogeology Journal,* v. 9, p. 570–583.

National Research Council, 1993, *Ground water vulnerability assessment, contamination potential under conditions of uncertainty:* National Academy Press, 204 p.

Natural Resources Conservation Service, 1998–2004, Soil Survey Geographic (SSURGO) database for Calumet County: U.S. Department of Agriculture, available online at <http://www.ncgc.nrcs.usda.gov/products/datasets/ssurgo/>.

Ryling, R.W., 1961, A preliminary study of the distribution of saline water in the bedrock aquifers of eastern Wisconsin: Wisconsin Geological and Natural History Survey Information Circular 5, 23 p.

Sherrill, M.G., 1979. Contamination potential in the Silurian dolomite aquifer, eastern Wisconsin: U.S. Geological Survey Water Resources Investigations 78-108, 2 sheets.

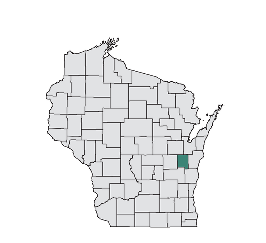
U.S. Geological Survey [1974–84], Digital raster graphics of topographic quadrangles (7.5-minute series), Calumet County, Wisconsin: U.S. Geological Survey, information available online at < http://topomaps.usgs.gov/drg/>.

U.S. Geological Survey, 2004, Ground-water data for Wisconsin: U.S. Geological Survey, available online at <http://wi.waterdata.usgs.gov/nwis/gw>.

U.S. Geological Survey, 2001, National elevation dataset: U.S. Geological Survey, available online at <http://gisdata.usgs.net/ned/>.

Wisconsin Department of Natural Resources, 1987, Groundwater contamination susceptibility in Wisconsin: Wisconsin Department of Natural Resources and Wisconsin Geological and Natural History Survey, scale 1:1,000,000.

Wisconsin Department of Natural Resources, 1936–2003, Well Constructor's Reports.



Published by and available from

UW Extension

Wisconsin Geological and Natural History Survey
3817 Mineral Point Road ◆ Madison, Wisconsin 53705-5100
☎ 608/263.7389 FAX 608/262.8086 www.uwex.edu/wgnhs/
James M. Robertson, *Director and State Geologist*

Digital cartography and editing by K.C. Roushar

Base map constructed from U.S. Geological Survey Digital Line Graph files (1990, scale 1:100,000), modified by Wisconsin Department of Natural Resources (1992) and Wisconsin Geological and Natural History Survey (2005). Wisconsin Transverse Mercator Projection 1991 adjustment to the North American Datum of 1983 (NAD 83/91).