HYDROGEOLOGY OF THE SURFICIAL AND BURIED AQUIFERS

By

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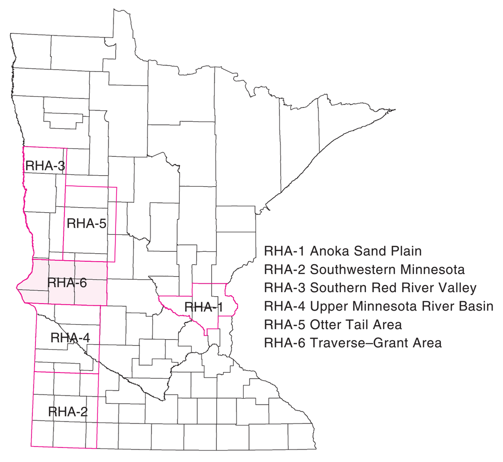
2008



INDEX OF REGIONAL HYDROGEOLOGIC ASSESSMENTS IN MINNESOTA

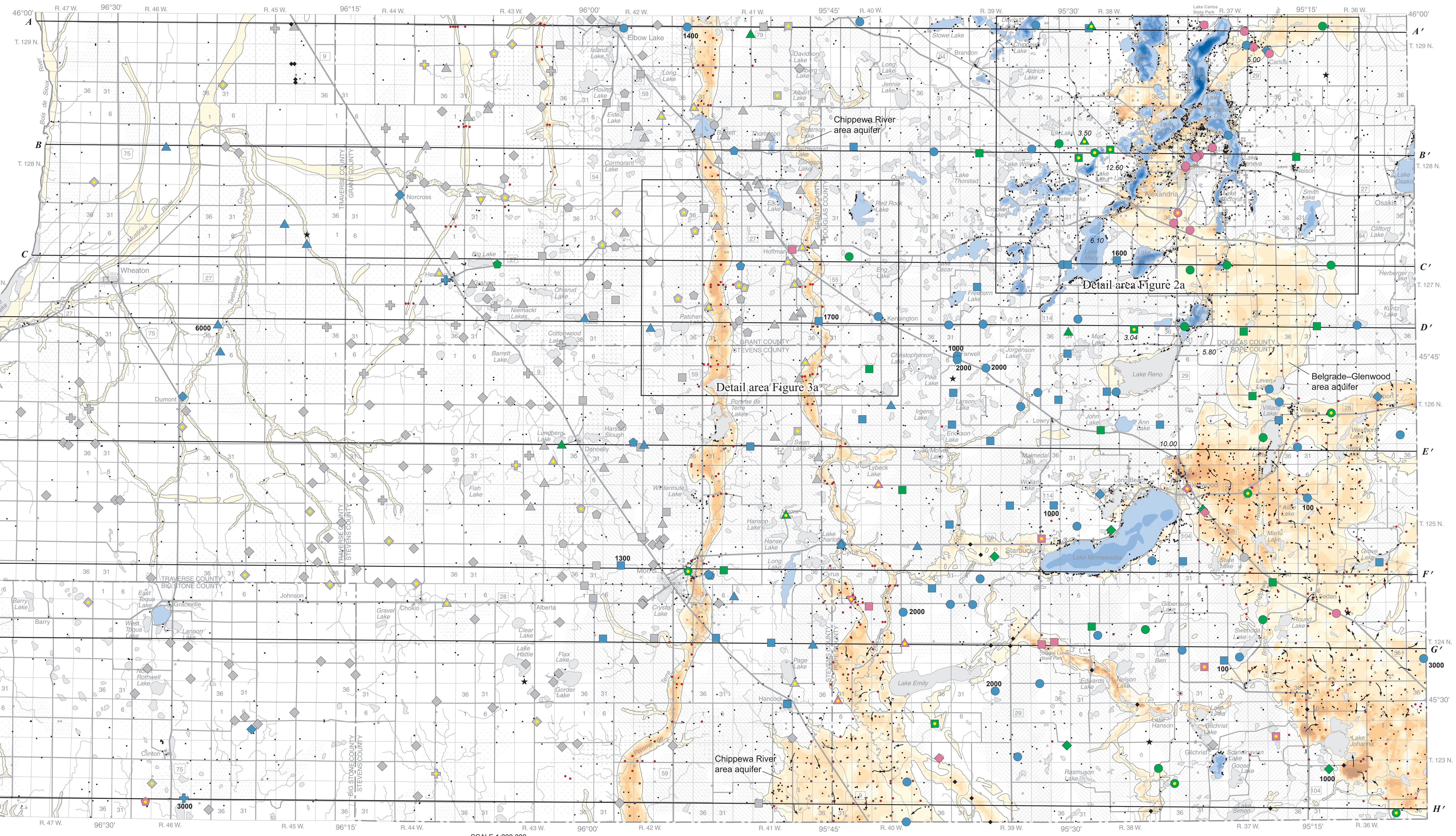


FIGURE 1. *Surficial sand and gravel aquifers in study area.* *The map shows the thickness and distribution of the surficial sand and gravel deposits. With some exceptions, the boundaries of these deposits are the same as the map units on Plate 1, Part A. The saturated thickness of the surficial aquifers is indicated on the cross sections on Plate 5. The gray patterns indicate the extent of buried aquifers described on Plate 4. The box on the upper right of the map identifies the detail area for Figure 2a. The box in the upper middle identifies the detail area for Figure 3a.*

MAP EXPLANATION
Figures 1, 2a, and 3a

Well and aquifer symbols
- Surficial sand and gravel aquifer
- Buried LG aquifer
- Buried OT aquifer
- Buried CW aquifer
- Buried aquifer 1
- Buried western aquifer
- Older, unmapped Pleistocene aquifers

Tritium age

Color indicates tritium age of water sampled in well.
- Recent—Water entered the ground since about 1953 (10 or more tritium units [TU]).
- Mixed—Water is a mixture of recent and vintage waters (greater than 1 TU to less than 10 TU).
- Vintage—Water entered the ground before 1953 (less than or equal to 1 TU).
- Well not sampled for tritium, but sampled for chloride and bromide.

Map labels
- 12.60 If shown, nitrate as nitrogen concentration equals or exceeds 3 parts per million.
- 2000 If shown, ground-water age in years, estimated by carbon-14 isotope analysis.
- If shown on well symbol, chloride to bromide ratio greater than 175.

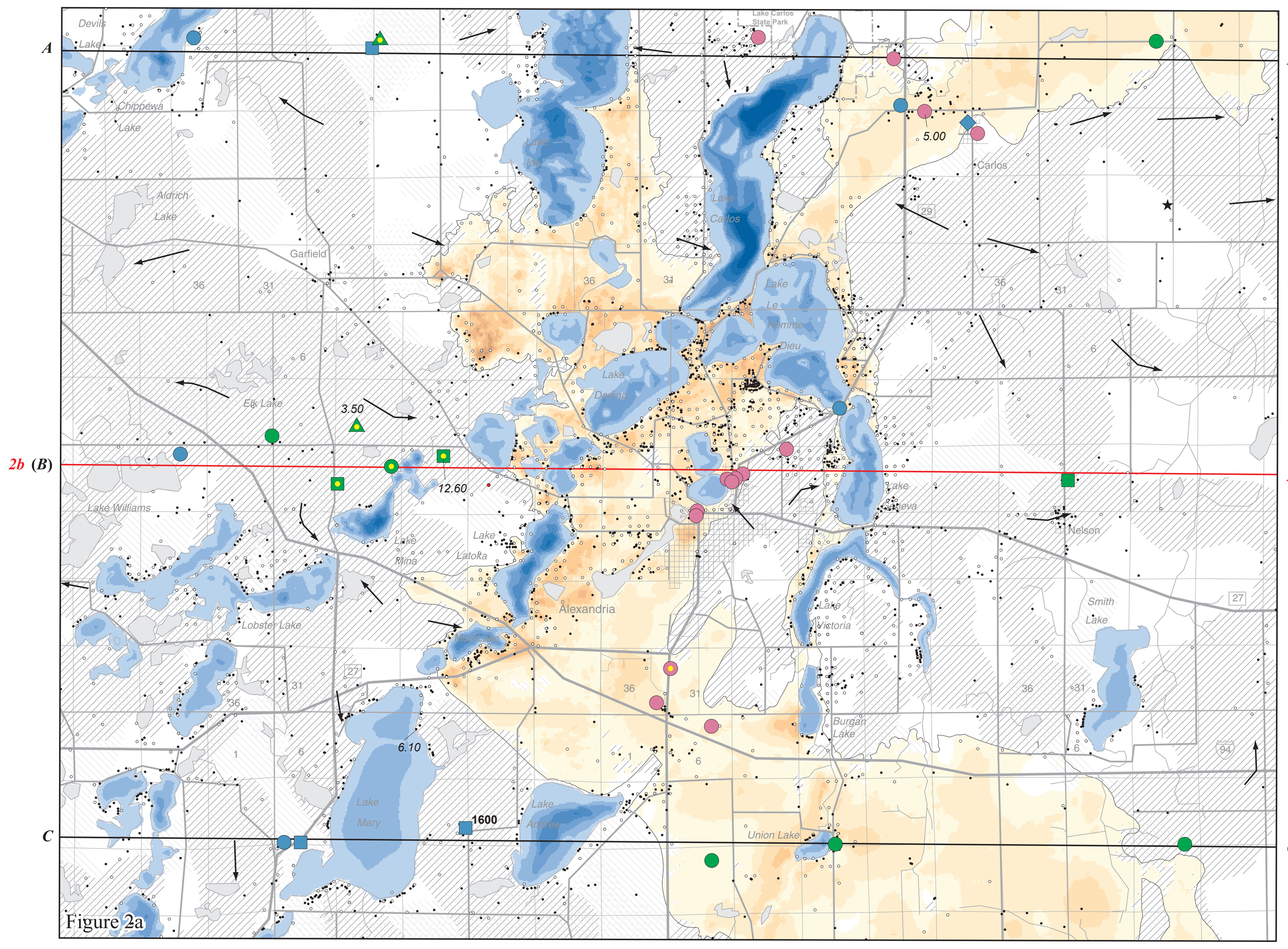
Buried aquifers
- LG aquifer
- OT aquifer
- CW aquifer
- Aquifer 1
- Western aquifer

Thickness of surficial sand and gravel (feet)
- 0–20
- 20–40
- 40–60
- 60–80
- 80–100
- 100–120
- 120–140
- Greater than 140
- Data insufficient or deposit not present

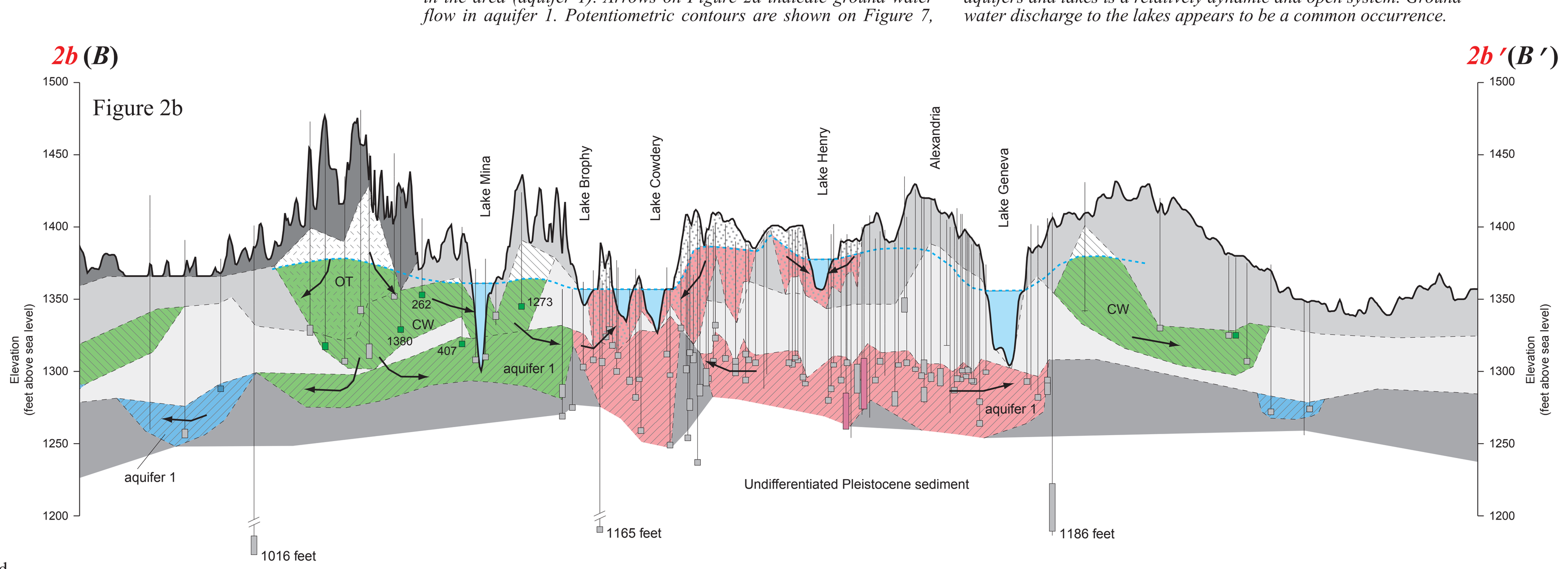
Depth of selected lakes (feet)
- 0–20
- 20–40
- 40–60
- 60–80
- 80–100
- 100–120
- Greater than 120
- Depth not shown

Map symbols
- Extent of mapped surficial sand and gravel.
- General direction of ground-water flow.
- Body of water.
- F F′ Line of cross section.

Types of data
- Verified well location.
- Unverified well location.
- U.S. Geological Survey well or test hole.
- Surficial electrical resistivity test.
- Rotosonic drill log.



FIGURES 2a and 2b. *Detail of stratigraphy and hydraulic connections near Alexandria.* *These figures show examples of the complex stratigraphy and hydraulic connections that exist in the Alexandria area between the surficial aquifer, lakes, and buried sand and gravel aquifers. The three mapped, buried aquifers are shown as gray patterns; the darker pattern represents the main water-supply aquifer in the area (aquifer 1). Arrows on Figure 2a indicate ground-water flow in aquifer 1. Potentiometric contours are shown on Figure 7, Plate 6. The main recharge areas for aquifer 1 are west and south of Alexandria where precipitation infiltrates through thick surficial sands (south area) or thinly covered and interconnected overlying layers of sand and gravel (west area). Arrows on Figure 2b indicate ground-water flow within and between aquifers. Recent and mixed tritium values in the buried aquifers are evidence that the complex of aquifers and lakes is a relatively dynamic and open system. Ground-water discharge to the lakes appears to be a common occurrence.*



EXPLANATION
Figures 2b–3b

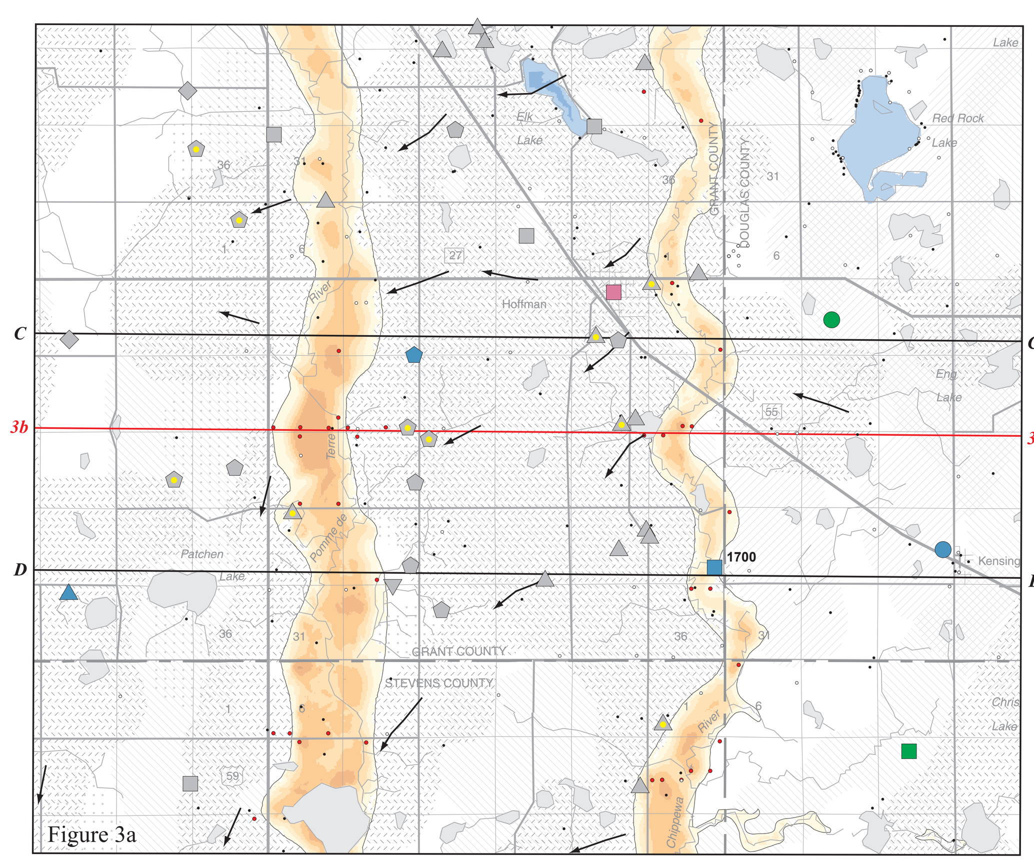
Tritium age

Darker color in small vertical rectangle (well screen symbol) indicates tritium age of water sampled in well. Lighter color indicates tritium age of water in aquifer.
- Recent—Water entered the ground since about 1953 (10 or more tritium units [TU]).
- Mixed—Water is a mixture of recent and vintage waters (greater than 1 TU to less than 10 TU).
- Vintage—Water entered the ground before 1953 (less than or equal to 1 TU).
- Well not sampled for tritium.

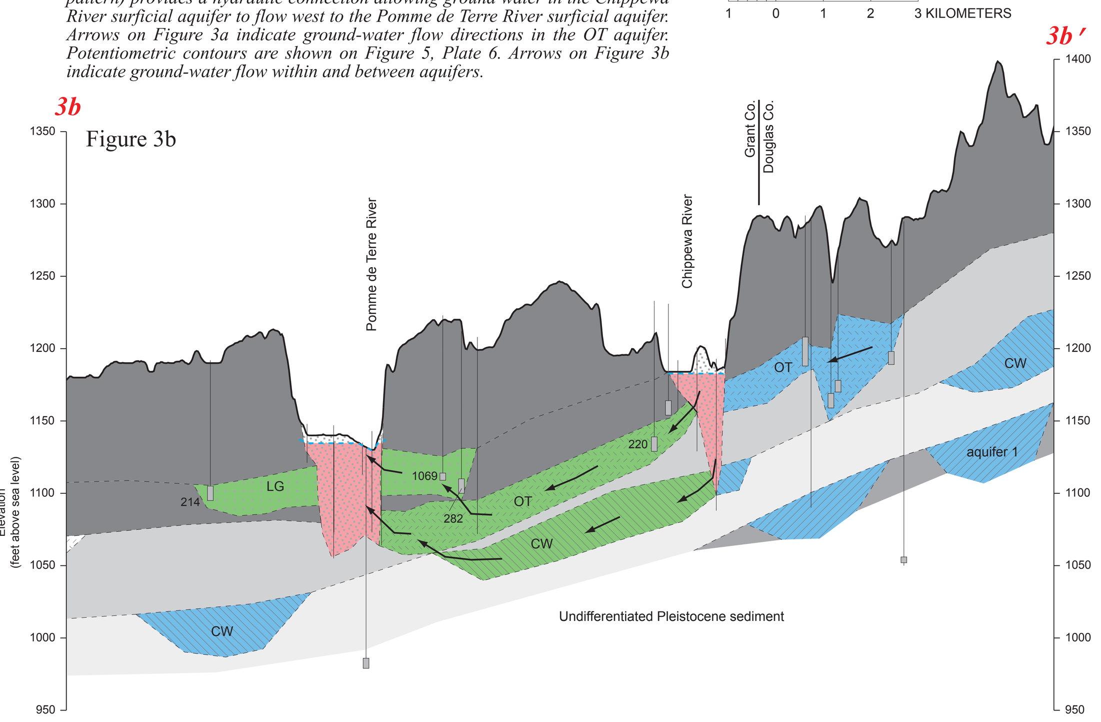
Cross-section symbols and labels
- Water-table surface.
- 407 If shown, chloride to bromide ratio greater than 175.
- General direction of ground-water flow.
- Geologic unit contact, uncertain.
- Land surface.
- Lake.

Low-permeability geologic units (aquitards)
- Upper and Lower Goose River groups.
- Otter Tail River group.
- Crow Wing River group.
- Browerville formation and other unnamed till units.

Aquifers
- Surficial sand and gravel aquifer
- Buried LG aquifer
- Buried OT aquifer
- Buried CW aquifer
- Buried aquifer 1
- Buried western aquifer



FIGURES 3a and 3b. *Detail area showing connections of rivers to aquifers.* *Because it originated as glacial outwash channels, the sand and gravel associated with the Pomme de Terre and Chippewa rivers is relatively deep and hydraulically connected to buried aquifers in the area. In Figure 3a, the OT aquifer (darker gray pattern) provides a hydraulic connection allowing ground water in the Chippewa River surficial aquifer to flow west to the Pomme de Terre River surficial aquifer. Arrows on Figure 3a indicate ground-water flow directions in the OT aquifer. Potentiometric contours are shown on Figure 5, Plate 6. Arrows on Figure 3b indicate ground-water flow within and between aquifers.*



INTRODUCTION

This report is the sixth in a series of regional hydrogeologic assessments (RHAs) completed as a joint effort by the Division of Waters from the Minnesota Department of Natural Resource (DNR Waters) and the Minnesota Geological Survey (MGS). This report describes the geology and hydrogeology of all or parts of six counties in western Minnesota to create a regional inventory of aquifers and aquifer conditions. While similar in geographic scope to previous RHAs, this report contains a more extensive treatment of the regional buried aquifer characteristics such as thickness and depth (Plate 4); hydrogeology as illustrated by cross sections (Plate 5); and ground-water flow directions, hydrochemistry, and pollution sensitivity (Plate 6). These features make it similar to, but less detailed than, the companion county geologic atlas series. The southeastern part of the study area was described in the Pope County Geologic Atlas, Part A (2003) and Part B (2006). This RHA is designed for units of government and citizens to use in planning for land use, water supply, and pollution prevention.

GEOLOGIC DATA SOURCES

Much of the information used to produce the maps, cross sections, and figures of this report came from well records: the County Well Index (CWI) database of well logs maintained by MGS and the Minnesota Department of Health (MDH), as well as well logs from holes that were drilled for several previous hydrogeologic investigations of this region by the U.S. Geological Survey (USGS) (Van Voast, 1971a; Van Voast, 1971b; Wolf, 1976; Soukup and others, 1984; Delin, 1986; Delin, 1987; Delin, 1990). Another information source was electrical resistivity data collected by DNR Waters' staff for this project.

The CWI data include descriptions from drillers that are made as a well is drilled. Most of these well locations are verified in the field by staff from the MGS or MDH. The dataset also contains well logs with unverified locations. Some of the unverified data were used on the maps and cross sections of this report; however, some of the unverified data were ignored if the information seemed inconsistent with other more reliable information or if the locations were obviously incorrect.

CHARACTERISTICS OF SAND AND GRAVEL AQUIFERS

Depositional Characteristics

Figure 1 shows the thickness and distribution of surficial sand and gravel deposits in the study area. Some surficial sand boundaries shown in Part A were revised based on CWI information and soil surveys (Lewis and others, 1971; DeMartelaere, 1975; Diers, 1995). Buried sand and gravel deposits that underlie the surficial deposits are shown for reference in faded gray patterns. These deposits are presented and discussed in more detail on Plates 4 and 5. The geologic history of surficial sand deposition is derived from descriptions from Plate 1, Part A. Several advances and recessions of ice lobes, which moved into Minnesota from the northwest through the area that is now occupied by the Red River Valley, dominated the late glacial history of the region. Ice margins shown on Plate 1, Part A, represent the approximate positions that the ice lobe edges occupied long enough for huge volumes of meltwater and associated sand and gravel to be discharged from the melting ice.

The largest and thickest deposit from glacial meltwater is the Belgrade-Glenwood sand plain in the eastern portion of the study area. The thickest portions of this sand plain, where thicknesses from 50 feet to 70 feet are common, occur in the Alexandria area of central Douglas County, the Glenwood area of northeastern Pope County, and the Lake Johanna area of southeastern Pope County. Crop irrigation is a common use for the relatively thick portions of the Belgrade-Glenwood area aquifer in Pope County (Figure 1).

The two major rivers of the central portion of the study area, the Chippewa and the Pomme de Terre, are associated with thick, linear glacial outwash deposits from two separate ice margin locations. This sand and gravel was deposited along the eastern edge of a major ice lobe that existed to the west. The surficial sand and gravel beneath the Chippewa River broadens in the southern portion of the study area, west of Lake Emily in southwestern Pope and southeastern Stevens counties. This broader portion of the Chippewa River area aquifer represents deposits from a delta associated with Glacial Lake Benson that existed to the south in Swift and Chippewa counties (Patterson and others, 1999). Thickness values of 20–40 feet are common in this deposit; the thickest portion (40–60 feet) occurs generally west of Lake Emily. The glacial outwash beneath the Pomme de Terre River appears to have a relatively uniform width and maximum thickness range of 50–70 feet in the study area. Crop irrigation, especially in the broad southern portion of the Chippewa River area aquifer, is common in these thick areas of surficial aquifer.

West of the Pomme de Terre River in Traverse, northern Big Stone, and western Grant and Stevens counties, occurrences of surficial sand are limited and thin. The dendritic pattern of surficial sand shown on the western portion of Figure 1 occurs in small creek valleys; was deposited during the postglacial period (Holocene); and consists of silty, clayey sand. The largest river in this portion of the study area is the Mustinka, which crosses Grant and Traverse counties. USGS borehole data (Soukup and others, 1984) indicate maximum sand and gravel thicknesses of 40–60 feet in the Grant County portion of the Mustinka River valley. The other thick surficial sand occurs in the Beardsley area of northern Big Stone County with maximum thicknesses of approximately 40–50 feet (Soukup, 1980). Thicknesses of the other Holocene alluvial deposits in the western portion of the study area are unknown but probably much less than those of the Mustinka alluvium or the Beardsley area surficial sand. Pleistocene (ice age) glacial lake beach ridges occur as a curved pattern of surficial sand in Grant, northwest Stevens, and Traverse counties. These beach ridges are roughly perpendicular to the creek and river alluvial deposits. Thicknesses commonly range from 10 feet to 15 feet.

Ground-water flow directions are shown on Figure 1 as black arrows for the major surficial aquifers in Pope County and small portions of adjoining areas. Very little water-level information pertaining to the water-table aquifer was available from other portions of the study area. The ground-water flow directions of the Chippewa River area aquifer of southwestern Pope County and southeastern Stevens County have a relatively simple pattern of southerly flow and flow toward the river. By comparison, ground-water flow in the Belgrade-Glenwood area aquifer is very complex because it occupies portions of three major surface watersheds. These two major aquifers in Pope County are described with greater detail in the Pope County Geologic Atlas, Part B (Berg, 2006a).

Ground-Water Residence Time

The ground-water residence times of samples from selected wells across the study area are shown in Figure 1. The interpretation of the ground-water residence time data is explained in more detail on subsequent plates. Geochemical data collected by DNR Waters for this project were supplemented by additional data from MDH collected during two previous investigations of water-quality issues of western Minnesota (Walsh, 2000; Minnesota Department of Health, 2001).

The pink, green, and blue symbols on Figure 1 and detailed, enlarged versions (Figures 2a and 3a) and associated cross sections (Figures 2b and 3b) represent tritium values that indicate ground-water residence time. This is the approximate time that has elapsed from when the water infiltrated the land surface to when it was pumped from the aquifer for this investigation. Ground-water residence time is closely related to the pollution sensitivity concept described on Plate 6. In general, short residence time suggests high pollution sensitivity, whereas long residence time suggests low sensitivity.

Tritium (^{3}H) is a naturally occurring isotope of hydrogen. Concentrations of this isotope in the atmosphere were greatly increased from 1953 through 1963 by aboveground detonation of hydrogen bombs (Alexander and Alexander, 1989). This isotope decays at a known rate, with a half-life of 12.43 years. Ground-water samples with concentrations of tritium equal to or greater than 10 tritium units (TU) are considered recent water (mostly recharged in the past 50 years, shown in pink). Concentrations equal to or less than 1 TU are considered vintage water (recharged prior to 1953, shown in blue). Concentrations between these two limits are considered a mixture of recent and vintage and are referred to as mixed water (shown in green).

Aquifer symbols with a yellow dot indicate elevated values of chloride (chloride to bromide ratio greater than 175) originating from human activities (anthropogenic). Chloride concentrations and ratios of chloride to bromide (Cl/Br) from water samples have been used in previous ground-water studies (Berg, 2004 and 2006b) as an indicator of chloride contamination from human activities. Samples containing high Cl/Br ratios (above 175) were found throughout the study area from all the mapped aquifers. Some of the occurrences of elevated Cl/Br ratios in samples from deep wells, especially in the western portion of the study area, may be due to leaky well construction.

Ground-water age for the vintage samples also can be estimated with the carbon-14 (^{14}C) isotope. This isotope, which also occurs naturally, has a much longer half-life than tritium (5730 years). Carbon-14 is used to estimate ground-water residence in a time span from about 100 years to 40,000 years (Alexander and Alexander, 1989). The residence time of the 17 ground-water samples tested for carbon-14 ranged from approximately 100 years to 6000 years. Some of the oldest residence times were found in water samples from buried aquifers, including aquifer 1 in southeastern Pope County northwest of Brooten (3000 years), the western aquifer south of Clinton in Traverse County (3000 years), and the OT aquifer southeast of Wheaton in Big Stone County (6000 years).

Most recent or mixed tritium values (pink and green symbols) and those well symbols indicating anthropogenic chloride (yellow dots) were directly or indirectly resulted from infiltration of precipitation to buried aquifers through the thick surficial sand areas outlined in the previous section. Many of these occurred in water samples from aquifer 1 and the CW aquifer that underlie the Belgrade-Glenwood area aquifer in the eastern portion of the study area.

In areas where vintage tritium values dominated, such as much of northwestern Pope County and western Douglas County, recharge to buried aquifers through thick overlying layers of fine-grained glacial till is very slow. Carbon-14 values in the hundreds of years and thousands of years within aquifer 1 and the CW aquifer also support this conclusion. Fewer water samples were collected for analysis from buried OT and older, unmapped Pleistocene aquifers of Traverse and Big Stone counties because of the sparse well density. However, for the six water samples that were collected, vintage tritium values and carbon-14 ages of more than 1000 years predominate in this western portion of the study area and indicate very slow recharge and hydraulically isolated aquifers.

Where the overlying fine-grained till layer is thin, typically less than 40 feet, evidence of relatively recent recharge was indicated by the high Cl/Br ratios in water samples from the LG aquifer in eastern Grant County and the recent tritium values in water samples from the OT aquifer in western Pope County. Additional recharge conditions are shown and discussed on the following plates.

Alexandria Detail Area

The city of Alexandria sits on the crest of the Alexandria moraine, which is the largest geomorphic feature of western Minnesota and extends south to the Spicer-New London area and north to the Upper and Lower Red Lakes. A major surface-water divide passes through this area splitting surface-water flow between the Minnesota River to the west and the Mississippi River to the east. Regional ground-water flow of the shallow buried aquifers mapped in this report is similarly split. Superimposed on this regional flow pattern is a complex local ground-water system in which ground water passes through the surficial sand aquifer or shallow buried occurrences of the OT or CW aquifers into aquifer 1. Some ground water within aquifer 1 appears to discharge into the cluster of lakes in the area that ultimately flows into Lake Carlos and the Long Prairie River.

Figures 2a and 2b feature ground-water flow into, through, and out of aquifer 1 in the northeastern part of the study area. The two major recharge zones include an area in the south-central portion of Figure 2a within the surficial sand area surrounded by Andrew, Union, Burgan, Mud, and Latoka lakes. The thick surficial sand and connected buried aquifers allow recharge to aquifer 1 in this area. The other major recharge zone is in the western portion of Figure 2, south of the city of Garfield and north of Lobster Lake and Lake Mina and shown on the left portion of Figure 2b (cross-section B-B′ on Plate 5). Surface water can infiltrate the thin cover of glacial till that covers the OT aquifer in the area, pass through the CW aquifer into aquifer 1, and ultimately discharge to the lakes. Nitrate concentrations in ground water above approximately 3 parts per million (ppm) are usually caused by anthropogenic sources such as fertilizer application and septic or sewage systems. Four water samples collected within this detail area had nitrate concentrations higher than this background value. Two were located in the Lake Mina area, one on the east shore of Lake Mary, and one located east of Lake Carlos. All the ground-water samples but one in the study area were collected from buried or confined aquifers where reducing conditions (absence of dissolved oxygen) predominate. Dissolved nitrate is naturally removed by bacteria under these conditions, which may account for the general lack of elevated nitrate values from these sampled wells.

Ground-water flow pathways in the eastern and western portions of Figure 2a and Figure 2b represent regional ground-water flow directions not influenced by the Alexandria area lakes.

Pomme de Terre-Chippewa River Detail Area

The detail area shown on Figure 3a (central part of the study area) is west of the Alexandria moraine, and the regional ground-water flow of the shallow buried aquifers is to the west. The thick glacial outwash beneath the Pomme de Terre and Chippewa river valleys commonly intersects the OT aquifer that is somewhat laterally continuous and, at fewer locations, the deeper CW aquifer. These intersecting aquifer conditions appear to allow recharge to the OT aquifer and less commonly to the CW aquifer from the Chippewa River and associated aquifer. Ground water within the OT and CW aquifers migrates to the southwest discharging to the Pomme de Terre River and associated aquifer.

Geochemical evidence is limited in this area, but there were three OT ground-water samples with elevated Cl/Br ratios and one sample from the CW aquifer with a recent tritium value in the Hoffman area (northeast portion of Figure 3a), as well as a CW ground-water sample at the northern end of Swan Lake with an elevated Cl/Br ratio (Figure 1). These samples suggest a movement of ground water to the west from the Chippewa River aquifer.

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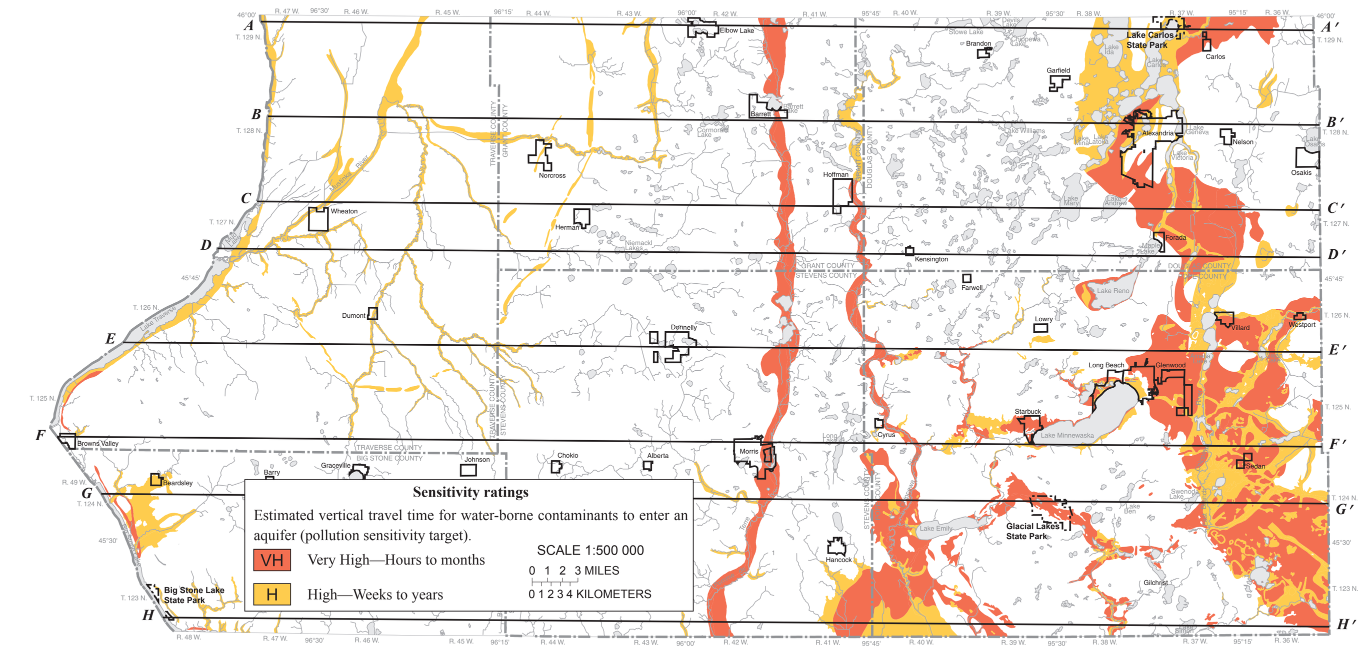

FIGURE 4. *Pollution sensitivity of surficial aquifers.* *The surficial aquifers described on this plate are relatively sensitive to pollution. The sensitivity rating of these aquifers is based mainly on the relative content of fine- and coarse-grained sediments in the aquifers. The sediment descriptions of the map units in Part A, Plate 1, were evaluated according to the described sediment texture. The coarsest sediments that consist mainly of sand and gravel were rated as very high sensitivity. These map unit codes include* bd, bsl, hc, hsl, lgo, lgc, ogs, ogo, ogc, *and* qc. *The map units containing sand, silt, and clay were rated as high and include* bns, ha, ho, hns, lgd, olw, *and* ugd. *In selected areas, map units that generally consist of a thin cover (less than a few feet) of fine-grained material such as clay, silt, and organic material or till but are underlain by sand or sand and gravel were also included in the high sensitivity category. These map units include* hp, hs, lgp, *and* op. *Finally, based on well logs and other mapping considerations, portions of some other units were included in the high sensitivity category.*

This map was compiled and generated using geographic information systems (GIS) technology. Digital data products, including chemistry and geophysical data, are available from DNR Waters at http://www.dnr.state.mn.us/waters.
This map was prepared from publicly available information only. Every reasonable effort has been made to ensure the accuracy of the factual data on which this map interpretation is based. However, the Department of Natural Resources 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 Minnesota Geological Survey and the Minnesota Department of Natural Resources. Every effort has been made to ensure the interpretation shown conforms to sound geologic and cartographic principles. This map should not be used to establish legal title, boundaries, or locations of improvements.
Base modified from Minnesota Geological Survey, Traverse-Grant Area Regional Hydrogeologic Assessment, Part A, 2006.
Project data compiled from 2004 to 2007 at a scale of 1:100,000. Universal Transverse Mercator projection, grid zone 15, 1983 North American datum. Vertical datum is mean sea level. GIS and cartography by Jim Berg and Gregg Massaro. Edited by Nick Kroska.

REGIONAL HYDROGEOLOGIC ASSESSMENT
TRAVERSE–GRANT AREA, WEST-CENTRAL MINNESOTA