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Bayfield County [Wisconsin] water-table map and water well database

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Open-File Report 2017-02

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Bayfield County water-table map and water well database

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Wisconsin Geological and Natural History Survey
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Executive summary

This report provides information about well construction, groundwater flow, and resulting implications for well susceptibility in Bayfield County, Wisconsin. The project deliverables include a countywide water-table map and water well database. These are the first two elements of a proposed Hydrogeologic Atlas, an inventory and analysis of groundwater conditions in Bayfield County. The work reported here follows recommendations from a groundwater study in 2015 that focused on two agricultural areas within Bayfield County (Gotkowitz and Li, 2016). This project expands that work to the entire county (fig. 1). The project was funded by the Bayfield County Health Department.

The hydrogeologic setting in Bayfield County is influenced by regional geology. Glacial deposits cover most of the county, primarily consisting of two formations: the Miller Creek and the Copper Falls Formations. Fine-grained deposits of the Miller Creek Formation cover most of the Bayfield lowlands near Lake Superior (fig. 2). This material is primarily composed of low-permeability sandy silt and clay with discontinuous lenses of sand and gravel. In the higher-elevation regions of central and southern Bayfield County, the uppermost material is a coarse-grained glacial deposit, the Copper Falls Formation. Water can infiltrate more easily into areas covered by the Copper Falls than areas beneath Miller Creek deposits. The glacial deposits are several hundred feet thick in central Bayfield County and thin towards Lake Superior. Beneath these deposits, sandstone is generally present north of Bibon Marsh, and crystalline bedrock south of the marsh.

The countywide well database consists of 3,360 well records maintained by the Wisconsin Department of Natural Resources (DNR). The database was expanded from the 660 records compiled by Gotkowitz and Li (2016). These well construction reports contain information about the well location; depth of well and casing, liner, or screen; geologic materials observed by the driller; and water level and pumping test results.

The well database includes information about well construction and geologic setting, which influence the susceptibility of a well to contamination originating at or near the land surface. In general, wells drilled to a shallow depth are more susceptible to contamination than deeper wells. Although not recorded in the database, wells with poorly sealed casings are also more vulnerable to contamination than properly cased wells. Some geologic settings offer natural protection for wells; fine-grained sediment above the well screen can help protect the well from land surface activities. Conversely, wells in areas of thin or coarse-grained sediment have less protection. Wells completed in sandstone and sand-and-gravel can both be susceptible to contamination; sandstone is especially vulnerable where fractures are present, such as near the Lake Superior shoreline.

To better evaluate the susceptibility of wells to surface contamination, wells in the database with sufficient geologic information were analyzed for properties that can affect well susceptibility (table 1). These wells were categorized by the type of material recorded at the well screen (fig. 3), well depth (fig. 4), and the thickness of fine-grained sediment above the well screen (figs. 5 and 6).

Most wells in Bayfield County are completed in sand-and-gravel deposits, and are commonly located in the southern two-thirds of Bayfield County. Susceptible sand-and-gravel wells with little natural protection from fine-grained overlying deposits are most commonly located in southern and southwest Bayfield County in the sandy Copper Falls Formation. Some sand-and-gravel wells completed in the Miller Creek Formation in eastern Bayfield County have greater protection from overlying deposits.

Near Lake Superior, where fine-grained glacial deposits of the Miller Creek Formation are present near the land surface, sandstone wells and deeper sand-and-gravel wells are common. Wells in Bayfield County that are completed in sandstone are generally deeper than sand-and-gravel wells, and are open to an aquifer beneath a clay layer, providing a thicker layer of natural protection. However, wells with little natural protection are also common near the Lake Superior shore where glacial deposits are thin. Sandstone wells drilled in this shallow bedrock are particularly vulnerable to contamination due to the fractured nature of the sandstone.

The water-table map (plate 1) indicates the general directions of groundwater flow. Most groundwater recharge occurs in upland areas in central and southern Bayfield County where the sandy Copper Falls Formation is present. Groundwater flows downward and away from these recharge areas, ultimately discharging to streams, lakes, and wells. Upward gradients are common where groundwater discharges to tributaries of Lake Superior. The water-table map is useful to determine facilities or fields located hydraulically up-gradient of any well or stream or, conversely, to identify wells or streams down-gradient of specific facilities or agricultural fields.

Acknowledgments

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Introduction

This project is part of a larger effort to develop a Hydrogeologic Atlas for Bayfield County, Wisconsin. When completed, the Hydrogeologic Atlas will provide an inventory and analysis of groundwater conditions in Bayfield County useful as an educational resource for citizens, as a guide in land use planning, and as regional-scale information to guide site-specific questions and investigations related to groundwater resources. The atlas is envisioned to include a groundwater well database and maps of the water-table elevation, depth to bedrock, groundwater recharge, and groundwater susceptibility.

Project scope and deliverables

The purpose of this project was to complete the first two elements of the Hydrogeologic Atlas: compilation of a private water well database, including analysis of these well records, and preparing a countywide water-table map.

The work reported here follows recommendations from a groundwater study in 2015 that focused on two agricultural areas within Bayfield County (Gotkowitz and Li, 2016). The 2015 project included a series of maps and cross sections illustrating groundwater resources and typical well construction in the agricultural regions. A water-table map and well database were also developed for these areas. This project expands that work to the entire county.

The following tasks were performed for this project:

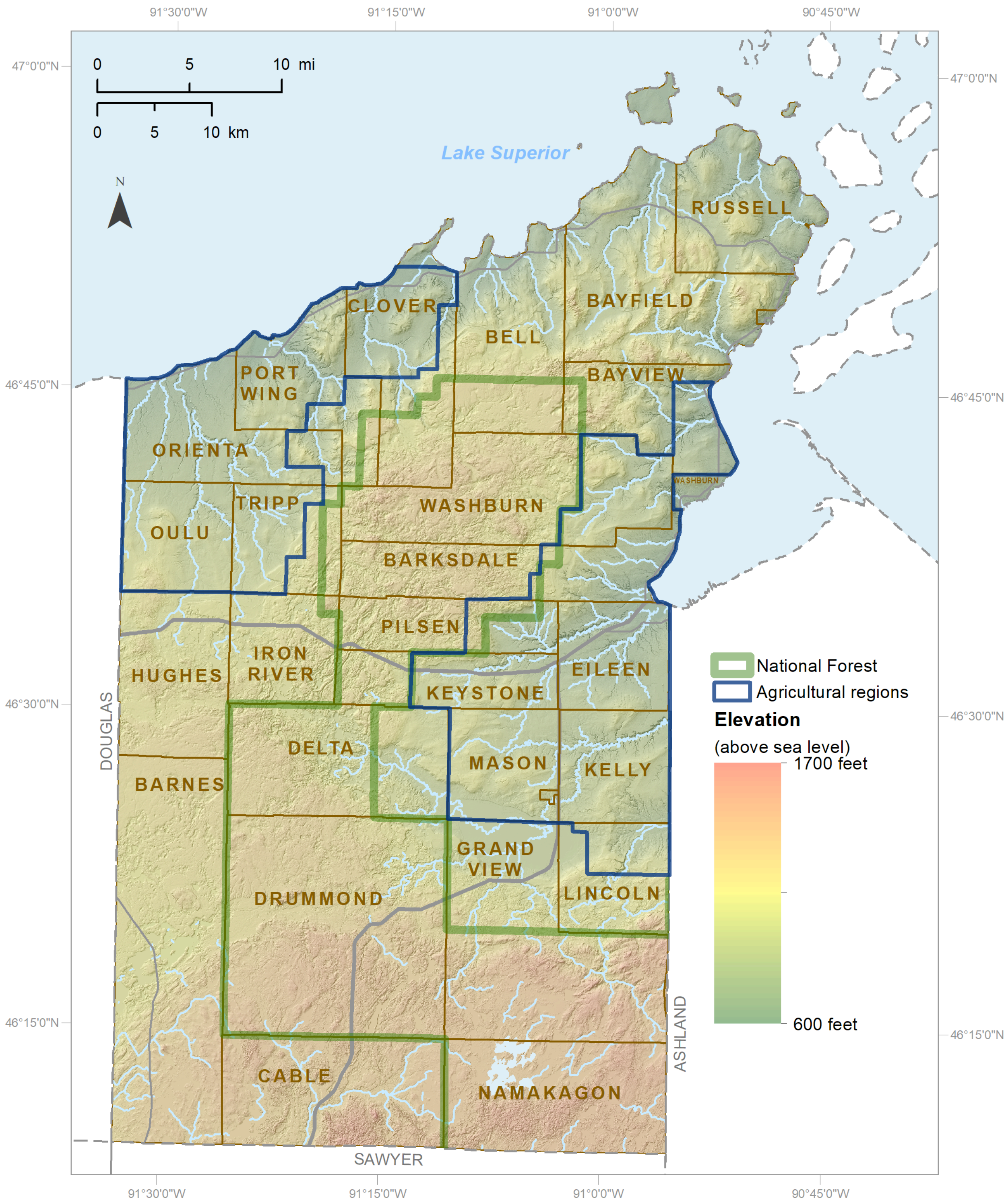
1. Created a countywide well database from well construction reports maintained by the Wisconsin Department of Natural Resources (DNR).
2. Categorized well records by aquifer type (e.g. sand, sandstone, granite), and the presence or absence of fine-grained geologic sediment overlying the well screen. This information is useful in evaluating the susceptibility of wells to surface contamination.
3. Provided scanned images of well records from 1936-1989 and a data-entry form for Bayfield County staff to add these older well records to the database.
4. Developed a water-table elevation map showing general direction of groundwater flow.

Project deliverables include this report, a countywide water-table map, and a database of well records and well characteristics. 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.uwex.edu).

Project setting

The study area covered all of Bayfield County in northern Wisconsin (fig. 1). This project expanded on previous work in two agricultural regions shown for reference on fig. 1. Most agricultural land use in the county is located within these two lowland regions. Outside of the agricultural regions, the Chequamegon-Nicolet National Forest covers much of central and southeast Bayfield County. The portion of the National Forest that lies between the two agricultural regions, in the Bayfield highlands, is characterized by sandy, high-relief topography around 1,300 feet in elevation with few surface-water features. In southern Bayfield County, lower-relief uplands over 1,500 feet in elevation have abundant lakes and streams. Between these areas is a transition zone where the land surface dips steeply to the north.

Figure 1. Shaded topographic relief map of Bayfield County showing agricultural regions and National Forest boundaries.



Geology

The following description of Bayfield County geology expands on the description previously reported in Gotkowitz and Li (2016).

Surficial geology

The uppermost (surficial) geologic sediment covering much of the Bayfield lowlands near Lake Superior 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). Lenz and others (2003) hypothesize that these alternating layers of sand and clay can create perched shallow groundwater conditions that are over 100 feet above the water elevations in deeper wells.

The Miller Creek Formation was not deposited in areas above the Lake Superior lowlands; here, the uppermost material is a coarse-grained glacial sediment, the Copper Falls Formation. The coarsest of these deposits are found in the Bayfield highlands; some moderately coarse sediment consisting of clayey, silty sand is present in parts of southeast Bayfield County (Clayton, 1984).

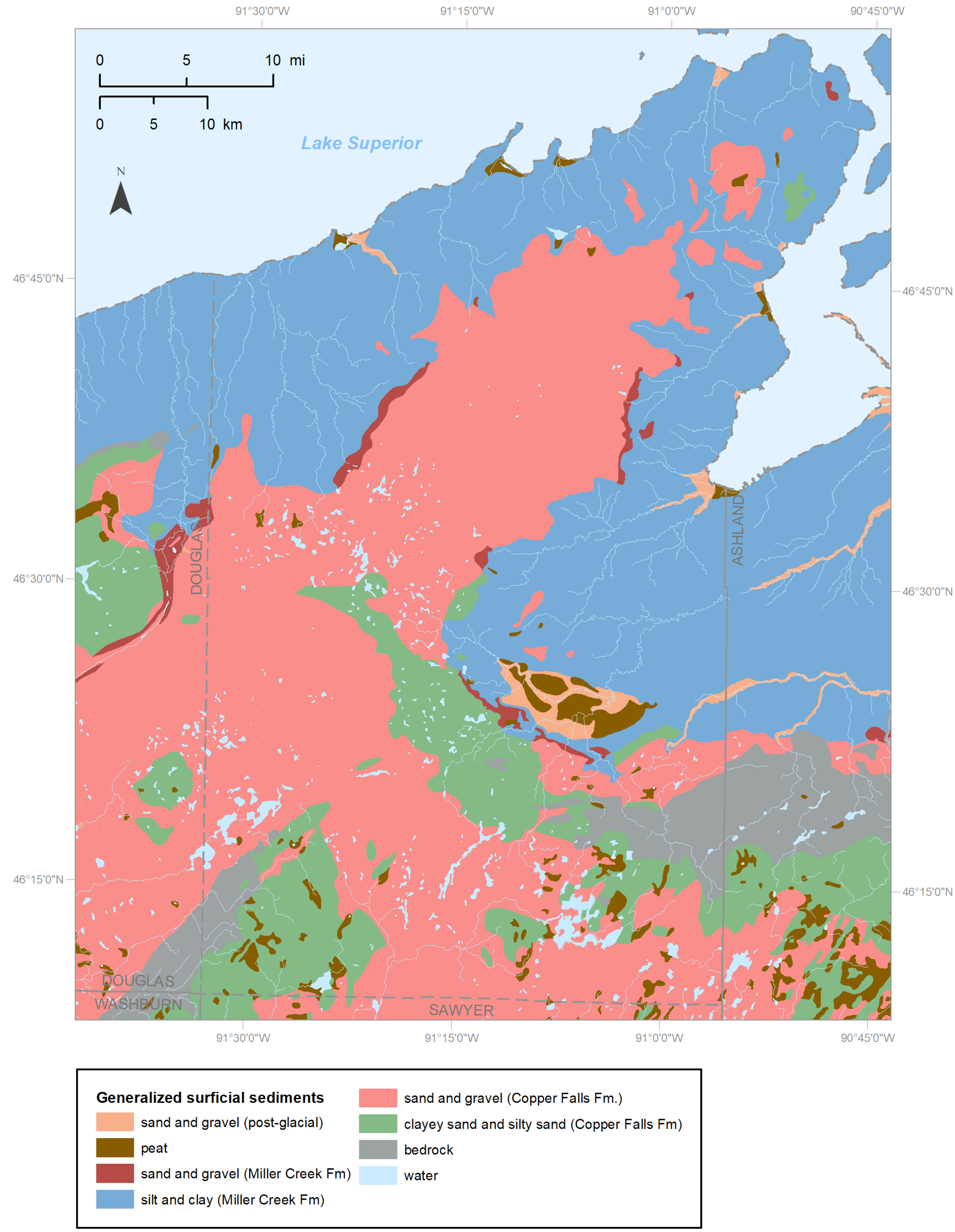
The Bibon Marsh wetlands are located north of the steeply north-sloping topography near the southern extent of the Miller Creek deposits. Peat deposits are at the land surface in this low-lying area (fig. 2).

Glacial deposits are hundreds of feet thick in the central peninsula and thin towards Lake Superior. Sediments are thin to absent in some parts of the southeast and in the high-relief transition zone where bedrock outcrops at the surface (Clayton, 1984).

Bedrock geology

Bedrock of the Bayfield Group consists of a series of quartzose sandstone formations that underlie most of northern Bayfield County (Ojakangas and others, 2001). Estimated to be several thousand feet thick, these rocks form a prolific aquifer due to this thickness (Fienen and others, 2016). South of the sandstone is a belt of igneous rock that generally corresponds to the steeply north-dipping topography. Bedrock in the southeast consists of Archean crystalline rock, primarily granite (Mudrey and others, 1982).

Figure 2. Generalized map of surficial geologic deposits in Bayfield County, modified from Clayton (1984).



Well database

The well database for Bayfield County includes 3,360 well records maintained by the Wisconsin Department of Natural Resources (DNR) that were compiled as part of a separate project (Mauel and others, 2010). These well construction reports contain information about the well location; depth of well and casing, liner, or screen; geologic materials observed by the driller; and water level and pumping test data. Additional fields were appended to the database by WGNHS to facilitate interpretation of the hydrogeologic setting. Wells were placed in the best-known location in GIS and assigned a value in a field designated for "location accuracy." The elevation of the land surface at the well was subsequently assigned based on the Bayfield County lidar elevation (Scott Galetka, pers. comm., 2017) at that location. For wells that reached bedrock, the bedrock elevation was calculated by subtracting the depth to bedrock from the land surface elevation.

For this project, fields based on well construction were added to the well database; these are discussed in more detail in "Typical well construction in Bayfield County" below.

Well construction

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 to eliminate downward leakage around the casing. Casing usually consists of steel or plastic pipe that extends from a foot or so above the ground surface to a depth determined by state well codes and by the well driller. Water enters the well along the length of open well bore between the bottom of the casing and the bottom of the well. The casing is sealed in place with grout or cement to prevent surface runoff from flowing down along the well casing. Shallow wells and wells with poorly sealed casings are more susceptible to contamination from the land surface.

Some geologic settings offer natural protection from surface contaminant sources. Wells completed in shallow, fractured bedrock and wells with thin or coarse overlying soil typically have more direct routes for groundwater to infiltrate from the surface, and are therefore more susceptible to contamination. As described by Gotkowitz and Li (2016), 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.

Typical well construction in Bayfield County

Of the 3,360 wells in the county database, 3,044 wells had sufficient geologic information to be catalogued in more detail. These wells were first categorized by the type of material recorded at the well screen (fig. 3, table 1). Of these wells, 2,458 (about 80 percent) are completed in glacial deposits and screened in sand, gravel, or a mix of sediments. The remaining wells are drilled into bedrock, with 481 completed in sandstone and 105 completed in other bedrock such as basalt or granite. Table 1 shows the average and range of well depths in each group; figure 4 shows the spatial distribution of well depths for all wells.

Wells were also categorized by the presence of fine-grained sediment above the well screen (figs. 5 and 6, table 1). Fine-grained materials such as clay, when present above a well screen, can act locally as an impediment to downward groundwater flow. This fine-grained material, here referred to as a cap, can protect a well from surface contamination. Based on analysis of well construction records, these fine-grained deposits seem to vary significantly in depth and thickness at wells located relatively close together, as illustrated in figures 5 and 6. Figure 5 shows wells with no fine-grained sediment above the well screen; these wells are considered most susceptible to surface contamination. Figure 6 shows all wells classified by the thickness of fine-grained sediment, with greater thickness corresponding to greater likelihood of protection from contaminants. Sediments were classified as fine-grained if the well construction report described sediment as clay, clay and gravel, mud or muck, or silt. Descriptions on construction reports that suggest coarser sediment, such as sand and clay, till, and hardpan, were conservatively excluded from this analysis, as were definitive descriptions, such as sand and gravel.

Figure 3. Well records in Bayfield County, categorized by the type of geologic material recorded at the well screen.

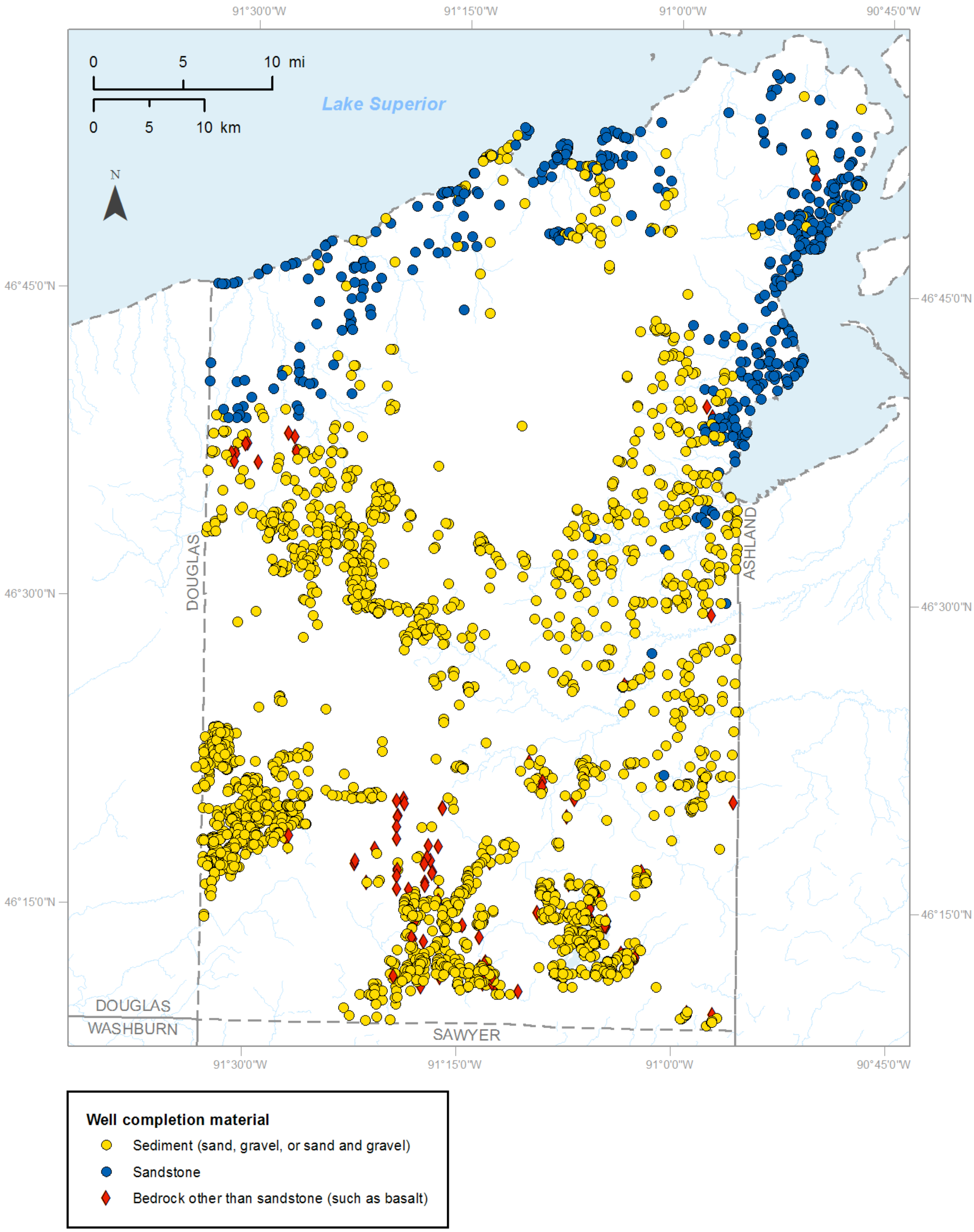


Figure 4. Well records in Bayfield County, categorized by the depth to the bottom of the well.

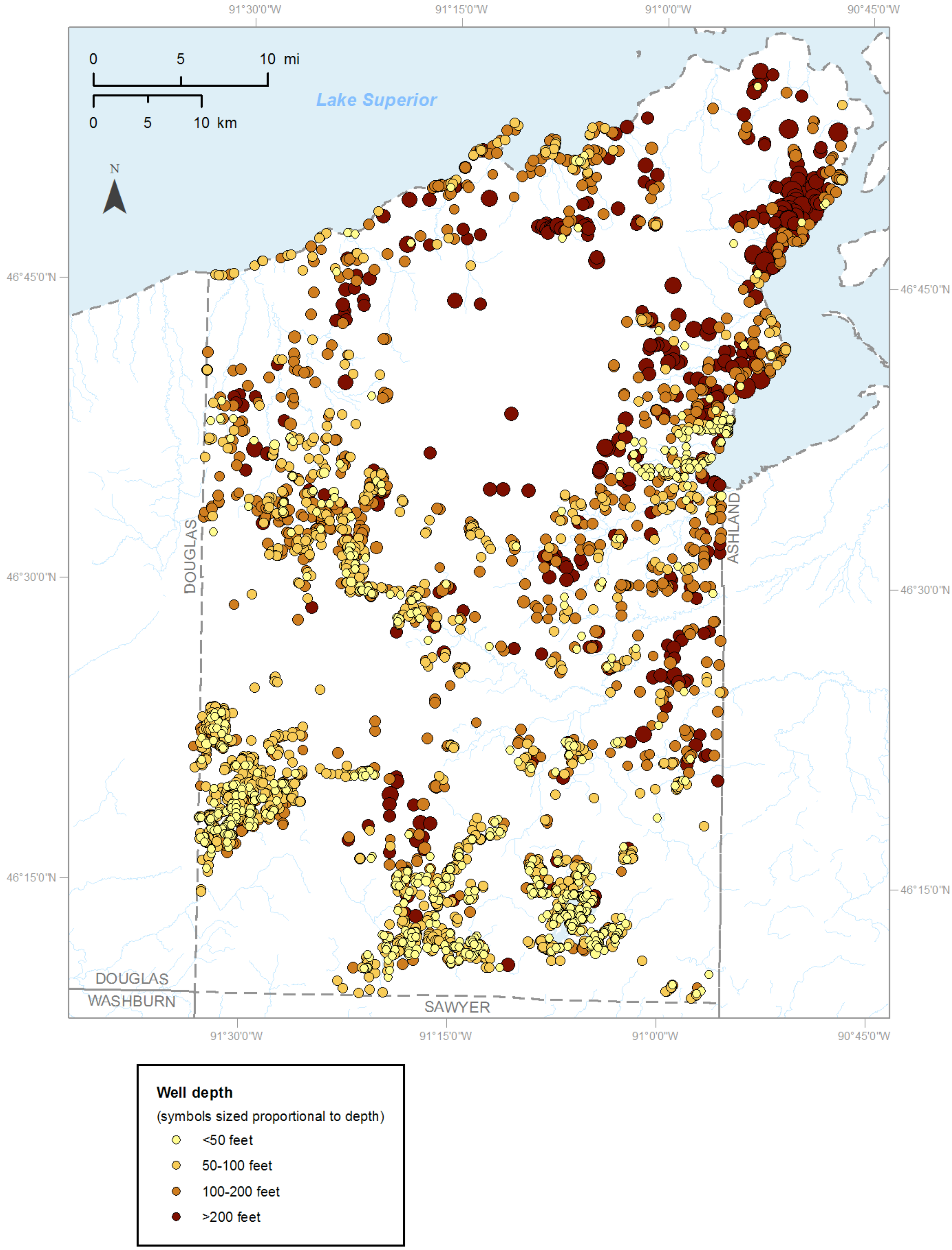


Figure 5. Wells in Bayfield County with no natural protection from overlying fine-grained sediment. The degree of natural protection for all wells in the county is shown on figure 6.

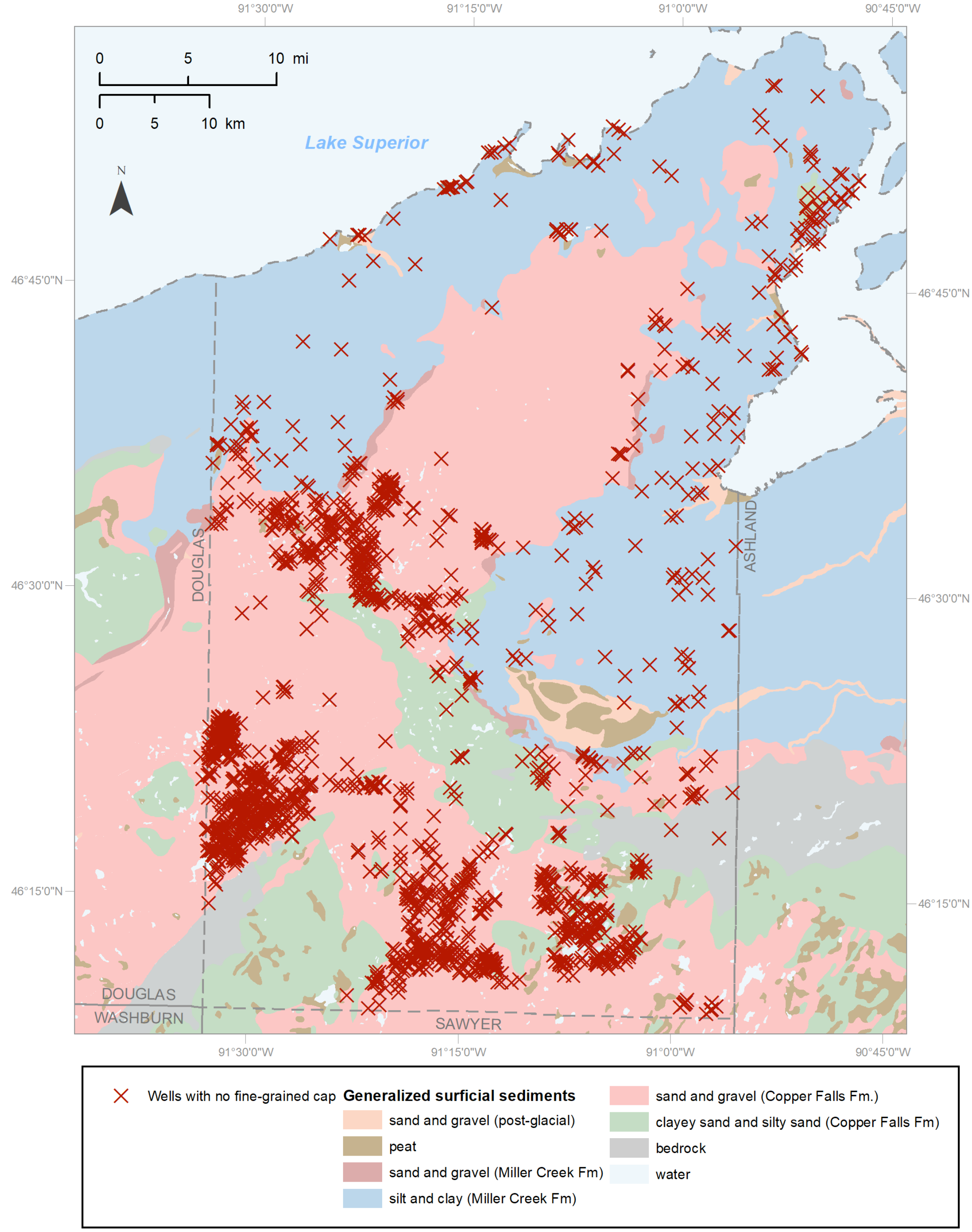
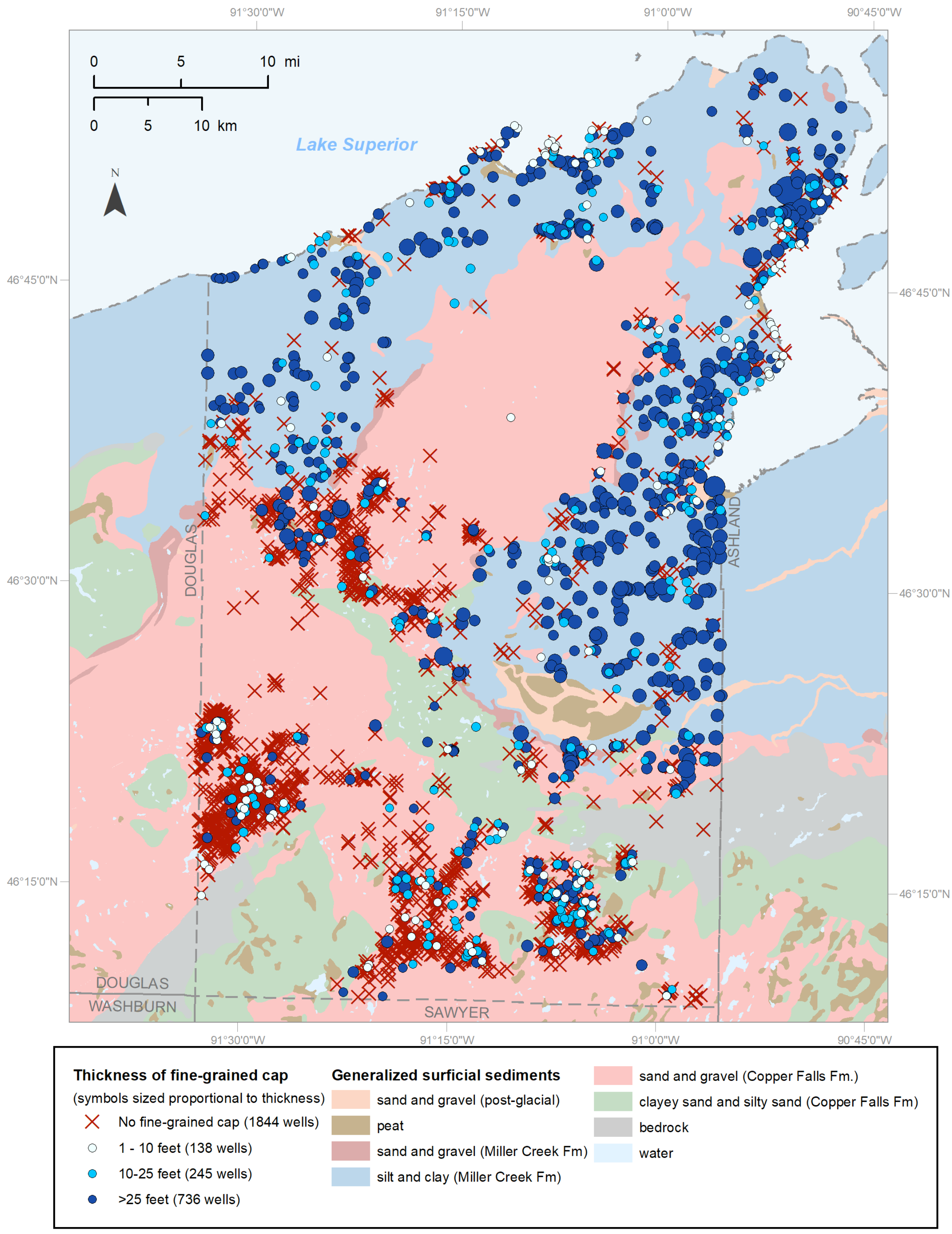


Figure 6. All wells in Bayfield County, showing degree of natural protection from overlying fine-grained sediment. The well symbol size is proportional to the thickness of this protective cap of sediment. For a map of the most vulnerable wells with no protection, see figure 5. Wells with unverified locations not shown.



For this analysis, each well was classified by both the number of fine-grained layers and the total thickness (sum) of these layers. A well with a single 20-foot thick clay layer and a well with 10 feet of clay over 10 feet of silt have the same thickness (20 feet), but a different number of layers (1 vs. 2). Wells with alternating sand and clay, while better protected than a well with no clay at all, have the potential to route contaminants through the coarse-grained sand lens. As a result, wells with multiple layers are interpreted as having some uncertainty in the level of protection. Well construction records in the database can help to further evaluate a specific well of interest.

Table 1. Well characteristics in the study area

Completion material	Number of wells	Average depth of well (feet)	Minimum depth (feet)	Maximum depth (feet)	Average thickness of fine-grained cap (feet)
Sand, gravel	2,458	100	21	494	10
Sandstone (bedrock)	481	219	59	800	42
Bedrock other than sandstone	105	177	32	420	19

Implications for protecting groundwater quality at wells

The majority of wells in Bayfield County are completed in sand and gravel, particularly where the sandy Copper Falls Formation is present (fig. 2). These wells are, on average, relatively shallow with a thin cap of fine-grained sediments, suggesting higher vulnerability (table 1). However, both sandstone and sand-and-gravel wells can be susceptible to contamination. Sandstone wells are particularly vulnerable where fractures are present in the subsurface. 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. Many shallow wells are present in the southern portion of Bayfield County and immediately west of Chequamegon Bay (fig. 4).

About 60 percent of the catalogued wells have no protective fine-grained sediment cap and therefore potentially more susceptible to contamination from the land surface (fig. 5). Although such wells are present throughout the county, they are most prevalent in the south where the sandy Copper Falls Formation is present. Wells with little natural protection are also located along the Lake Superior shoreline where bedrock is near the land surface and the water table is shallow. Many of these wells are completed in fractured sandstone; the fractures provide a pathway for contamination to migrate with groundwater flow, with little to no natural attenuation. 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.

In other areas of Bayfield County, sandstone wells are generally deeper and have more over-lying fine-grained sediment than sand and gravel wells (table 1). Sandstone wells are often located in areas where the fine-grained Miller Creek Formation is present near the surface. In these areas, wells are typically drilled deeper to reach geologic materials with sufficient well yield (figs. 4 and 6). Wells protected by a fine-grained cap are most commonly located in lowland areas where the clay-rich Miller Creek Formation is present at the land surface (fig. 6).

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.uwex.edu/water-environment/well-records/.

Water-table map

The water-table map (plate 1) shows the approximate elevation of the water table in Bayfield County. This map and the following description are extensions of the map and report created for the 2015 agricultural areas project (Gotkowitz and Li, 2016).

The water table is the top of the saturated zone, where all pore space and fractures are completely filled with groundwater. A water-table map is used to identify the direction of shallow groundwater flow. The map allows one to easily understand and illustrate which wells, streams, or lakes are hydrogeologically down-gradient or up-gradient of an area on the land surface.

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 located in lowland areas near Lake Superior, such as the flowing wells at Maslowski Park in the city of Ashland and Sprague Well at Thompson's West End Park in the city of Washburn, tap groundwater at pressures that exceed the elevation of land surface. This indicates areas of upward vertical gradients within the groundwater system and causes water to flow without the need for a pump. In contrast, deep wells in upland areas of Bayfield County with water levels lower than the local water table indicate areas of downward vertical gradients.

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. The water-table elevation ranges from less than 625 feet along the Lake Superior shoreline to nearly 1,500 feet in southeast Bayfield County. Water-table contours represented as dashed lines indicate higher uncertainty due to a lack of known water elevations.

The configuration of the water table (that is, its shape and the resulting groundwater flow directions) reflect the regional hydrogeologic setting and topography. 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 groundwater divides, 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 vertically, or 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.

Groundwater divides in Bayfield County are shown on the map as thick gray lines. Groundwater flows away from a divide and ultimately discharges to wells, streams, and lakes. The location of regional groundwater divides often approximately corresponds to the location of surface water divides. For example, a major surface water divide in southern Bayfield County marks the boundary between flows to the Lake Superior Basin and to the Mississippi River Basin. Similarly, a regional groundwater divide runs roughly northwest–southeast across the southern third of the county.

Groundwater north of the divide flows towards the Lake Superior Basin and groundwater to the south flows into the Mississippi River Basin. A smaller divide splits northern Bayfield County along the Bayfield Peninsula: groundwater in the northwest flows to the northwest towards Lake Superior; in the northeast, groundwater flows generally east towards Chequamegon Bay.

In Bayfield County, the water table is typically highest in areas with relatively high amounts of recharge (Fehling and others, in review). 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 (Fienen and others, 2016; Fitzpatrick and others, 2014).

Locations of perennial streams (streams that flow year-round) are shown on the water-table map. The absence of streams in the area capped by Copper Falls indicates that rainfall and snowmelt readily infiltrate to the groundwater system in this area (fig. 2). Where the fine-grained Miller Creek till is present, infiltration to the water table is more limited and surface water runoff supports stream generation.

Map development

As with the 2015 agricultural regions project, map development began with water-table elevations simulated by an existing computerized groundwater flow model (Fehling and others, in review). 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.

To expand the water-table map to the entire county, detail was added to the existing model. The model domain included the entire county but focused on National Forest property, and some streams were represented in less detail than others. Surface elevations of these smaller streams were therefore added to improve model detail and maintain consistency. The simulated contours were then exported from the model for further editing.

The simulated elevation of the water table was refined by comparing it to elevations of land surface, streams, and lakes. Where present, perennial surface water features are considered the highest quality data because they provide long-term indications of groundwater elevation. Water levels in shallow wells were also used to help interpret the water table (plate 1). These wells reflect the water table with varying degrees of accuracy. Wells with shallowest depths are most likely to represent the water table. Water levels in deeper wells might reflect upward or downward gradients and may not match the water-table elevations shown on the map; these wells were used to gain a better understanding of the aquifer system as a whole. In general, downward gradients are more common in the center of the peninsula where most groundwater recharge occurs, whereas upward gradients are often observed near the Lake Superior shore. Artesian (or flowing) wells near the shore are evidence of these upward gradients.

Using the map

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 down-gradient 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.

Conclusions

Groundwater flow and well construction in Bayfield County are influenced by the distribution of glacial deposits. Precipitation and snowmelt infiltrate in the sandy Copper Falls Formation in central and southern Bayfield County. Shallow sand-and-gravel wells are common in these areas. Groundwater flows away from the upland recharge area, and ultimately discharges to streams, wells, and lakes. Upward gradients are common where groundwater discharges to tributaries of Lake Superior. Here, the fine-grained glacial deposits of the Miller Creek Formation result in the drilling of sandstone wells and deeper sand-and-gravel wells.

Most wells in Bayfield County are completed in sand-and-gravel deposits. In general, wells completed at shallow depths, and with thinner overlying deposits of fine-grained materials, have less protection from surface contamination than deeper sand-and-gravel wells. Susceptible wells with little natural protection are most commonly located in southwest Bayfield County in the sandy Copper Falls Formation, as well as near the Lake Superior shore where glacial deposits are thin. Wells completed in sandstone are generally drilled deeper than sand-and-gravel wells, and have a thicker layer of natural protection. However, sandstone wells drilled in the shallow bedrock near Lake Superior are vulnerable to contamination due to the fractured nature of the sandstone.

The water-table map indicates the direction of groundwater flow. 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 down-gradient of specific facilities or agricultural fields.

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