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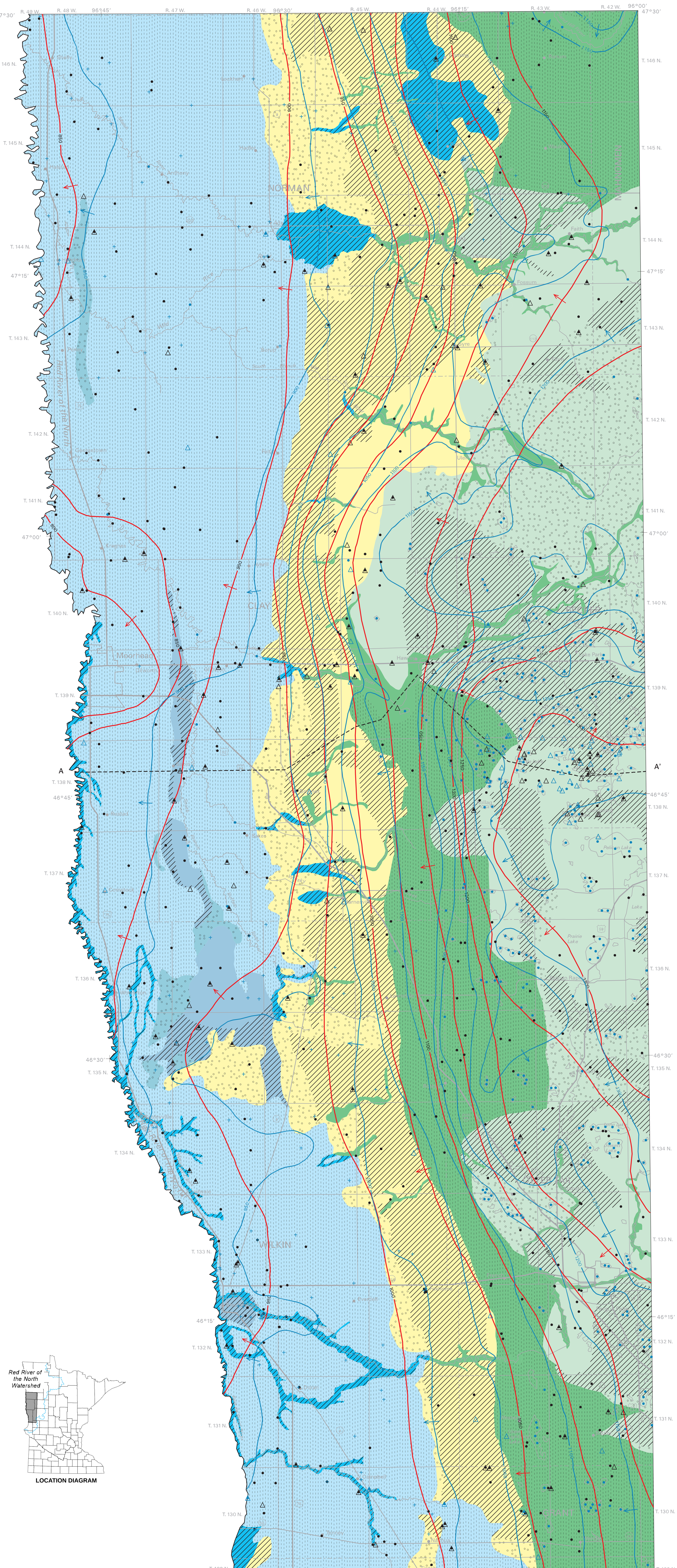


Red River of the North Watershed

LOCATION DIAGRAM

EXPLANATION

- 1000 Regional water-table contour
- 1000 Potentiometric contour of deep regional system
- General direction of ground-water flow in regional water-table system
- General direction of ground-water flow in deep regional system
- Well measured for water level*
- Water-table elevation estimated from well logs
- Surface-water elevation
- Well sampled for chemical analysis*
- Surface water sampled for chemical analysis

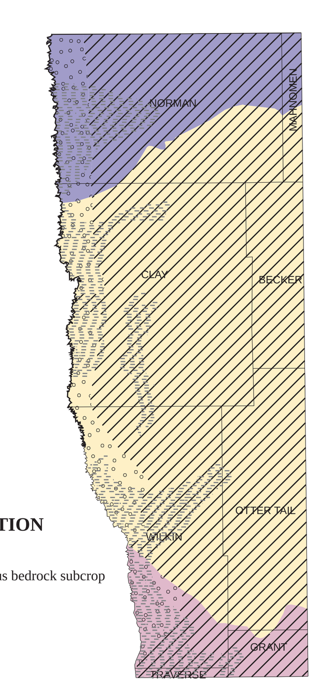
* Locations for both surficial and deep regional systems shown on 1:200,000 map

- no pattern — **Downward hydraulic gradients. Recharge to surficial aquifers and leakage to regional systems.**
- **Vertical gradients vary but flow is primarily horizontal.**
- **Upward hydraulic gradients. Discharge to rivers and wetlands.**
- **Surficial sediments with limited water-supply capacity.**

Matrix of Hydrologic Regime Characteristics

[mg/L, milligrams per liter; n.s., not sampled; A, active near-surface system; I, inactive near-surface system; n.a., not applicable]

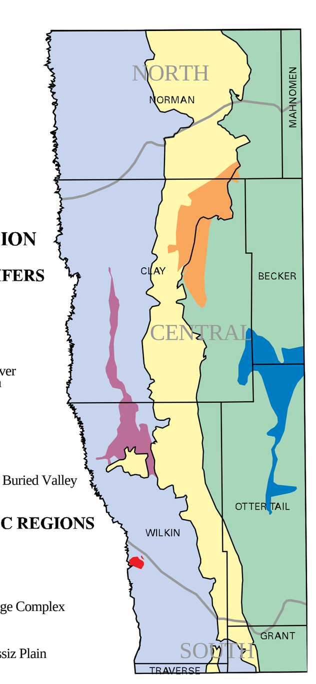
Ground Water System	Type	Region	Regime	Description	Selected characteristics of ground-water chemistry: Ca+Mg+Na+K (mg/L)	Na+K / Ca+Mg	SO_4 (mg/L)	No. of potential aquifers within ground-water system
Near Surface	A	Moraine	1	Recharge area for local and regional systems; numerous lakes fed by ground water; some high-yield aquifers present; source of recharge to underlying regional Regime 16.	141	0.10	28	3 to 5
			2	Lateral flow of ground water in local confined systems originating in Regime 1; downward hydraulic gradients contribute some recharge to Regime 16; fewer lakes than Regime 1.	192	0.26	37	2 to 4
			3	Upward hydraulic gradients with ground-water discharge of local systems associated with Regimes 1 and 2; numerous wetlands.	129	0.46	44	2 to 4
			4	Limited-capacity aquifers may exist in surficial sand and gravel alluvium; ground-water movement in these aquifers affected by local streams and rivers.	168	0.25	55	1 to 2
	I		5	Glacial deposits, primarily till; limited capacity for water supply.	n.s.	n.s.	n.s.	Few scattered and isolated
	A	Beach Ridge Complex	6	Recharge area for local systems in Beach Ridge Complex; downward hydraulic gradients.	204	0.16	59	2 to 3
			7	Lateral flow of ground-water systems originating in Regime 6; flow paths and travel times are relatively short; some ground-water discharge to scattered wetlands.	198	0.53	89	2 to 3
			8	Upward hydraulic gradients with discharge of local ground-water systems in Beach Ridge Complex; numerous wetlands.	222	0.57	76	2 to 3
	A	Lake Agassiz Plain	9	Limited-capacity aquifers may exist in windblown deposits or surficial sands and gravels deposited by existing rivers; ground-water movement in these aquifers affected by local streams and rivers.	388	6.98	151	1 to 2
			10	Unconfined portion of Buffalo Aquifer.	178	0.22	173	1
	I		11	Confined portion of Buffalo Aquifer or Wahpeton Buried Valley Aquifer.	213	6.14	164	1
			12	Isolated aquifers in surficial near-shore lake deposits; high dissolved-ion concentrations; few aquifers exist vertically.	512	0.32	625	1
			13	Lake Agassiz sediments, mostly silts and clays; inadequate supply for domestic use.	n.s.	n.s.	n.s.	0
Deep Regional (See Figures 1 and 3)	n.a.	North	14	Deep regional ground-water system with recharge from areas in eastern Mahnomen County.	221	2.75	17	2 to 4 above Cretaceous deposits
			15	Deep regional ground-water system with discharge to Red River of the North.	452	4.41	175	2 above Cretaceous deposits
		Central	16	Deep regional ground-water system with recharge areas in western Becker County; additional recharge from Regimes 1 and 2.	208	1.23	111	4
			17	Deep regional ground-water system with discharge to Red River of the North.	319	1.88	89	4 above Cretaceous deposits
		South	18	Deep regional ground-water system with recharge areas in central and southwestern Otter Tail County.	367	0.76	204	2 to 4
			19	Deep regional ground-water system with discharge to Red River of the North.	216	2.13	15	2 above Cretaceous deposits



EXPLANATION

Cretaceous bedrock subcrop

FIGURE 1. *Map of deep regional hydrogeologic regimes and area of Cretaceous subcrop. Key to color and pattern and summary information for deep regional regimes is shown above in the Matrix of Hydrologic Regime Characteristics.*



EXPLANATION

MAJOR AQUIFERS

Surficial
- Unnamed
- Pelican River Sand Plain
- Buffalo

Buried
- Wahpeton Buried Valley

GEOMORPHIC REGIONS
- Moraine
- Beach Ridge Complex
- Lake Agassiz Plain

FIGURE 2. *Key map of geographic areas, major aquifers, and geomorphic regions for the study area. Table 1 summarizes the surface and ground water chemical analysis data for these areas.*

TABLE 1. Natural characteristics of surface and ground water in the Southern Red River Valley RHA study area.

[Samples collected during 1992 and 1993 by Minnesota Department of Natural Resources staff; µS/cm, microsiemens per centimeter; TDS, total dissolved solids, calculated by multiplying the measured conductivity value by 0.66 (Hounslow, 1995); mg/L, milligrams per liter; NO_3-N, nitrate as molecular nitrogen: 1 mg/L nitrogen equals 4.4 mg/l nitrate; TU, tritium units; n.a., not applicable]

Area, geomorphic region, or aquifer (see Figure 1)	Number of Samples	Conductivity µS/cm	TDS mg/L	Dissolved oxygen mg/L	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 + CO_3 mg/L	Cl mg/L	SO_4 mg/L	NO_3-N mg/L	Tritium: Number of samples	Tritium: Percent samples >0.8 TU
GEOGRAPHIC AREA (all wells sampled in area)														
North	35	626	413	0.29	73	31	59	4.5	329	29	52	0.03	32	31.3
Central	60	689	455	0.48	92	37	43	4.8	357	17	53	0.67	39	46.2
South	35	1302	859	0.06	125	53	151	9.1	386	38	185	0.06	16	12.5
GEOMORPHIC REGION (all wells sampled in region unless otherwise noted)														
Moraine	50	687	453	0.65	105	41	18	4.8	360	7	53	0.81	40	45.0
Beach Ridge Complex	31	712	470	0.20	89	41	44	4.4	323	10	91	0.04	23	34.8
Lake Agassiz Plain[1] (except Buffalo Aquifer)	42	1061	700	0.05	89	36	162	8.1	381	57	119	0.04	21	9.5
Buffalo Aquifer	7	1124	742	0.10	98	44	119	6.6	329	47	140	0.09	3	66.7
SURFACE WATER[2]	67	525	347	5.21	93	47	15	8.0	256	8	132	0.39	0	n.a.
AQUIFER														
Unconfined (surficial) sand and gravel	15	628	414	1.25	95	39	13	3.8	311	20	81	1.70	15	73.3
Confined (buried) sand and gravel aquifers	111	844	557	0.19	98	41	72	6.0	364	19	89	0.16	70	27.1
Cretaceous	4	1491	984	0.10	34	9	420	10.8	349	246	101	<0.09	2	0.0
SUMMARY (combines ground and surface water samples)														
Number of samples	n.a.	196	196	132	135	135	135	135	160	135	135	135	87	n.a.
Minimum	n.a.	220	145	<0.01	2	1	1	1.2	161	0.4	0.1	<0.09	n.a.	0.0
Maximum	n.a.	2540	1676	10.42	497	165	629	21.4	879	485	1720	14.70	n.a.	73.3
Mean	n.a.	731	482	0.84	96	40	74	6.0	330	25	90	0.34	n.a.	34.5
Standard deviation	n.a.	390	n.a.	2.03	61	26	102	3.4	105	57	173	1.48	n.a.	17.2

Note: Mean values are shown unless otherwise defined. [1]Regional system samples only. [2]Six surface water locations sampled for cations and anions.

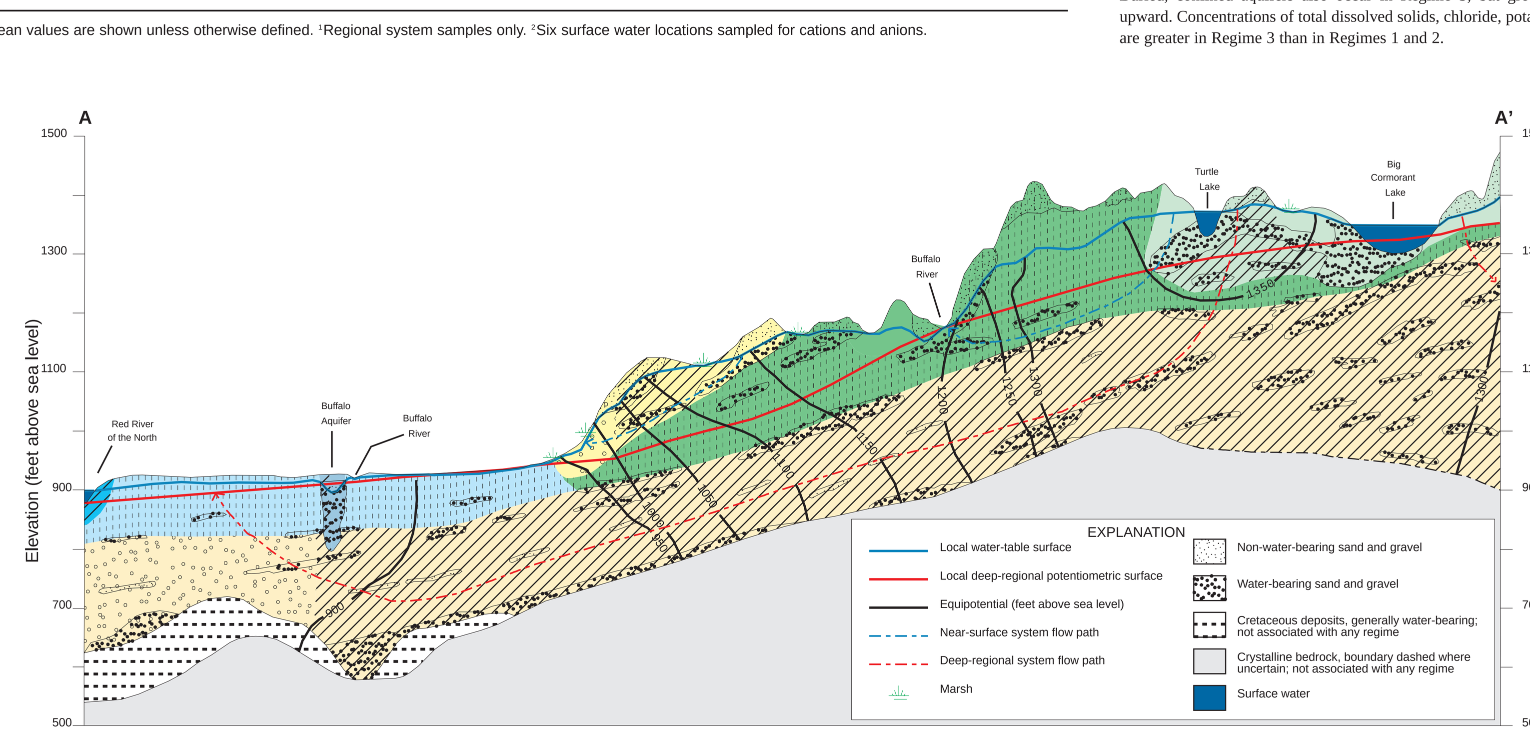


FIGURE 3. *Generalized hydrologic cross section A-A' illustrating major surface and ground water features. The cross section schematically portrays local hydrologic conditions along and approximately three miles either side of A-A'. Refer to the hydrologic regimes characteristics matrix above for the key to colors and patterns. The thickness of buried sand and gravel deposits is exaggerated for illustration purposes. Not drawn to scale.*

SURFICIAL HYDROGEOLOGY

By
Michael D. Trojan
Minnesota Pollution Control Agency
1997

INTRODUCTION

This plate describes the distribution, hydrology, and chemistry of ground water in the southern portion of the Red River of the North valley, Minnesota. This work was completed as part of the Southern Red River Valley Regional Hydrogeologic Assessment, conducted by the Minnesota Department of Natural Resources in cooperation with the Minnesota Geological Survey. Ground water is an important resource in the study area. Ground water provides drinking water for most people in the study area and is a source of water for irrigation, livestock, and industry.

The following hydrogeologic concepts are used in this discussion. Ground water is water occupying all the voids within a geologic deposit. An aquifer is a geologic formation that contains sufficient saturated permeable material to yield sufficient quantities of water to wells and springs (United States Geologic Survey, 1972). Unconfined ground water, which includes unconfined (surficial) aquifers, is water at atmospheric pressure. Confined ground water, including confined (buried) aquifers, is water at pressures greater than atmospheric pressure. Water in unsaturated deposits exists at pressures less than atmospheric pressure.

Ground water originates as precipitation that falls on the earth's surface and infiltrates through unsaturated deposits into unconfined saturated deposits. Ground water flows within unconfined saturated deposits laterally to surface water and vertically into confined deposits. Ground water in confined deposits eventually is discharged to surface water, but only after long periods of time. Although processes occurring within unconfined and confined saturated geologic deposits are discussed independently in the following text, processes occurring within these deposits are not independent of each other.

OCCURRENCE AND DISTRIBUTION OF AQUIFERS

In the study area, ground water occurs within both fine- and coarse-textured deposits. Aquifers occur within sand and gravel (coarse-textured) deposits and are categorized as either surficial or buried aquifers. More detailed descriptions of the materials which comprise aquifers can be found in Stoner and others (1993). Processes which lead to formation of aquifers are described in Todd (1980). Cretaceous bedrock aquifers underlie approximately 30 percent of the area (Figure 1).

Surficial Aquifers

Surficial (unconfined) aquifers occur in approximately 30 percent of the study area. These aquifers are recharged from precipitation. They have low concentrations of total dissolved solids and therefore have high-quality water, but they are vulnerable to contamination.

In western Becker and northwestern Otter Tail counties there are numerous, relatively small surficial aquifers. These aquifers are focal points for recharge to deeper, buried aquifers (Maclay and others, 1969; Winter and others, 1969). Average annual recharge is 3 to 10 inches. Approximately 20 percent of the surface area is covered with lakes, including Big Cormorant, Pelican, Long, Ida, Jewitt, Prairie, and Lizzie. Most of the larger lakes in the study area are areas where ground water is exposed at the land surface. Ground water flows through these lakes rather than discharging to them.

The Pelican River Sand Plain aquifer (Figure 2) is a large surficial aquifer in western Becker and Otter Tail Counties (Miller, 1981; Miller, 1982). It extends from Big Cormorant Lake to Long Lake and in some places has a saturated thickness greater than 100 feet. Average annual recharge to the aquifer is 3 to 6 inches (Miller, 1981).

The Buffalo aquifer (Figure 2) in western Clay County is an important aquifer within the study area (See Figure 4, Plate 2, Part A). The aquifer provides drinking water for the city of Moorhead and is used for irrigation. The saturated thickness exceeds 100 feet in places.

Another large surficial aquifer occurs along the eastern margin of the Lake Agassiz beach ridges in southern Clay County (Figure 2). Saturated sand and gravel deposits exceed 50 feet in thickness and annual recharge may be as much as 12 inches.

Other surficial aquifers occur along the Buffalo, Wild Rice, Otter Tail, Pelican, and Sand Hill Rivers and along Whiskey Creek (Maclay and others, 1968; Maclay and others, 1969; Winter and others, 1969; Winter and others, 1970). These aquifers have a saturated thickness of less than 20 feet. Average annual recharge is 3 to 6 inches.

Surficial sands associated with Lake Agassiz beach deposits are water-bearing. However, water levels within beach deposits fluctuate greatly. They are therefore not a reliable source of water.

Buried Glacial Aquifers

During glacial history extensive water-bearing sand and gravel deposits were buried by fine-textured glacial till, lacustrine material, loess (wind-blown deposits), or fine-grained alluvial sediments, which now act as confining units. Buried sand and gravel aquifers vary in thickness from 10 to 40 feet, being thickest in the eastern portion of the study area. Annual recharge to buried aquifers ranges from less than an inch to more than 2 inches. Recharge rates are greatest in the Moraine region and approach zero in the Lake Agassiz Plain region. Recharge rates typically decrease with depth.

Some buried, confined aquifers occur in buried bedrock valleys that were partially filled with sand and gravel deposited by glacial meltwater. These deposits may be more than 50 feet thick. The most important of these is the Wahpeton Buried Valley aquifer (Figure 2) near Breckenridge (Ripley, 1992).

Buried aquifers comprise deep regional aquifer systems. Mapping all individual buried aquifers is not possible. Deep regional aquifer systems underlie the entire study area and dip toward the west at a slope of approximately 0.6% beneath the Moraine region and less than 0.1% beneath the Lake Agassiz Plain region.

Cretaceous Aquifers

Weathered, water-bearing Cretaceous deposits occur along the Red River of the North and in southern Wilkin County (Figure 1) and may be greater than 100 feet thick. These aquifers are recharged in central and western North Dakota and often occur in bedrock valleys. They are in contact with buried glacial aquifers and ground-water flow is upward into glacial deposits except where heavy pumping has reversed ground-water flow directions. This flow reversal, which is due to pumping in the vicinity of Moorhead, is illustrated in Figure 3. Water from Cretaceous deposits has high concentrations of sodium, chloride, and total dissolved solids. It is primarily used for irrigation, but where sand and gravel aquifers are absent it may be used as drinking water.

GROUND WATER SYSTEMS

Figure 3 suggests a distinct boundary between deep regional ground-water systems and overlying systems. This boundary is not distinct because ground water flows across these boundaries. However, ground water may be divided into active near-surface, inactive near-surface, and deep regional systems. The hydrologic and chemical properties of these systems differ significantly from each other (see matrix of regime characteristics).

The active near-surface system is affected by hydrologic processes occurring at the land surface. These processes include precipitation; runoff; evapotranspiration; interaction with lakes, rivers, and wetlands; and infiltration through the unsaturated zone. Most of the water in these systems is less than 50 years old as indicated by the presence of tritium, low to moderate concentrations of total dissolved solids, water dominated by calcium and bicarbonate, and stable isotope values similar to those of precipitation (Magner and others, 1997). Active near-surface systems underlie most of the Moraine and Beach Ridge Complex regions and include the Buffalo aquifer in the Lake Agassiz Plain region. Hydrologic Regimes 1–4 and 6–11 are active near-surface systems.

Inactive near-surface systems are areas where ground water is close to the land surface but there is little interaction with processes occurring at the land surface. Ground water in these systems is not used for water supply. The upper few feet of these systems may be recharged annually, but ground water in this upper few feet moves laterally and is discharged to ditches, streams, and rivers. Water below this upper few feet may be very old, perhaps as much as several hundreds or even thousands of years. Hydrologic Regimes 5, 12, and 13 are included in these systems.

Deep regional ground-water systems are slowly affected by processes occurring at the land surface. Deep regional aquifers extend from approximately 100 to 300 feet below the land surface. Flow within deep regional systems is generally downward, being slightly downward in the Moraine region and upward near the Red River of the North. Water in deep regional systems varies in age from a few hundred to several thousand years. Deep regional ground water is characterized by high concentrations of total dissolved solids, greater proportions of chloride and sodium than in active near-surface systems, and stable isotope values similar to snowmelt (Magner and others, 1997). Hydrologic Regimes 14–19 are deep regional systems.

Active Near-Surface Systems

Regimes 1, 2, and 3 comprise an active near-surface ground-water system found in much of the Moraine region. There are numerous sand and gravel aquifers within 75 feet of the land surface. Water-table aquifers are found in Regime 1. These aquifers are recharged directly by precipitation and snowmelt and have low concentrations of total dissolved solids. They provide recharge to underlying deep regional systems (Regimes 14, 16, and 18). Buried, confined aquifers occur in Regime 2. The aquifers are recharged by water infiltrating from Regime 1. Ground water flows laterally within aquifers and concentrations of total dissolved solids increase as ground water proceeds farther from the point of recharge. Buried, confined aquifers also occur in Regime 3, but ground-water flow is upward. Concentrations of total dissolved solids, chloride, potassium, and sulfate are greater in Regime 3 than in Regimes 1 and 2.

Alluvial water-table aquifers occur in Regime 4. These aquifers have limited areal extent. Total dissolved solid concentrations are low. There is little interaction between Regime 4 and underlying deep regional systems. Ground water in Regime 4 mostly discharges locally to streams and rivers.

In the Beach Ridge Complex region recharge occurs in Regime 6. Water-table aquifers are found in surficial sands. Water levels in these aquifers fluctuate widely throughout the year. Aquifers in Regime 7 occur in buried beach sands. These aquifers are recharged both from percolation and by lateral flow from Regime 6. Water levels fluctuate less than in Regime 6, but the areal extent of these aquifers is small. Aquifers in Regime 8 occur in buried beach sands, but ground-water flow is upward. Numerous wetlands occur in Regime 8 as the result of ground-water discharge. Concentrations of total dissolved solids are relatively low throughout the Beach Ridge Complex region because ground-water flow paths and travel times are short.

The Buffalo aquifer is an active near-surface ground-water system. Portions of the Buffalo aquifer are recharged directly by percolation through the unsaturated zone (Regime 10). The confined portions of the Buffalo aquifer (Regime 11) are recharged by water moving laterally from Regime 10. The water quality of the Buffalo aquifer varies with the distance from recharge areas.

Inactive Near-Surface Systems

No hydrologically active, near-surface system was identified in Regimes 5 and 13. A water table occurs close to the land surface within these regimes, but this ground water is not suitable for domestic use because of high concentrations of total dissolved solids and low yields to wells. The water table in these regimes is recharged annually, but this water moves laterally to streams, rivers, and ditches. This makes surface water vulnerable to contamination in these areas. Water beneath the upper few feet of these systems interacts very little with overlying water or with water within underlying deep regional systems.

Ground water in Regime 12 is found in near-surface sand and gravel deposits that are isolated from the land surface. These deposits yield sufficient quantities of water for domestic use, but concentrations of dissolved solids are very high. Since there are few wells completed in these systems, there is very little water-quality information for Regimes 5, 12, and 13.

Deep Regional Systems

Deep regional ground-water systems underlie the entire study area (Figure 1). Ground water within deep regional systems moves laterally westward within coarse- and fine-textured deposits. Aquifers are composed of coarse-textured deposits. There is little interaction between aquifers and ground water in surrounding fine-textured deposits. Deep regional systems are recharged by water percolating downward from active near-surface systems.

Regimes 14, 16, and 18 differ in the source of recharge. Regime 14 is recharged in eastern Mahnomen County in areas similar to those found in Regime 1. Regime 18 is recharged in central Otter Tail County. Because of the longer travel paths for these two regimes compared to Regime 16, ground water is much older than in Regime 16. Concentrations of total dissolved solids are greater than in Regime 16. Significant portions of Regime 18 are underlain by Cretaceous aquifers. As a result, ground water in Regime 18 has greater concentrations of chloride and sodium than Regimes 14 and 16. Regimes 15, 17, and 19 are continuous with Regimes 14, 16, and 18, respectively, but ground-water flow is upward.

GROUND-WATER CHEMISTRY

The major controls on ground-water chemistry in the study area are age of the water, quantity of recharge, and the presence or absence of Cretaceous deposits. Table 1 summarizes the results of water chemistry samples collected as part of the project. The data are summarized by geographic area, geomorphic region, and aquifer.

As water moves westward within confined deposits, concentrations of dissolved solids and the ratio of sodium and chloride to calcium, magnesium, and bicarbonate increases. Water within deep regional systems in the northern (Regime 14) and southern (Regime 18) thirds of the study area has traveled farther than water has in the central third (Regime 16), resulting in greater concentrations of dissolved solids and increased proportions of sodium and chloride. Similar patterns can be seen when comparing the ground-water chemistry of the Moraine and Lake Agassiz Plain regions. Ground water in the Moraine region receives more recharge than the Lake Agassiz Plain region and contains lower concentrations of dissolved solids, greater proportions of calcium, magnesium, and bicarbonate, and greater concentrations of dissolved oxygen and tritium than the Lake Agassiz Plain region. The Buffalo aquifer also receives more recharge than the surrounding buried aquifers of the Lake Agassiz Plain region. As a result, proportions of sodium and chloride and concentrations of dissolved solids are less than in the buried aquifers of the Lake Agassiz Plain region.

Surface water receives direct precipitation and has very low concentrations of dissolved solids. Unconfined aquifers are recharged by precipitation that percolates through the unsaturated zone. These aquifers contain dissolved oxygen and tritium, low concentrations of dissolved solids, and are dominated by calcium, magnesium, and bicarbonate. Confined aquifers receive little recharge and have older water than unconfined aquifers, resulting in greater concentrations of dissolved solids, greater proportions of sodium, potassium, and chloride, and fewer detections of tritium and dissolved oxygen. Ground water in Cretaceous deposits contained no detectable tritium or dissolved oxygen and large concentrations of sodium, potassium, and chloride (Magner and others, 1997).

Nitrate concentrations are within acceptable limits throughout the study area. Only one well exceeded the health risk limit of 10 mg/L.

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This information is available in an alternative format upon request.

This map was compiled and generated using geographic information system technology. Digital data products are available from the Land Management Information Center, Minnesota Planning Office, St. Paul.

Digital base data modified from 1984 and 1985 Digital Line Graph (DLG) files from the U.S. Geological Survey (source scale, 1:100,000); digital base annotation by the Minnesota Geological Survey. Hydrologic regimes and contour data compiled at the scale of 1:200,0000.

Projection:	Albers Equal Area Conic
Spheroid:	Clarke, 1866
Standard Parallels:	29° 30´N and 45° 30´N
Origin Latitude:	23° N
Origin Longitude:	97° W

1927 North American Datum. Vertical datum is mean sea level. Compiled 1996.

GIS and cartography by Shawn Boeser, Randy McGregor, Malathi Bhattacharjee, and Michael Scharber, Minnesota Department of Natural Resources and Norman Anderson, Land Management Information Center, Minnesota Planning Office. Desktop publishing layout by Kim Anderson, Communications.Media Division, Minnesota Department of Administration. Digital assembly by Nordic Press.

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SCALE 1:200 000

5 0 5 10 15 MILES

5 0 5 10 15 KILOMETERS

CONTOUR INTERVAL 50 FEET
DATUM IS MEAN SEA LEVEL

REGIONAL HYDROGEOLOGIC ASSESSMENT
SOUTHERN RED RIVER VALLEY, MINNESOTA