Geologic Atlas of Renville County, Minnesota

County Atlas Series C-28

Part B, Hydrogeology

Report

To accompany these atlas components:

Map Figures 1–27

Plate 6, Chemical Hydrogeology

Plate 7, Hydrogeologic Cross Sections, A–A′ through D–D′

Plate 8, Hydrogeologic Cross Sections, E–E′ through I–I′

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County Geologic Atlas Program

The Minnesota County Geologic Atlas series has been produced since 1982. Recent atlases are produced in two parts.

Part A covers the geology and was produced by the Minnesota Geological Survey (MGS) in 2013. It contains the following: Plate 1, Data-base map; Plate 2, Bedrock geology; Plate 3, Surficial geology; Plate 4, Quaternary stratigraphy; Plate 5, Bedrock topography, depth to bedrock; and sand distribution model.

Part B covers the hydrogeology and is produced by the Minnesota Department of Natural Resources (DNR).

Explanations of the history and purpose of the program, atlas applications, and descriptions of the Part A and Part B components are available online:

- Part A, MGS (http://www.mngs.umn.edu/county_atlas/countyatlas.htm)
- Part B, DNR (mndnr.gov/groundwatermapping)

Technical Reference

Maps were compiled and generated in a geographic information system. Digital data products are available on the DNR County Geologic Atlas Program page (mndnr.gov/groundwatermapping).

Maps were prepared from DNR and other publicly available information. Every reasonable effort has been made to ensure the accuracy of the factual data on which the report and map interpretations were based. However, the DNR does not warrant the accuracy, completeness, or any implied uses of these data. Users may wish to verify critical information. Sources include both the references here and information on file in the offices of the MGS and the DNR. Every effort has been made to ensure the interpretations conform to sound geologic and cartographic principles. These maps should not be used to establish legal title, boundaries, or locations of improvements.

These bases were modified from the MGS, Renville County Geologic Atlas, Part A, 2013. Universal Transverse Mercator projection, zone 15, North American Datum of 1983. North American Vertical Datum of 1988.

Conversion Factors	
12 inches = 1 foot	1 kilometer = 0.621 miles
5,280 feet = 1 mile	1 inch per hour = 7.056 x 10^{-6} meters per second
1 foot = 0.3048 meters	1 part per million = 1 milligram per liter
1 meter = 1000 millimeters	1 part per billion = 1 microgram per liter
1,000 meters = 1 kilometer	1 milligram per liter = 1,000 micrograms per liter

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Geologic Atlas of Renville County, Minnesota, Part B

By Randy J. Bradt

Introduction

This report, the map figures, and the plates are **Part B** of the Renville County Geologic Atlas. Part B describes the county's hydrogeology and is produced by the Minnesota Department of Natural Resources (DNR). It builds on the geology described in Part A, which was published by the Minnesota Geological Survey (MGS).

The purpose of this atlas is to help users understand the hydrogeologic setting and inherent pollution sensitivity of the aquifers in the county. This information can be used to make land-use decisions that take aquifer sensitivity, water quality, and sustainability into account.

This atlas contains three parts.

1. The **Report** provides a description of the hydrogeologic setting, water levels, chemistry, pollution sensitivity, use of aquifers within the county, and descriptions of the map figures and plates.
2. **Map Figures 1–27** include maps referenced in this report at a 1:250,000 scale, including the water table, potentiometric surface, and pollution sensitivity.
3. **Map Plates 6–8** are at a 1:100,000 scale to provide greater detail in areas of interest. Plate 6 illustrates the water chemistry and Plates 7 and 8 use hydrogeologic cross sections to illustrate groundwater flow directions and residence time within the buried sand and gravel aquifers and bedrock aquifers.

The following information is incorporated into the maps and cross sections to illustrate the distribution of aquifers, aquitards, groundwater recharge, and subsurface flow within the county.

Geology and physical hydrogeology outlines the characteristics of the geologic units from the land surface to the bedrock. Hydrostratigraphic characteristics of aquifers or aquitards are identified with their corresponding geologic units from Part A.

Groundwater elevation maps provide a broad look at the direction of groundwater flow in unconfined conditions (water-table elevation) and confined conditions (potentiometric elevation surfaces).

Chemical hydrogeology provides information about the water source, flow path, travel time, and residence time of groundwater. The groundwater chemistry supports the results of the pollution sensitivity models and is used to identify areas of interest, such as those with high pollution sensitivity or elevated levels of potentially harmful chemicals.

Hydrogeologic cross sections bring the physical hydrogeology and groundwater chemistry together to illustrate groundwater flow, residence time, and distribution of chemical characteristics. Cross sections help define areas of interest, such as important groundwater recharge and discharge areas, and pollution sensitivity.

Pollution sensitivity is modeled for the near-surface materials and for the mapped buried sand and gravel aquifers and the bedrock surface.

The sensitivity of *near-surface materials* is an estimate of the time it takes for water to infiltrate the land surface to a depth of 10 feet. This model is based on hydrologic soil groups and surficial geologic matrix textures.

The sensitivity of *buried sand and gravel aquifers* and *the bedrock surface* is based on the cumulative thickness of fine-grained sediment (aquitard material) overlying an aquifer or the bedrock surface. The pollution sensitivity ratings are compared to tritium and carbon-14 data for residence time, and to inorganic chemistry constituents for model evaluation.

Aquifer characteristics and groundwater use summarize specific capacity tests, aquifer tests, and water use records (from groundwater appropriation permits) for each aquifer, where available. These data help hydrogeologists plan for new well installations to meet requirements for a given use. The DNR groundwater level monitoring data is summarized to identify monitoring efforts that are underway in the county.

A **Geologic Atlas User's Guide** is available from the MGS for additional information on the history and purposes of the program, various atlas applications, and descriptions of the Part A components (Setterholm, 2014).

Geology and physical hydrogeology

Renville County is located in the west-central portion of southern Minnesota, with the southern boundary largely defined by the Minnesota River (Map Figure 1). It comprises approximately 987 square miles and less than 5 percent is open water. The topography is flat to rolling in most of the county except along the southern border, where the Minnesota River and its tributaries are deeply incised, creating river gorges with wooded bluffs and tributary ravines.

Portions of four major watersheds occur in the county (Map Figure 2). Three watersheds drain surface water from approximately 74 percent of the county south to the Minnesota River. The fourth watershed in the northeast corner drains and discharges the remaining 26 percent to Buffalo Creek eastward to the South Fork Crow River and eventually to the Mississippi River. The Minnesota River has several tributaries in the county, the largest of which are Hawk Creek and Beaver Creek. The largest tributary to the South Fork Crow River is Buffalo Creek.

Surficial geologic units and aquifers

Surficial deposits in Renville County are dominated by glacial sediment of the Des Moines lobe (Part A, Plate 3). This sediment was deposited in multiple phases of glacial ice advance and retreat resulting in multiple layers of glacial till with slightly different lithologic compositions. As ice streams retreated from the region, meltwater became ponded in glacial lakes on the low-relief landscape, leaving deposits of silt and clay. The largest and longest duration of these lakes, glacial Lake Benson, formed in western Renville County (Part A, Plate 3, Figure 2). As the Des Moines lobe retreated to the northwest, the lake formed between its ice margin and the small recessional moraine near Sacred Heart Creek. Lacustrine deposits from these lakes occur primarily in the northern and western portions of the county. Most of these sediments are less than ten feet thick.

Surficial sand and gravel deposits are typically no more than 20 feet thick and are found in modern and older glacial stream channels (Part A, Plate 5, Figure 3). These sand and gravel deposits occur in an east-west meandering channel in northern Renville County as a result of glacial Lake Benson discharge during high water events. This is outlined in Part A, Plate 3: “Glacial Lake Benson had at least two levels and outlets. It initially drained east through a valley now occupied in part by Chetamba Creek (Rittenour and others, 1998) and the South Fork Crow River. As the ice retreated, it subsequently drained to the south through valleys now occupied by Hawk, Beaver, and Sacred Heart creeks.”

After the Des Moines ice lobe retreated, drainage from a distant large glacial lake (glacial Lake Agassiz) created the 150–200-foot deep glacial River Warren valley that is currently occupied by the Minnesota River. This large valley locally exposes underlying bedrock along the southern boundary of the county. The sudden creation of the deep valley caused all of the preexisting tributaries to adjust their gradients to the new local base level, a process that is ongoing. Fluvial and slope processes have altered the sides of the Minnesota River valley, creating ravines that lead to fans on the valley floor and gravitational failure of sediment and rock in steeper portions of the landscape. Locally thick sand and gravel deposits (exceeding 100 feet) are found in the Minnesota River valley. Some of these sands were deposited as terraces at higher elevations and may not have sufficient saturated sediments to be considered aquifers. A water-table aquifer occurs where these sediments are sufficiently saturated.

Water table

The water table is the surface between the unsaturated and saturated zones where the water pressure equals the atmospheric pressure. The water table occurs in both aquifer and aquitard sediment across the entire county.

Surficial sand and gravel aquifers are present below the water table where there is sufficient saturated thickness and yield to install a well and economically pump groundwater.

The water-table elevation (Map Figure 2) is estimated from several sources of data:

- The elevation of surface-water bodies (such as rivers, perennial streams, lakes, and wetlands)
- Static water levels in surficial sand wells obtained from well records in the County Well Index database (converted to elevations*)
- Estimates of wet soil conditions from the Natural Resources Conservation Service county soil survey (converted to elevations*)

**Data were converted to elevations using a digital elevation model derived from Light Detection and Ranging technology.*

The depth to water table (Figure 3) is derived by subtracting the water-table elevation from the land-surface elevation. More details on how these maps were made can be found in *Methods for estimating water-table elevation and depth to water table* (DNR, 2016a).

The water-table maps provide guidance for many applications, but additional site-specific information should be used to refine information at local scales. Certain conditions can affect the fluctuation of the water table and can create locally different results from the maps that were created using this procedure. Some of these include, but are not limited to, seasonal weather conditions, extent and composition of surficial geology units, land-use practices, vegetation composition and distribution, and pumping of large-capacity wells. There are also limited data along the valley walls of the high-relief Minnesota River valley. The resulting water-table elevation in those locations can be variable and is poorly constrained.

The water table generally follows the surface topography. Based on the data, the water table is estimated to be within ten feet of the land surface across most of the county. The depth to water table is estimated to be greater than 10 feet near the upland valley edges and terraces within the Minnesota River valley.

Buried sand and gravel aquifers

Deeper unconsolidated sediment layers were deposited during multiple episodes of glaciation dating between 14,000 and 780,000 years before present (Part A, Plate 4). An unsorted mixture of clay, silt, sand, and gravel was brought to the region by glaciers and deposited directly by the ice (till). Sand and gravel deposits may be found between these till layers, most of which were deposited in glacial streams. These stream deposits were confined to narrow drainages and low areas on the landscape.

Later ice advances, may have eroded and limited the lateral extent of these sand and gravel deposits to no more than a few miles, and often much less (Part A, Plates 4 and 5). The buried sand and gravel deposits are generally less than 20 feet thick with locally thicker deposits in the sz aquifer, and to a lesser extent in the s3, s5, and su aquifers.

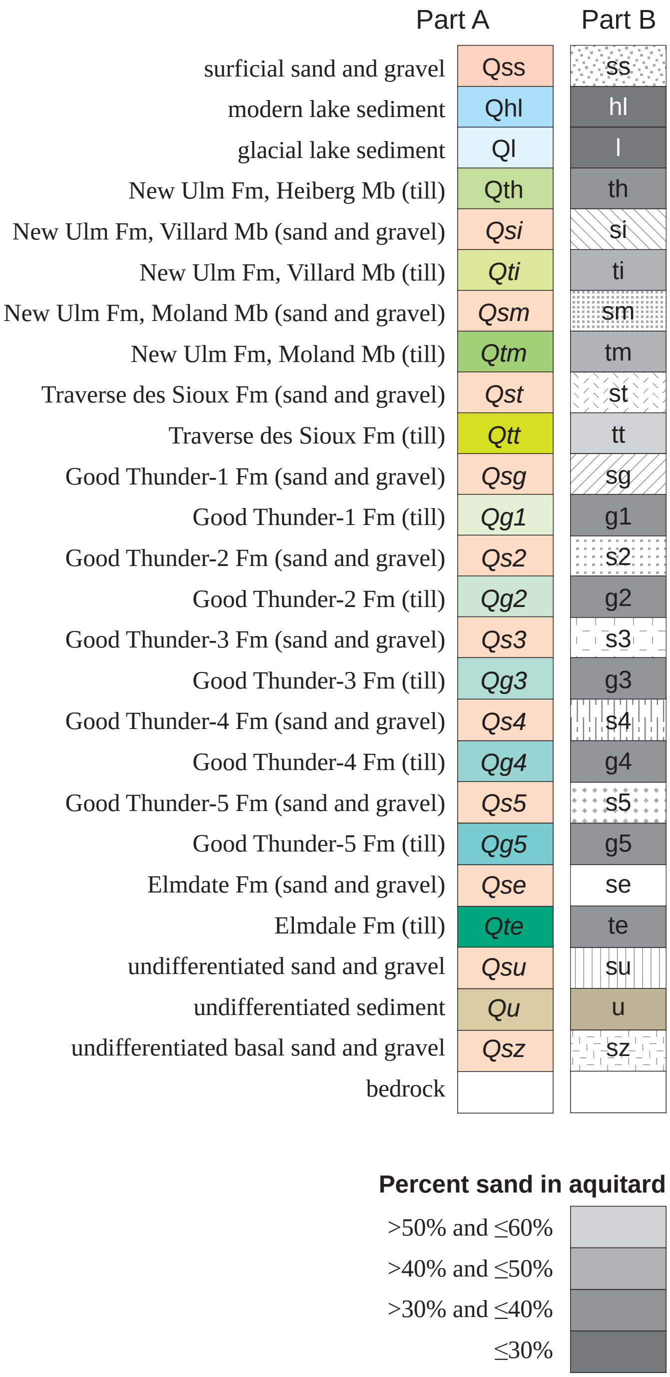
The unconsolidated sediment thickness in Renville County varies from 0 to over 450 feet because the bedrock surface elevation varies 350 feet throughout the county. The thickest deposits in the central portion of the county are associated with a large west-to-east trending preglacial valley carved into the bedrock surface (Part A, Plate 5). In areas within the Minnesota River valley, the sediment is often less than 50 feet thick, and there are local outcrops of Precambrian bedrock.

The stratigraphic column summarizes the geologic units and hydrogeologic properties of the glacial sequence and correlates the corresponding Part A and B unit names and map labels.

The Part B units are represented as follows in Report Figure 1 and Plates 7 and 8.

- *Aquifers* are represented with *patterns.*
- *Aquitards* are shown as *shades of gray*, representing the relative hydraulic conductivity. Lighter shades represent units with more sand, implying a higher hydraulic conductivity. The shades of gray are based on the average sand content of the aquitard, which is determined from the portion of the matrix that is less than 2 millimeter grain size.

  Lacustrine sediment textural information (hl and l) is not described in Part A (Plate 4, Table 1) but is shaded as having less than or equal to 30 percent sand (A.R. Knaeble, oral commun., 2016).
- *Undifferentiated* sediment (u) with an unknown texture is shown in *brown*.



Report Figure 1. Hydrostratigraphy of Quaternary unconsolidated sediment

Aquifers are shown with patterns and aquitards are shown in shades of gray. Shades of gray on the aquitards correspond to the sand content within the till (Part A, Plate 4, Table 1).

Glacial and modern lake sediments (hl and l) are not included in Part A, but are shaded to reflect a less than or equal to 30 percent sand content.

Elmdale sands are not symbolized as they are not present in cross sections on Plates 7 and 8.

Potentiometric surfaces of buried sand and gravel aquifers

Note: the "buried sand and gravel aquifers" will subsequently be referred to as the "buried sand aquifers."

In confined aquifers, pressure causes water to rise in a well to a level higher than the top of the aquifer. These water levels are measured and contoured to create a map of the *potentiometric surface* for each aquifer. The resulting groundwater-level elevation maps show changes in water levels similar to the way topographic maps show changes in land-surface elevations.

The potentiometric surface of an aquifer represents the potential energy that is available to move groundwater. As groundwater moves from higher to lower potentiometric elevations it flows perpendicular to the potentiometric elevation contours. Flow directions are shown in Map Figures 4 through 12.

Groundwater flows from recharge areas through the aquifer to discharge locations within a wide continuum of depth, distance, and time. Flow into, through, and out of shallow aquifers can take days to weeks to travel distances of up to a mile. Flow in deeper aquifers can take centuries to millennia to travel dozens of miles. When combined with other information, high elevation areas on the potentiometric surface can indicate important recharge areas.

Potentiometric surface maps for Renville County incorporate static water-level data from well information in the County Well Index, measurements made by DNR staff, and river elevation points along the Minnesota River and portions of its perennial tributaries (every 500 meters). The tributaries points were only used where the target aquifer was within 50 feet of the overlying stream bottom. River elevation points are included because perennial rivers receive groundwater discharge from buried sand aquifers. The County Well Index records used in the map development were measured from the 1960s to 2014 and represent various climatic and seasonal conditions over that time period, so some uncertainty is present in the potentiometric surface elevations.

The potentiometric contours are shown as solid lines inside mapped aquifers and dashed lines outside mapped aquifers. Although the potentiometric surface of an aquifer does not extend beyond the aquifer boundary, the dashed lines are shown to indicate general groundwater flow direction. The extent and thickness of buried sand aquifers are often not well constrained, especially for deeper aquifers, and the aquifers may extend over a broader area than shown.

Potentiometric surfaces were created for 9 of the 10 buried aquifers in Renville County (Map Figures 4 through 12). There are no wells completed in aquifer se so no potentiometric surface is mapped. Aquifers si and sm are combined into one map since they are both within 50 feet of the land surface and their respective water levels appear to suggest they act as one aquifer system. Many of the potentiometric surface maps share similar patterns of highest water levels in the north-central portion of the county, including a second elevated region located south of the city of Bird Island. Groundwater flow is generally toward the Minnesota River for most of the county. In the northeastern portion of the county, flow is more easterly with some of the flow toward Buffalo Creek and eventually to the South Fork Crow River. For the shallow and intermediate depth aquifers, the potentiometric contours bend near the larger streams as flow moves toward discharge areas along portions of those streams. The best examples are Hawk Creek and Beaver Creek.

Potentiometric surface maps for aquifers s4, s5, su, and sz show depressions in the potentiometric surface which are interpreted to be associated with large, long-term groundwater withdrawals. In some cases pumping appears to have lowered the potentiometric surface up to tens of feet below historical levels. Hachured potentiometric contours represent approximate locations of these pumping induced depressions (Map Figures 9 through 12). Evidence for these depressions is limited and is inferred from static water levels in areas where water levels may have been drawn down at the time a water level was collected. Additional pumping depressions may exist but are not shown on these maps. Other evidence supporting the existence of these depressions can be seen in the hydrograph for observation well 420053 (Report Figure 8, bottom). The hydrograph shows lowered water levels caused by the city of Granite Falls pumping large volumes of water. For a detailed discussion on large capacity water use associated with these depressions, go to the "Groundwater use" section of this report.

Bedrock geologic units and aquifers

The bedrock ranges in age from Paleoarchean (3,600 to 3,200 million years old) to Late Cretaceous (approximately 90 million years old) and records a complex history involving multiple igneous, sedimentary, metamorphic, and tectonic events, as well as protracted episodes of weathering and erosion (Part A, Plate 2). The majority of bedrock is Precambrian crystalline rock with little or no primary porosity. These rocks generally do not function as an aquifer except where secondary porosity has developed by fracturing or leaching. Well yield is variable and often poor as evidenced by greater well screen lengths and long sections of open hole in many of these wells.

A mantle of saprolite covers most of the Precambrian bedrock surface in the county, varying in thickness from a few feet to several hundred feet (Part A, Plate 2). Saprolite is a residuum of extensive chemical weathering that converted some or nearly all of the minerals in the bedrock into various clay minerals. It is present nearly everywhere in the county, except along the Minnesota River valley and some tributary valleys where it was presumably removed by erosion.

Saprolite is covered locally by isolated and thin patches of Cretaceous sedimentary strata (unit Ku), at thicknesses of less than 50 feet. These Cretaceous deposits are mostly clay and shale with less abundant sandstone. The extent of these deposits is shown in Part A, Plate 2. Yields to wells completed in these Cretaceous deposits are generally 5 to 50 gallons per minute (gpm) (Kanivetsky and Walton, 1979).

Chemical hydrogeology (Plate 6)

The types and concentrations of dissolved elements and compounds in groundwater provide information about the recharge areas, the geologic layers that the water has flowed through, and approximately how long the water has been underground (residence time). All groundwater originated as precipitation or surface water that seeped into the ground, through the soil layer, and into the pores and crevices of aquifers and aquitards. Water moves in complicated but definable patterns: into aquifers as *recharge*, through aquifers, and out of aquifers as *discharge*. Water chemistry is used to provide information such as the following:

- Groundwater recharged from surface water can be identified from the effect of evaporation on the isotopes of hydrogen and oxygen.
- Groundwater residence time is estimated from tritium and carbon-14 isotopes. Tritium is used to identify water that has moved into the subsurface since the 1950s. Carbon-14 is used to determine groundwater residence times of centuries to millennia.
- The distribution of select naturally occurring elements can indicate areas where groundwater consumption is a potential concern to human health.

Water sampling

To better understand groundwater movement and pollution sensitivity in the county, 91 groundwater samples were collected from wells in a range of aquifers along with 1 lake sample. Samples were collected according to the protocols outlined in the Appendix.

Chemical data from well-water samples were used along with primary physical data (static water level and aquifer tests) to understand water movement. Wells were selected for sampling based on their hydrogeologic setting and aquifers were selected for their significance for domestic water supply. An ideal well-sampling network is evenly distributed across the county, includes the more populated areas, and targets surface water and groundwater interaction in the vicinity of lakes and large rivers.

The network distribution depends on citizen willingness to participate. Approximately 1000 well owners were contacted through letters that included a description of the project and a reply card to return if they were willing to participate. Approximately one-third of those contacted gave permission for sampling.

Groundwater recharge sources

As water moves from precipitation to groundwater, chemical changes occur that can help determine whether groundwater was recharged directly from precipitation, lake water, or a mixture of the two. Stable isotopes of oxygen and hydrogen are useful for determining groundwater and surface-water interactions. Oxygen and hydrogen each have two main stable isotopes: ^{18}O and ^{16}O, and ^{2}H and ^{1}H. The different mass of the isotopes causes evaporation at different rates, which results in *fractionation,* leaving behind different ratios of heavy to light isotopes. This results in isotopic signatures that are unique to groundwater with different sources.

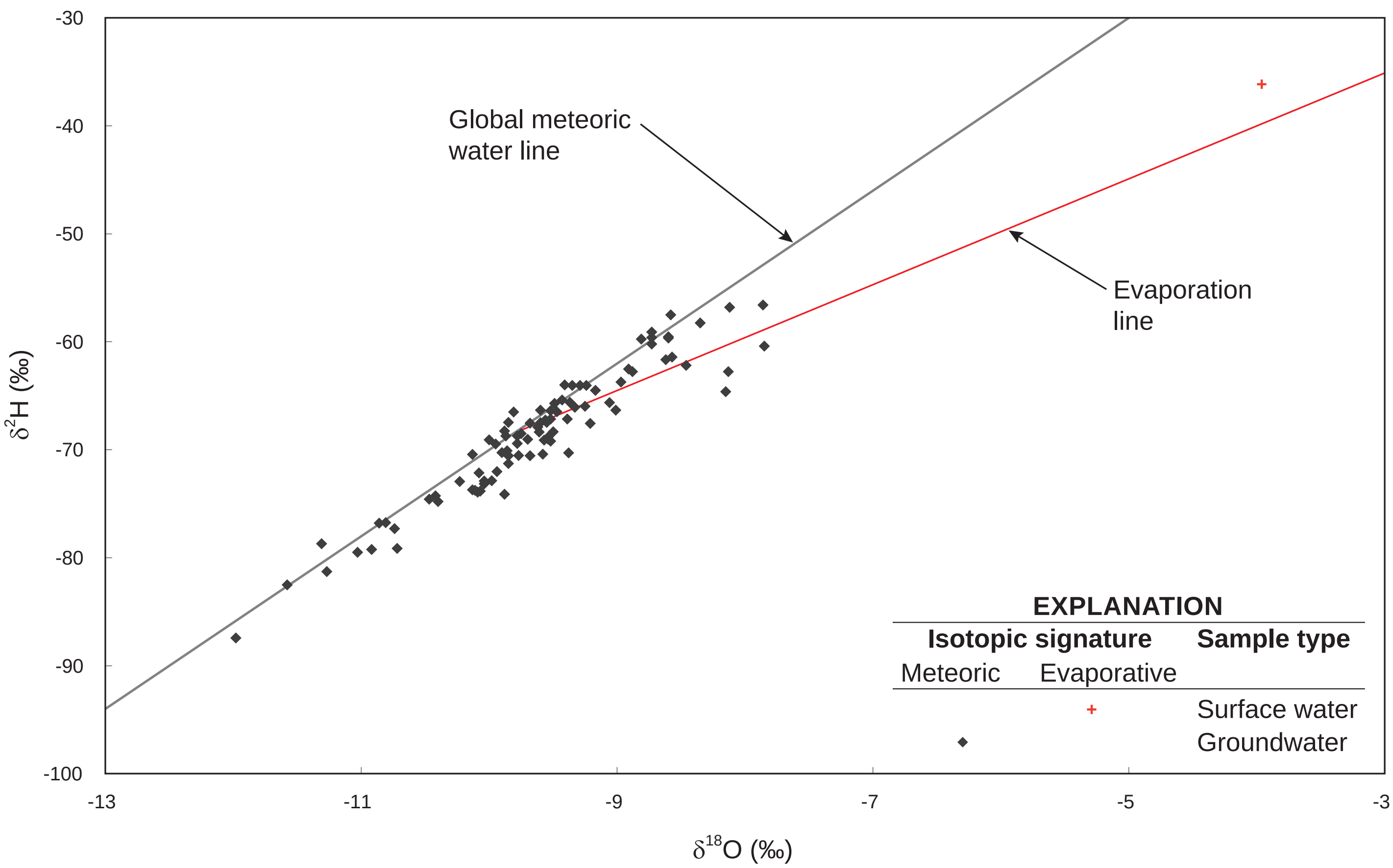
- Groundwater recharged from *precipitation* exhibits a *meteoric* isotopic signature. It infiltrates directly into the ground, leaving the isotopic ratio unchanged.
- Groundwater recharged from *open water* such as lakes or wetlands exhibits an *evaporative* isotopic signature. It has been subjected to fractionation where light isotopes evaporate into the atmosphere, leaving a ratio favoring heavier isotopes.

To identify the source (precipitation or surface water) of a groundwater sample, oxygen and hydrogen isotopic data are plotted against each other. The x-axis represents the oxygen isotope value ($\delta^{18}O$) and the y-axis represents the hydrogen isotope value ($\delta^{2}H$). The measured ratio in the sample is divided by the ratio in a standard (Vienna Standard Mean Ocean Water [VSMOW]). The $\delta^{18}O$ value is calculated from the $^{18}O/^{16}O$ ratio of the sample divided by the $^{18}O/^{16}O$ VSMOW standard. The $\delta^{2}H$ value is calculated from the $^{2}H/^{1}H$ ratio in the sample divided by the $^{2}H/^{1}H$ VSMOW standard.

Definition of delta (δ)

The stable isotope composition of oxygen and hydrogen are reported as δ values. δ (0/00) = (Rx /Rs-1)*1000 where R represents the ratio of the heavy to light isotope, $^{18}O/^{16}O$ or $^{2}H/^{1}H$ and Rx represents the ratio of the sample and Rs represents the ratio in VSMOW. Delta values are reported in units of parts per thousand (0/00 or permil) relative to VSMOW.

The groundwater samples collected for this atlas plot close to and along the global meteoric water line (Report Figure 2). A surface-water sample collected from Allie Lake plots far to the right and below the line, consistent with waters subjected to evaporation. The lack of any significant departure below the line for the 91 groundwater samples indicates that direct infiltration of precipitation dominates groundwater recharge, and recharge from surface-water bodies is not a significant component of recharge.



Report Figure 2. Stable isotope values from water samples compared to the meteoric water line

Precipitation values from rapid infiltration generally plot along the meteoric water line. The global meteoric water line was developed using precipitation samples from around the world (Craig, 1961).

Groundwater recharged from surface water sources plots along an evaporation line, a shallower slope. None of the wells sampled for this project had an evaporative signature.

Groundwater residence time indicators

Groundwater residence time is the approximate time that has elapsed since water infiltrated the land surface to the time it was pumped from a well or discharged to a surface-water body. Short residence time suggests high recharge rates or short travel paths; long residence time suggests low recharge rates or long travel paths. Isotopic analysis of the radioactive elements tritium and carbon-14 is used to estimate the residence time of the groundwater.

Tritium

Groundwater residence time can be interpreted from the concentration of tritium. Although tritium is a naturally occurring isotope of hydrogen, atmospheric concentrations were greatly increased between 1953 and 1963 by atmospheric testing of nuclear weapons (e.g., Alexander and Alexander, 1989). Hydrologists can estimate recharge timing using tritium's half-life of 12.32 years (Lucas and Unterweger, 2000).

Tritium age is important in the interpretation of the hydrogeologic cross sections (Plates 7 and 8) and pollution sensitivity maps. The pollution sensitivity maps are assessed by comparing groundwater chemistry (including concentrations of tritium, nitrate, and chloride) with the calculated sensitivity (Map Figures 15 through 25).

Groundwater residence time is measured in tritium units (TU) and is divided into the following ranges of values.

- **Cold War era**: water entered the ground from the peak period of atmospheric tritium concentration from nuclear bomb testing, 1958–1959 and 1961–1972 (greater than 15 TU).
- **Recent**: water entered the ground since about 1953 (8 to 15 TU).
- **Mixed**: water is a mixture of recent and vintage (greater than 1 TU to less than 8 TU).
- **Vintage**: water entered the ground before 1953 (less than or equal to 1 TU).

Carbon-14

Carbon-14 (^{14}C) is a naturally occurring isotope with a half-life of 5,730 years, and is used to estimate groundwater residence time ranging from 100 to 35,000 years (Alexander and Alexander, 1989). The term *modern* is used for samples of less than 100 years. This isotope was used to estimate the residence time for nine vintage and one mixed tritium-age samples.

Inorganic chemistry of groundwater

As soon as precipitation infiltrates the soil layer and becomes groundwater, the water begins dissolving minerals in the soil, sediment, and bedrock. Inorganic chemical analysis of groundwater samples is useful for characterizing the changes in water chemistry as it moves deeper into the earth and for identifying the presence of anthropogenic (human caused) pollution sources.

Water quality can be used to describe the aesthetics of water including hardness, taste, odor, and color. It can also be used to describe natural or manmade contaminants that are potentially harmful to humans. The U.S. Environmental Protection Agency has developed standards for a number of dissolved constituents (EPA, [1996]).

Environmental Protection Agency (EPA) standards

Secondary Maximum Contaminant Level (SMCL): nonenforceable guidelines for contaminants that may cause cosmetic or aesthetic effects in drinking water.

Maximum Contaminant Level (MCL): legally enforceable federal standards that apply to public water systems, to limit the levels of contaminants in drinking water.

This report includes analysis of water samples for inorganic chemistry, primarily the major cations and major anions which are typically found in parts per million (ppm), and select elements that typically are found in trace amounts in parts per billion (ppb).

Organic chemicals, which are usually of anthropogenic origin, were not studied (including pesticides and their breakdown products, solvents, degreasers, etc.). Studies of these may be found at other state agencies.

Several naturally occurring major cations and anions commonly found in groundwater are listed below with brief descriptions about their sources and other useful characteristics.

- **Calcium and magnesium** sources include limestone, dolomite, and gypsum minerals present in the soil and glacial sediments.
- **Bicarbonate** can come from two sources: carbon dioxide and dissolution of carbonate minerals. A lesser amount of carbon dioxide comes from the atmosphere and a greater amount comes from the soil where plant respiration provides a significant source of carbon dioxide.
- **Sodium** is often present in deeper aquifers or at mineral interfaces. As groundwater moves through the aquifer systems, calcium and magnesium cations are exchanged for sodium ions (Hounslow, 1995).
- **Sulfate** is largely naturally occurring, and is an important constituent of groundwater in parts of the county. Common sources of sulfate are dissolution of gypsum and oxidation of sulfide minerals. High concentrations in groundwater can negatively affect the taste and may act as a laxative. Sulfate has an SMCL of 250 ppm.

Chloride and nitrate-nitrogen (nitrate) can be used to indicate anthropogenic contamination and evaluate pollution sensitivity.

- **Chloride** concentrations above 5 ppm in groundwater are considered to be elevated. Natural sources of chloride include weathering of bedrock or saline groundwater (brines). Anthropogenic sources of chloride include road salts, water softener salts, fertilizers, or animal and human waste. Its presence can indicate a short ground-water residence time. Distinguishing between natural and anthropogenic sources can be done by looking at the chloride/bromide mass ratio. Chloride has a SMCL of 250 ppm.

- **Nitrate** concentrations above 1 ppm in groundwater are considered to be elevated. Elevated nitrate is most likely anthropogenic and comes from sources such as chemical fertilizer and animal or human waste. Its presence can indicate a short groundwater residence time and high aquifer sensitivity. The MCL for nitrate is 10 ppm.

Results

- The **sulfate** SMCL of 250 ppm was exceeded in 39 of the 91 wells sampled.
- **Chloride** concentrations above 5 ppm and a chloride/bromide ratio above approximately 200 may indicate anthropogenic sources and high pollution sensitivity. The break point of 200 was determined for samples with bromide concentrations equal to or greater than 0.07 ppm coupled with tritium data. Lower bromide concentrations were found to be unreliable for distinguishing between natural and anthropogenic chloride.

  Thirty samples had elevated chloride concentration above 5 ppm (Plate 6). Five or these had bromide less than 0.07 ppm and were not used for determining chloride source. Of the remaining samples, six had chloride/bromide ratios above 200 indicating anthropogenic sources and recent recharge. Those samples came from relatively shallow aquifers and wells less than 100 feet deep. Nineteen samples had chloride/bromide ratios below 200, all but one of the wells were over 100 feet deep, and were from bedrock or deep Quaternary aquifers.
- **Nitrate** concentrations greater than 1 ppm were found in four samples, one exceeded the 10 ppm MCL. The presence of elevated nitrates in two of the samples is not likely representative of aquifer conditions. Both samples were collected from wells over 150 feet deep, dissolved oxygen levels were low to absent, and one sample had vintage tritium. The presence of nitrates in these samples may be due to problems during sample collection or well deficiencies. The other two wells are constructed in the sm aquifer at depths of just over 50 feet deep.

Piper diagram

The piper diagram (Report Figure 3) shows the water chemistry results graphically. The sample points are color coded into four well depth categories to facilitate interpretation of the results. The sample points on each triangle (ternary diagram) reflect the relative percentages in milligram equivalents per liter of the major cations and anions in each sample. The central diamond-shaped field shows the overall chemical behavior of the groundwater by plotting a third point representing the intersection of lines projected from the cation and anion ternary diagrams. An example is shown in the piper diagram.

The lower left ternary diagram compares the major cations calcium, magnesium, and sodium plus potassium. There is a fairly constant ratio of calcium to magnesium for all of the samples superimposed on a trend toward the sodium plus potassium axis. This trend generally corresponds to well depth, and indicates that calcium and magnesium are exchanging with sodium in glacial sediments as water moves from shallow local flow systems into the deep regional groundwater systems.

The lower right ternary diagram compares the major anions, bicarbonate, sulfate, and chloride plus nitrate. Most samples plot along a narrow band ranging from bicarbonate-dominated waters toward sulfate-dominated waters. Sulfate concentrations range from less than 1 to 1,194 ppm. While not shown on this diagram, this trend towards higher sulfate generally corresponds to higher total dissolved solids.

Two regions outlined on the cation ternary diagram and on the central diamond are labeled A and B. Water samples in these regions appear to relate to shallow groundwater flow systems that recharge over shorter distances and times for samples in Area A, and to deeper regional flow systems recharging over much larger distances and longer times for samples in Area B. Many of the samples in Area B also appear to have undergone chemical changes resulting in the reduction or removal of sulfate and in some cases, the release of methane gas.

Area A

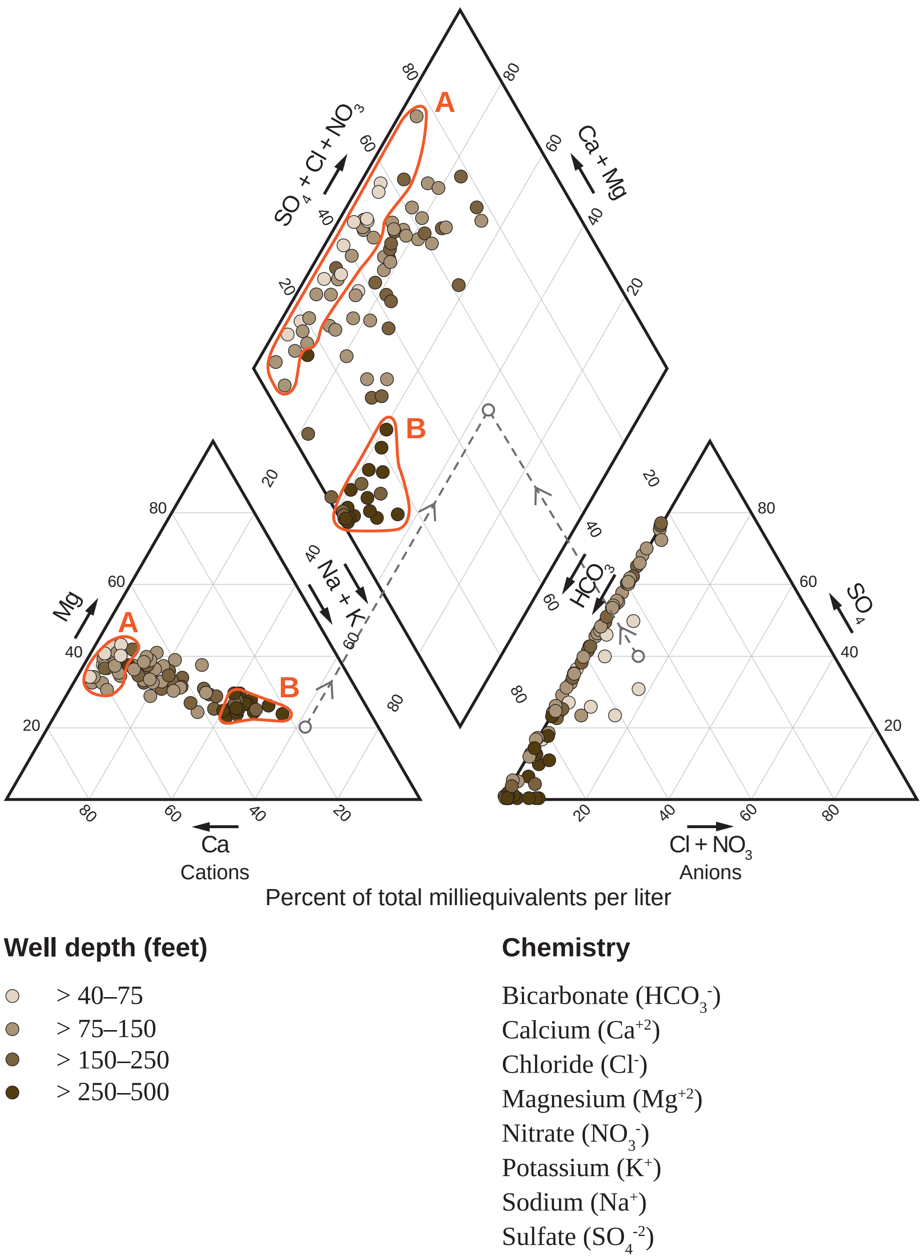
- Twenty wells are less than 100 feet deep. Seven wells are at depths between 100 and 173 feet deep.
- Groundwater recharge in over half of these wells occurred in a few years to several decades as indicated by their mixed and recent tritium results. One vintage tritium sample was carbon dated to approximately 3,000 years.
- Anthropogenic chloride was indicated in six samples.
- Anion chemistry ranged from bicarbonate dominated water to sulfate dominated water.
- The mean sulfate concentration is 253 ppm.
- Samples exhibit little or no cation exchange of calcium and magnesium with sodium.

Area B

- Twenty-one wells are greater than 200 feet deep. One well is 184 feet deep.
- Groundwater recharge takes more than 60 years as indicated by the absence of tritium in all of the samples. Recharge may take hundreds to thousands of years as

evidenced by three of the samples that were carbon-14 dated greater than 35,000 years old.

- Chloride from natural sources is indicated in 12 samples. Most of the elevated chlorides are coming from deeper aquifers suggesting a natural source possibly associated with Cretaceous sediments or from weathered bedrock.
- Anion chemistry is bicarbonate dominant.
- The mean sulfate concentration is 32 ppm. Thirteen of the 22 samples had less than 3 ppm sulfate. A sulfur smell was noted during the collection of many of these water samples and several sites had gas coming out of solution. One of these was flame tested, confirming the presence of methane. These observations support that water from these wells is going through sulfate reduction (removal of sulfate) or methanogenesis (fermentation reactions producing methane gas).
- Samples exhibit a fair amount of cation exchange of calcium and magnesium with sodium.



Report Figure 3. Piper diagram of groundwater samples

This diagram compares the relative proportions of cations and anions in groundwater from all the sampled wells. The cations and anions are shown in the left and right triangles, respectively. The center diamond shows a composite of cations and anions as shown by the hypothetical sample projection (dashed lines).

Naturally occurring elements of health concern

Some chemicals present in water may be naturally occurring but can potentially pose a human health risk in elevated concentrations. Exposure to arsenic has been linked to both cancer and noncancerous health effects (EPA, 2001). Low levels of manganese are a benefit to humans, but high exposures can harm the nervous system (MDH, 2012).

Arsenic

Arsenic is a naturally occurring element in Minnesota groundwater. Current science cannot predict which wells will have high arsenic concentrations, therefore newly constructed wells are tested for arsenic if they are used as a potable water supply, according to Minnesota Rule 4725.5650 (2008).

The factors affecting elevated arsenic concentrations in groundwater are not completely understood. There is a strong correlation with wells completed in aquifers associated with materials bearing glacial sediment derived from rocks that lie northwest of Minnesota. Research also indicates that arsenic concentrations are increased in wells that have short screened sections near the boundary of an aquitard and the aquifer (Erickson and Barnes, 2005a; McMahon, 2001).

The original arsenic reservoir is thought to be arsenic-bearing minerals from small shale particles in these tills. Some of this arsenic has been previously released and then adsorbed to surfaces of the mineral crystals and other small particles during earlier oxidizing conditions. This surface-adsorbed arsenic, the most chemically available form, is released to groundwater under reducing conditions (Erickson and Barnes 2005b; Nicholas and others, 2011; Thomas, 2007).

The EPA requires that community water supplies not exceed 10 ppb arsenic (EPA, 2001), but there is no requirement for domestic wells. Well-water samples that exceed 5 ppb or more arsenic should be resampled to determine if the arsenic level of the first sample is a representative value.

Arsenic results for Renville County:

- Arsenic concentrations greater than or equal to 10 ppb were found in 25 of the 91 water samples: 24 in buried sand aquifers and 1 completed in undifferentiated regolith.
- Arsenic concentrations for wells sampled in the western part of Renville County west of the city of Renville were below the 10 ppb standard (Map Figure 13).
- No clear trends were observed between aquifers and arsenic concentration.

Statewide arsenic distribution in Minnesota groundwater is variable and unpredictable with arsenic concentrations varying from one well to the next, even over small areas. Elevated levels of arsenic are more likely to occur in groundwater from the Twin Cities west to the South Dakota border and north along Minnesota's western border. As of 2008, all new private wells in Minnesota are tested for arsenic. Data from 2008 to 2015 show that 10.7 percent of these wells have arsenic levels above 10 ppb (MDH, 2016).

Manganese

Manganese is a naturally occurring element in Minnesota groundwater. The Minnesota Department of Health (MDH) Health Risk Limit (HRL) is 100 ppb. For more details, see the Minnesota Ground Water Association white paper on manganese and groundwater (MGWA, 2015).

Minnesota Department of Health (MDH) standards

Health Risk Limit (HRL): the concentration of a groundwater contaminant, or a mixture of contaminants, that can be consumed with little or no risk to health and has been promulgated under rule.

Manganese results for Renville County:

- Concentrations exceeding 100 ppb were found in 48 of the 91 groundwater samples (53 percent).
- Concentrations had a mean of 195 ppb and a median of 115 ppb.
- All of the Quaternary aquifers had at least one water sample that exceeded 100 ppb HRL.

For a statewide comparison, manganese distribution is highly variable with a median concentration of 93 ppb. Water table and buried sand aquifers had the highest median manganese concentrations, 155 and 160 ppb, respectively. In water-table aquifers, 57 percent of drinking water wells sampled had manganese concentrations greater than 100 ppb. In buried sand aquifers, 63 percent of drinking water wells sampled had manganese concentrations greater than 100 ppb (MDH, 2014).

Hydrogeologic cross sections (Plates 7 and 8)

Nine hydrogeologic cross sections shown on Plates 7 and 8 illustrate the horizontal and vertical extent of aquifers and aquitards, groundwater residence time, and general directions of groundwater flow. They were selected from a set of 50 regularly spaced, west-to-east cross sections created by the MGS, to display the higher density sections of chemistry data and a variety of recharge examples. These were constructed using a combination of well data from County Well Index and the following components of the Part A atlas: bedrock geology (Plate 2), surficial geology (Plate 3), and Quaternary stratigraphy (Plate 4). The well information for each cross section was projected from distances no greater than one-half kilometer.

Relative hydraulic conductivity

Hydraulic conductivity is a function of the porosity (volume of pores) and permeability (connectedness of pores) of a sediment or rock layer. Percent sand content in the glacial sediment matrix is a proxy for permeability because coarse grains typically add permeability to sediment. Glacial aquitards with a higher sand content are assumed to have a higher hydraulic conductivity than aquitards with lower sand content. This assumption does not account for the occurrence of larger clasts (pebbles, cobble, and boulders), the potential for fine sediment to fill pore spaces, or fractures in the shallow till units.

Glacial and lacustrine sediments that act as aquitards are shown in shades of gray on Plates 7 and 8. Lighter shades indicate aquitards with higher relative hydraulic conductivity. Darker shades represent aquitards with lower relative hydraulic conductivity.

The percent sand in each of the aquitards is based on the average matrix texture of each glacial till (Part A, Plate 4, Table 1). No textural information is available for the Quaternary undifferentiated (u) unit; therefore, no inference of hydraulic conductivity should be made. Low permeability units mapped in cross section include Quaternary and Holocene lake sediments, l and hl respectively. Their textures are not characterized in Part A, Plate 4, Table 1, but are described as primarily composed of clay and silt with local occurrences of sand. Lacustrine sediments can generally be described as having a sand content equal to or less than 30 percent (A. R. Knaeble, oral commun., 2016).

Groundwater flow direction

Groundwater moves from areas with higher potential energy to areas with lower potential energy. The direction of groundwater movement is interpreted from the equipotential contours constructed from measured water levels in wells (Plates 7 and 8). These contours can be used to identify the groundwater flow direction, recharge zones, and discharge zones.

The equipotential contours and flow arrows show that for most of Renville County the groundwater flow is initially downward, then laterally toward the Minnesota River. In the northeastern portion of the county, groundwater flow is generally northeast to southeast. For the Minnesota River valley, most of the area is underlain by high permeability sand and gravel deposits and bedrock at or near the surface. Outside of the Minnesota River valley, Renville County has low permeability glacial sediment at the land surface that limits the rate of recharge to the groundwater system. Smaller focused groundwater recharge areas are identified in the following section where aquifers are interconnected and where tritium, chloride, or nitrate concentrations indicate recent recharge from the land surface.

Recharge interpretations

Most of Renville County has fine-grained glacial sediment at the land surface with relatively low permeability that impedes groundwater recharge. A few areas are underlain by a surficial sand aquifer or a stacked sequence of sand aquifers. These areas act as focused groundwater recharge zones. Recent or mixed tritium-age water may occur in the following recharge situations, indicated using the symbols shown below, on Plates 6–8, and Map Figures 15–25.

Examples of the specific types of recharge can be seen on the accompanying cross sections with recent or mixed tritium-age samples.

1 Water from the surface moves through a thin layer of overlying fine-grained material to an underlying aquifer.

This condition is present in many regions or areas of the si and sm aquifers with fewer occurrences of the sg aquifer, and stratigraphically deeper aquifers. This recharge type is described in the following cross sections:

- B–B′, just over 4.5 miles west of Beaver Creek. The sm aquifer is shallow at 30 feet; the sample had mixed tritium (6.1 TU), elevated nitrate (2.68 ppm), and anthropogenic chloride.
- B–B′, approximately one-half mile east of Beaver Creek, east fork. The si aquifer is shallow at 26 feet; the sample has mixed tritium (5.7 TU) and anthropogenic chloride.
- C–C′, less than 2 miles west of Beaver Creek. The si aquifer is shallow at 28 feet; the sample has mixed tritium (3.8 TU) and a high amount of anthropogenic chloride (128 ppm).

② Groundwater moves from an overlying surficial aquifer to a buried aquifer.

This condition is indicated by deeper occurrences of elevated tritium. It usually occurs where the ss aquifer intersects shallow buried aquifers, typically the si and sm aquifers. One site shows this type of recharge.

- B–B′, approximately 8 miles west of Beaver Creek. The sm aquifer is connected to and beneath the ss aquifer, and has mixed tritium water (6.3 TU).

③ Groundwater moves from an overlying buried aquifer to an underlying buried aquifer.

This is another way for groundwater to recharge to greater depths. One site shows this type of recharge.

- B–B′, just over one mile west of Hawk Creek. The sm aquifer overlies and is in direct communication with the underlying sg aquifer. Mixed tritium (6.1 TU) was found in a 64-foot deep well completed in the sg aquifer.

Ⓛ Groundwater flows laterally.

One location shows lateral groundwater flow.

- D–D′, approximately 1,500 feet east of Beaver Creek. The well is completed at 51 feet in the sm aquifer, with mixed tritium (6.9 TU), elevated nitrate (10.1 ppm), and anthropogenic chloride.

Beaver Creek's glacial predecessor eroded into and hydraulically connected the surficial sands with portions of the underlying sm aquifer. Just over 300 feet southwest of the well, the overlying till has been removed and the sm aquifer is hydraulically connected to the surficial sand aquifer.

Ⓤ Groundwater flowpath is unknown.

Unknown was assigned to those water samples where tritium was not expected based on the available information. For most of these wells the depth that tritium was found is deeper than suggested by surrounding wells with similar geology.

In some cases major ion water chemistry suggests the water is older and should not have tritium. Groundwater flow direction was also considered when determining whether the presence of tritium was consistent with other available information.

Some possible factors that could explain the presence of tritium when it's not expected are: well construction or post construction degradation of the well casing due to corrosive water chemistry, the grouting of the well annulus which serves to prevent water from entering the aquifer through the well borehole from other aquifers and from the land surface, or an incomplete knowledge of aquifer distribution due to sparse and scattered well log information.

There are seven water samples that have a mixed tritium age and the type of recharge is not readily apparent. Locations for wells with this recharge classification are as follows:

- B–B′, approximately 350 feet east of Hawk Creek. The well is completed at 85 feet in the s3 aquifer, has mixed tritium (2.7 TU) and anthropogenic chloride.

  Although groundwater flow shown on the cross section is toward the creek, suggesting gaining conditions, periodically water could reverse direction and flow from the creek into the subsurface providing recharge to this sand body. In addition, this sand unit might be more extensive and better connected to the base of the creek than is shown on the cross section.
- E–E′, approximately 4 miles west of Sacred Heart Creek: The well is completed at 84 feet in the s3 aquifer with mixed tritium (1.4 TU).
- F–F′, 4.8 miles east of Birch Coulee Creek. The well is completed at 185 feet in the s3 aquifer with mixed tritium (1.5 TU).

  Water chemistry indicates a fair amount of cation exchange with sodium. This was shown to be positively correlated to well depth and increasing groundwater residence time. Additionally, this and only one other well have elevated tritium and water chemistry plotting outside of the outlined area on the piper diagram (Report Figure 3, Area A).
- F–F′, 5.8 miles west of High Island Creek. The well is completed at 98 feet in the st aquifer with mixed tritium (2.5 TU).

- G–G′, approximately ¾ mile east of Beaver Creek. The well is completed at 95 feet in the s3 aquifer with mixed tritium (1.3 TU).
- G–G′, 2.6 miles east of Birch Coulee Creek. The well is completed at 160 feet in the s3 aquifer with elevated nitrate (1.98 ppm) and mixed tritium (2.5 TU).

  The presence of nitrate cannot be explained as the sample taken from this well has no dissolved oxygen and denitrification would likely have removed nitrates long before reaching this depth. The mixed tritium at this depth is highly unlikely and suggests possible well construction problems.
- H–H′, 1.5 miles west of Little Rock Creek. The well is completed at 188 feet in the su aquifer with mixed tritium (6.5 TU).

  This high value of tritium at this depth is highly unlikely and suggests possible well construction problems. The aquifer is not mapped at this location, but it is reasonable to assume that it would have very low sensitivity due to the substantial thickness of overlying low permeability material.

  Water chemistry indicates a fair amount of calcium and magnesium exchange with sodium. This was shown to be positively correlated to well depth and increasing groundwater residence time. Additionally, this and only one other well have elevated tritium and water chemistry plotting outside of the outlined area on the piper diagram (Report Figure 3, Area A).

Carbon-14 data

Carbon-14 samples were collected from 10 wells. One had mixed tritium age and was sampled for the purpose of calibrating the carbon dating model. From the remaining 9 samples, 8 are shown in the cross sections (Plates 7 and 8).

In far northeastern Renville County (B–B′) two closely located wells are completed at 85 feet (sg) and 249 feet (su). Water from the shallow well was dated at 3,000 years; the deeper well 20,000 years.

In far western Renville County along Hawk Creek (C–C′) there are two wells completed at 103 feet (s4) and 280 feet (sz). Water from the shallow well had a date of 19,000 years; the deeper well water was dated at greater than 35,000 years. Along this same cross section just under one mile east of East Fork Beaver Creek is a 250-foot-deep well (s5) with water dating at greater than 35,000 years.

The remaining three wells are completed in the s3 aquifer at depths between 145 and 171 feet and date between 6,000 and 8,000 years. The 6,000 year-old sample is located on cross section D–D′ just over 1.5 miles east of Beaver Creek. The 7,000 year old sample is near the center of cross section G–G′ just over 3 miles west of Fort Ridgley Creek. The 8,000 year old sample is just over 2 miles east of Fort Ridgley Creek in cross section I–I′.

Discharge interpretations

Ⓓ Groundwater discharges to a surface-water body.

Groundwater discharge to rivers, lakes, and wetlands supplies water vital to aquatic ecosystems. There are a number of perennial streams that receive groundwater discharge to keep them flowing all year. The equipotential lines on the cross sections indicate that most of the buried aquifers in Renville County ultimately discharge to the portion of the Minnesota River that forms the southern border of the county. Groundwater discharge locations for the Minnesota River and tributary perennial streams are shown in cross sections on Plates 7 and 8.

Pollution sensitivity

Pollution sensitivity maps generated on a county scale are intended to assist citizens and local government in protecting and managing groundwater resources. Pollution sensitivity is defined as the potential for groundwater to be contaminated due to the hydrogeologic properties of the material hosting or overlying it. Migration of contaminants dissolved in water through unsaturated and saturated sediment is a complex process that is affected by biological degradation, oxidizing or reducing conditions, and other factors. The methods to interpret pollution sensitivity use the following generalizing assumptions:

- Flow paths are vertical and downward from the land surface through the soil and underlying sediment to an aquifer.
- River valleys are typically important groundwater discharge areas (see Hydrogeologic cross sections). Local upward groundwater movement is characteristic of these areas and the actual pollution sensitivity in these areas will be less than rated.
- A contaminant is assumed to travel at the same rate as water.
- A contaminant that is dissolved and moving with water from the surface is not chemically or physically altered over time.

Two models are used to estimate the pollution sensitivity, based on the different properties of the materials. The following assumptions apply to these models.

- **Near-surface sensitivity** (to a depth of 10 feet): sediment texture is the primary property used to create this sensitivity map. The permeability of the sediment matrix texture is estimated based on hydrologic theory or empirical data to establish a downward flow rate. The rate multiplied by the vertical travel distance equals the estimate of the vertical travel time.
- **Buried aquifer sensitivity**: sediment above and between buried sand aquifers is fine grained with low hydraulic conductivity. The method only considers the cumulative thickness of fine-grained sediment overlying aquifers. It does not consider differences in sediment texture or permeability of aquitard materials.

Near-surface sensitivity

Methods

The pollution sensitivity of near-surface materials is an estimate of the time it takes for water to infiltrate the land surface, travel through the unsaturated zone, and reach the water table, which is assumed to be 10 feet below land surface. The first 3 feet is assumed to be soil and the next 7 feet (3–10 feet) is assumed to be surficial geological material. If there is no soil data, the transmission rate is based on 10 feet of the surficial geologic unit.

The transmission rate of a soil or surficial geologic unit will vary depending on the texture. In general, coarse-grained materials have faster transmission rates than fine-grained materials. The two primary inputs used to estimate transmission rate are the hydrologic soil group and the surficial geologic matrix texture. Attributes of both are used to estimate the time of travel (Report Table 1) (USDA-NRCS, 2011; Part A, Plate 4). Further details of how the near-surface pollution sensitivity map was created are available in *Methods to Estimate Near-Surface Pollution Sensitivity* (DNR, 2016b).

- Areas with a relatively short time of travel (hours to a week) are rated as having high sensitivity
- Areas with a longer time of travel (weeks to a year) are rated low or very low.
- Areas of more than a year are rated ultra low, but are not present in the county.

Results

The time of travel through the near-surface materials in Renville County varies from hours to approximately a year (Report Figure 4). The map for pollution sensitivity of near-surface materials (Map Figure 14) indicates that the interior areas of the county have very low to low near-surface sensitivity. The very low sensitivity areas are generally found in the northern and western portions of the county where lacustrine sediments are mapped (Ql, Qhl, and Qtl). These sediments are nearly absent in most of the southeastern portion of the county where sensitivity is low. Moderate to high pollution sensitivity ratings are found throughout the Minnesota River valley along the southern border. Moderate to high pollution sensitivity ratings are found throughout the Minnesota River valley and sporadically distributed through the interior of the county coincident with the surficial sand (ss) aquifer.

Report Table 1. Transmission rates used to assess pollution sensitivity rating of the near-surface materials

Hydrologic Soil Group (0–3 feet)		Surficial Geologic Texture (3–10 feet)		
Group*	**Transmission rate (in/hr)**	**Classification**	**Transmission rate (in/hr)**	**Surficial geology map unit (Plate 3)**
A, A/D	1	gravel, sandy gravel, silty gravel	1	Qrk, Qs, Qsc, Qsw
		sand, silty sand	0.71	Qa
B, B/D	0.50	silt, loamy sand, units with eolian sand designation	0.50	Qf, Qp
		sandy loam	0.28	Not present in county
--	--	loess (Peoria)	0.218	Not present in county
C, C/D	0.075	silt loam, loam	0.075	Qc, Qtm, Qtw, Qtz, Qhl
		sandy clay loam	0.035	Not present in county
D	0.015	clay, clay loam, silty clay loam, sandy clay, silty clay	0.015	Qtl, Ql
--	--	glacial lake sediments of lakes Agassiz and Duluth	0.000011	Not present in county

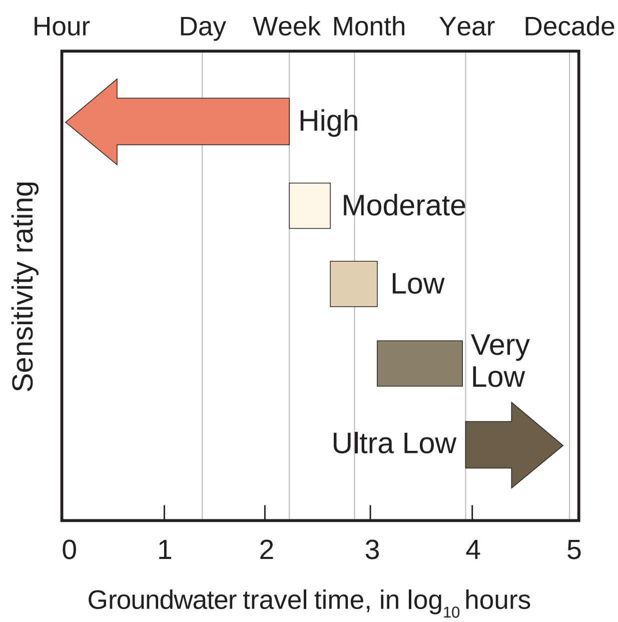
*The Natural Resources Conservation Service defines hydrologic soil groups primarily based on texture and the occurrence of low permeability layers (USDA-NRCS, 2009):

Group A: water is freely transmitted. Soils are more than 90 percent sand and gravel.

Group B: soils are less permeable but water transmission is still unimpeded.

Group C: water transmission is somewhat restricted.

Group D: water movement is restricted or very restricted.



Report Figure 4. Geologic sensitivity rating for the near-surface materials

Buried sand aquifer and bedrock surface sensitivity

Methods

The sensitivity rating for the buried sand aquifers and the bedrock surface are based on estimated vertical travel times defined by the Geologic Sensitivity Workgroup (1991). The travel time varies from days to thousands of years (Report Figure 5).

- Areas with relatively short travel times of less than a few years are rated high or very high.
- Areas with estimated travel times of decades or longer are rated low or very low.

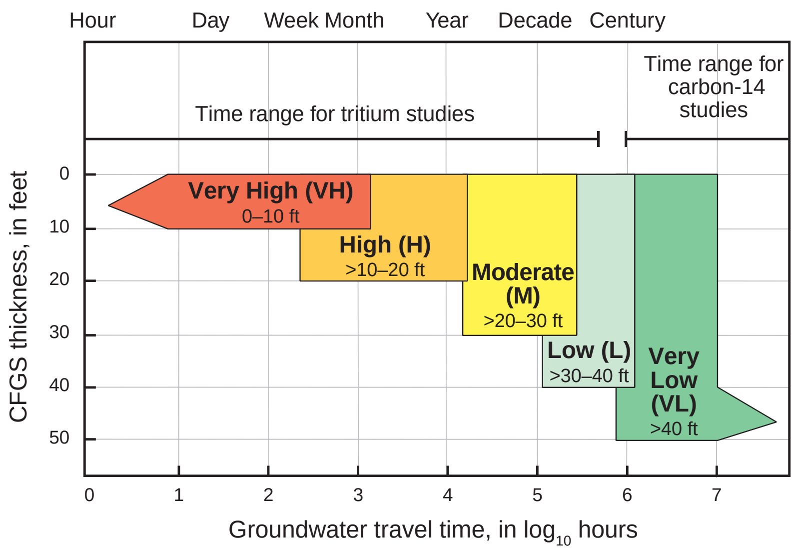
The DNR developed a method using geographic information systems (GIS) for mapping pollution sensitivity of buried sand aquifers and the bedrock surface based on a simplified two-dimensional model.

The model represents how water from precipitation infiltrates the land surface and recharges portions of deeper aquifers. The central concept of this process is focused (relatively rapid) recharge: portions of the aquifers overlap and are connected by complex pathways that can allow surface water to penetrate into even the deepest aquifers.

The model assumes the thickness of fine-grained sediment overlying an aquifer is inversely proportional to the sensitivity of an aquifer (Report Figure 6). The thicker the fine-grained sediment overlying an aquifer, the longer it will take for water to move through it. GIS software is used to calculate a cumulative thickness of these sediment layers. Thicknesses of 10 feet or less are rated very high sensitivity, thicknesses greater than 40 feet are rated very low, and intermediate thicknesses have intermediate sensitivity ratings. Thicknesses are modified from discussion of fine-grained layers in *Criteria and Guidelines for Assessing Geologic Sensitivity of Ground Water Resources in Minnesota* (Geologic Sensitivity Workgroup, 1991). A more detailed explanation of this method is available in *Buried aquifer and bedrock surface pollution sensitivity based on cumulative fine-grained sediment (CFGS) thickness* (DNR, 2016c).

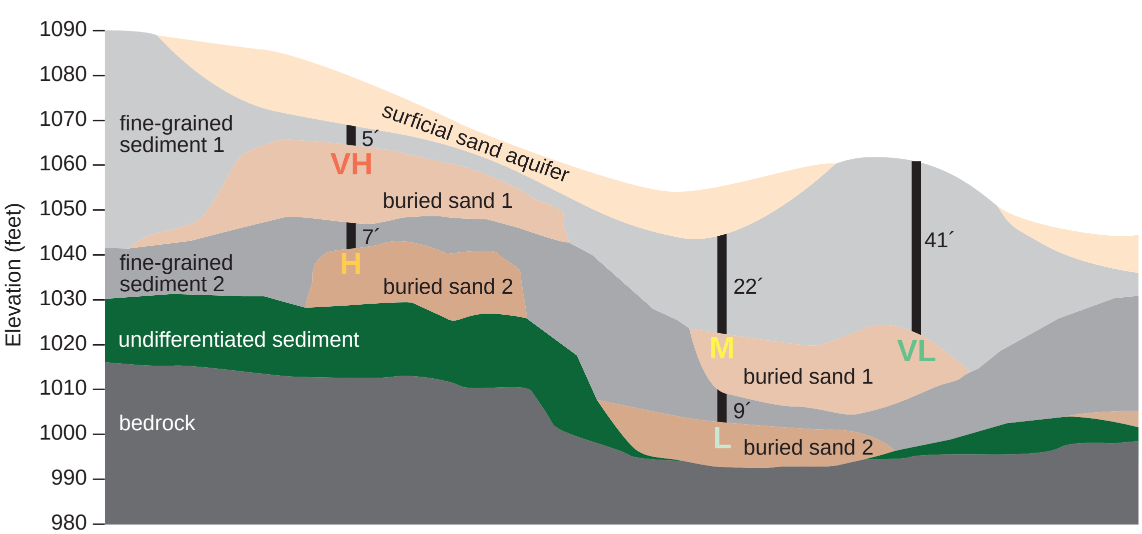
Report Figure 5 (right). Geologic sensitivity rating for the buried sand aquifers and the bedrock surface

Sensitivity is defined by vertical travel time. The numbers following each rating represent the cumulative fine-grained sediment (CFGS) thickness overlying an aquifer.



Report Figure 6 (below). Cross section showing examples of pollution sensitivity ratings

Based on the cumulative thickness of overlying fine-grained sediment. Each vertical black line in the figure is labeled with the thickness of fine-grained sediment. The letter at the base of the line indicates the sensitivity rating determined from the cumulative thickness.



Results

The following discussion of each aquifer's pollution sensitivity is in stratigraphic order from the shallowest to the deepest. The model results include groundwater flow direction derived from potentiometric surfaces to help interpret the distribution of particular chemical constituents. The pollution sensitivity values and spatial distributions are compared to tritium age of groundwater (recent, mixed, and vintage).

si aquifer (Map Figure 15):

Pollution sensitivity ranged from very low to very high with only 8 percent classified as very low. The aquifer had a mean depth of 27 feet below the land surface; over 90 percent did not exceed a depth of 40 feet. Two tritium samples were collected and are categorized as follows.

Mixed tritium-age was found in two samples, consistent with the predominant pollution sensitivity ratings for this aquifer. One of the samples is located north of the city of Renville along C–C′; the other is northeast of Olivia along B–B′. Chloride/bromide ratios for both sites were indicative of anthropogenic sources of chloride. Recharge is through overlying thin low permeability materials.

sm aquifer (Map Figure 16):

Pollution sensitivity ranged from very low to very high with 39 percent classified as very low. In general, there is a greater occurrence of very low sensitivity in the eastern half of the county due to a greater depth of burial. The aquifer has a mean depth of 38 feet below land surface, with over 97 percent not exceeding a depth of 75 feet. Six tritium samples were collected and are categorized as follows.

Recent tritium age was found in one sample along the Minnesota River bluff just over 3.5 miles northwest of Morton and less than ½ mile west of Beaver Creek. The sensitivity in the vicinity of this sample is very low with small areas of higher sensitivity along the aquifer margins. The western portion of the aquifer is approximately 25 feet below an overlying unnamed tributary stream. Additionally, there is a downward hydraulic gradient where water from the stream channel may be recharging the aquifer at the margin.

Mixed tritium age was found in four samples. Two samples are from shallow buried aquifers that are wholly or in part hydraulically connected to surficial sand deposits. Recharge to the sampled aquifer northwest of the city of Renville (B–B′) is through overlying sand deposits. For the sample located on the east side of Beaver Creek (D–D′), there is 32 feet of till above the aquifer at the well, and till cover is absent just over 250 feet to the southwest. High nitrate (10.1 ppm) and anoxic water suggests fairly rapid and recent recharge, which is more likely to occur as lateral flow from unconfined portions of the aquifer southwest of the well. The third sample is located east of Timms Creek between cross sections E–E′ and F–F′. The pollution sensitivity ratings for this site ranged from very low and low near the well to high in the northern portion of the aquifer less than ½ mile north of the well. This northern portion is likely where most of the recharge is occurring. The fourth sample site is located north of the city of Renville along B–B′. The aquifer is rated low at the well site and moderate less than ¼ mile to the north. Three of the four wells have low chloride/bromide ratios indicating anthropogenic chloride.

Vintage tritium age was found in one sample (B–B′, north of Sacred Heart), the shallowest well (42 feet) with vintage-age water.

st aquifer (Map Figure 17):

Pollution sensitivity is rated very low for 98 percent of the aquifer, with low, moderate, and high ratings for the remaining 2 percent. The aquifer has a mean depth of 71 feet below land surface with the majority of occurrences between 50 and 100 feet, and a limited extent. The three chemistry samples collected southwest of the city of Hector are of similar depth (86–98 feet) and are in aquifers rated as very low sensitivity. Three tritium samples were collected and are categorized as follows.

Mixed tritium age was found in one well (F–F′). The source of recharge is unknown.

Vintage tritium ages found in two wells located along F–F′ and G–G′ are consistent with the aquifer's very low pollution sensitivity ratings.

sg aquifer (Map Figure 18):

Pollution sensitivity is rated very low for 80 percent of the aquifer, low for 11 percent, and moderate, high, and very high for the remaining 9 percent. In general, there is a greater occurrence of very low sensitivity in the southern and eastern portions of the county due to a greater depth of burial. The aquifer has a mean depth of 61 feet below land surface with the majority of occurrences between 30 and 100 feet. Six tritium samples were collected and are categorized as follows.

Mixed tritium age was found in one sample from on the western end of B–B′ in the northwestern portion of the county. This aquifer mapped with a moderate sensitivity rating and recharge appears to be originating from an overlying shallow buried aquifer. The chloride/bromide ratio (185) is below the minimum anthropogenic threshold of 200. Therefore the source of chloride was determined to be natural.

Vintage tritium age was found in five samples from wells varying in depth from 60 to 109 feet. Their respective sensitivity ratings are mapped as very low. One of the samples located at the far eastern end of B–B′ was carbon dated at 3,000 years old.

s2 aquifer (Map Figure 19):

Pollution sensitivity is dominated (97 percent) by very low ratings. Higher sensitivity ratings are found in a few locations near the city of Sacred Heart in the northwest part of the county, and in incised portions of several river valleys. The aquifer has a mean depth of 95 feet below land surface, with most occurrences between 50 and 150 feet. Eleven tritium samples were collected and are categorized as follows.

Vintage tritium age was found in 11 samples, consistent with their location in areas with very low sensitivity ratings. One sample has a low chloride/bromide indicating a natural chloride source.

s3 aquifer (Map Figure 20):

Pollution sensitivity is rated very low across the county (99 percent) except those locations where the Minnesota River valley and its tributaries are deeply incised, leaving less low permeability material above portions of some aquifers. The aquifer has a mean depth of 116 feet below land surface, with most occurrences between 75 and 175 feet. Twenty-one tritium samples were collected and are categorized as follows.

Mixed tritium age was found in six of the samples with values ranging from 1.3 to 2.7 tritium units. Two of the deepest samples (160 and 185 feet) were determined to be compromised and tritium results not representative of aquifer conditions. A third sample was located on the east side of Hawk Creek (B–B′) with 2.7 tritium units and anthropogenic chloride (29.7 ppm). An exception to the aquifer's very low sensitivity is on the western margins where Hawk Creek removed most of the overlying till leaving only a few feet of separation between the aquifer and Hawk Creek. The remaining three samples are located in areas mapped as having very low sensitivity. Very low tritium values, ranging from 1.3 to 1.4 tritium units, are close to the detection limit and within the margin of error. Additionally, there is no geologic explanation for its presence in these aquifers.

Vintage tritium age was found in 15 samples collected in areas with a very low pollution sensitivity rating. Three of these samples were also carbon dated between 6,000 and 8,000 years old. The three wells ranged in depth from 145 to 171 feet and are located along a line starting just south of Danube southeast to Fairfax.

s4 aquifer (Map Figure 21):

Pollution sensitivity is rated very low across the county (99 percent) except those locations where the Minnesota River valley and its tributaries are deeply incised, leaving less low permeability material above portions of some aquifers. The aquifer has a mean depth of 167 feet below land surface, with most occurring between 100 and 225 feet. Ten tritium samples were collected and are categorized as follows.

Vintage tritium age was found in all 10 samples, consistent with this aquifer's very low pollution sensitivity rating. One sample along Hawk Creek near C–C′ was collected from a 103-foot deep well and was carbon dated at 19,000 years.

s5 aquifer (Map Figure 22):

Pollution sensitivity is rated very low across the county (100 percent). The aquifer has a mean depth of 237 feet below land surface, with most occurring between 175 and 275 feet. Five tritium samples were collected and are categorized as follows.

Vintage tritium age was found in all five samples, consistent with their location in areas with very low pollution sensitivity ratings. One sample located north of Bird Island along C–C′ was collected from a 250-foot deep well and was carbon dated at greater than 35,000 years. The deepest well (315 feet) has a very low chloride/bromide ratio indicating a natural source of chloride.

su aquifer (Map Figure 23):

Pollution sensitivity is rated very low across the county (99 percent) except for those locations where the Minnesota River valley and its tributaries are deeply incised, leaving less low-permeability material above portions of some aquifers. The aquifer has a mean depth of 210 feet below land surface, with most occurrences between 100 and 300 feet. Sixteen tritium samples were collected and are categorized as follows.

Mixed tritium age was found in two samples. One sample from a 185-foot deep well west of Little Rock Creek (H–H′) had 6.5 tritium units. The water chemistry showed significant cation exchange, which is typically found in older and deeper groundwater systems. There is no supporting geologic or chemistry information that supports the elevated tritium in this sample. The other well located 2.2 miles east of Birch Coulee Creek and approximately 1.8 miles south of cross section G–G′, is 127 feet deep, and had 1.2 tritium units. The low value for tritium and the absence of other supporting evidence for tritium at this depth gave a low confidence for its presence in this aquifer.

Vintage tritium age was found in fourteen samples, consistent with their location in areas with very low sensitivity ratings. One sample from the eastern end of B–B′ was taken from a 249-foot deep well and was carbon dated at 20,000 years. Three samples had low chloride/bromide ratios indicating natural chloride sources.

sz aquifer (Map Figure 24):

Pollution sensitivity is rated very low across the county (99 percent). The few exceptions are those locations where the Minnesota River valley and its tributaries are deeply incised, leaving less low permeability material above portions of some aquifers. The aquifer has a mean depth of 316 feet below land surface, with most occurrences between 150 and 450 feet. Seven tritium samples were collected and are categorized as follows.

Vintage tritium age was found in all seven samples, consistent with their location in areas with very low pollution sensitivity ratings. Samples from two of these wells were carbon dated greater than 35,000 years. One well is 280 feet deep and located close to Hawk Creek along C–C′; the other is 395 feet deep and located southwest of Olivia near Beaver Creek. All seven samples have low chloride/bromide ratios indicating natural chloride sources.

Bedrock surface (Map Figure 25):

A variety of Precambrian age crystalline bedrock underlies all of Renville County. Cretaceous shales and sandstone occur in scattered locations on top of the crystalline bedrock and cover approximately 8 percent of the area of Renville County. Approximately 5 percent of the wells are completed in either Cretaceous or Precambrian bedrock.

In Cretaceous deposits, wells are generally completed a few tens of feet into these deposits, and are usually screened in sandstone. Cretaceous aquifer deposits have pore spaces between sand grains that yield water to wells.

Precambrian rocks are generally devoid of primary porosity, and water is typically coming from voids in weathered portions of bedrock, or from joints and fractures. Wells drilled into crystalline bedrock are completed tens to several hundreds of feet into bedrock. The reason for drilling so deep into bedrock is to intersect enough fractures or weathered zones to provide sufficient water for the well, and to provide for storage of water in the well bore between times of pumping, since yields to these wells is often poor.

The pollution sensitivity assigned to the aquifer was very low across the county (98 percent) except those locations along the Minnesota River valley. Most of the bedrock surface is 100 to 450 feet below the land surface. Approximately 3 percent is less than 100 feet below the surface at locations primarily in the Minnesota River valley and lower reaches of tributaries. Four tritium samples were collected and are categorized as follows.

Vintage tritium age was found in all four water chemistry samples, consistent with their location in areas with very low pollution sensitivity ratings. The samples were collected from bedrock wells; 2 from the Cretaceous, 1 from undifferentiated regolith, and 1 from Precambrian crystalline bedrock. Two samples had low chloride/bromide ratios indicating natural chloride sources.

Aquifer characteristics and groundwater use

A water-use appropriation permit from the DNR is required for groundwater users withdrawing more than 10,000 gallons of water per day or 1 million gallons per year. This provides the DNR with the ability to assess and regulate which aquifers are being used and for what purpose.

DNR water appropriation permits require that the water usage be reported annually. Information pertaining to these permits is recorded using Minnesota (DNR) Permitting and Reporting System (MPARS). This helps the DNR track the volume, source aquifer, and type of water use.

In Renville County 1,998 wells from the County Well Index were field located and used for this study. The majority of these wells are completed in buried sands within the Quaternary sediments. Most of the wells (1,348) were sorted into eleven stratigraphic aquifer codes using the Quaternary geology information presented in Part A. The aquifer assignment was based on the location of each well's screened or uncased interval relative to the location of the aquifer. For the remaining wells, 25 percent were not assigned because of insufficient data, 7 percent were in bedrock, and 1 percent were screened in more than one aquifer.

Aquifer specific capacity and transmissivity

Aquifer characteristics such as specific capacity and transmissivity are used to describe how water is transmitted by an aquifer. Larger values of each of these parameters indicate more productive aquifers.

Specific capacity is the rate of discharge of water produced from a well per unit depth of drawdown. It is typically expressed in gallons per minute per foot (gpm/ft) and is determined from short-term pumping or well-development tests performed when a well was drilled. To ensure that the specific capacity values reflect actual pumping the pumping-test data were obtained from the County Well Index for wells with the following conditions:

1. The casing diameter was at least 12 inches.
2. The well was pumped for at least 4 hours.
3. The pumping water level was inside the well casing, at least 2 feet above the well screen or open hole.

In Renville County, 13 wells met these conditions: 4 wells in unconfined aquifers, and 9 wells in confined aquifers. The unconfined water-table aquifers had the highest mean specific capacity of 25 gpm/ft, whereas the more commonly used buried sand aquifers were at 14 gpm/ft (Report Table 2).

Transmissivity is an aquifer's capacity to transmit water. It is calculated from longer-term and larger-scale aquifer tests that provide a more accurate representation of the aquifer properties. Aquifer tests provides more accurate information than do specific capacity tests determined at individual wells. Transmissivity is determined by multiplying the thickness of the aquifer by the hydraulic conductivity of the aquifer material (the rate at which groundwater flows through a unit cross section of an aquifer).

Transmissivity values for 13 aquifer tests in Renville County are also included in Report Table 2. These tests included one water-table aquifer and 12 buried sand aquifers. The highest transmissivity (20,000 ft^2/day) was associated with the single water-table aquifer test. Transmissivity for the buried sand aquifers averaged 4,620 ft^2/day, and ranged from a 400 ft^2/day to over 18,000 ft^2/day. Transmissivity values were summarized from a variety of reports and evaluation approaches. A more rigorous analysis may be needed to get a better understanding of the aquifer test results.

Report Table 2. Specific capacity and transmissivity of selected wells

[Specific capacity data adapted from the County Well Index (CWI); gpm/ft, gallons per minute per foot. Transmissivity data are from aquifer test data compiled by the DNR; ft²/day, --, no data.]

Aquifer (CWI aquifer code)	Specific Capacity (gpm/ft)					Transmissivity (ft2/day)				
	Well Diameter (Inches)	Mean (gpm/ft)	Min (gpm/ft)	Max (gpm/ft)	Number of Tests	Well Diameter (Inches)	Mean (ft2/day)	Min (ft2/ day)	Max (ft2/day)	Number of Tests
Surficial sand (QWTA)	12	25	14	41	4	12	20,000	--	--	1
Buried sand (QBAA)	12–30	14	3	34	9	6-12	4,620	401	18,400	12
sm	12–30	20	3	41	6	12	20,000	--	--	1
s4	--	--	--	--	--	6 & 10	2,680	750	4,400	2
s5	--	--	--	--	--	12	1,080			1
s5 & su	16	4	--	--	1	--	--	--	--	--
su	12	20	8	34	3	12	6,010	1,300	12,500	2
sz	12	17	14	20	3	6–12	6,140	401	18,400	7

Groundwater level monitoring

The DNR maintains a statewide groundwater level monitoring program using observation wells for the following purposes: assessing groundwater resources, determining long term trends, interpreting impacts of pumping and climate, planning for water conservation, evaluating water conflicts, and otherwise managing water resources. Hydrographs of the data can illustrate the effects that precipitation and high-capacity pumping have on groundwater resources.

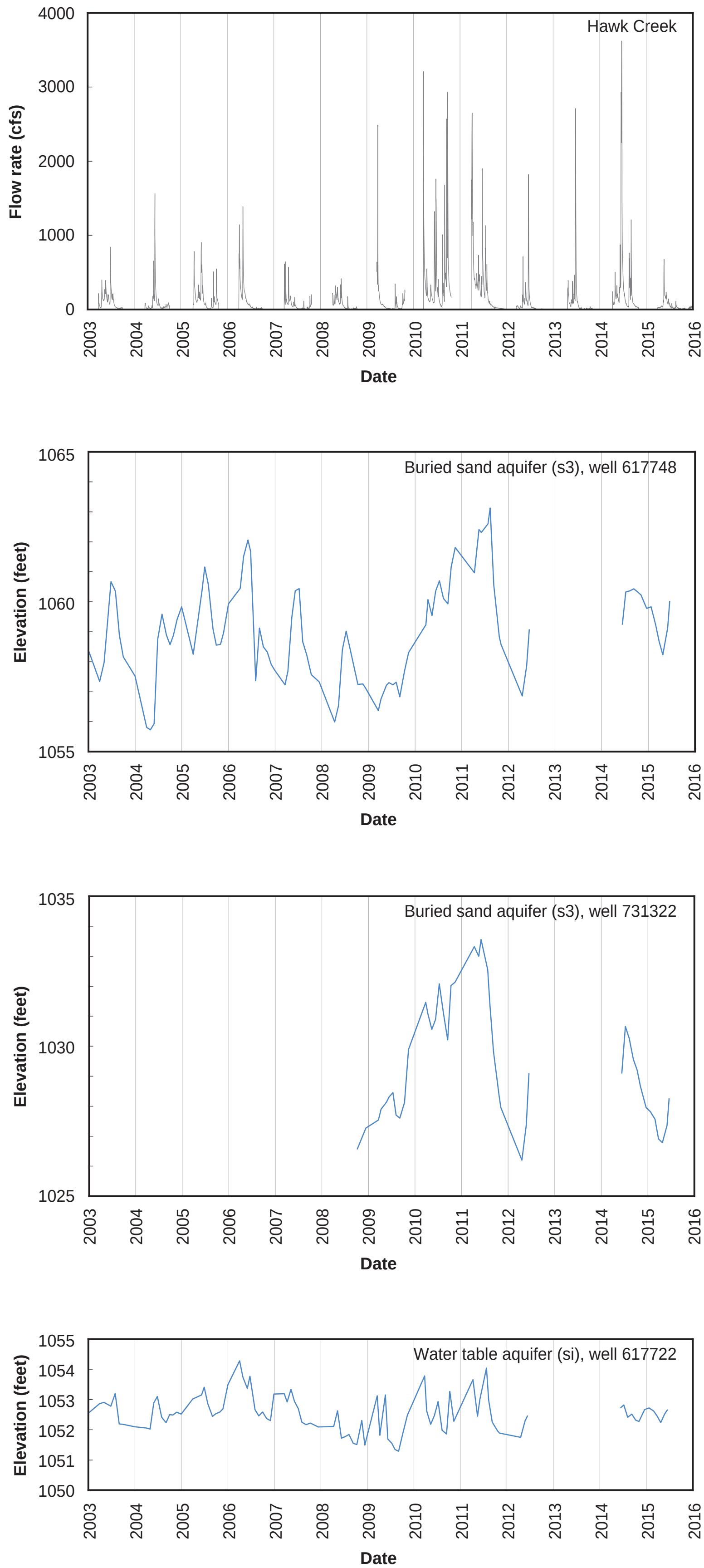
The relationship between precipitation and *water-table elevation* is a result of the direct hydraulic connection of the aquifer to the land surface. Rising water levels correspond to aquifer recharge and lowered water levels result from aquifer discharge. For *confined aquifers*, the water level patterns reflect changes in pressure in the aquifer. Precipitation recharging the water table results in an increase in pressure loading to the underlying buried sand aquifers, causing water levels to rise. A decrease in recharge at the surface or groundwater pumping may lead to declining water levels.

Renville County had four active DNR observation wells at the time of this report (Map Figure 26). Three are compared by water level hydrographs to Hawk Creek flow in Report Figure 7.

- Buried sand aquifer (s3), well 617748: located ½ mile north of the city of Renville.
- Buried sand aquifer (s3), well 731322: located just west of Beaver Creek approximately seven miles south of the city of Olivia.
- Water-table aquifer (si), well 617722: located approximately one mile northeast of the city of Renville and 75 feet from County Ditch 37.

Spikes in Hawk Creek flow rate indicate conditions where recharge to the water table is high and excess water is going to streams. The Hawk Creek hydrograph shows a particularly wet period for the years 2010 and 2011 which corresponds to positive water level trends in the two confined sand (s3) well hydrographs. A review of hydrographs for similarly confined wells located in counties adjacent to Renville County found similar trends.

Water levels in the water-table well (si) vary by three feet for the period of record and are likely varying in response to recharge from rainfall and possibly from changes in flow in the adjacent ditch. The absence of any water level trend for the 2010–2011 wet period may be due this well's location near the top of the watershed. Additionally, water levels in this well are generally within five feet of the land surface which increases evapotranspiration water losses from vegetation and limits water level increases.



Report Figure 7. Hydrographs showing water level trends over time

Top: Hawk Creek Hydrograph showing annual high water events. A particularly wet period is evidenced in 2010 and 2011.

Middle: two observation wells in the buried sand aquifer (s3) are over 13 miles apart. Both hydrographs show rising water levels over the 2010-2011 wet period.

Bottom: the water-table well is located at the top of the watershed. Water levels fluctuate with seasonal variations in groundwater recharge.

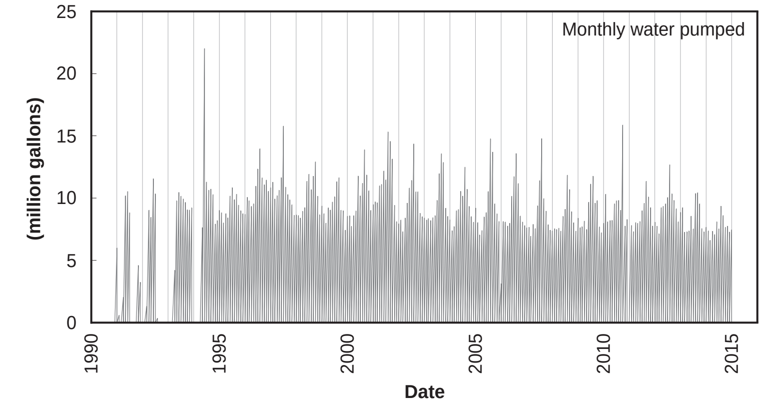
The city of Granite Falls has a well field located just over one-half mile west of the Renville County line. DNR observation well 420053 is completed in the same aquifer (s3) as the city's production wells. This observation well was installed in June of 1986 and water-level collection was initiated prior to the onset of pumping of the city's wells (December 1990). Report Figure 8 includes a hydrograph for well 420053 and a time series graph of monthly volumes of water pumped from Granite Fall's production wells.

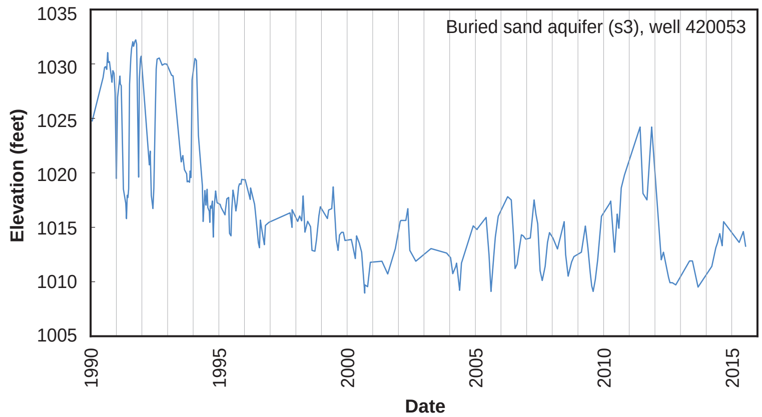
Prior to the onset of pumping, water levels in well 420053 fluctuated between elevations of 1025 and 1033 feet. Starting in December 1990 and until March 1994, there were five multi-month periods of pumping followed by similar intervals of no pumping. Water levels in the observation well similarly fluctuated in response to this cyclical pumping, with a water level range of approximately 15 feet.

Continuous pumping began in April 1994 and resulted in the average water level dropping approximately 20 feet. The smaller annual water level fluctuations appear to be related to cyclical water demand by the city: higher in the summer and lower in the winter.

There was a rise in water levels starting in 2010 and peaking in 2011 that corresponds to the same wet period in Figure 7. There was no change in pumping. This suggests that there was increased recharge to the near surface groundwater system over this time frame.

The observation wells continue to be monitored by the groundwater level monitoring program of the DNR and data are available to be downloaded from the DNR Cooperative Groundwater Monitoring website (DNR, 2015).





Report Figure 8. Hydrograph showing pumping effects associated with the city of Granite Falls production wells

Top: Monthly pumping volumes for the city of Granite Falls are plotted from the onset of pumping in the early 1990s through 2015.

Bottom: Hydrograph for observation well 420053 located just over one-half mile east of the Granite Falls well field. The trend shows a drop in water levels of 10 to 20 feet since pumping was initiated.

Groundwater use

Water use for Renville County in 2014 is listed in Report Table 3. The information shows water use by Quaternary aquifer not determined, Quaternary sand and gravel aquifers grouped by depth, and Cretaceous bedrock. Quaternary aquifers are grouped into three stratigraphic depth intervals with ss through sg assigned to shallow, s2 through s4 assigned to intermediate, and s5 through sz assigned to deep. It is also divided into 6 types of water use. The bottom row of the table lists the highest water use for each use type category for the period 2010–2014.

Some categories like municipal water use varied little from year to year, in contrast to ethanol production which ranged from 120 mgy in 2012 to 15.5 mgy in 2014.

For the year 2014, the majority of water was used by municipalities (62 percent) which drew most of their water from buried sand aquifers, with a lesser amount coming from surficial sand aquifers or Cretaceous bedrock aquifers. The next highest uses were livestock watering (15 percent), agricultural/food processing (13 percent), and agricultural crop irrigation (5 percent). The remaining 5 percent includes golf course irrigation (3 percent) and petroleum-chemical processing/ethanol (2 percent). Approximately half of all water use in 2014 (56 percent) came from the deep buried sand deposits.

Maps are broken out by aquifer (Map Figure 26) and by type of water use (Map Figure 27). The majority of high-capacity water use in Renville County occurred in the northern portion of the county, primarily along US Hwy 212. The most notable examples of significantly higher past water use are for the ethanol plant in the city of Buffalo Lake and for the city of Renville water-table wells. Nine sand and gravel pits in Renville County dewater to facilitate the removal of product from their pits. None of the pits dewatered in 2014, and only three reported water use in the previous five years.

In areas where there is large and long-term water use, water levels from surrounding wells may define a depression in the potentiometric surface. These depressions can be seen on the potentiometric surface maps s4, s5, su, and sz (Map Figures 9 through 12). These depressions are associated with the deeper Quaternary aquifers in the vicinity of the cities of Renville, Olivia, and Buffalo Lake. Reported water use in MPARS was reviewed for large water appropriation permits in these depressions for the period 1988 through 2014.

The city of Renville has two production wells completed in the su aquifer, with reported annual water use ranging from just over 42 mgy in 1994 to as much as 127 mgy in 2004. Since 2010, water use has declined to less than 80 mgy. Renville also has a golf course appropriating water from the sz aquifer. For the period 2001 to 2014, water use has varied with a peak of just over 22 mgy in 2012.

The city of Olivia has production wells completed in the s5 and sz aquifers. Annual water use for the city of Olivia ranged from 180 mgy in 1988 to 85 mgy in 2014. The city's golf course appropriated as much as 50 mgy from a well completed in the sz aquifer. Pumping from these deeper aquifers also appears to be affecting the s4 aquifer (Map Figure 9), as the cone of depression in the s4 aquifer is not associated with any pumping in the aquifer. The s4 and s5 aquifers in this area have very little separation so groundwater communication could be occurring between the two aquifers.

The city of Buffalo Lake has three wells completed in the su aquifer. Since 1988, reported water use has varied from 25 to 39 mgy. This use continued until 2010, when the city stopped appropriating from these wells and began getting their water from a new well field seven miles to the north. In 1997, an ethanol plant in the city began pumping water from the su aquifer for their operations. The amounts of water appropriation peaked at 124 mgy in their first year, declined to a range of 75 to 101 mgy until 2009. Since then water use has declined significantly with the exception of a spike of 97 mgy in 2012. The only other large appropriator in the city was a beef processing facility which also pumped from the su aquifer (20 to 30 mgy). Appropriations from the beef processing facility ceased in 2008. From 1999 through 2009, the total combined appropriations from the city, beef processing plant, and the ethanol plant exceeded 100 mgy, with a peak of 180 mgy in 1997. The location and extent of potentiometric surface depressions will vary as pumping demands change over time and location.

Report Table 3. Reported 2014 water use from DNR groundwater permit holders

[Data from MPARS; mgy, million gallons per year; dash marks (--), no use in those categories; NA, not applicable]

Aquifer	Municipal/public water supply	Livestock watering	Agricultural/food processing	Agricultural crop irrigation	Golf course irrigation	Petroleum-chemical processing/ethanol	Total (mgy)	Total (percent)
Sand and gravel*								
Quaternary aquifer not determined	28.4	10.5	--	--	--	--	38.9	6
Shallow: ss through sg	17.5	4.7	91.5	0.6	--	--	114.3	17
Intermediate: s2 through s4	82.8	52.3	--	7.3	--	--	142.4	21
Deep: s5 through sz	285.5	33.1	--	23.9	18.8	15.5	376.8	56
Bedrock								
Cretaceous	6.1	--	--	--	--	--	6.1	1
Total (mgy)	420.3	100.6	91.5	31.8	18.8	15.5	678.5	NA
Total (percent)	62	15	13	5	3	2	NA	100+
Highest annual water use 2010–2014	420.3	102.6	150.5	31.8	31.7	120.0	NA	NA

*Confined conditions exist for most (99%) of the wells completed in the sand and gravel aquifers.

+Percentage may not add up to 100 due to rounding.

Summary and conclusions

The water table generally follows the surface topography; it is higher in the uplands and lower in the valleys. The depth to water table map shows that the water table is within 10 feet of the surface across most of the county with the exception of the upland valley edges and terrace sands in the Minnesota River valley.

Potentiometric surface maps, compiled from the static water level data in Renville County, indicate a pattern of groundwater flow toward the Minnesota River valley and its larger perennial tributaries for most of the county, except for the northeastern portion of the county where flow is to Buffalo Creek which discharges eastward to the South Fork Crow River. In the deeper aquifers (s4, s5, su, and sz), there are depressions in the potentiometric surface that appear to be caused by large long-term water appropriations. Most of the depressions are associated with city water supply wells, industrial use wells, and golf courses, all located within or in close proximity to cities.

Groundwater recharge sources can be differentiated through stable isotope analysis. Results plot along the global meteoric water line, indicating that most of the groundwater recharge is by precipitation directly infiltrating into the subsurface and not from lakes or other surface-water bodies.

Dissolved constituents indicate that as precipitation recharges into the groundwater system, there is a rapid chemical evolution as carbon dioxide dissolves into the water and this more acidic water dissolves various soluble minerals along its flow path. The relatively young waters have calcium and magnesium as their dominant cations, and either bicarbonate or sulfate or a mixture of both as the dominant anion(s). For the older and deeper groundwater, calcium and magnesium are being removed from solution through a process of exchange with sodium. Additionally, sulfate levels in some of these deeper aquifers are generally low to absent indicating reducing conditions sufficient for sulfate removal. Other evidence for significant reducing conditions is the presence of methane in several of the sampled wells.

Naturally occurring elements of health concern were found as elevated levels of arsenic and manganese in some of the samples. Arsenic concentrations exceeding the maximum contaminant level (10 ppb) were found in 25 of the samples (27 percent). There was an observed lack of elevated arsenic noted in samples located in the northwestern portion of the county. Manganese concentrations exceeded the Health Risk Limit (100 ppb) in 53 percent of the samples.

Pollution sensitivity was dominated by a very low rating for the bedrock surface and for all but three of the ten mapped buried aquifers. The three aquifers with the least amount of protection are the si aquifer (8 percent, very low), sm (38.5 percent, very low), and sg (80.3 percent, very low).

Residence-time analysis of groundwater samples using the radioactive isotope tritium generally validated pollution sensitivity models based on the thickness of lower permeability materials above the aquifer of interest. Groundwater samples with recent and mixed tritium values correspond to areas of very high to low sensitivity and those with vintage tritium values correspond to areas of very low sensitivity.

Groundwater use is mostly from buried sand aquifers with less than 7 percent getting their water from bedrock aquifers. The surficial sand deposits are seldom used as a water supply. Groundwater appropriation permits for large capacity wells across Renville County are located primarily near cities, with municipal water supplies accounting for 62 percent of the pumped water in 2014. After municipal use, livestock watering (15 percent) and agricultural/food processing (13 percent) are the next largest appropriators followed by agricultural irrigation, golf course irrigation, and ethanol production, which make up the remaining 10 percent.

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Glossary

anion—a negatively charged ion in which the total number of electrons is greater than the total number of protons, resulting in a net negative electrical charge.

anisotropic—a condition in which a property (e.g., hydraulic conductivity) varies with the direction.

anthropogenic—of, relating to, or resulting from the influence of humans on nature.

aquifer—an underground layer of water-bearing permeable rock or unconsolidated materials (sand and gravel) from which groundwater can be extracted using a water well.

aquitard (or confining layers)—layers made up of materials with low permeability, such as clay and shale, which prevent any rapid or significant movement of water.

arsenic (As)—a chemical element that is sometimes dissolved in groundwater and is toxic to humans. Natural arsenic contamination of groundwater is a problem that affects millions of people across the world, including over 100,000 people served by domestic wells in Minnesota.

bedrock—the consolidated rock underlying unconsolidated surface materials such as soil or glacial sediment.

buried aquifer—a body of porous and permeable sediment or bedrock which is buried beneath the ground surface by a low permeability layer.

carbon-14 (^{14}C)—a radioactive isotope of carbon that has a half-life of 5,730 years. It is used to identify groundwater that entered the ground from 100–35,000 years before present.

cation—a positively charged ion in which the total number of electrons is less than the total number of protons, resulting in a net positive electrical charge.

County Well Index (CWI)—a database developed and maintained by the Minnesota Geological Survey and the Minnesota Department of Health containing basic information for wells drilled in Minnesota. Information includes location, depth, static water level, construction, and geological information. The database and other features are available through the Minnesota Well Index online mapping application.

deuterium (^{2}H)—one of two stable isotopes of hydrogen. The nucleus of deuterium contains one proton and one neutron.

dolostone, or dolomite rock—a sedimentary carbonate rock that contains a high percentage of the mineral dolomite. Most dolostone formed as a magnesium replacement of limestone or lime mud prior to lithification. It is resistant to erosion and can either contain bedded layers or be unbedded. It is less soluble than limestone, but it can still develop solution features over time.

equipotential line—a line along which the pressure head of groundwater is the same. Groundwater flow (shown on cross sections) is perpendicular to these lines in the direction of decreasing pressure.

fluvial—term used in geography and geology to refer to the processes associated with rivers and streams and the deposits and landforms created by them. When the stream or rivers are associated with glaciers, ice sheets, or ice caps, the term glaciofluvial or fluvioglacial is used.

formation—a fundamental unit of lithostratigraphy. A formation consists of a certain number of rock strata that have a comparable lithology, facies or other similar properties.

fractionation—a separation process in which a certain quantity of a mixture (solid, liquid, solute, suspension, or isotope) is divided into a number of smaller quantities (fractions) in which the composition varies according to a gradient. Fractions are collected based on differences in a specific property of the individual components. Stable isotopes are fractionated by mass.

glacial—of, relating to, or derived from a glacier.

groundwater—water that collects or flows beneath the surface of the earth, filling the porous spaces below the water table in soil, sediment, and rocks.

half-life—the time required for one half of a given mass of a radioactive element to decay.

hydrogeology—the study of subsurface water, including its physical and chemical properties, geologic environment, role in geologic processes, natural movement, recovery, contamination, and use.

hydraulic—relating to water movement.

hydraulic conductivity—the rate at which groundwater flows through a unit cross section of an aquifer.

infiltration—the movement of water from the land surface into the subsurface under unsaturated conditions.

isotope—variants of a particular chemical element. All isotopes of an element share the same number of protons, but each isotope has a different number of neutrons.

lacustrine—pertaining to, produced by, or formed in a lake.

meteoric—of, relating to, or derived from the earth's atmosphere.

neutron—a subatomic particle contained in the atomic nucleus. It has no net electrical charge and a mass of approximately 1 (slightly greater than a proton).

nitrate (nitrate-N, NO_3^-)—humans are subject to nitrate toxicity, with infants being especially vulnerable to methemoglobinemia, also known as blue baby syndrome. Elevated nitrate (>1 ppm) is primarily from fertilizer sources.

observation well—a well that is used to monitor the water level of groundwater. It is not used as a water source.

Paleozoic—an era of geologic time from about 542 to 251 million years ago.

potentiometric surface—a surface representing the total head of groundwater in an aquifer and defined by the levels to which water will rise in tightly case wells.

provenance—the place of origin of a glacier.

Quaternary—geologic time period that began 2.588 million years ago and continues to today. The Quaternary Period comprises the Pleistocene and Holocene epochs.

radioactive—a property of an element that spontaneously decays or changes to a different element through the emission of radioactive particles.

recharge—the process by which water enters the groundwater system.

regolith—the layer or mantle of fragmented and unconsolidated rock material, residual or transported, that nearly everywhere forms the surface of the land and overlies or covers the bedrock.

residence-time indicators—a chemical and/or isotope used to interpret groundwater residence time.

saprolite—a residuum of extensive chemical weathering that converted some or nearly all of the minerals in the bedrock into various clay minerals.

specific capacity—the discharge of a well divided by the drawdown in the well.

stable isotope—chemical isotopes that are not radioactive.

static water level—the level of water in a well that is not affected by pumping.

stratigraphy—a branch of geology that studies rock layers and layering (stratification). It is primarily used in the study of sedimentary and layered volcanic rocks. Also used to refer to the sequence of rock layers in a region.

till—unsorted glacial sediment deposited directly by ice. It is derived from the erosion and entrainment of rock and sediment over which the glacier has passed.

transmissivity—an aquifer's capacity to transmit water, determined by multiplying the hydraulic conductivity of the aquifer material by the thickness of the aquifer.

tritium (^3H)—a radioactive isotope of hydrogen. The nucleus of tritium contains one proton and two neutrons.

tritium unit (TU)—one tritium unit represents the presence of one tritium atom for every 10^{18} hydrogen atoms.

unconfined—an aquifer that has direct contact with the atmosphere through an unsaturated layer.

vadose zone (unsaturated zone)—layer between the land surface and the top of the water table.

water table—the surface between the unsaturated and saturated zone where the water pressure equals the atmospheric pressure.

watershed—the area of land drained by a single stream or river.

well nest—two or more wells completed in different aquifers in close proximity to each other.

Appendix

Well owners were contacted through letters that included a description of the project and a reply card to return if they were willing to participate. Groundwater samples were collected from an outside faucet or hydrant. The wells were purged prior to sampling to remove stagnant water from the well bore and plumbing system. Samples were filtered and preserved according to protocols listed below and submitted to laboratories for analysis. Samples were analyzed by DNR staff, the University of Minnesota Department of Earth Sciences Laboratory (U of M), or the University of Waterloo Environmental Isotope Laboratory (Waterloo). The well owners received a copy of the results including some background reference information regarding their meaning.

Groundwater field sample collection and handling details

Parameter	Enriched tritium	^{18}O ^{2}H	Cations	Anions	Trace constituents	Alkalinity
Lab	Waterloo	Waterloo	U of M	U of M	U of M	DNR Staff
Sample container	500 ml HDPE	60 ml HDPE	15 ml, Fisherbrand BLUE cap	50 ml Argos BLACK bottle***	15 ml Sarstedt RED cap	500 ml plastic
Head space	yes	yes	yes	yes	yes	no
Rinse	no	no	yes*	yes*	yes*	yes**
Filter	no	no	yes	yes	yes	no
Preservative	no	no	1 drop 6N HCl	no	5 drops 15N HNO_3	no
Refrigeration	no	no	yes	yes	yes	yes, if not analyzed onsite
Shelf life	long	long	2–3 weeks	2–3 weeks	2–3 weeks	24–48 hours
Field duplicate	1 for every 20 samples	1 for every 20 samples	1 for every 20 samples	1 for every 20 samples	1 for every 20 samples	none
Field blank	none	none	1 for every 20****	1 for every 20****	1 for every 20****	none
Storage duplicate	yes	yes	no	no	no	no

*Rinse the bottle three times with sample water prior to collecting the sample (filtered if sample is filtered). Rinsing means fill the bottle with sample water and then pour the contents out over the cap.

**Rinse the bottle three times with sample water prior to collecting the sample. Fill bottle submerged with cap in hand. Seal bottle submerged ensuring no remnant bubbles.

***Fill 50 ml anion bottle unless filtering is very difficult. Bottle must be at least 1/3 full.

****Use deionized (DI) water from small bottle for field blanks. Pour DI water into the back of the syringe when the plunger is removed. Fill bottles through filter.

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