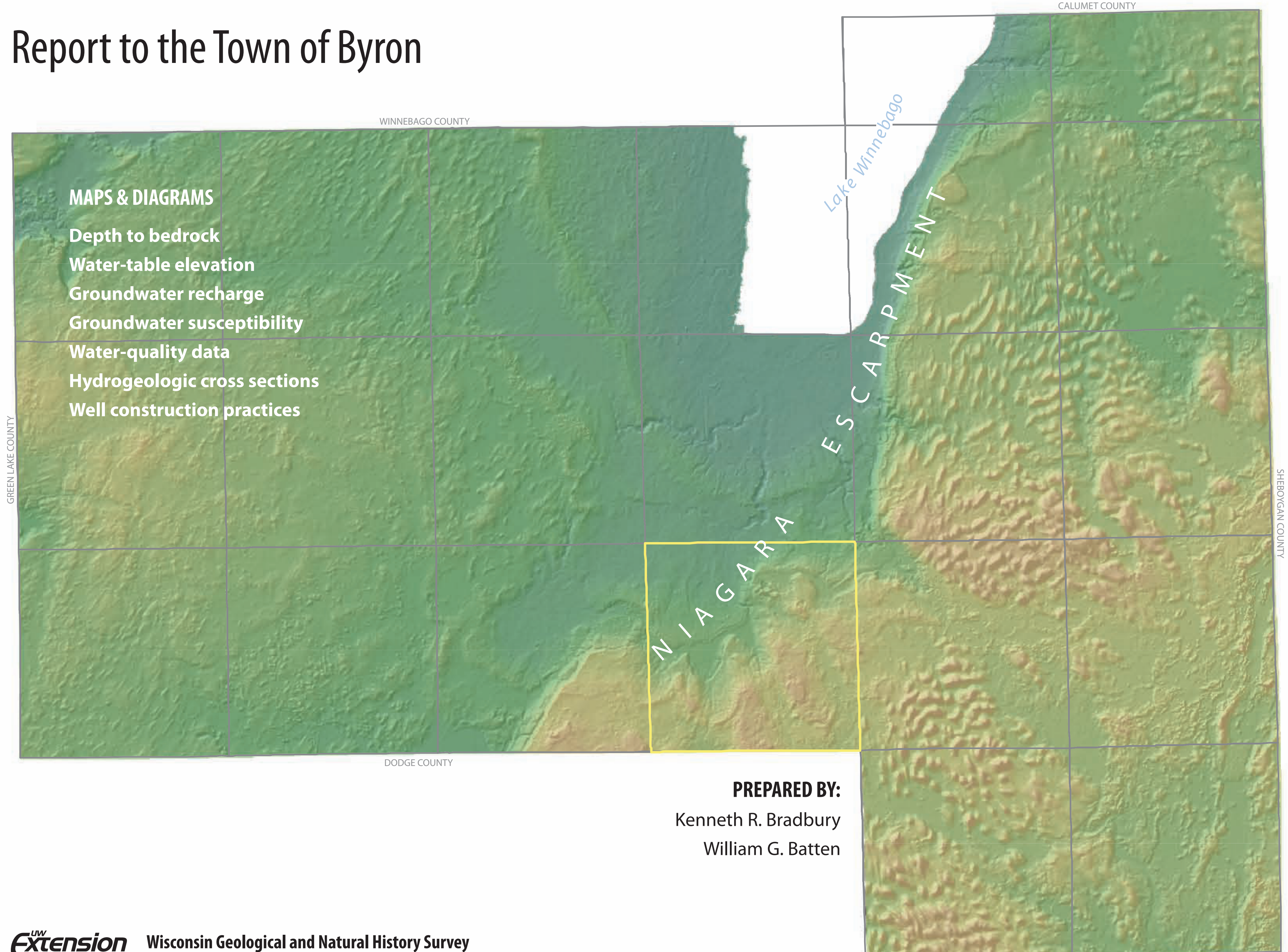
Groundwater susceptibility maps and diagrams for the Town of Byron, Fond du Lac County, Wisconsin

Report to the Town of Byron

MAPS & DIAGRAMS

Depth to bedrock
Water-table elevation
Groundwater recharge
Groundwater susceptibility
Water-quality data
Hydrogeologic cross sections
Well construction practices



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March 2010

Depth to bedrock

What is a depth-to-bedrock map?

This map shows the depth to the top of bedrock in the Town of Byron. It indicates the depth, in feet below land surface, at which solid bedrock is encountered. One can also consider this map as showing the thickness of soil and glacial deposits that overlie the bedrock. Shallow bedrock is a key factor in determining where groundwater is most susceptible to contamination.

How was this map constructed?

The map was constructed by examining the thickness of soil and glacial deposits indicated on about 800 drillers' construction reports for wells drilled in and adjacent to the town. Each of these construction records reports a depth to bedrock at the location where the well was drilled. These depths were plotted on a base map along with information from previous reports and observations of rock outcrops. Using these data, contour lines were constructed showing the depth to bedrock.

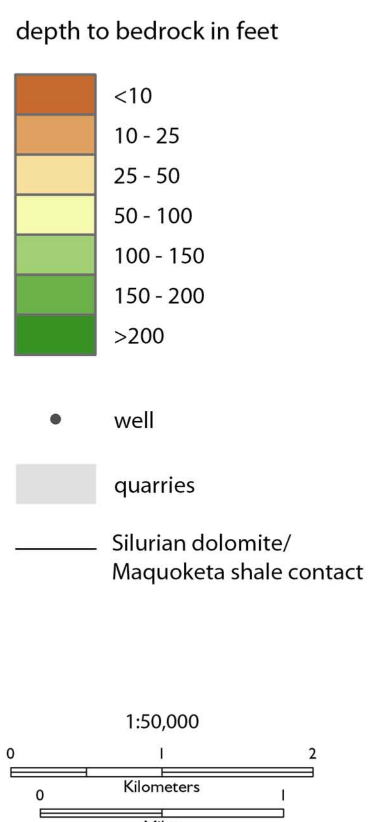
What does the map show?

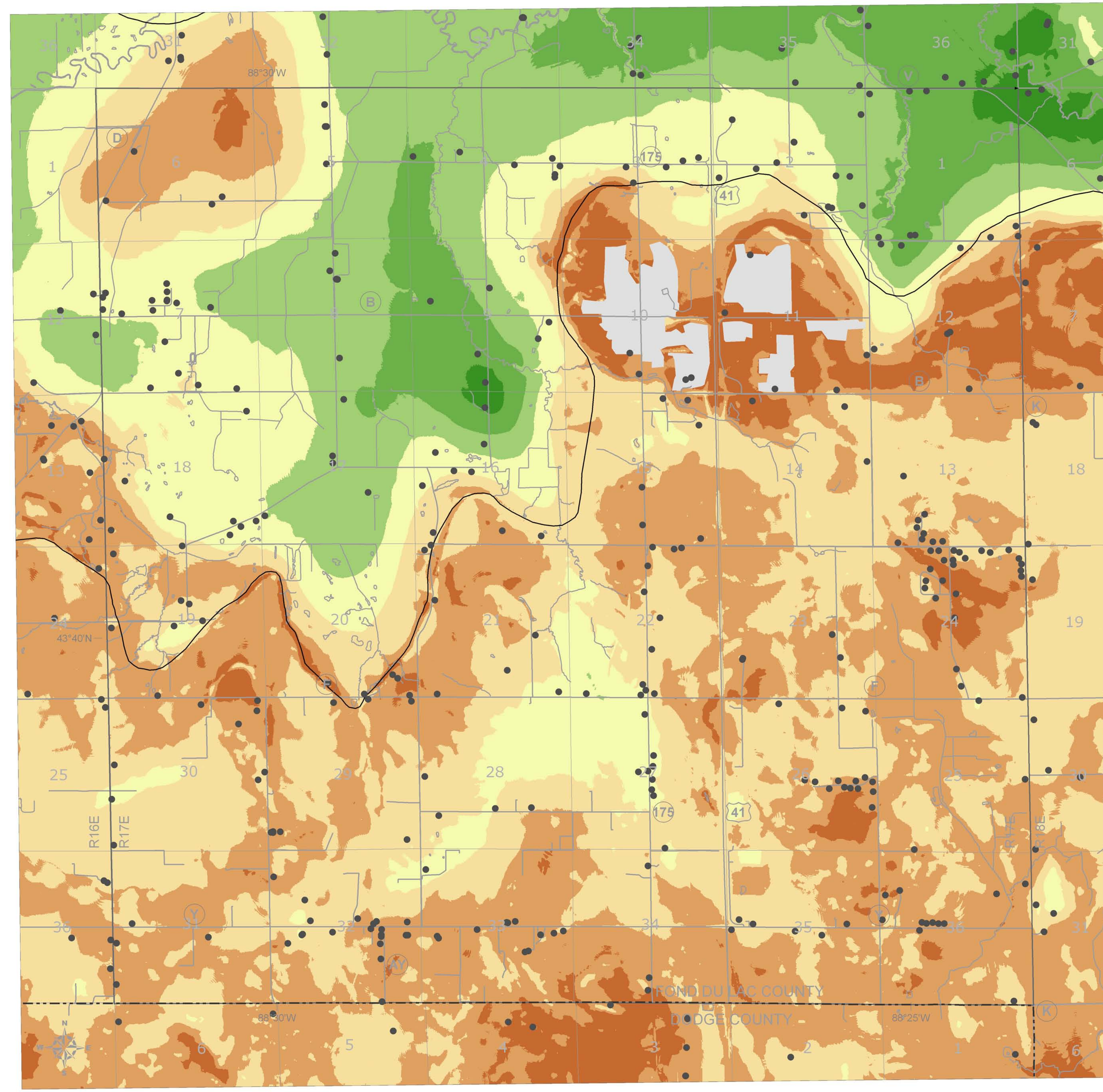
This map shows how far below the soil surface the top of the bedrock is located. Depth to bedrock ranges from 0 to 10 ft in the east-central and southern parts of the town to over 200 ft in some areas in the north-central and extreme northeast. Areas in gray generally depict areas where Silurian dolomite, commonly referred to as the Niagaran limestone, is quarried (note: the words "Silurian" and "Niagaran" are geologic terms referring to the age of this rock). In these areas, the bedrock is at or very near land surface.

Silurian dolomite forms the Niagaran escarpment (locally called the "ledge"), which is the cliff prominent along the east side of Lake Winnebago a few miles north of the Town of Byron. The escarpment extends to the southwest into the Town of Byron, but is not continuous. The escarpment is limited to several cliff segments, up to several tens of feet high, that extends from the northeast to the west-central part of the town. This escarpment marks the northern edge of the Silurian dolomite. The entire thickness of this dolomite, which exceeds 200 ft in the southern part of the town, has been completely eroded away north of the escarpment. This erosion exposes the Maquoketa shale as the uppermost bedrock unit directly underlying glacial deposits in the northern part of the town. The geologic contact between these two bedrock units is shown on the map.

Why is this map important?

The depth to bedrock and the type of bedrock are very important in evaluating groundwater susceptibility. The two bedrock types that directly underlie the land surface in the Town of Byron are Silurian dolomite and Maquoketa shale. The Silurian dolomite is highly fractured and is much more susceptible to groundwater contamination than the shale. Accordingly, areas where the dolomite bedrock is near the surface tend to be much more susceptible to contamination than areas where the bedrock is composed of shale and/or the depth to bedrock is greatest.





What is a water-table map?

This map shows the approximate elevation of the water table in the Town of Byron. The water table represents the top of the saturated zone. Below the water table, all pores, cracks, fissures, and other voids in the subsurface are filled with water. Above the water table these voids are mostly filled with air. The water table is the elevation below which water will freely fill a hole or well. Streams, lakes, and wetlands in the town are places where the water table intersects the land surface.

The water table fluctuates seasonally in response to periods of precipitation, snowmelt, and drought. These fluctuations are greatest where the water table is highest and far from surface water features. In such areas, such as in the south-central part of the town, the water table fluctuates by as much as 10 feet annually. In lowland areas, such as in the northwest part of the town, the water table fluctuates only 2 to 3 feet.

What the map shows

The contour lines on the map represent lines of uniform elevation of the water table, in feet above mean sea level. For instance, at every point along the 1000-foot contour, the water table occurs at 1000 feet above sea level.

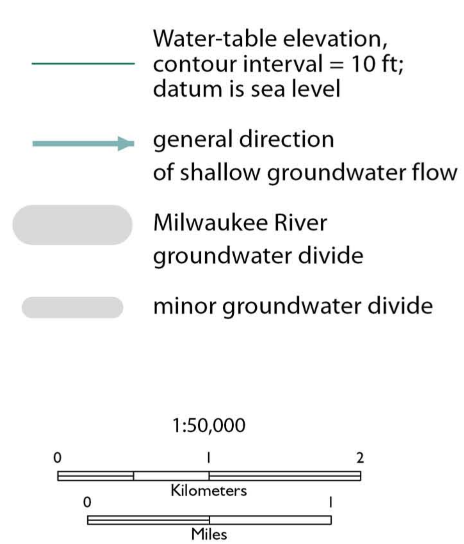
Water-table elevations are lowest (about 820 feet above sea level) along Parsons Creek in the north-central part of the town, and are highest (over 1040 feet above sea level) in the southern part of the town, just east of the Village of Byron. Groundwater moves from higher to lower water-table elevations in directions approximately perpendicular to the water-table contours. Over most of the town, groundwater moves to the north or northwest, discharging to Campground Creek, Parsons Creek, or De Neveu Creek, all tributaries of the Fond du Lac River. In the southeast part of the town groundwater moves to the southeast, into the Milwaukee River watershed. The approximate line along which this flow diverges is called a groundwater divide.

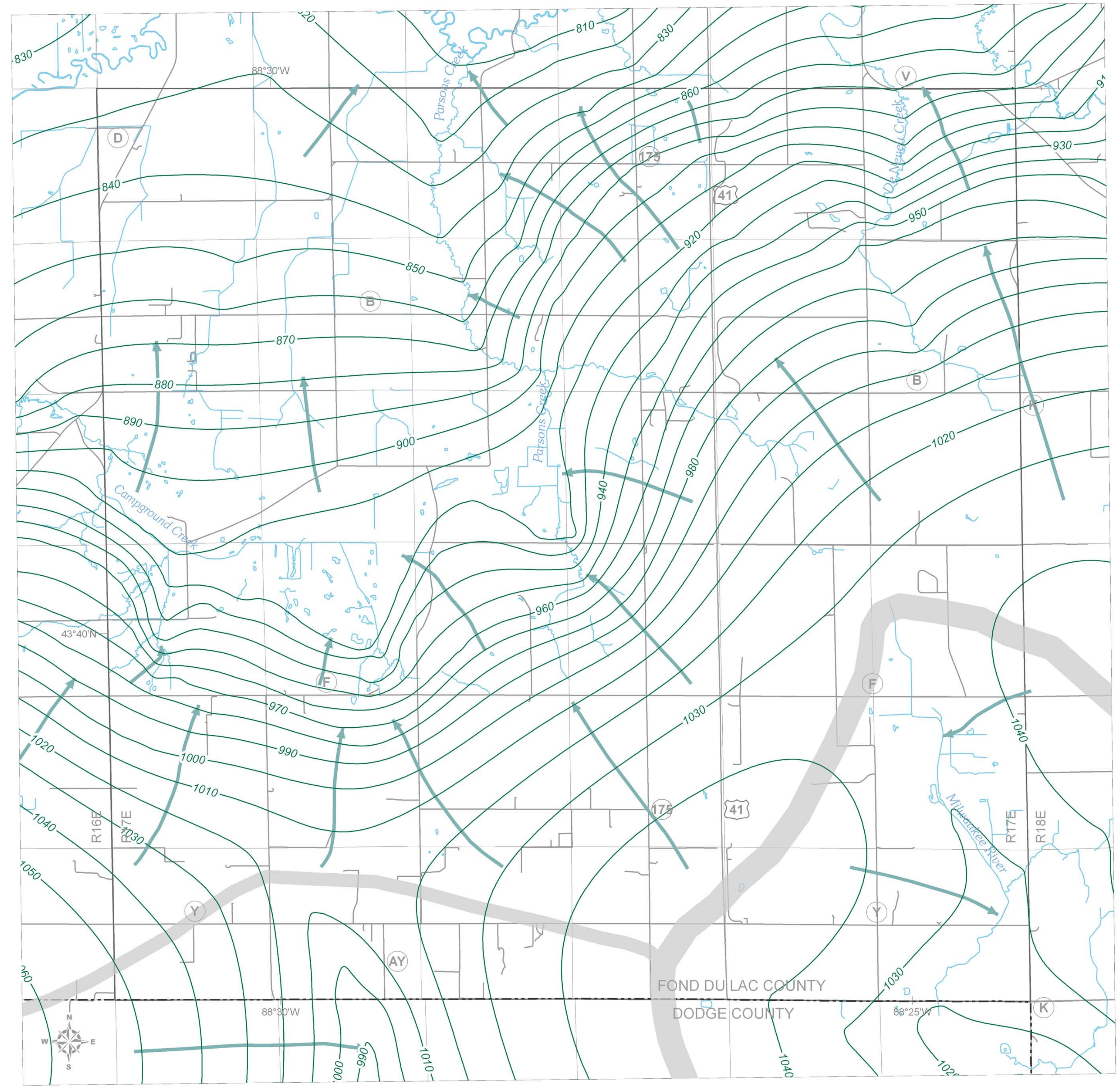
How was this map constructed?

The water-table map shown here was constructed using a computerized groundwater flow model called GFLOW. This model accounts for groundwater recharge, variations in aquifer properties and thickness, and the connections between groundwater and lakes, streams, and springs. The model was adjusted to best match the water-level measurements available and to be consistent with local streamflow measurements collected for this study. Often, a water-table map is constructed by measuring water levels in many shallow wells and then contouring these data points. However, the Town of Byron contains very few shallow wells suitable for this purpose, which is why the model was used. Most wells in the town are drilled and cased many feet below the water table, and water levels in such wells may not represent the water table. Installation of dedicated wells for water-table measurement would be very expensive and was beyond the scope of the current project.

Why is this map important?

The water-table map has many uses. As discussed above, the map can be used to indicate the directions of shallow groundwater flow, because groundwater generally moves perpendicular to the contour lines on the map. By comparing the water-table contours to the elevation of the land surface one can calculate the depth to the water table. Depth to the water table is one component of groundwater susceptibility; shallow groundwater is generally more susceptible to contamination than deep groundwater. In addition, knowing the depth to the saturated zone can be useful in construction activities such as excavations, foundation design, and highway planning.





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Groundwater recharge

What is a recharge map?

This map shows the locations and rates of average groundwater recharge in the Town of Byron. Groundwater recharge is water that has moved from the land surface to the groundwater system; recharge is thus the ultimate source of all groundwater. Understanding recharge and its distribution is important in making informed land-use decisions so that the groundwater needs of people and the environment can be met. The rate of groundwater recharge that occurs varies depending on the physical location and the time of year. Locational variation is due primarily to differences in land use, soils, and topography. Seasonal variation occurs due to variations in climate and precipitation.

What does the map show?

The map shows recharge rates for an average year. Actual recharge rates vary from year to year in response to variations in precipitation, temperature, the timing of snowmelt, and other factors. The map indicates recharge rates using colors ranging from yellow (low recharge) to dark blue (high recharge). Recharge in the Town of Byron varies from as little as 4 inches per year to about 14 inches per year. Average recharge is about 8 inches per year. In general, the highest recharge rates (greater than 10 inches per year) occur in the higher-elevation parts of the town where soils are thin and bedrock is close to the surface. Such areas are generally located in the southern third of the town. Lower recharge rates occur in areas of wetlands, such as the wetlands near Campground Creek, and in regions of clayey soils in the northwest third of the town. Although this map shows recharge for an average year, the pattern of recharge in wetter or dryer years remains similar even though the absolute rates differ.

How was this map constructed?

The map is based on a soil-water balance model that accounts for the various processes that occur when precipitation falls on the landscape. The soil-water balance model considers the following components of the hydrologic system: the amount of water entering the system, how much water falls to the earth as rain or snow, how much evaporates or flows across the land surface, how much plants intercept and use, and how much the soil can hold. The model uses historical measurements for temperature and precipitation. It is then customized using topographic data as well as details about soil type and land-use to plot runoff across the landscape. Based on these data, the model then calculates recharge rates in inches per year, and the different colors on this map illustrate these values.

Limitations of the map

This map is based on available information for the entire Town of Byron, and might not be accurate for site-specific applications. The modeling method used assumes that deep infiltration equals recharge. However, it is possible that in some areas of the town this assumption is violated, and deep infiltration does not reach the groundwater system. For example, water that leaves the soil zone might flow laterally along bedrock fractures to discharge at a cliff face far above the water table; such water would not be considered recharge.

Why is this map important?

Recharge is the ultimate source of all groundwater in the town and is the source of baseflow to streams. Understanding the amount and distribution of groundwater recharge is important in land-use planning. Areas of high recharge tend to be more susceptible to groundwater contamination than areas of lower recharge.

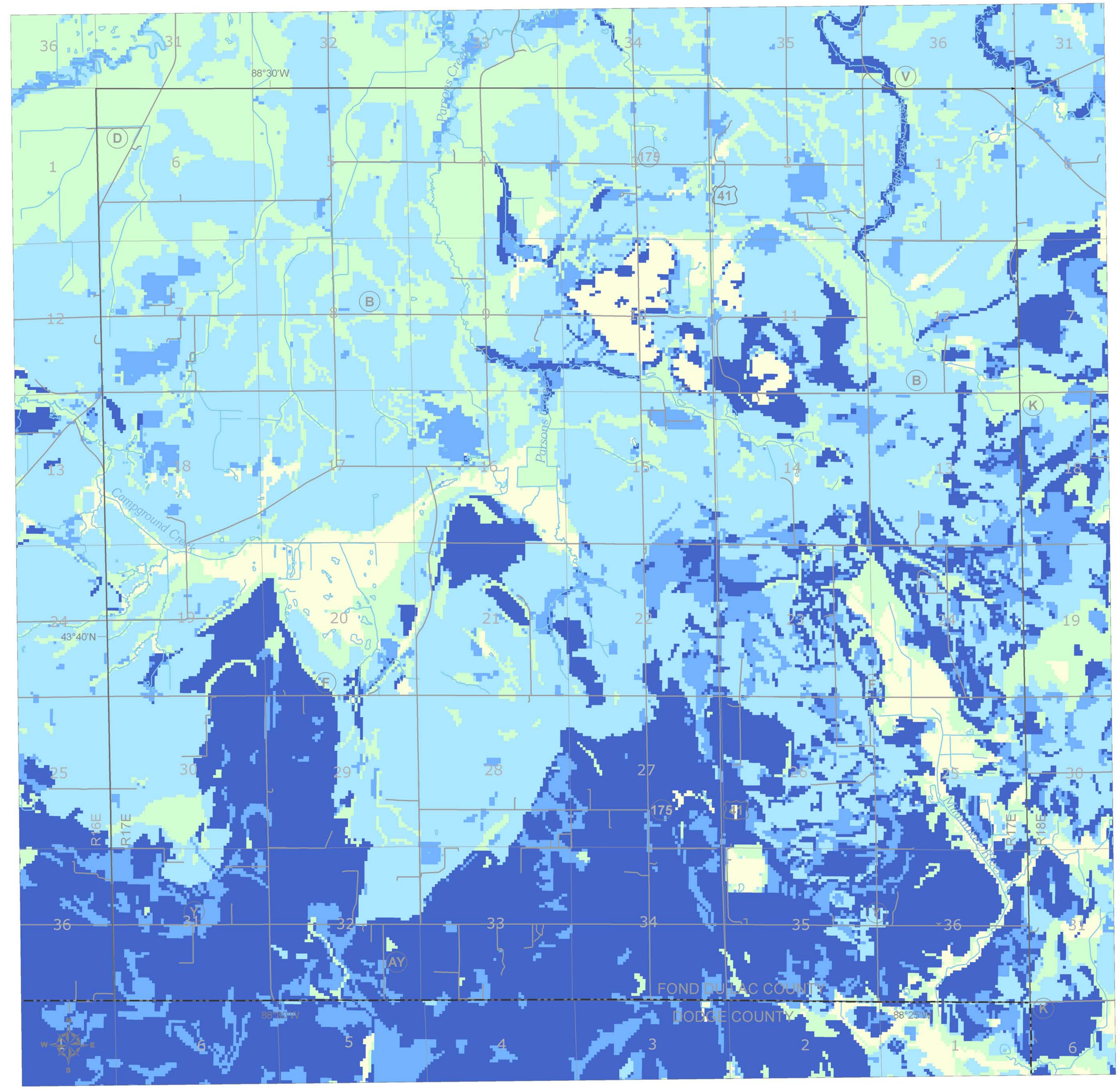
Recharge in inches/year

- <4
- 4 -6
- 6 - 8
- 8 - 10
- >10

1:50,000

0 1 2 Kilometers

0 1 Miles



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Groundwater susceptibility

What is a groundwater susceptibility map?

This map shows the relative susceptibility of different areas of the Town of Byron to groundwater contamination originating from surface or near-surface sources. Such potential sources of contamination include waste disposal, chemical spills, septage or manure spreading, septic systems, leaking under-ground storage tanks, leaking sewers, and fertilizer and pesticide application. The map is simply a depiction of relative risk of contamination, and does not indicate that contamination either has occurred or will occur.

The map indicates relative contamination susceptibility using a three-color system. In areas shaded red, the susceptibility to contamination is highest. In areas shaded green, the susceptibility is lowest. The yellow areas have intermediate susceptibility. The map also shows areas of active rock quarries, which are very susceptible to contamination.

How was this map constructed?

The susceptibility map represents a combination of four environmental or geologic factors known to influence the movement of contaminants to groundwater. These four factors are type of bedrock, depth to bedrock, groundwater recharge rate, and depth to the water table. Each of these factors has been mapped separately for the Town of Byron.

Depth to bedrock – The amount of soil, sand, gravel, and clay overlying bedrock helps slow the downward movement of contaminants and increases the time for contaminant attenuation and breakdown. Areas where bedrock is near the surface are more susceptible than areas where it is deeply buried.

Type of bedrock – Two types of bedrock occur in the Town of Byron. The Silurian dolomite is the gray, fractured limestone that forms the escarpment in the middle of the town and outcrops in cliffs and road cuts. This dolomite contains numerous voids, fractures, and solution cavities through which water (and contaminants) can move very rapidly. This rock is very susceptible to contamination. Maquoketa shale is the uppermost bedrock in the northern part of the town. This formation is far less permeable and fractured than the dolomite, and allows much less water to pass through it. It is rated as least susceptible to contamination.

Depth to the water table – Depth to the water table indicates the thickness of the unsaturated zone, where the pores in rock and soil are partially filled with air. Within this unsaturated zone, biological processes can break down and attenuate contaminants, and thicker unsaturated zones allow more time to pass before contaminants can enter the groundwater system. Accordingly, areas with shallow depths to groundwater are considered more vulnerable than areas with greater depths to groundwater.

Recharge rate – The groundwater recharge rate is the annual rate, expressed as inches per year, of water entering the groundwater system from the surface. In general, areas where more recharge occurs are more susceptible than areas where less recharge occurs.

Overall ranking – The overall ranking is based on a simple addition of ranking scores from each of the four categories. These numerical scores were then grouped into three categories of low, medium, and high susceptibility to contamination.

How should this map be used?

This map is primarily an informational and educational tool to indicate which parts of the Town of Byron are more or less susceptible to groundwater contamination. Decision makers and private land owners can use this map as a guide to the relative risk of locating facilities and for making land-use decisions in various parts of the town. Likewise, the map can be used to help assess the relative risk of contamination from spills or other accidents in different parts of the town. For example, a spill of petroleum products in the red areas of the map is far more likely to contaminate groundwater than a spill occurring in the green areas of the map.

This map should not be used as the sole criterion for making siting or land-use decisions. The map is based on regional data; site-specific decisions should always be made using site-specific information.

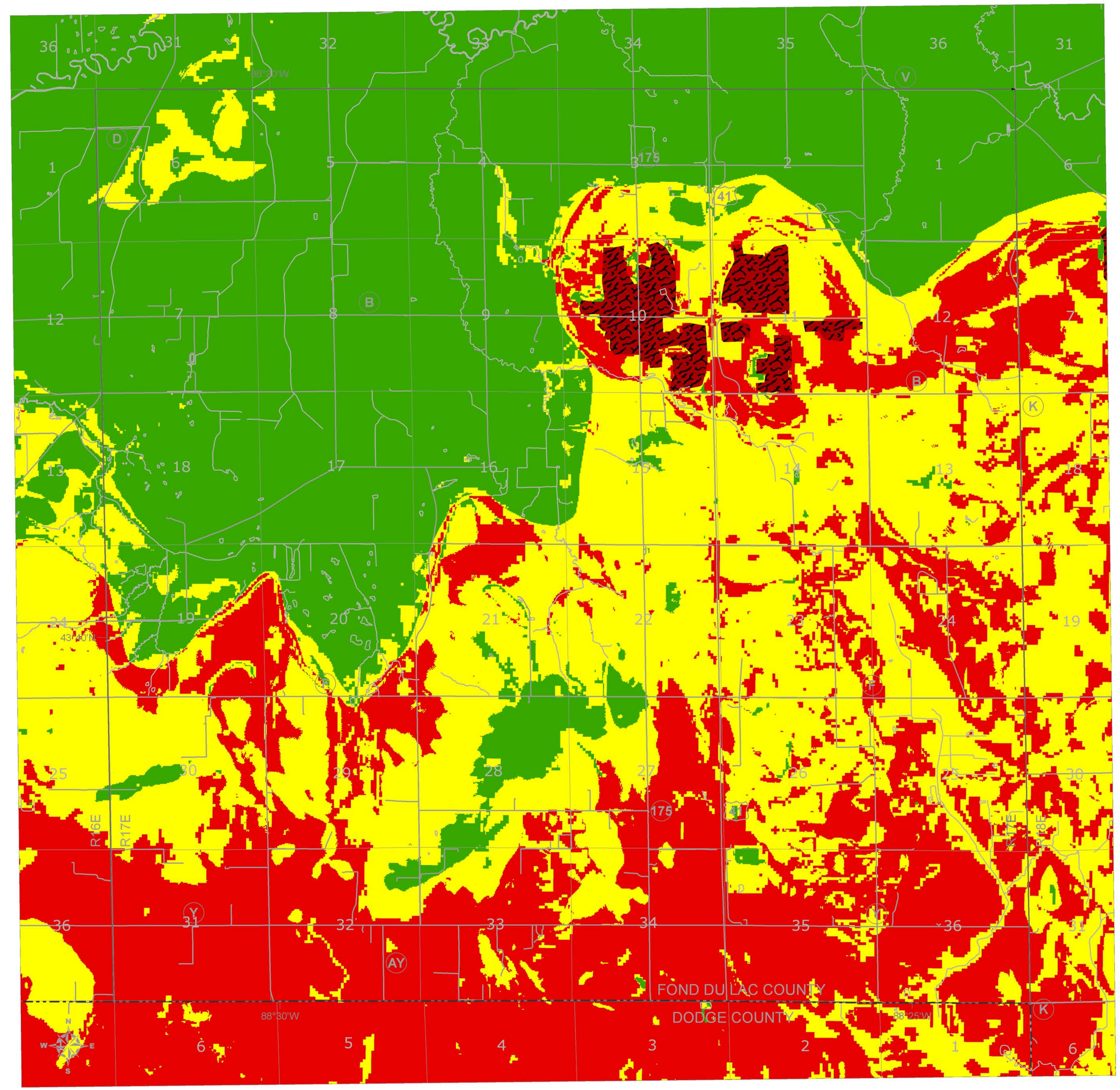
Relative susceptibility

- very high (quarries)
- high
- intermediate
- low

1:50,000

0 1 2 Kilometers

0 1 Miles



Groundwater quality

These maps show the results of past water-quality sampling of private wells in the Town of Byron. Although many different chemical constituents are of interest in assessing drinking-water quality, these maps show results for only nitrate and coliform bacteria, the most commonly tested parameters. Nitrate and coliform bacteria are often called indicator parameters because their presence can indicate contamination of a well from near-surface sources. Colored dots on the maps indicate either the concentration of nitrate-nitrogen or the presence or absence of coliform bacteria.

Nitrate and coliform bacteria both originate at or near the land surface. Nitrate-nitrogen is a major component of lawn and agricultural fertilizers, and is also generated during decomposition of sewage and manure. Coliform bacteria naturally exist in surface water and soil and do not usually cause health problems. However, some bacteria originate from either human or animal feces and their presence in a water sample indicates contamination from one or both sources. Tests for both contaminants are required from new wells or whenever a well is opened for pump or well repair.

Nitrate map

Nitrate analyses are generally reported as the concentration of the nitrogen component of nitrate (NO_3-N) in milligrams per liter (mg/l). The drinking-water standard for nitrate is 10 mg/l. Sample results are indicated by three different colored dots. Green dots indicate nitrate levels of less than 3 mg/l, assumed to be approximately the natural background level of nitrate in Wisconsin groundwater. Yellow dots indicate nitrate levels between 3 and 10 mg/l. These levels are considered elevated above background values but do not exceed the drinking-water standard. Red dots indicate samples exceeding the 10 mg/l drinking-water standard. State and federal laws are not directly enforced on private water systems, but 10 mg/l is recommended as an advisory level for private wells.

Nitrate-contaminated water (higher than 10 mg/l) should never be fed to infants under 6 months of age. In young infants, ingestion of nitrate can reduce the blood's ability to carry oxygen. In severe cases it can cause a condition that doctors call methemoglobinemia. The condition is also called "blue baby syndrome" because the infant's skin turns blue-gray or lavender in color. All infants less than 6 months of age are at risk of nitrate toxicity, but premature babies and babies with other health problems are more sensitive than healthy infants.

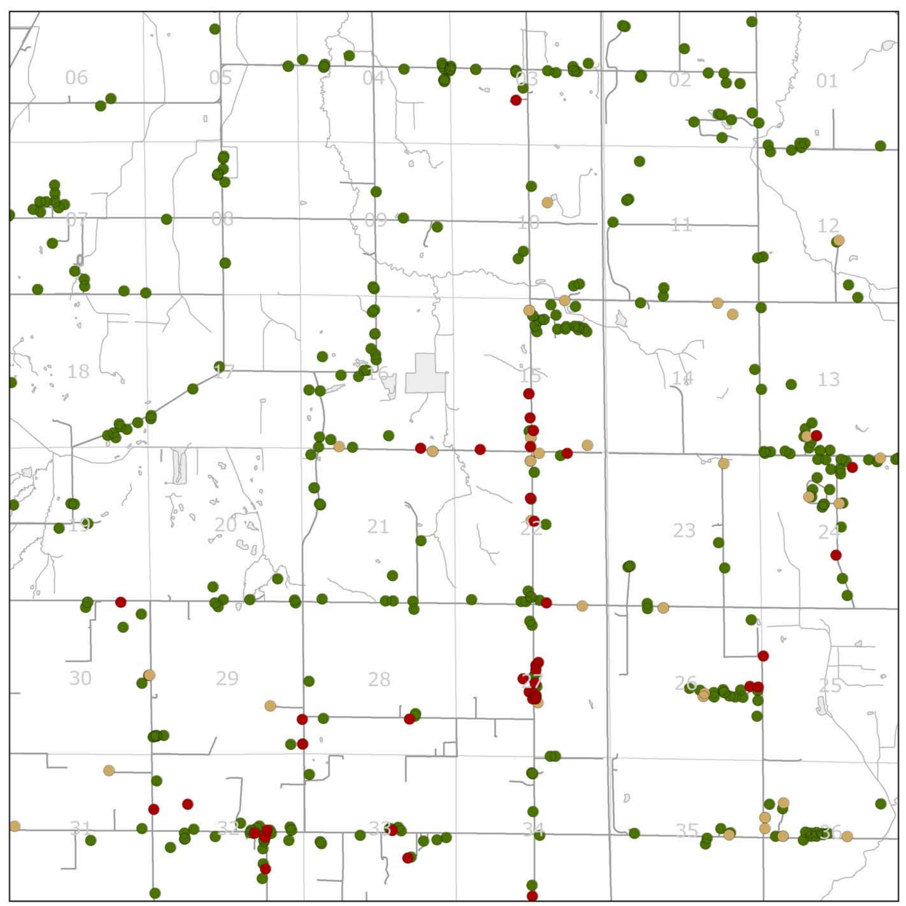
The nitrate map shows that most wells in the Town of Byron have produced water with nitrate-nitrogen concentrations less than 3 mg/l. However, several clusters of wells with a history of higher nitrate levels occur in the southern part of the town. While explaining the causes of nitrate contamination in a specific well is beyond the scope of this study, the clustering of elevated nitrate values suggests that these areas, which generally have shallow soils over fractured bedrock, are very vulnerable to groundwater contamination.

Bacteria map

The bacteria map shows the presence or absence of coliform bacteria in sampled wells. Coliform bacteria are naturally occurring in soil and are found on vegetation and in surface waters. Water from a well that has been properly located and constructed should be free of coliform bacteria. While coliform bacteria do not cause illness in healthy individuals, their presence in well water indicates the water system is at risk to more serious forms of contamination. Green dots on this map represent wells where bacteria were not detected. Red dots indicate wells where bacteria were detected. Water that tests positive for bacteria should not be consumed without boiling or otherwise disinfecting due to the threat of waterborne disease.

Bacteria have been found occasionally in wells from all areas of the Town of Byron. Explaining the cause of bacterial contamination of any specific well is generally not possible. Some of these detections could be false positives caused by failure to sterilize equipment and bottles during sampling. Others could result from problems with the well itself, such as a missing or damaged cap, insects in the well, or improperly sealed casing. All these situations can provide paths for surface bacteria to enter a well. In some situations, however, bacteria can enter the well through the groundwater system. This contamination pathway is most likely where bedrock is fractured and soils are thin, as they are in the southern portion of the town.

Nitrate



1:80,000

0 1 2 Kilometers

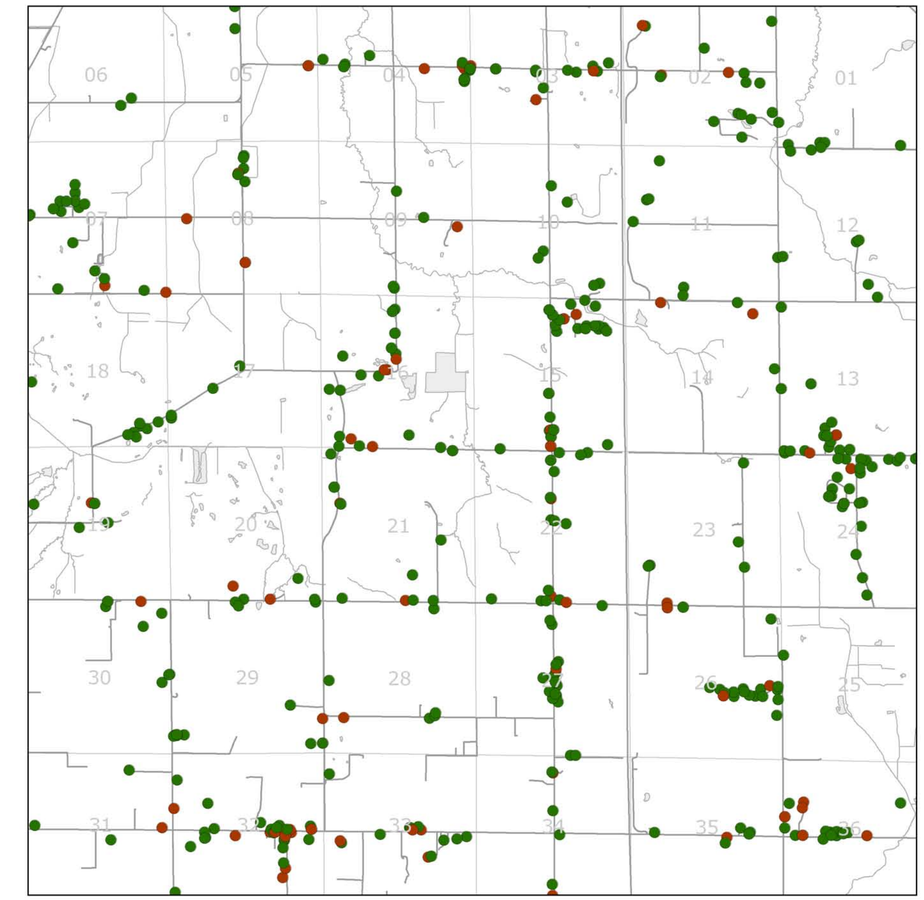
0 1 Miles

Nitrate in sampled wells

maximum in ppm

- >10
- 3 - 10
- <3

Bacteria



1:80,000

0 1 2 Kilometers

0 1 Miles

Bacteria in sampled wells

- not detected
- detected

Where do the sample results come from?

The sample results for these maps come from three sources: Fond du Lac County UW-Extension well testing program, the Fond du Lac County Health Department, and the Wisconsin Department of Natural Resources Ground Water Retrieval Network (http://prodoasext.dnr.wi.gov/inter1/grn$.startup). The data shown on these maps is a compilation of available data collected over several years and not the results of a single survey or sampling program. Some wells were sampled numerous times, and others sampled only once. The sampled wells shown on these maps represent far less than half of the existing wells in the Town. Many wells have no sample data. Only wells with publically-available sample data are plotted on these maps.

Sources of additional information

The following web sites contain additional information about nitrate and bacteria in wells in Wisconsin.

Wisconsin Department of Natural Resources—
Nitrate in drinking water
(www.dnr.state.wi.us/org/water/dwg/Forms/nitrate.pdf);
Bacteriological contamination of drinking water wells
(www.dnr.state.wi.us/org/water/dwg/pubs/BactiInWell.pdf)

Wisconsin State Laboratory of Hygiene—
Test your well water annually
(www.fdlco.wi.gov/Modules/ShowDocument.aspx?documentid=639)

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Hydrogeologic cross sections

What is a hydrogeologic cross section?

A hydrogeologic cross section is a diagram that illustrates the subsurface rock layers as if the earth were cut open and seen from the side and also shows how groundwater flows through these rock layers. The geology is based on interpretation of drillers' descriptions of the rock material in wells along each cross section and on limited rock outcrop information. The movement and direction of groundwater flow is based on water-level data in well-construction reports and the water-bearing properties of each type of rock. The two cross sections shown here extend about 7 miles along the land surface and each extends about 1,000 feet below land surface.

Surficial geology

The uppermost (surficial) material throughout the town is sediment deposited by glacial processes. The sediment in the southern and eastern parts of the town is till, a silty to sandy, somewhat coarse-grained glacial material deposited by glacial ice. These deposits are relatively thin, generally ranging from less than 10 feet to up to about 30 feet thick.

Conversely, much of the glacial material in the low-lying northern parts of the town is composed of fine-grained silt and clay deposited as layers of glacial melt-water lake sediment. Some coarser-grained till deposits are found deeper below the surface. Unlike the southern part of the town, glacial sediments in the lowland areas are quite thick, generally ranging from about 100 feet to over 200 feet in thickness (north end of section A–A').

Bedrock geology

The rocks are described as they appear in the cross-section, from top to bottom (and from youngest to oldest).

Silurian dolomite--Silurian dolomite, ranging from about 150 to 200 feet thick, lies directly below the glacial deposits in the southern and eastern part of the town. This dolomite forms the Niagara Escarpment where it crops out at land surface, and is near land surface throughout much of the town. The Silurian dolomite has been completely eroded away north of the escarpment (A–A') and west of the escarpment (B–B'). This dolomite rock is highly fractured both vertically and along horizontal bedding planes. It forms an important but vulnerable shallow aquifer in the Town of Byron.

Maquoketa shale--Maquoketa shale lies directly under glacial deposits where the Silurian dolomite has been completely eroded away in the northern part of section A–A' and on the western half of section B–B'. The shale is about 225 to 250 feet thick where it is directly below the Silurian dolomite. The upper part of the Maquoketa shale also has been eroded where it directly underlies the glacial deposits in the northern part of the town.

Sinnipee dolomite--The deeper bedrock layers shown on the cross sections play a lesser role in the aquifer susceptibility and hydrogeology of the town. Immediately underlying the Maquoketa shale is the Sinnipee dolomite. This dolomite unit is generally about 200 to 250 feet thick throughout the town. Unlike the highly fractured Silurian dolomite, the Sinnipee dolomite, where it is overlain by the Maquoketa shale, contains very few fractures.

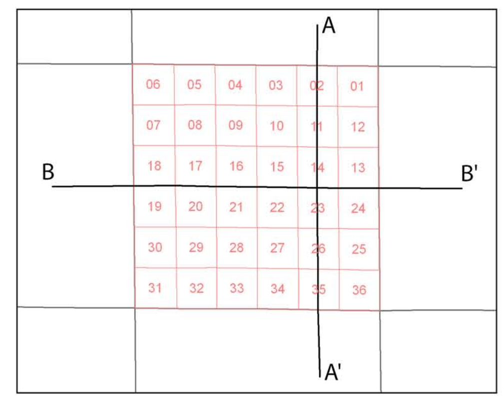
St. Peter sandstone--The St. Peter sandstone directly underlies the Sinnipee dolomite. Thickness of the St. Peter sandstone ranges from about 125 to 200 feet in the Town of Byron. The St. Peter sandstone is an important aquifer for the town. Since the early 1990s, drillers have completed many wells in this sandstone to avoid the contamination issues of wells completed in the Silurian dolomite.

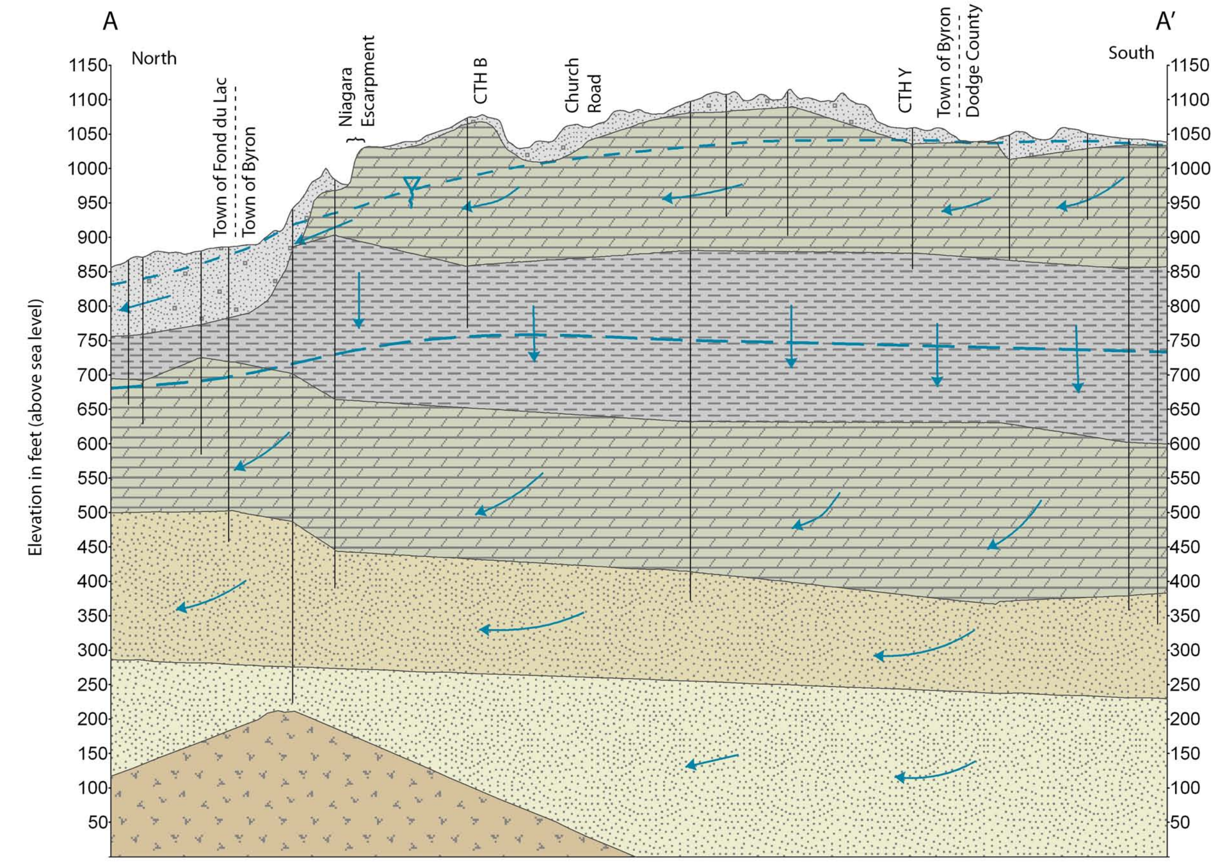
Cambrian sandstones--A series of several Cambrian-age sandstone units underlies the St. Peter sandstone. In the Town of Byron, the composite thickness of these units ranges from none to more than 500 feet. Public-supply wells for the nearby City of Fond du Lac and the Villages of Oakfield, Brownsville, and Lomira all obtain large quantities of water from these deep sandstone units. However, no wells in the Town of Byron have been drilled to obtain water from these rocks.

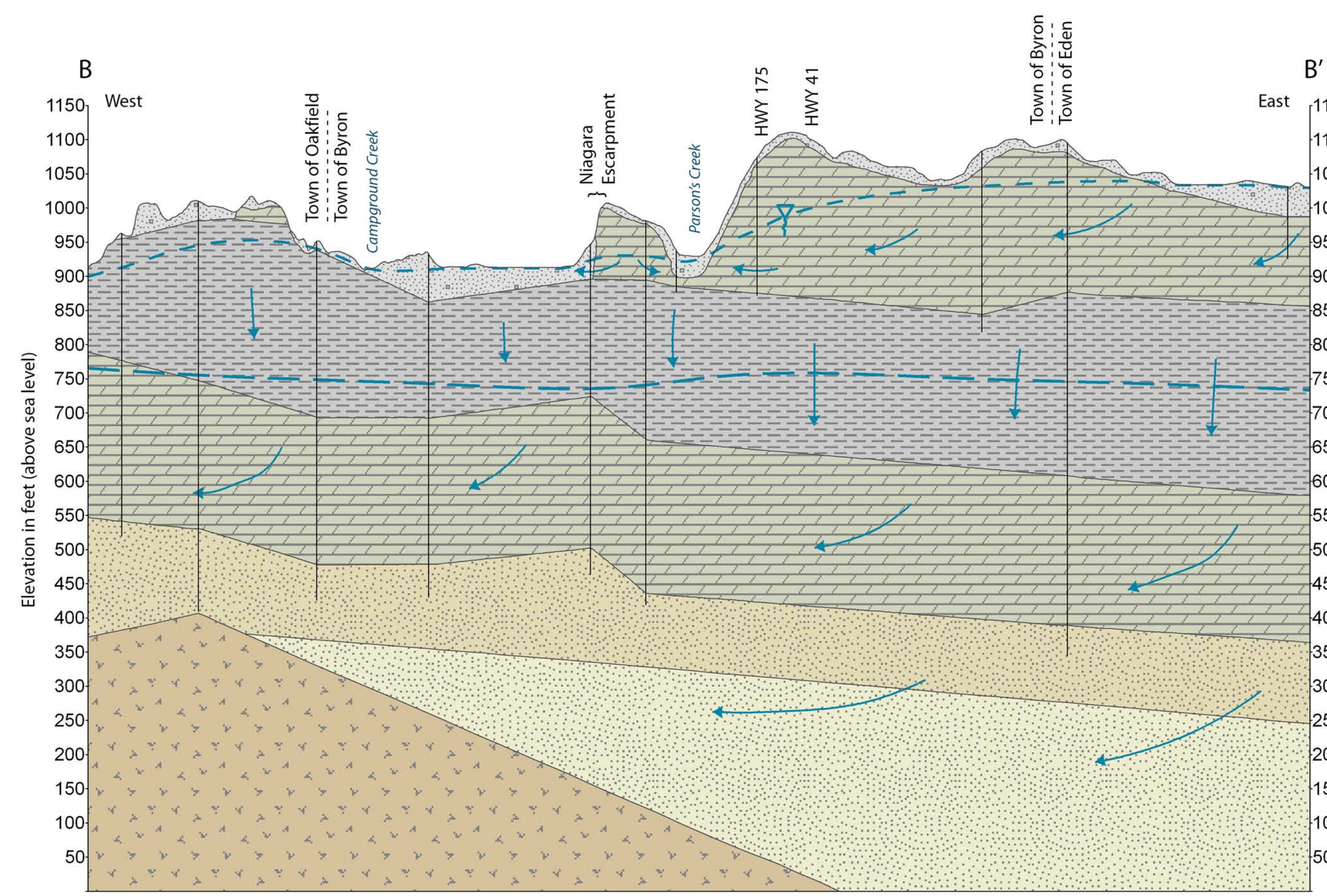
Precambrian crystalline rocks--Underlying these layered bedrock units are dense crystalline granite, quartzite, and rhyolite rocks of Precambrian age. The surface of these rocks appears to be uneven, and is within 500 to 600 feet of land surface in the northeastern and western part of the town. Crystalline granitic rock was encountered in a well at a depth of over 1200 feet in the Village of Lomira several miles south of the town. Based on historical data collected in southern and eastern Wisconsin, these crystalline rocks contain little or no water, and form the base of the groundwater system in the area.

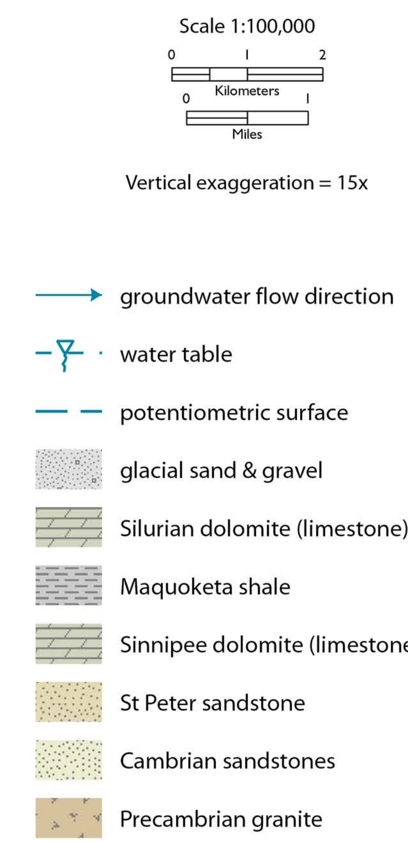
Groundwater movement

The two sections also show profiles of the water table and the potentiometric surface of the deeper sandstones. The water table represents the top of the saturated zone. Below the water table all pores and cracks in the rock are filled with water. The potentiometric surface represents the pressure of water in the deeper aquifers, and is the approximate level at which water will stand in deeply cased wells. Arrows on the cross sections indicate the approximate directions of groundwater flow. Groundwater tends to flow mostly horizontally through aquifers such as the Silurian dolomite and mostly vertically through aquitards like the Maquoketa shale.









Well construction in the southern part of the Town of Byron

Why discuss well construction?

When contaminants such as coliform bacteria and high concentrations of nitrate are found in well water, they are an indication that water originating at or near land surface is entering a well. These contaminants are not found in natural groundwater at depths from which wells typically obtain water. Bacteria and nitrate are being found in many wells in the Town of Byron. Well construction practices can influence the likelihood of this contamination.

Typical older well construction

The well on the left side of the schematic shows the basic features of "typical" (older) shallow rural domestic wells in the southern part of the town. The vast majority of wells drilled 20 or more years ago were constructed in this way, and some are still constructed in a similar fashion today. The construction procedure consisted of drilling a 10-inch diameter hole a short distance into the dolomite and installing continuous 6-inch diameter steel casing to the bottom of this 10-inch hole. The space between the 6-inch casing and the 10-inch hole was then back-filled with a mixture of drill cuttings and drilling mud called puddled clay. This puddled clay was intended to seal the space between the casing and the 10-inch hole. An open 6-inch diameter borehole was then drilled out below the bottom of the casing until the driller decided enough water was flowing into the well from fracture openings in the surrounding dolomite bedrock.

These older wells are generally 100 to 200 feet deep, but construction varies from well to well. First, the casing in these wells can extend from as little as a few feet to many tens of feet into the dolomite. Secondly, the length of open hole in the rock below the casing can vary from as little as 20 feet to more than 100 feet. The casing depths and the amount of open hole in these "typical" wells were and still are determined by the driller's experience drilling in the area and by conditions encountered while drilling.

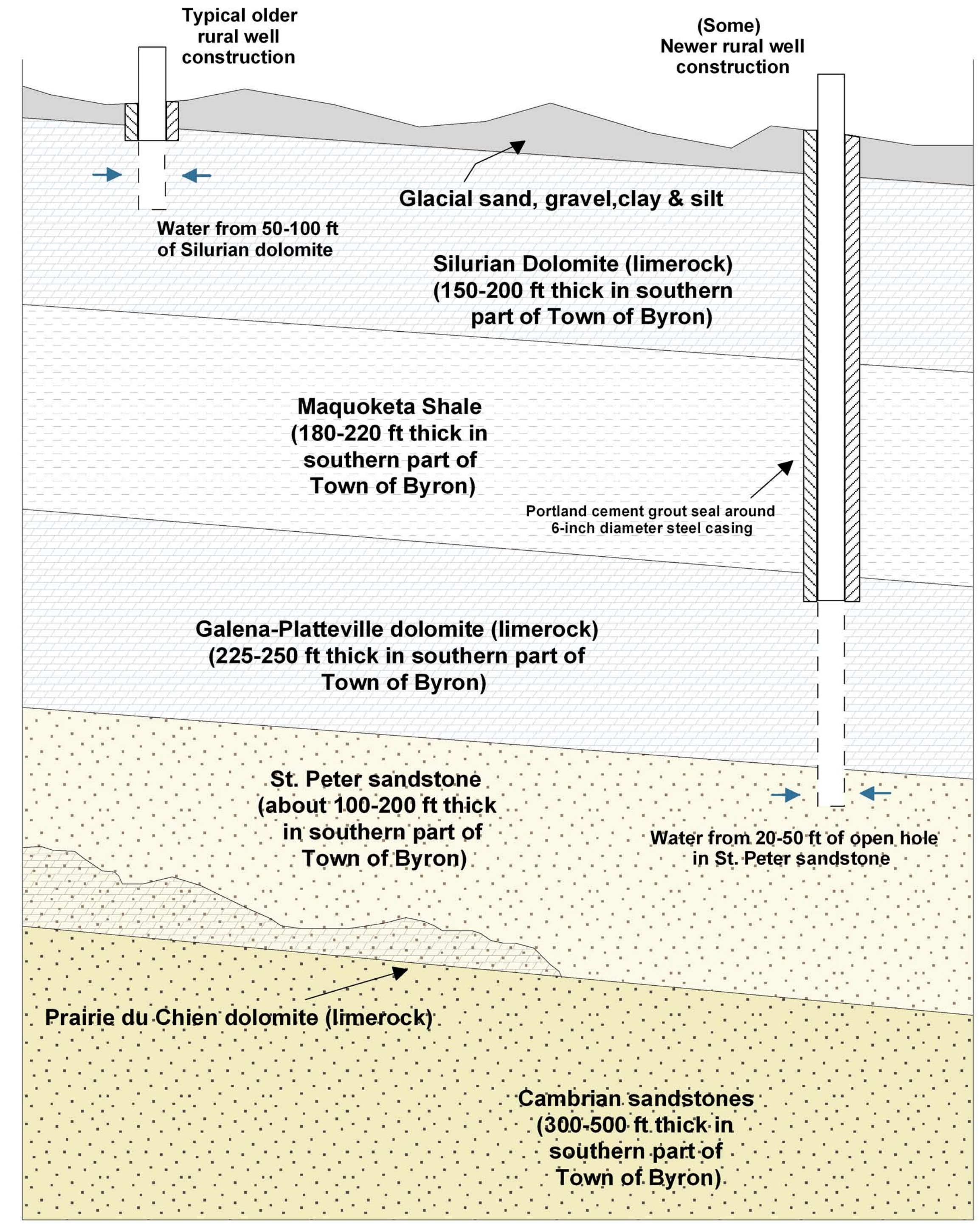
Newer well construction

A major change in the construction of many wells took place in the early 1990s in response to improved drilling methods and changes in state well codes. The well shown on the right side of the schematic is typical of about 40 percent of the domestic wells drilled in the town since about 1990. While drilling procedures are much the same as for the older wells, the depth of these new wells ranges from about 575 to 650 feet and casing depths often extends more than 400 feet below land surface. These deep wells obtain water from a bedrock aquifer called the St. Peter sandstone. The top of this bedrock unit is more than 600 feet below land surface in the southern part of the town. The continuous steel casing in these deep wells extends through both the Silurian dolomite and over 200 feet of the underlying Maquoketa shale. Thus, water cannot enter from the Silurian dolomite and the low permeability of this shale significantly impedes potentially contaminated groundwater in the shallow Silurian dolomite from reaching underlying bedrock aquifers. The Galena-Platteville dolomite, which is directly below the Maquoketa shale in the southern part of the town, does not produce an adequate supply of water for wells. For this reason, the open borehole must be extended through over 200 feet of this dolomite unit to reach the St. Peter sandstone. Wells can obtain adequate water from the upper 50 feet of the St. Peter sandstone aquifer.

Discussion

Most wells drilled more than 25 years ago in the southern part of the Town of Byron were open just to the upper part of the fractured Silurian dolomite which is very susceptible to contamination. Furthermore, the puddled-clay grout used at that time did not provide a particularly effective barrier to contaminated water at land surface moving downward along the outside of the casing into the open borehole. It should be noted that over half of the wells drilled since about 1990 still are completed in the Silurian dolomite in the southern part of the town. However, there are two differences between these newer wells and the old wells. First, newer Silurian wells are generally cased to over 100 feet below land surface, a depth much greater than most of the older wells. Also, the grout used to seal around the casing of new wells is a slurry of Portland cement and water which provides an improved barrier to water movement down the outside of the casing. Unfortunately, some fractures in the Silurian dolomite are interconnected to depths that intersect the open borehole below the casing. Therefore, new Silurian dolomite wells are still somewhat susceptible to contamination.

The new deep wells finished in the St. Peter sandstone are, by virtue of their construction, far less vulnerable to contamination than the wells finished in the Silurian dolomite, particularly in areas of high groundwater susceptibility. The disadvantages are that these wells are more expensive, being over 600 feet deep and often requiring over 400 feet of casing. Also, non-pumping water levels in these deep wells are over 300 feet below land surface which requires additional discharge pipe and larger horsepower well pumps. This results in a substantial increase in the cost of well construction. The choice of well construction is ultimately up to the well owner.



Groundwater Susceptibility of the Town of Byron, Fond du Lac County, Wisconsin

Letter Report to the Town of Byron

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March, 2010

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Summary

This report and accompanying maps provide residents and local officials with basic information about groundwater and geologic conditions in the Town of Byron, Fond du Lac County, Wisconsin. This information is intended to be both educational and a basic reference for discussing and making land-use decisions. The primary motivation for this cooperative project between the Town of Byron and the Wisconsin Geological and Natural History Survey was concern over the susceptibility of groundwater in the town to contamination and the quality and safety of drinking water from local wells. The Town of Byron is located in an area of eastern Wisconsin where natural groundwater conditions and shallow, fractured, dolomite bedrock create a somewhat high incidence of elevated nitrate concentrations and the presence of bacteria in rural drinking-water wells.

The main product of this study is a series of resource maps depicting geologic and groundwater conditions in the town. These maps use information summarized from over 800 water wells in the town and surrounding area. Soil and glacial sediment thickness were compiled to create a depth-to-bedrock map, an important tool in determining groundwater susceptibility. A water-table map was constructed using a computer model and surface-water data. This map can be used to indicate the directions of groundwater movement and depth to the water table. A map of relative groundwater recharge rates is based on precipitation, soil, land-cover, and topographic information. Combining the depth-to-bedrock, water-table, and recharge maps produced a map of relative susceptibility to groundwater contamination.

In addition to the maps described above, geologic cross sections illustrate general subsurface geology and groundwater movement, a map shows locations and results of nitrate and bacteria analyses, and a schematic diagram compares two types of well construction with respect to contamination potential.

Parts of the Town of Byron are very susceptible to groundwater contamination from surface sources. The most susceptible areas occur in the southern quarter of the town, where bedrock is shallow and the water table is high. Areas with low or moderate susceptibility occur in the north and northwest parts of the town, north of the Silurian escarpment, where soils are thick and clayey. Other smaller areas of higher and lower susceptibility occur through the town, as indicated by the susceptibility map.

Proper well construction practices are important for the protection of individual wells from contamination. Shallow wells finished and cased into the upper dolomite are most susceptible to contamination because contaminants can move rapidly through cracks and fractures in the rock to enter the well. Wells drilled and cased into the underlying sandstone aquifer are much less vulnerable to contamination, but are more expensive to construct. Deep wells with short casings should be avoided because these wells provide a potential pathway for contaminants to move from the shallow bedrock to the deep aquifers.

Introduction

Background

This project compiled and analyzed existing groundwater and other information to develop a groundwater susceptibility analysis for the Town of Byron in Fond du Lac County, Wisconsin. The town is located on the edge of the Niagara Escarpment (locally called the "ledge") and the southeastern two-thirds of the town are underlain by fractured dolomite of Silurian age. The dolomite forms an important local aquifer, or water-bearing unit, that provides water for domestic wells in the town. Due to its fractured nature and generally thin soil cover, the dolomite is very susceptible to groundwater contamination and there have been numerous reports of impaired water quality in local wells, with elevated nitrate and bacteria levels being the most common problem. At least one large confined animal feeding operation (CAFO) has been proposed for the town, and local decision-makers need an improved information base for making land-use decisions.

This project was designed to provide baseline groundwater information for the town. It utilized existing records and previously unpublished information combined with a geographic information system (GIS) database and computer modeling. The study area was confined to the 36-square-mile legal township, but most mapping extended 1 to 2 miles outside the town boundaries to account for conditions along the boundaries. The project was based mainly on the analysis of data from over 800 existing water wells in the town. The investigators also made several site visits to evaluate rock outcrops and to measure base flow in local streams.
All deliverable products of this study (described below) are provided to the town both as hard-copy printed maps and as digital files. Work for this project was conducted during 2009 and 2010.

Acknowledgments

The Town of Byron funded this work through a contractual arrangement with the Wisconsin Geological and Natural History Survey (WGNHS), a unit of the University of Wisconsin–Extension. The WGNHS contributed in-kind services, including staff time, to this project. We thank Mr. Francis Ferguson, Town Board Chair, for facilitating this project, and also thank Wendy Geise and the staff at Fond du Lac County for their assistance. Steve Mauel, Kathy Campbell Roushar, Peter Schoephoester, and Linda Deith provided important assistance with graphics, data management, and editing.

Project deliverables

The primary results of this project are a series of resource maps of the town showing information about geology and the susceptibility of groundwater to contamination. These maps were compiled at a scale of 1:24 000 (1 inch to the mile), and are more accurate than previously-available geologic maps for the town. All maps and datasets will be made available in digital form for use in Geographic Information System (GIS) applications.   These maps include the following:

- Depth to bedrock
- Elevation of the water table
- Relative groundwater recharge potential
- Susceptibility to contamination
- Summary of groundwater quality

In addition, the deliverables include two diagrams:

- Hydrogeologic cross sections
- Description of well construction practices

For ease of use, each of these maps and diagrams has been laid out on a single sheet of paper with map information on the right and a written description of the map on the left. This report also describes the maps and diagrams, and in general repeats the text used on the maps, but includes additional details of map construction and references to other materials.

Maps and descriptions

Depth-to-bedrock map

What is a depth-to-bedrock map?

This map shows the depth to the top of bedrock in the Town of Byron. It indicates the depth, in feet below land surface, at which solid bedrock is encountered. Shallow bedrock is a key factor in determining where groundwater is most susceptible to contamination. One can also consider this map as showing the thickness of soil and glacial deposits that overlie the bedrock.

How was this map constructed?

The map was constructed by examining the thickness of soil and glacial deposits indicated on about 800 drillers' construction reports for wells drilled in and adjacent to the town. Each of these construction records reports a depth to bedrock at the location where the well was drilled. These depths are plotted on a base map along with information from previous reports and observations of rock outcrops in the town. Using these data, contour lines were constructed showing the depth to bedrock.

What does the map show?

The depth to the top of bedrock map shows zones of equal depth to the top of bedrock. Depth to bedrock ranges from 0 to 10 ft in the east-central and southern parts of the town to over 200 ft in some areas in the north-central and extreme northeast. Areas in gray generally depict areas where Silurian dolomite, commonly referred to as the Niagaran limestone, is quarried (note; the words Silurian and Niagaran are geologic terms referring to the age of this rock unit). In these areas, this bedrock unit is at or very near land surface. This bedrock unit forms the Niagaran escarpment (locally called the "ledge"), which is the cliff prominent along the east side of Lake Winnebago a few miles north of the Town of Byron. The escarpment extends to the southwest into the Town of Byron, but is not continuous. The escarpment is limited to several cliff segments, up to several tens of feet high, in parts of sections 2, 3, 9, 10, 11, 12, 16, 19, 20, and

21 in the town. This escarpment marks the northern edge of the Silurian dolomite. The entire thickness of this dolomite, which exceeds 200 ft in the southern part of the town, has been completely eroded away north of the escarpment. This erosion exposes the Maquoketa shale as the uppermost bedrock unit directly underlying glacial deposits in the northern part of the town. The geologic contact between these two bedrock units is shown on the map. This layered relationship also is shown on the two geologic cross sections on the cross section diagram.

Why is this map important?

The depth to bedrock and the type of bedrock are very important in evaluating groundwater susceptibility. The two bedrock types that directly underlie the land surface in the Town of Byron are the Silurian dolomite and the Maquoketa shale. The Silurian dolomite is highly fractured and is much more susceptible to groundwater contamination than the shale. Accordingly, areas of near-surface dolomite bedrock tend to be much more susceptible to contamination than areas where the bedrock is composed of shale and/or the depth to bedrock is greatest.

What types of bedrock occur in the town?

As discussed earlier, Silurian dolomite is the uppermost bedrock unit in the southern two thirds of the town. This dolomite tends to be highly broken up by vertical fractures. Rain water, which is slightly acidic, infiltrates the soil and glacial deposits, and further dissolves the dolomite rock along these fractures and also along the bedding-plane openings of the dolomite. These fractures and bedding-plane openings are readily visible along the faces of quarry walls in the area. These openings act as open conduits for water infiltrating the land surface to move rapidly into the bedrock. In addition, this dolomite rock is overlain by thin (less than 25 ft thick) deposits of somewhat coarse-grained, sandy, glacial deposits in large portions of the southern half to two-thirds of the Town of Byron.

The second type of bedrock, the Maquoketa shale, directly underlies glacial deposits in the northern-most quarter to one third of the town. Shale is a rock made up of very fine-grained, compacted, clay particles that allows only very small amounts of water to move through it. Such geologic units that limit water movement through them are referred to as *aquitards*. The Maquoketa shale is one of the best aquitards found in Wisconsin. Furthermore, the shale in the northern part of the town is overlain by 100 ft or more of glacial material. Unlike the somewhat sandy glacial deposits in the southern part of the town, the deposits in the low area of the northern part of the town are generally fine-grained lake-bottom silt and clay. These sediments were deposited in the lowlands of central Fond du Lac County by glacial melt-water lakes about 15,000 to 20,000 years ago. As a result, these two geologic units, the glacial lake clays and the shale, provide a strong barrier to the movement of groundwater in bedrock units below them.

Water-table map

What is a water-table map?

The water-table map shows the approximate elevation of the water table in the Town of Byron. The water table represents the top of the saturated zone. Below the water table, all pores, cracks, fissures, and other voids in the subsurface are filled with water. Above the water table, these voids are mostly filled with air. The water table is the elevation below which water will freely fill a hole or well. Streams, lakes, and wetlands in the town are places where the water table intersects the land surface.

The water table fluctuates seasonally in response to periods of precipitation, snowmelt, and drought. These fluctuations are greatest where the water table is highest and far from surface water features. In such areas, such as in the south-central part of the town, the water table fluctuates by as much as 10 feet annually. In lowland areas, such as in the northwest part of the town, the water table fluctuates only 2 or 3 feet.

What the map shows

The contour lines on the map represent lines of uniform elevation of the water table, in feet above mean sea level. For instance, at every point along the 1000-ft contour, the water table occurs at 1000 feet above sea level.

Water-table elevations are lowest (about 820 feet above sea level) along Parsons Creek in the north-central part of the town, and are highest (over 1040 feet above sea level) in the southern part of the town, just east of the Village of Byron. Groundwater moves from higher to lower water-table elevations in directions approximately perpendicular to the water-table contours. Over most of the town, groundwater moves to the north or northwest, discharging to Campground Creek, Parsons Creek, or De Neveu Creek, all tributaries of the Fond du Lac River. In the southeast part of the town, groundwater moves to the southeast, into the Milwaukee River watershed. The approximate line along which this flow diverges is called a groundwater divide.

How this map was constructed

The water-table map was constructed using a computerized groundwater flow model called GFLOW (Haitjema, 1995). This model simulates groundwater flow using a series of mathematical equations. This model accounts for groundwater recharge, variations in aquifer properties and thickness, and the connections between groundwater and lakes, streams, and springs. The model was adjusted to best match the water-level measurements available and to be consistent with local streamflow measurements collected for this study. Often, a water-table map is constructed by measuring water levels in many shallow wells and then contouring these data points. However, the Town of Byron contains very few shallow wells suitable for this purpose, which is why the model was used. Most wells in the town are drilled and cased many feet below the water table, and water levels in such wells may not represent the water table. Installation of dedicated wells for water-table measurement would be very expensive and was beyond the scope of the current project.

Groundwater Recharge Map

What is a recharge map?

The recharge map shows the locations and rates of average groundwater recharge in the Town of Byron. Groundwater recharge is water that infiltrates the land surface, reaches the water table and is thus added to the groundwater system; recharge is the ultimate source of all groundwater. Understanding recharge and its distribution is important in making informed land-use decisions so that the groundwater needs of society and the environment can be met. Groundwater recharge varies in space and time. The spatial variation is due primarily to physical differences in land use, soils, and topography. Recharge also varies temporally with climate and precipitation. Local planning decisions cannot significantly alter the weather or geology, but can impact land use.

What does the map show?

The map shows recharge rates for an average year. The recharge rates vary from year to year in response to variations in precipitation, temperature, the timing of snowmelt, and other factors. The map indicates recharge rates using colors ranging from green (low recharge) to red (high recharge). Recharge in the Town of Byron varies from place to place, ranging from about 4 inches per year to about 14 inches per year. Average recharge is about 8 inches per year. In general, the highest recharge rates (greater than 10 in/yr) occur in the higher-elevation parts of the town where soils are thin and bedrock is close to the surface. Such areas generally occur in the southern third of the town. Lower recharge rates occur in areas of wetlands, such as the wetlands near Campground Creek, and in regions of clayey soils in the northwest third of the town. Although this map shows recharge for an average year, the pattern of recharge in wetter or dryer years is similar even though the absolute rates differ.

How was this map constructed?

The map is based on a soil-water balance model developed in Wisconsin (Dripps and Bradbury, 2007; Westenbroek and others, 2010). The model uses soil-water balance (SWB) accounting to determine the fate of precipitation on the land surface and within the soil zone. This method accounts for the various processes that divert precipitation from becoming recharge. The difference between processes that divert water (indicated by negative signs in the following equation) and precipitation represents estimated recharge.

RECHARGE = precipitation – interception – runoff – evapotranspiration – (total soil moisture storage capacity of the root zone – antecedant soil moisture)

The terms of the equation are defined below. Each term uses the same units as precipitation, amount/time period (for example, inches/year).

Recharge – The volumetric rate of water entering the groundwater flow system over some area.

Precipitation – The amount of water that falls to the earth as rain, sleet, snow, or hail.

Interception – The amount of water that falls on the plant canopy and is used by the plants or evaporates, never reaching the ground surface.

Runoff – The amount of water that flows across the land surface.

Evapotranspiration – The quantity of water that is either evaporated or taken up by plants and transpired through their leaves.

Total soil moisture storage capacity of the root zone – The amount of water that the soil type can hold.

Antecedant soil moisture – The amount of water already stored in the soil.

Input to the SWB recharge model consisted of daily climate records for the model period and four map data layers for the model extent: topography, soil hydrologic group, soil available water storage, and land use. The model was centered on the Town of Byron and included portions of surrounding towns. The spatial resolution of the model grid was 30 meters (approximately 98 feet), corresponding to the resolution of the land-surface elevation input data. Daily temperature and precipitation observations recorded at the Fond du Lac weather station were tabulated for model input. Although these climate parameters vary across the county, this dataset is representative of the county on average.

The recharge model uses topographic data, in the form of surface water flow direction, to route runoff. A standard flow direction calculation was applied to a 30-meter digital elevation model (DEM) from the US Geological Survey's National Elevation Dataset.

Digital soil data from the Natural Resources Conservation Service Soil Survey Geographic (SSURGO) Database were used for two input datasets to the model—the hydrologic group and available water storage. The hydrologic group is a classification of the infiltration potential of a soil map unit, and is used in the recharge model input to calculate runoff. The primary categories range from A to D, representing low runoff potential to high runoff potential. Several map units in the model domain were classified with dual designations, such as "A/D," where the lower-runoff designation typically indicates artificially drained land. Since any infiltration occurring in this situation would not contribute to groundwater recharge, all dual-designation soil map units were reassigned to the higher-runoff category for input to the recharge model. Available water storage, a measure of the amount of water held in a specified soil thickness, is used by the model for root zone moisture accounting. Land-use data are used in calculations of interception, runoff, evapotranspiration, and for determination of root zone depth. Land-use data were obtained from the 1992 WISCLAND data set.

Data grids for the four map inputs were generated from these source datasets for input to the model. Climate data from 1981, an average precipitation year was chosen for input as daily precipitation and temperature observations.

Limitations of the map

This map is based on available town-wide information, and might not be accurate for site-specific applications. The modeling method used assumes that deep infiltration equals recharge, but it is possible that in some areas of the town this assumption is violated, and deep infiltration does not reach the groundwater system. For example, water that leaves the soil zone might flow laterally along bedrock fractures to discharge at a cliff face far above the water table; such water would not be considered recharge.

Groundwater susceptibility map

What is a groundwater susceptibility map?

This groundwater susceptibility map shows the relative susceptibility of different areas of the Town of Byron to groundwater contamination originating from surface or near-surface sources. Such potential sources of contamination include waste disposal, chemical spills, septage or manure spreading, septic systems, leaking underground storage tanks, leaking sewers, and fertilizer and pesticide application. The map is simply a depiction of relative *risk* of contamination, and does not indicate that contamination either has occurred or will occur. The map indicates relative contamination susceptibility using a three-color system. In areas shaded red, the susceptibility to contamination is highest. In areas shaded green, the susceptibility is lowest. The yellow areas have intermediate susceptibility. The map also shows areas of active rock quarries. These active quarry areas are very susceptible to contamination, but because they are disturbed they do not fit into the classification scheme described below.

How was this map constructed?

The susceptibility map represents a combination of four environmental or geologic factors known to influence the movement of contaminants to groundwater. These four factors are *type of bedrock*, *depth to bedrock*, *groundwater recharge rate*, and *depth to the water table*. Each of these factors has been mapped for the Town of Byron. Once mapped, various categories within each factor were assigned a value of 1 to 5, with 1 being least susceptible to 5 being most susceptible, as shown in the following tables.

Table 1. Depth to bedrock

Depth range, feet	Ranking
0–10	5
10–25	4
25–50	3
50–100	2
>100	1

Depth to bedrock. Depth to bedrock influences contamination susceptibility because the soil, sand, gravel, and/or clay that overlie the bedrock help to prevent downward movement of contaminants and increase the time for contaminant attenuation and breakdown. Accordingly, areas with shallow bedrock are more susceptible than areas of deep bedrock (table 1). Depth to bedrock in the Town of Byron ranges from zero, where bedrock outcrops at the land surface, to over 200 feet in the northern part of the town.

Table 2. Type of bedrock

Bedrock type	Ranking
Silurian dolomite	5
Sinnipee dolomite	4
-	3
-	2
Maquoketa shale	1

Type of bedrock. Three types of bedrock occur in the Town of Byron (table 2). The Silurian dolomite is the gray, fractured limestone that forms the escarpment in the middle of the town and outcrops in cliffs and road cuts. This dolomite contains numerous voids, fractures, and solution cavities through which water can move very rapidly, with little or no attenuation of contaminants. Accordingly, this rock is very susceptible to contamination. A second dolomite formation, called the Sinnipee dolomite, occurs beneath the Silurian dolomite and is the uppermost rock just to the west of the town boundary. This rock also contains numerous fractures and is only slightly less vulnerable than the Silurian dolomite. Maquoketa shale is the uppermost bedrock in the northwest part of the town. This formation is far less permeable and fractured than the dolomite, and allows much less water to pass through it. Accordingly, it is rated as least susceptible to contamination. Note that the two categories between the shale and the dolomite were not used in this ranking because the town only contains three significant rock types.

Table 3. Depth to water table

Depth range, feet	Ranking
0–20	5
20–50	4
50–100	3
100–200	2
>200	1

Depth to the water table. Depth to the water table controls the thickness of the unsaturated zone, where the pores in rock and soil are partially filled with air. Within this unsaturated zone, biological processes can break down and attenuate contaminants, and thicker unsaturated zones allow more time to pass before contaminants can enter the groundwater system. Accordingly, areas with shallow depths to groundwater are considered more vulnerable than areas with greater depths to groundwater (table 3). In the Town of Byron, some of the deepest depths to groundwater occur in topographically high areas in the south-central parts of the town, while shallow depths to groundwater occur in the lowlands in the northwest part of the town and near wetlands and stream valleys.

Table 4 Recharge rate

Recharge, in/yr	Ranking
>10	5
8–10	4
6–8	3
4–6	2
<4	1

Recharge rate. The groundwater recharge rate is the annual rate, expressed as inches per year, of water entering the groundwater system from the surface. Recharge varies from place to place across a landscape, and is controlled by topography, soil type, vegetation, and land use. Recharge for the Town of Byron was determined using a soil-water balance model described in more detail on the groundwater recharge map. In general, areas where more recharge occurs are more susceptible than areas where less recharge occurs (table 4).

Table 5. Overall ranking

Numerical score total	Susceptibility ranking
8–13	low
13–16	medium
16–20	high

Overall ranking. The overall ranking is based on a simple addition of the ranking scores from each of the four categories (table 5). Based on the ranking system, the highest possible score (most susceptible) is 20, and the lowest possible score is 4. However, no area in the town ranked lowest in every category, and so the lowest actual score is 8. These numerical scores were then grouped into three categories of low, medium, and high susceptibility to contamination.

How should the map be used?

The susceptibility map is primarily an informational and educational tool to indicate which parts of the Town of Byron are more or less susceptible to groundwater contamination. In general, groundwater is more susceptible in upland areas with shallow dolomite bedrock and rapid recharge and is less susceptible in lowland areas with thicker soils underlain by shale. Decision makers can use this map as a guide to the relative risk of locating facilities and making land-use decisions in various parts of the town. Likewise, the map can be used to help assess the relative risk of contamination from spills or other accidents in different parts of the town. For example, a spill of petroleum products in the red areas of the map is far more likely to contaminate groundwater than a spill occurring in the green areas of the map.

The susceptibility map should not be used as the sole criterion for making siting or land-use decisions. The map is based on regional data, and site-specific decisions should always be made using site-specific information.

Groundwater quality maps

The groundwater quality maps show the results of past water-quality sampling of private wells in the Town of Byron. Although many different chemical constituents are of interest in assessing drinking-water quality, these maps show results for only nitrate and coliform bacteria, which are the most commonly tested parameters. Nitrate and coliform bacteria are often called *indicator parameters* because their presence can indicate contamination of a well from near-surface sources. Colored dots on the maps indicate either the concentration of nitrate-nitrogen or the presence or absence of coliform bacteria.

Nitrate and coliform bacteria both originate at or near the land surface. Nitrate-nitrogen is a major component of lawn and agricultural fertilizers, and is also generated during decomposition of sewage and manure. Coliform bacteria naturally exist in surface water and soil and do not usually cause health problems. However, some bacteria originate from either human or animal feces and their presence in a water sample indicates contamination from one or both sources. Tests for both contaminants are required from new wells or whenever a well is opened for pump or well repair.

Nitrate map

Nitrate analyses are generally reported as the concentration of the nitrogen component of nitrate (NO_3-N) in milligrams per liter (mg/l). The drinking-water standard for nitrate is 10 mg/l. Sample results are indicated by three different colored dots. Green dots indicate nitrate less than 3 mg/l, assumed to be approximately the natural background level of nitrate in Wisconsin groundwater. Yellow dots indicate nitrate between 3 and 10 mg/l. These levels are considered elevated above background values but do not exceed the drinking-water standard. Red dots indicate samples exceeding the 10 mg/l drinking-water standard. State and federal laws are not directly enforced on private water systems, but 10 mg/l is recommended as an advisory level for private wells. Nitrate-contaminated water should never be fed to infants less than 6 months of age. In young infants, ingestion of nitrate can reduce the blood's ability to carry oxygen. In severe cases it can cause a condition that doctors call methemoglobinemia. The condition is also called "blue baby syndrome" because the infant's skin appears blue-gray or lavender in color. All infants less than 6 months of age are at risk of nitrate toxicity, but premature babies and babies with other health problems are more sensitive than healthy infants.

The nitrate map shows that most wells in the Town of Byron have produced water with nitrate-nitrogen concentrations less than 3 mg/l. However, several clusters of wells with a history of higher nitrate levels occur in the southern part of the town. While explaining the causes of nitrate contamination in a specific well is beyond the scope of this study, the clustering of elevated nitrate values suggests that these areas, which generally have shallow soils over fractured bedrock, are very vulnerable to groundwater contamination.

Bacteria map

The bacteria map shows the presence or absence of coliform bacteria in water produced by sampled wells. Coliform bacteria are naturally occurring in soil and are found on vegetation and in surface waters. Water from a well properly located and constructed should be free of coliform bacteria. While coliform bacteria do not cause illness in healthy individuals, their presence in well water indicates the water system is at risk to more serious forms of contamination. Green dots on this map represent wells where bacteria were not detected. Red dots indicate wells where bacteria were detected. Water that tests positive for bacteria should not be consumed without boiling or otherwise disinfecting due to the threat of waterborne disease.

Bacteria have been found occasionally in wells from all areas of the Town of Byron. Explaining the cause of bacterial contamination of any specific well is generally not possible. Some of these detections could be false positives caused by failure to sterilize equipment and bottles during sampling. Others could result from problems with plumbing breaks or from problems with the well itself, such as a missing or damaged cap, insects in the well, or improperly sealed casing. All these situations can provide paths for surface bacteria to enter a well. In some situations, however, bacteria can enter the well through the groundwater system. This contamination pathway is most likely where bedrock is fractured and soils are thin, as they are in the southern portion of the town.

Where do the sample results come from?

The sample results for these maps come from three sources: Fond du Lac County UW-Extension well testing program, the Fond du Lac County Health Department, and the Wisconsin Department of Natural Resources Ground Water Retrieval Network (http://prodoasext.dnr.wi.gov/inter1/grn$.startup). The data shown on these maps is a compilation of available data collected over several years and not the results of a single survey or sampling program. Some wells were sampled numerous times, and others sampled only once. The sampled wells shown on these maps represent far less than half of the existing wells in the town. Many wells have no sample data. Only wells with publicly available sample data are plotted on these maps.

Sources of additional information

The following web sites contain additional information about nitrate and bacteria in wells in Wisconsin.
Wisconsin Department of Natural Resources—Nitrate in Drinking Water (http://www.dnr.state.wi.us/org/water/dwg/Forms/nitrate.pdf);
Bacteriological Contamination of Drinking Water Wells (http://www.dnr.state.wi.us/org/water/dwg/pubs/BactiInWell.pdf)

Wisconsin State Laboratory of Hygiene—Test your well water annually (http://www.fdlco.wi.gov/Modules/ShowDocument.aspx?documentid=639)

Hydrogeologic cross sections

What is a hydrogeologic cross section?

A geologic cross section is a diagram that illustrates the subsurface rock layers as if the earth were cut open and seen from the side. A hydrogeologic section shows this same information and also shows, in a general or schematic way, how groundwater flows through these rock layers. The geology is based on interpretation of drillers' descriptions of the rock material in wells along each cross section and on limited rock outcrop information. The movement and direction of groundwater flow is based on water-level data in well-construction reports and the water-bearing properties of each type of rock. The two cross sections shown here extend about 7 miles along the land surface and each extends about 1,000 feet below land surface. They are representative of the entire Town of Byron.

Surficial geology

The uppermost (surficial) material throughout the town is sediment deposited by glacial processes. The sediment in the southern and eastern parts of the town is till, a silty to sandy, somewhat coarse-grained glacial material deposited by glacial ice. These deposits are relatively thin, generally ranging from less than 10 feet to up to about 30 feet thick.

Conversely, much of the glacial material in the low-lying northern parts of the town is a sequence of fine-grained silt and clay deposited as layers of glacial melt-water lake sediment. Some coarser-grained till deposits are encountered at depth. Unlike the southern part of the town, glacial sediments in the lowland areas are quite thick, generally ranging from about 100 feet to over 200 feet in thickness (north end of section A–A').

Bedrock geology

Silurian dolomite—Silurian dolomite, ranging from about 150 to 200 feet thick, lies directly underneath the glacial deposits in the southern and eastern part of the town. This dolomite forms the Niagara Escarpment where it crops out at land surface, and is near land surface throughout much of the town. The Silurian dolomite has been completely eroded away north of the escarpment (A–A') and west of the escarpment (B–B'). This dolomite rock is highly fractured both vertically and along horizontal bedding planes. It forms an important but vulnerable shallow aquifer in the Town of Byron.

Maquoketa shale—Maquoketa shale lies directly under glacial deposits where the Silurian dolomite has been completely eroded away in the northern part of section A–A' and on the western half of section B–B'. The shale is about 225 to 250 feet thick where it is directly beneath the Silurian dolomite. The upper part of the Maquoketa shale also has been eroded where it directly underlies the glacial deposits in the northern part of the town.

Sinnipee dolomite—The deeper bedrock layers shown on the cross sections play a lesser role in the aquifer susceptibility but are important to the overall hydrogeology of the town. Immediately underlying the Maquoketa shale is the Sinnipee dolomite. This dolomite unit is generally about 200 to 250 feet thick throughout the town. Unlike the highly fractured Silurian dolomite, the Sinnipee dolomite, where it is overlain by the Maquoketa shale, contains very few fractures and bedding-plane openings. Thus, it is not a source of water for Town of Byron wells.

St. Peter sandstone—The St. Peter sandstone directly underlies the Sinnipee dolomite. Thickness of the St. Peter sandstone appears to range from about 125 to 200 feet in the Town of Byron. The St. Peter sandstone is an important aquifer for the town. Since the early 1990s, drillers have completed many wells in this sandstone to avoid the contamination issues of wells completed in the Silurian dolomite.

Cambrian sandstones—A series of several Cambrian-age sandstone units underlies the St. Peter sandstone. The composite thickness of these units ranges from zero to more than 700 feet in the Town of Byron. Public-supply wells for the nearby City of Fond du Lac and the Villages of Oakfield, Brownsville, and Lomira all obtain large quantities of water from these deep sandstone units. Two City of Fond du Lac wells are located in the northern part of the Town of Byron. Each of these wells is capable of pumping about 800 gallons of water per minute from a combined thickness of about 700 feet of St. Peter and Cambrian sandstones.

Precambrian crystalline rocks—Underlying these layered bedrock units are dense crystalline granite, quartzite, and rhyolite rocks of Precambrian age. The surface of these rocks appears to be uneven, and is within 500 to 600 feet of land surface in the northeastern and western part of the town. Crystalline granitic rock was encountered in a well at a depth of over 1200 feet in the Village of Lomira several miles south of the town. Based on historical data collected in southern and eastern Wisconsin, these crystalline rocks contain little or no water, and form the base of the groundwater system in the area.

Groundwater movement

The two sections also show profiles of the water table and the potentiometric surface of the deeper sandstones. The water table represents the top of the saturated zone. Below the water table all pores and cracks in the rock are filled with water. The potentiometric surface represents the pressure of water in the deeper aquifers, and is the approximate level at which water will stand in deeply cased wells. Arrows on the cross sections indicate the approximate directions of groundwater flow. Groundwater tends to flow mostly horizontally through aquifers such as the Silurian dolomite and mostly vertically through aquitards like the Maquoketa shale.

Well construction in the southern part of the Town of Byron

Why discuss well construction?

The presence of coliform bacteria and high concentrations of nitrate in well water is an indication that water originating at or near the land surface is entering a well. These contaminants are not found in natural groundwater at depths from which wells typically obtain water. Bacteria and nitrate are being found in many wells in the Town of Byron. Well construction practices can influence the likelihood of this contamination.

Typical older well construction

The well on the left side of the adjacent schematic shows the basic features of “typical” (older) shallow rural domestic wells in the southern part of the town. The vast majority of wells drilled 20 or more years ago were constructed in this way, and some are still constructed in a similar fashion today. The construction procedure consisted of drilling a 10-inch diameter hole a short distance into the dolomite and installing continuous 6-inch diameter steel casing to the bottom of this 10-inch hole. The annular space between the casing and the 10-inch hole was then back-filled up to land surface with a mixture of drill cuttings and drilling mud called puddled clay. This puddled clay was intended to seal the annular space between the casing and the 10-inch hole. An open 6-inch diameter borehole was then drilled out below the bottom of the casing until the driller decided enough water was flowing into the well from fracture openings in the surrounding dolomite bedrock.

These older wells are generally 100 to 200 feet deep, but construction varies from well to well. First, the casing in these wells can extend from as little as a few feet to many tens of feet into the dolomite. Secondly, the length of open hole in the rock below the casing can vary from as little as 20 feet to more than 100 feet. The casing depths and the amount of open hole in these "typical" wells were and still are determined by the driller's experience drilling in the area and by conditions encountered while drilling.

Newer well construction

A major change in the construction of many wells took place in the early 1990s in response to improved drilling methods and changes in state well codes. The well shown on the right side of the schematic is typical of about 40 percent of the domestic wells drilled in the town since about 1990. Drilling procedures are much the same as the older wells. However, the total depth of these new wells ranges from about 575 to 650 feet and casing depths often exceed 400 feet below land surface. These deep wells obtain water from a bedrock aquifer called the St. Peter sandstone. The top of this bedrock unit is more than 600 feet below land surface in the southern part of the town. The continuous steel casing in these deep wells extends through both the Silurian dolomite and over 200 feet of the underlying Maquoketa shale. Thus, water cannot enter from the Silurian dolomite and the low permeability of this shale significantly impedes potentially contaminated groundwater in the shallow Silurian dolomite from reaching underlying bedrock aquifers. The Galena-Platteville dolomite, which directly underlies the Maquoketa shale in the southern part of the town, does not produce an adequate supply of water for wells. For this reason, the open borehole must be extended through over 200 feet of this dolomite unit to reach the St. Peter sandstone. Wells can obtain adequate water from the upper 50 feet of the St. Peter sandstone aquifer.

Discussion

Most wells drilled more than 25 years ago in the southern part of the Town of Byron were open just to the upper part of the fractured Silurian dolomite, which is very susceptible to contamination. Furthermore, the puddled-clay grout used at that time did not provide a particularly effective barrier to contaminated water at land surface moving downward along the outside of the casing into the open borehole. It should be noted that over half of wells drilled since about 1990 still are completed in the Silurian dolomite in the southern part of the town. However, there are two differences between these newer wells and the old wells. First, newer Silurian wells are generally cased to over 100 feet below land surface, a depth much greater than most of the older wells. Also, the grout used to seal around the casing of new wells is a slurry of Portland cement and water which provides an improved barrier to water movement down the outside of the casing. Unfortunately, some fractures in the Silurian dolomite are interconnected to depths that intersect the open borehole below the casing. Therefore, new Silurian dolomite wells are still somewhat susceptible to contamination.

The new deep wells finished in the St. Peter sandstone are, by virtue of their construction, far less vulnerable to contamination than the wells finished in the Silurian dolomite, particularly in areas of high groundwater susceptibility. The disadvantages are that these wells are more expensive, being over 600 feet deep and often requiring over 400 feet of casing. Also, non-pumping water levels in these deep wells are over 300 feet below land surface which requires additional discharge pipe and larger horsepower well pumps. This results in a substantial increase in the cost of well construction. The choice of well construction is ultimately up to the well owner**.**

References

Dripps, W.R., and Bradbury, K.R., 2007, A simple daily soil-water balance model for estimating the spatial and temporal distribution of groundwater recharge in temperate humid areas: *Hydrogeology Journal*, 15 no. 3: 433–444.

Haitjema, H.M., 1995, *Analytic Element Modeling of Groundwater Flow*: Academic Press, Inc.

Westenbroek, S.M., Kelson, V.A., Dripps, W.R., Hunt, R.J., and Bradbury, K.R., in review, SWB—A modified Thornthwaite soil-water balance code for estimating groundwater recharge: U.S. Geological Survey Open File Report.