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# Groundwater and wells in agricultural regions of Bayfield County, Wisconsin

## Report to the Large-Scale Livestock Study Committee

Technical Report 2 • 2016

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University of Wisconsin-Extension

# Wisconsin Geological and Natural History Survey

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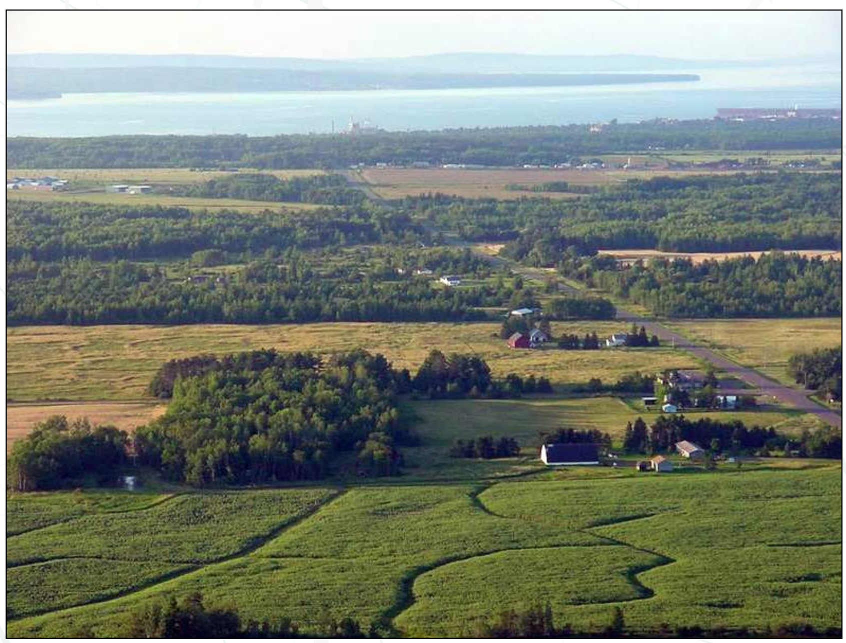

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**Cover photos**, Bayfield County by air, provided by Annie Boike.

# Contents

# Executive summary

This report and accompanying figures provide local officials, residents, and the agricultural community with basic information about groundwater and water supply wells in two agricultural regions of Bayfield County, Wisconsin. The work presented in this report was commissioned by the Large-Scale Livestock Study Committee and the Bayfield County Board of Supervisors.

The primary products of this study are a map and a series of cross sections illustrating groundwater resources and typical well construction in the agricultural regions. The study area consists of two regions, referred to collectively as "the study area" or separately as the "northwest" and "eastern" agricultural areas (fig. 1). The products were developed using information from over 660 wells located within and adjacent to the study area, previously published maps of surficial and bedrock geology, and an existing groundwater flow model.

This work fills a need for information about the groundwater resources in the county's agricultural regions. This compilation and interpretation of data is intended to support discussions and decisions surrounding land use in the study area. The agricultural regions are home to farms and residences that rely on groundwater for drinking water supply, and the committee requires information about the quality and safety of water from wells as they consider management of livestock operations.

Bayfield County Health Department personnel sampled groundwater collected from 66 private water wells in the eastern agricultural region as a part of the effort to characterize current groundwater conditions. Sampling results are available from the Health Department. Efforts to expand well-water sampling in portions of the eastern region and across the northwestern agricultural regions would significantly improve the ability to assess the susceptibility of wells to existing surface contamination.

A broad overview of the agricultural area's groundwater resources follows.

The agricultural regions in Bayfield County (fig. 2) are primarily underlain by the Miller Creek Formation, which consists of fine-grained glacial deposits. In these areas, low-permeability silt and clay are at the land surface. This material supports increased runoff to streams compared to areas capped by the sandier, coarse-grained Copper Falls Formation. Precipitation and snowmelt tend to infiltrate to the water table in areas south of and between the two agricultural regions, where the Copper Falls Formation is at the land surface. Livestock operations and other activities that involve storage or land spreading of waste material within the agricultural regions have a greater potential to affect surface water runoff to streams than to impact groundwater quality.

The water-table map (plate 1) indicates the direction of groundwater flow across the agricultural regions. The map is useful to determine which facilities or fields are located hydraulically up-gradient of any well or stream, or conversely, to identify wells or streams downgradient of specific facilities or agricultural fields within the study area. Waste management or storage facilities should be sited with knowledge of the prevailing groundwater flow direction and the locations of nearby, downgradient water wells. Additional site-specific information is also necessary for appropriate design of facilities that have the potential to affect water quality.

The water-table map and an understanding of the hydrogeologic setting are important in the proper design of groundwater monitoring systems. In the agricultural regions, the extensive low-permeability clay and silt deposits likely result in a strong vertical component to groundwater flow. Monitoring wells should be designed to assess vertical and lateral groundwater flow away from facilities. These wells can be sampled at regular intervals to identify potential adverse impacts to groundwater quality.

A majority of private water supply wells in the eastern agricultural region are completed in sand and gravel deposits. In the northwest agricultural region, a high proportion of wells are completed in sandstone. Regardless of the material a well is completed in, a well is more susceptible to contamination from activities on the land surface if its total depth is relatively shallow, particularly in areas where there is little to no overlying clay or silt.

In general, wells with deep casings are better protected from land surface activities than wells with shallow casings. Although protection varies from place to place due to soil type, soil thickness and several other factors, wells constructed with 200 feet of casing are much better protected than wells with 60 feet of casing. Information about well depth and casing depth is available from the county to land owners or developers who apply for a building permit. Such information allows individuals to consider water quality when working with a driller to plan a water supply well. County personnel can examine the results of the recent well water sampling effort in conjunction with well construction information to evaluate whether water quality results, for example, detectable concentrations of nitrate, correlate to well construction specifications, such as well or casing depth.

All residents should test their well water annually. Well water quality is site-specific, meaning that a given well can yield different water quality than a neighbor's well. Well-to-well differences in water quality can be due to differences in well construction (for example, casing or total depth), slight variations in the geology or rock chemistry near a well, or recharge. Testing should include bacteria and nitrate, which are common well contaminants in Wisconsin's aquifers. University of Wisconsin–Extension and the Wisconsin Department of Natural Resources provide information about well-water testing.

Bayfield County and town government officials may find additional natural resource evaluations useful in discussions surrounding land use and development in the region. Such information might include updating and expanding the database of well locations and construction compiled for this project. County personnel have the expertise necessary to complete this work. Additional maps that would inform natural resource protection include the depth to bedrock and groundwater susceptibility across Bayfield County. Depth to bedrock is used to identify areas with thicker protective deposits above the sandstone bedrock aquifer. A groundwater susceptibility map integrates information about permeability of surficial deposits, groundwater recharge rates, depth to bedrock, and depth to the water table. Groundwater susceptibility maps show locations where groundwater and wells are more or less protected from contamination sources at the land surface. Thus, such maps might be used to identify sites where more groundwater monitoring would be useful to safeguard water quality. Although such maps are available for the entire state, the scale is not sufficiently detailed to inform discussions about land use within Bayfield County.

Livestock operations, including waste storage and spreading, can be managed to reduce potential impacts to water resources in the agricultural regions. The primary concern at such facilities should be guarding against run-off to surface water, due to the low infiltration capacity of the glacial deposits. A secondary concern is reducing the risk of groundwater contamination. Practices such as lining manure storage facilities and limiting the quantity of waste applied to any one field help limit losses of nutrients and other pollutants to groundwater. State regulations address appropriate setbacks from water supply wells for animal waste and other biosolid applications. Conformance to these standards helps prevent nutrients and pathogens from entering the groundwater system around well casings. Targeted groundwater monitoring at livestock facilities and fields using monitoring wells is useful for assessing whether manure management practices are sufficient. Additionally, residential wells should be routinely tested for potential changes to groundwater.

## Acknowledgments

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# Project scope and deliverables

This project focused on evaluating the susceptibility of groundwater supplies to contamination from activities at the land surface within the study area. The following tasks were performed:

- **Compiled and analyzed geologic and hydrogeologic data** from the study area. Data sources included well construction reports and geologic logs on file at the WGNHS and previously published related studies and maps from this region. The Bayfield County Land Information Office provided datasets of land parcels, addresses, and roads to assist in determining well locations. Unpublished information compiled recently for ongoing projects at the Wisconsin Geological and Natural History Survey (Bradbury and others) and the U.S. Geological Survey (Dunning and others, in review) were also used.
- **Evaluated the depth and lateral extent of sand lenses** within the glacial deposits and prepared four cross sections illustrating these conditions.
- **Developed a water-table map** for the two areas of interest to show general direction of groundwater flow.
- **Presented findings to Livestock Committee and public** in a written report and in-person meetings.

Project deliverables include this report, which describes the hydrogeologic setting and typical well construction. Four cross sections, a water-table map, and three associated figures are included. The maps and datasets, including a database of the well construction reports, are available in digital form for use in Geographic Information System (GIS) applications. The report, maps, and data are downloadable from the Wisconsin Geological and Natural History Survey's website (http://wgnhs.org).

# Project area

Bayfield County staff identified two agricultural regions within Bayfield County that are the focus of this study. These are referred to in this report as the northwest and eastern agricultural regions and together make up the study area. As shown in figure 1, the northwest region encompasses all or parts of the towns of Clover, Orienta, Oulu, Port Wing, and Tripp. The eastern agricultural region includes all or portions of the towns of Barksdale, Bayview, Eileen, Kelly, Keystone, Lincoln, Mason, Pilsen, and Washburn. The rest of the county is not farmland; the county chose to limit the study focus to agricultural areas.

## Geologic setting

### Surficial geology

The uppermost (surficial) geologic sediment covering most of the two agricultural regions is referred to as the Miller Creek Formation (fig. 2). This material, which is made up of fine-grained sandy silt and clay with discontinuous lenses of sand and gravel, was deposited by glaciers that advanced through low-lying areas in the region (Clayton, 1984; Need and Johnson, 1984).

The Miller Creek Formation was not deposited in the upland areas outside the two agricultural regions; here, the uppermost material is a coarse-grained glacial sediment called the Copper Falls Formation. This formation was described by Clayton (1984) as predominantly gravelly, clayey, silty sand. It includes some sand and gravel deposited by glacial meltwater streams. Small sand dunes, such as those in the blueberry barrens, are also found within the Copper Falls Formation. The Copper Falls Formation, which is older than the Miller Creek Formation, is thought to underlie the Miller Creek Formation throughout the study area (Need and Johnson, 1984).

The Bibon Marsh wetlands abut the southern border of the eastern agricultural region. Peat deposits are at the land surface in this low-lying area (fig. 2). Peat retains water, and the water table is close to the land surface in the marsh. This creates conditions that support the marsh's wetland ecology.

### Bedrock geology

The Bayfield Group bedrock is a quartzose sandstone that underlies most of the study area (Ojakangas and others, 2001). Estimated to be several thousand feet thick, it is a relatively prolific aquifer due to this thickness (Dunning and others, in review). Laterally extensive bedding-plane fractures are visible in the sandstone where it crops out in ravines along the Lake Superior shoreline. In some limited portions of the study area, the sandstone is absent and the uppermost bedrock is basalt (Mudrey and others, 1982).

**Figure 1.** Shaded topographic relief map of Bayfield County with town boundaries. The northwestern and eastern agricultural regions are outlined in blue.

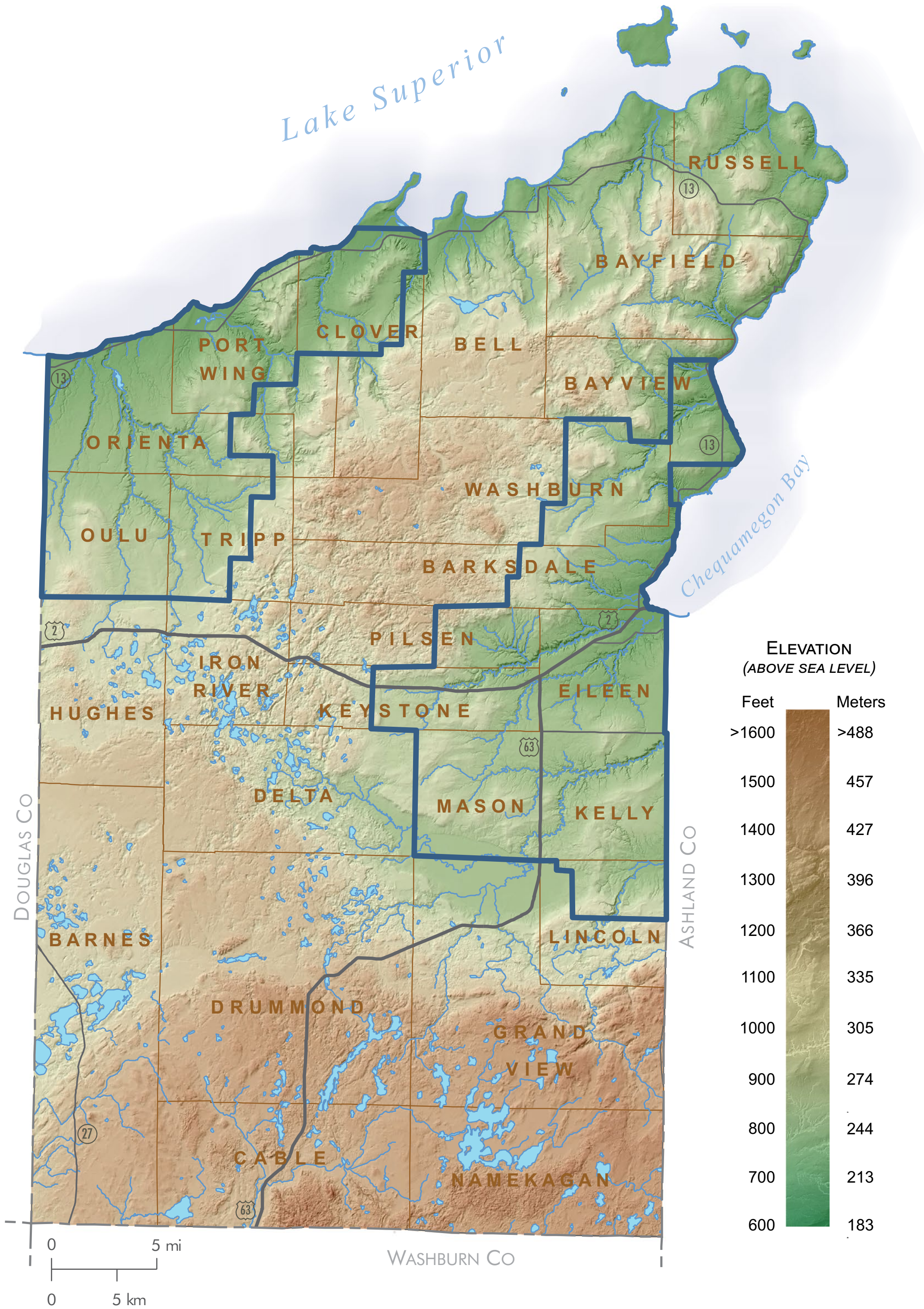
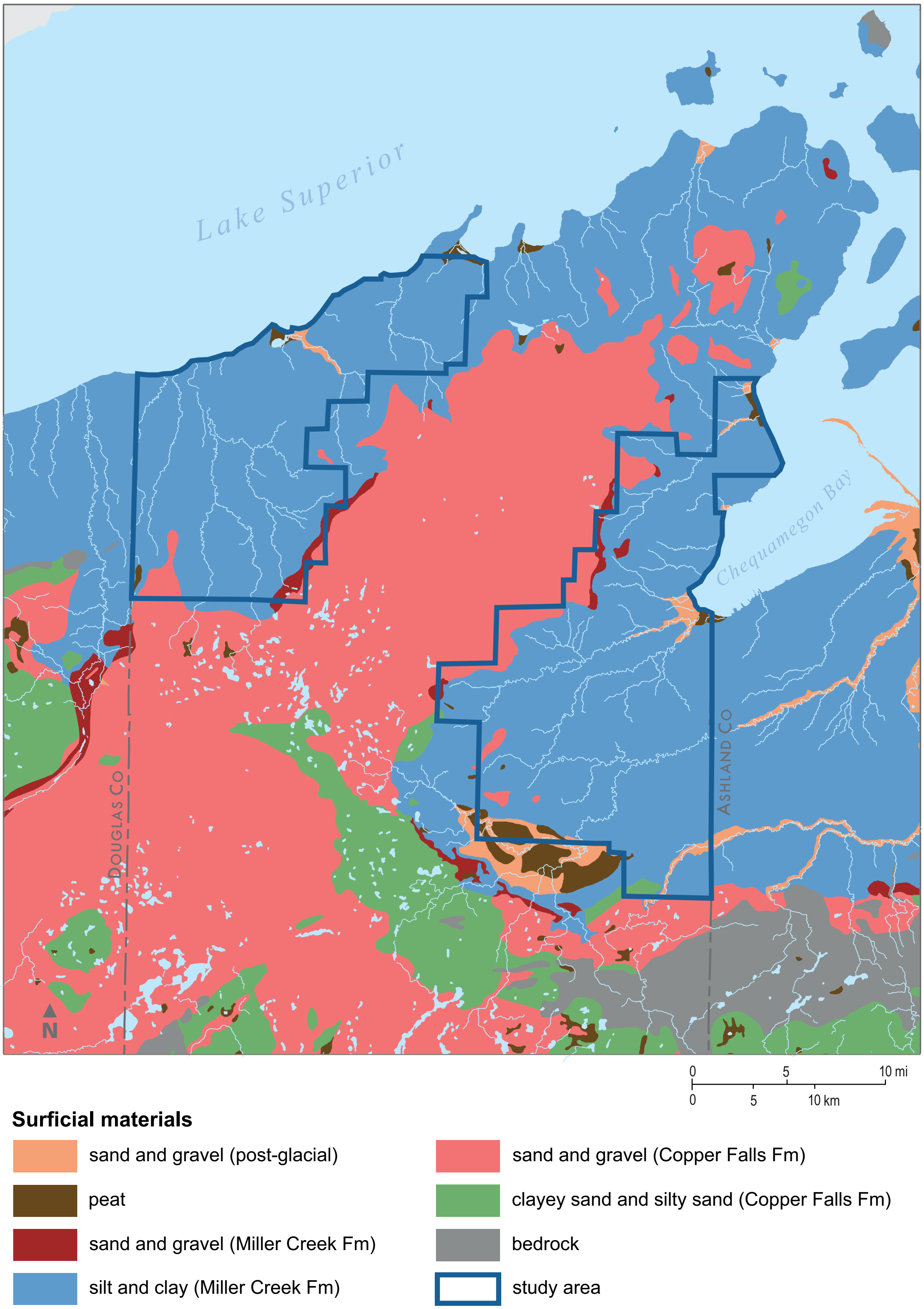


**Figure 2.** Simplified representation of the surficial geologic deposits in the study area, categorized by dominant grain size. (Adapted from Clayton, 1984.)



# Water-table map

The water-table map (plate 1) shows the approximate elevation of the water table in the agricultural areas of Bayfield County. The water table is the top of the saturated zone; beneath the water table, all of the pores and cracks (fractures) are filled with water. Above the water table, in the unsaturated zone, the pores are filled with a combination of air and water. The water table meets the land surface at Lake Superior as well as at inland lakes, streams, and springs.

The water table is the elevation that water rises to in a shallow well. However, in deep wells, including many water supply wells in Bayfield County, the water level may not reflect the elevation of the water table. Water levels in deep wells indicate the potentiometric surface, which is the water pressure at the bottom of the well casing. The potentiometric surface can be higher or lower than the water table. Artesian wells, such as the flowing wells at Maslowski Park and Sprague Well at Thompson's West End Park, tap groundwater at pressures that exceed the elevation of land surface, causing water to flow without the need for a pump.

The water table fluctuates from season to season, and is typically highest during rainy periods and in the spring following snowmelt. Seasonal changes in the water table tend to be greatest at higher elevations in the landscape; the water table is less responsive to seasonal changes near large bodies of water, such as along the shore of Lake Superior.

## What the map shows

The contour lines on the map represent lines of elevation of the water table, in feet above mean sea level. Similar to a topographic map, everywhere along the 800-foot contour line, the water table is at an elevation of 800 feet.

In the agricultural regions of Bayfield County, the water table is at its lowest—less than 625 feet above sea level—along the Lake Superior shoreline. It's at its highest in the southern portion of Bayfield County and in the area between the two agricultural regions.

Groundwater flows from higher to lower water-table elevations, as indicated by arrows on the map, generally perpendicular to the contours. Groundwater moves away from the groundwater divide, as shown on the map. A groundwater divide is analogous to a ridgetop on a topographic map—just as the land surface slopes away on either side of a ridgetop, so does the water table slope away from a groundwater divide. Although not illustrated by a water-table map, groundwater also flows downward through the flow system. In particular, the area's clay-rich deposits create conditions that result in downward flow in upland areas and upward flow where groundwater discharges into streams and springs.

In Bayfield County, a major groundwater divide is centered on the peninsula, between the two agricultural regions. It is shown on the map as a diagonal gray strip. Groundwater flow diverges along the divide: Groundwater to the northwest of the divide flows through the northwest agricultural region where it ultimately discharges to wells, tributary streams, and Lake Superior; to the southeast of the divide, most of the groundwater flows through the eastern agricultural region, discharging to wells, tributary streams, and Chequamegon Bay. Groundwater that originates south of the eastern region flows into the White River basin and Bibon Marsh.

The configuration of the water table (that is, its shape and the resulting groundwater flow directions) reflect the regional hydrogeologic setting. The water table is highest in areas with relatively high amounts of recharge to the water table. Recharge is rainfall and snowmelt that infiltrate through the land surface and enter the groundwater system at the water table. In Bayfield County, recharge rates are affected by the distribution of the Miller Creek and Copper Falls Formations. The Miller Creek has a high proportion of silt and clay. These materials tend to reduce infiltration and recharge. By contrast, till that is predominantly sand, such as the Copper Falls Formation, is more permeable; rainfall and snowmelt can readily infiltrate through sandy till to the water table. Areas capped by the sandier Copper Falls Formation (fig. 2) are considered the primary groundwater recharge areas in this region (Dunning and others, in review; Fitzpatrick and others, 2014).

Locations of perennial streams (streams that flow year-round) are shown on the water-table map. The locations of streams in the study area support the conclusion that recharge occurs primarily where sandy till of the Copper Falls Formation caps the landscape. As can be seen by comparing the water-table map with figure 2, almost all of the streams in the agricultural areas have their headwaters (that is, they begin to flow) near the contact of the Miller Creek and the Copper Falls. The absence of streams in the area capped by Copper Falls indicates that rainfall and snowmelt readily infiltrate to the groundwater system. Where the fine-grained Miller Creek till is present, infiltration is more limited and surface water runoff supports stream generation.

## How was the map made?

Map development began with water-table elevations simulated by an existing computerized groundwater flow model (Bradbury and others, unpublished data). The model was developed with GFLOW (Haitjema, 1995), a two-dimensional analytic element computer code that solves for groundwater elevation. The method accounts for groundwater recharge, aquifer properties, and the surface elevation of streams and lakes. The model was adjusted in a process called model calibration, to achieve a good match between the simulated water table and data from the region. These data include measurements of streamflow and water levels in shallow wells.

For this project, the simulated elevation of the water table was refined by evaluating it for consistency with elevations of land surface, streams, lakes, and water levels in wells completed above bedrock. The geographic extent of well construction records and groundwater levels used to refine the map went beyond the agricultural regions and included records throughout Bayfield County and into Ashland and Douglas Counties. Note, though, that water-table contours outside the two agricultural regions have not been verified with other records.

## How can the map be used?

This water-table map has several uses. It illustrates where groundwater comes from prior to discharging to a stream, lake, or well. Similarly, it can be used to identify areas downgradient of proposed waste-management facilities, such as landfills or manure storage lagoons. Knowledge of the regional groundwater flow direction is helpful in design of a site-specific groundwater-quality monitoring system for such a facility.

The map can be used to estimate the depth to the water table, by subtracting the water-table elevation from land-surface elevation at any given point. The difference is the depth to the water table. Depth to the water table is one factor affecting the susceptibility of groundwater to contamination from the land surface—generally, the deeper the water table, the longer it takes for contaminants to migrate to groundwater. Knowing the depth to the water table is also useful for construction activities such as excavation and subsurface drainage requirements for basements, manure storage areas, landfills, and other underground structures.

# Hydrogeologic cross sections

A hydrogeologic cross section is a diagram that illustrates the subsurface sediment, rock, and groundwater system as if we were able to slice through the ground to look beneath the land surface. The cross sections developed for this project also show the depths of wells and the direction of groundwater flow through these geologic layers. The diagrams are based on drillers' descriptions of the geologic materials (such as sand, clay, or bedrock) encountered when installing wells. Reports describing the geologic setting and the distribution of glacially deposited sediment in the region (Goebel and others, 1983; Clayton, 1984; Need and Johnson, 1984) inform the interpretation shown in the cross sections.

## What the cross sections show

The four cross sections shown on plate 2 extend about 9 to 23 miles along land surface and about 500 feet below land surface. The vertical scale is exaggerated by about 30 times compared to the horizontal scale so that vertical features are visible. The elevation of the water table and the locations of wells used in developing the cross sections are also displayed. The cross-section locations were selected to illustrate conditions across the two agricultural regions.

The cross sections do not depict the depth of the contact between the Miller Creek and Copper Falls Formations. The thickness of the Miller Creek and Copper Falls units, and the elevation of the contact between them, are not evident from well construction records, nor are the thickness of these deposits documented in published reports. Thus, the interpretation illustrated in the cross sections differentiates sediment by the dominant material described on well construction reports.

Overall, these cross sections depict disconnected lenses of sand within finer-grained material. This interpretation is based on the degree of heterogeneity, or variation, common to glacial deposits in this area (Clayton, 1984). The cross sections represent one possible interpretation of the drillers' records, but the sand lenses may be more or less connected, or more prevalent, than shown here. Information gained in site-specific drilling programs can reduce the uncertainty about the extent and continuity of sand lenses at a specific location.

The cross sections also show the profile of the water table. Arrows indicate the general directions of groundwater flow. Although difficult to illustrate in two-dimensional drawings, groundwater flows in three dimensions in the subsurface, generally moving at an angle downward and away from recharge areas high on the landscape. Groundwater flow is typically upward in low-lying areas, where groundwater discharges to streams and lakes. While the water-table map (plate 1) shows the primary horizontal flow directions, the arrows on the cross sections illustrate the vertical dimension of groundwater flow in the subsurface. Monitoring wells in this hydrogeologic setting should be designed to instrument lateral and vertical components of groundwater flow.

# Well construction in the agricultural regions of Bayfield County

## Why is well construction important?

Techniques used to drill and complete wells can affect well water quality in several ways. Important considerations include the depth of a well casing below ground surface, the total depth of the well, and how effectively the well casing is sealed and capped. Casing consists of steel or plastic pipe that extends from the ground surface to the depth of groundwater withdrawal. The casing is sealed in place with grout or cement to prevent surface runoff from leaking down along the well casing. Shallow wells and wells with poorly sealed casings are more susceptible to contamination from the land surface. Wells completed in fractured bedrock with thin overlying soil or glacial deposits are also very susceptible to contamination.

Some geologic settings and well construction techniques offer natural protection from surface contaminant sources. Wells that are cased and grouted to greater depths are less likely to receive water originating nearby from the land surface. Wells that are drilled and cased through clay-rich deposits, such as the Miller Creek Formation, and are screened in deep sand lenses or bedrock, generally pump groundwater that recharged tens to hundreds of years ago. These wells are less susceptible to anthropogenic contamination compared to wells completed at shallow depths and wells completed in shallow bedrock.

The presence of contaminants such as coliform bacteria and elevated nitrate concentrations in well water indicates that water originating at or near the land surface is reaching the well. Coliform bacteria and nitrate are not naturally present in groundwater at depths from which wells typically pump water. In contrast, some contaminants can be present in groundwater as a result of naturally occurring interactions between rocks and sediment and groundwater. For example, arsenic is a common, naturally occurring contaminant that affects groundwater across Wisconsin.

## Typical well construction in the study area

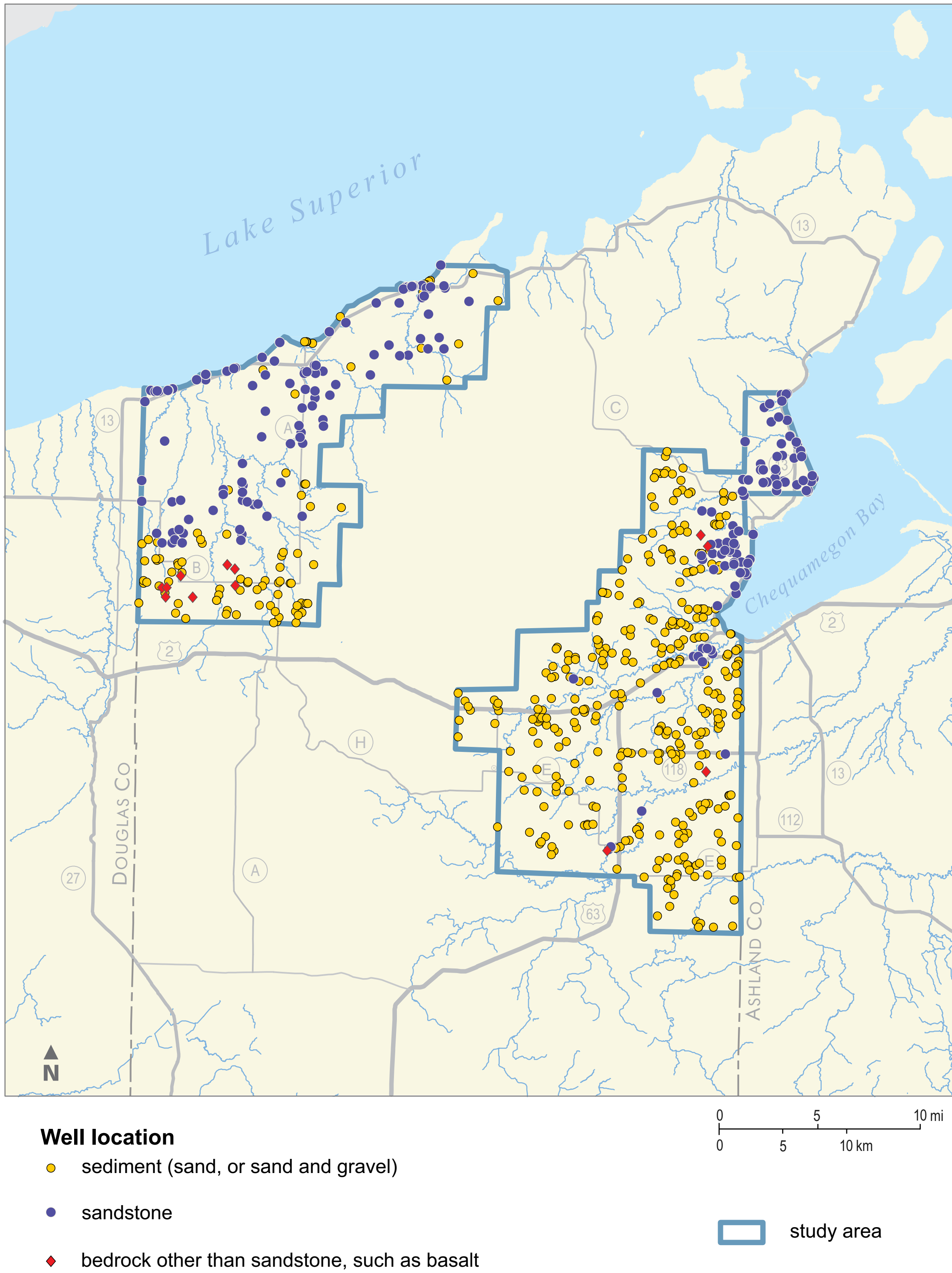
The locations of 660 wells catalogued for this study are shown in figure 3. Of these wells, 444 are completed in glacial deposits and screened in sand, or a mix of sand and gravel. The remaining wells are drilled into bedrock, with 205 completed in sandstone and 11 completed in basalt bedrock. Table 1 shows the range and average well depths in each group.

Wells in Bayfield County that are drilled for cities, villages, and fish hatcheries must supply large volumes of water. These wells are typically completed in the Bayfield Group sandstone. None of these large wells are located within the study area; however, many private wells in the agricultural regions are also completed in this sandstone formation (fig. 3). Most of these bedrock wells are located in areas where glacial deposits are relatively thin and bedrock is close to land surface. These wells are constructed with steel casing extending into the bedrock and are drilled with an open borehole below the casing, to the total depth. This allows groundwater to enter the well through the uncased portion of the well, which typically extends through tens of feet of bedrock. Wells completed in sand and gravel deposits are constructed with casing extended to the depth of water-bearing sand. A 3- to 10-foot stainless-steel well screen is installed at the base of the casing, in the water-bearing zone, to prevent sand from entering the well.

**Table 1.** Well characteristics in the study area.

| | | Well depth (feet) | | |
|---|---|---|---|---|
| Completion material | Number of wells | Average | Minimum | Maximum |
| Sand, gravel | 444 | 149 | 36 | 488 |
| Sandstone (bedrock) | 205 | 182 | 59 | 478 |
| Basalt (bedrock) | 11 | 220 | 105 | 410 |

**Figure 3.** Wells in the study area. The symbol indicates the type of geologic deposit that the well is completed in.



## Implications for water quality at wells

Overall, more wells in the northwest agricultural area are completed in sandstone compared to the eastern area, where a greater number of wells draw water from sand and gravel. This could be due to geologic factors. For example, the eastern area may have more extensive or well-connected water-bearing sand lenses compared to the northwest.

Wells completed in Bayfield Group sandstone that are located in areas with a shallow depth to bedrock have a high vulnerability to contamination from activities at the land surface, in part due to the fractured nature of the sandstone. For example, private water wells in the Town of Barksdale, where the depth to bedrock is less than 20 feet, have been affected by waste disposal practices at the former DuPont property on Nolander Road.

Regardless of the material a well is completed in, a well is more susceptible to contamination from activities on the land surface if its total depth is relatively shallow and if there is little or no overlying clay or silt. It is impossible to predict a depth at which groundwater will be safe from contamination, because protection varies from place to place and because many factors affect contaminant mobility. However, wells constructed with 100 to 200 feet of casing are much better protected from surface contamination than wells constructed with only 40 to 70 feet of casing. Wells completed beneath greater thicknesses of overlying silt or clay are also better protected. For example, groundwater within a sand lens overlain by 70 feet of clay is better protected than groundwater in a sand lens with only 10 feet of overlying clay.

Information about well construction techniques can be provided by Bayfield County to land owners or developers who apply for a building permit. Such information will allow individuals to consider water quality when working with a driller to plan for their well.

County personnel may use the database of well construction reports provided with this report to access individual well records at locations of interest. Private well owners may look online for their well construction record—the Wisconsin Geological and Natural History Survey provides guidance for searching for well records at http://wgnhs.org/water-environment/well-records/.

Understanding the quality of the well water is particularly important at private wells used for drinking water supply. State and federal laws require public water systems in cities and villages, such as those in Washburn and Bayfield, to routinely test groundwater for contaminants. Although there is no such requirement for private well owners, testing is necessary to understand the quality of the water.

The most direct way for a homeowner to evaluate the water quality at their well is to have their water analyzed for common contaminants, such as nitrate and bacteria. Residents may also choose to analyze their well water for chloride. Although chloride can occur naturally from the dissolution of minerals, elevated chloride concentrations may indicate impacts from agricultural activities, road deicing, or sewer systems.

Homeowners should also periodically inspect their well to ensure the casing, its seal, and the well cap retain their integrity, and deter surface water, insects, and rodents from entering the casing and well.

# Conclusions

The agricultural regions in Bayfield County are primarily underlain by the fine-grained glacial deposits of the Miller Creek Formation. The low permeability of these deposits causes increased runoff to streams compared to areas capped by the sandier Copper Falls Formation. Precipitation and snowmelt tend to infiltrate to the south of and between the two agricultural regions. Livestock operations and manure management within the agricultural regions have a greater potential to affect surface-water runoff to streams than to impact groundwater quality.

The water-table map indicates the direction of groundwater flow across the agricultural regions. The map is useful to determine facilities or fields located hydraulically up-gradient of any well or stream, or conversely, to identify wells or streams downgradient of specific facilities or agricultural fields. Site-specific hydrogeologic data are useful for adequate design and siting of groundwater monitoring systems. Waste management or storage facilities should be sited with knowledge of the prevailing surface water drainage patterns, groundwater flow direction, and locations of nearby downgradient water wells. Monitoring wells designed to sample groundwater downgradient of such facilities should be sampled at regular intervals to identify potential adverse impacts to groundwater quality.

A majority of private water supply wells in the eastern agricultural region are completed in sand and gravel deposits. Within this group, wells completed at greater depths, beneath thicker deposits of fine-grained material, have more protection from surface contamination than the shallower sand-and-gravel wells. In the northwest agricultural region, a high proportion of wells are completed in sandstone. Wells completed in sandstone are more vulnerable to contamination where there is little overlying fine-grained glacial till.

All residents should test their well water annually, or more frequently if there is a noticeable change in the water. Well water quality is very site specific, meaning that a well can yield different water quality than a neighbor's well. This can be due to differences in well construction, such as well depth, slight variations in the geology or rock chemistry near a well, or differences in land use where rainfall and snowmelt infiltrate to the groundwater system and flow to a particular well. Testing should include, at a minimum, bacteria and nitrate, which are common contaminants in Wisconsin's aquifers.

Bayfield County and town government officials may find additional natural resource evaluations useful in discussions surrounding land use and development in the region. Such information might include:

- **A map of the depth to bedrock across Bayfield County.** Depth to bedrock is significant because areas with a greater depth to bedrock have more natural protection of the bedrock aquifer. For example, private water wells in the Town of Barksdale were affected by waste disposal practices at the former DuPont property. The depth to bedrock in Barksdale is relatively shallow. A depth-to-bedrock map is available for Wisconsin, but it was produced at a scale that is not sufficiently accurate to inform discussions within Bayfield County.
- **A map of groundwater susceptibility in Bayfield County.** Such maps integrate information about permeability of surficial deposits, depth to bedrock, depth to the water table, and recharge rates. Groundwater susceptibility maps show locations where groundwater and wells are more or less protected from contamination sources at the land surface. Although such a map is available for Wisconsin, it is produced at a scale that is not sufficiently accurate to inform discussions about land use within Bayfield County.
- **Routine updates to the database of well construction records, and expansion of the database countywide.** County personnel familiar with GIS can compile and maintain such information. A countywide water well database is useful to identify well locations and their construction in areas of specific interest.
- **Expand program for sampling groundwater from private wells.** The initial sampling of 66 wells in the eastern agricultural region provides a useful data set to understand current groundwater quality in that area. Sampling wells in the remaining, unsampled portions of the study area would complete this effort.

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