

HYDROGEOLOGY AND WATER QUALITY OF THE SHELL VALLEY AQUIFER, ROLETTE COUNTY, NORTH DAKOTA

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CONTENTS

Abstract	1
Introduction	1
Purpose and scope	3
Previous work	3
Hydrogeology	5
Geology	5
Hydrology of the aquifer	6
Hydrology near the north and south well fields	13
Water quality	15
Major ions and trace elements	16
Agricultural chemicals	18
Hydrocarbons	18
Land use and susceptibility of the aquifer to contamination	23
Summary and conclusions	24
References	24

FIGURES

1. Map showing location of the Turtle Mountain Indian Reservation and the Shell Valley aquifer, Rolette County, North Dakota	2
2. Diagram showing township-range location-numbering system used to identify ground- and surface-water sampling sites	4
3. Map showing thickness of the outwash deposit	6
4. Map showing areas where the Fox Hills Sandstone underlies the outwash deposit	7
5. Map showing areas where clay or till overlies the outwash deposit	8
6. Map showing potentiometric surface of the Shell Valley aquifer and direction of ground-water flow in the aquifer, July 1995	9
7. Map showing depth to water in the Shell Valley aquifer, July 11, 1995	11
8. Graphs showing water levels in selected wells completed in the Shell Valley aquifer and precipitation at Rolla, 1978-95	12
9. Graphs showing volume of water withdrawn from the Shell Valley aquifer, water levels in observation wells completed near the north and south well fields, and precipitation at Rolla, 1974-95	14
10. Diagram showing water levels in observation wells completed near the south well field and approximate water levels in the production wells, September 1995	15
11. Map and diagrams showing locations of sites sampled for major ions and major-ion composition of the water, July 1995	17
12. Map showing locations of sites sampled for BTEX, PAH, PCB, and PCP, July 1995	21
13. Map showing locations of sites sampled for BTEX, PAH, PCB, and PCP, September 1995	22

TABLES

1. Locations of ground- and surface-water sampling sites in the Shell Valley aquifer and type of sampling	16
2. Pesticides for which water samples were analyzed, July and September 1995	19
3. Hydrocarbon detections in the Shell Valley aquifer, July and September 1995	20

GLOSSARY OF TERMS¹

- Aquifer.** A water-bearing layer of rock that will yield water in a usable quantity to a well or spring.
- Bedrock.** A general term for the consolidated (solid) rock that underlies soils or other unconsolidated surficial material.
- Cone of depression.** The depression of heads around a pumping well caused by the withdrawal of water.
- Drawdown.** The reduction in head at a point caused by the withdrawal of water from an aquifer.
- Ground water.** Water in the saturated zone that is under a pressure equal to or greater than atmospheric pressure.
- Hydraulic conductivity.** The capacity of a rock to transmit water. It is expressed as the volume of water at the existing kinematic viscosity that will move in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow.
- Hydraulic gradient.** Change in head per unit of distance measured in the direction of the steepest change.
- Porosity.** The voids or openings in a rock. Porosity may be expressed quantitatively as the ratio of the volume or openings in a rock to the total volume of the rock.
- Potentiometric surface.** A surface that represents the total head in an aquifer; that is, it represents the height above a datum plane at which the water level stands in tightly cased wells that penetrate the aquifer.
- Rock.** Any naturally formed, consolidated or unconsolidated material (but not soil) consisting of two or more minerals.
- Saturated zone.** The subsurface zone in which all openings are full of water.
- Sea level.** Refers to the National Geodetic Vertical Datum of 1929--a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.
- Storage coefficient.** The volume of water released from storage in a unit prism of an aquifer when the head is lowered a unit distance.
- Transmissivity.** The rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of an aquifer under a unit hydraulic gradient. It equals the hydraulic conductivity multiplied by the aquifer thickness.
- Unsaturated zone.** The subsurface zone, usually starting at the land surface, that contains both water and air.
- Water table.** The level in the saturated zone at which the pressure is equal to the atmospheric pressure.

¹Definitions from Heath (1983).

Hydrogeology and Water Quality of the Shell Valley Aquifer, Rolette County, North Dakota

By Michael L. Strobel

ABSTRACT

The Shell Valley aquifer is the sole source of water for the city of Belcourt and the primary source of water for most of the Turtle Mountain Indian Reservation. The Turtle Mountain Band of Chippewa Indians is concerned about the quantity and quality of water in the Shell Valley aquifer, which underlies about 56 square miles in central Rolette County and has an average saturated thickness of about 35 feet.

Water levels across most of the Shell Valley aquifer fluctuate with variations in precipitation but generally are stable. Withdrawals from the north well field decreased slightly during 1976-95, but withdrawals from the south well field increased during 1983-95. Water levels in the south well field declined as withdrawals increased. The average decline during the last 8 years was about 1.75 feet per year. The water level has reached the well screen in at least one of the production wells.

Most of the water in the aquifer is a bicarbonate type and has dissolved-solids concentrations ranging from 479 to 1,510 milligrams per liter. None of the samples analyzed had detectable concentrations of pesticides, but hydrocarbons were detected in both ground- and surface-water samples. Polycyclic aromatic hydrocarbons (PAH) were the most frequently detected hydrocarbons. Benzene, toluene, ethylbenzene, and xylene (BTEX), polychlorinated biphenyls (PCB), and pentachlorophenol (PCP) also were detected.

Generally, the Shell Valley aquifer is an adequate source of water for current needs, but evaluation of withdrawals in relation to a knowledge of aquifer hydrology would be important in quantifying sustainable water supplies. Water quality in the aquifer generally is good; the Turtle Mountain Band of Chippewa Indians filters the water to reduce concentrations of dissolved constituents. Hydrocarbons, although present in the aquifer, have not been quantified and may not pose a general health risk. Further analysis of the quantity and distribution of the hydrocarbons would be useful to understand their sources and implications for water use.

INTRODUCTION

The Turtle Mountain Indian Reservation covers about 72 square miles in Rolette County in north-central North Dakota (fig. 1). Tribal and trust lands in townships adjacent to the Reservation's northern, western, and southern boundaries constitute another 70 square miles. The Reservation has a population of 4,987 (U.S. Department of Commerce, Bureau of the Census, written commun., 1994), and an additional 2,119 people live on trust lands outside the Reservation. Belcourt, which has a population of 2,458 (Bureau of Indian Affairs, written commun., 1993), is the only community located within the Reservation.

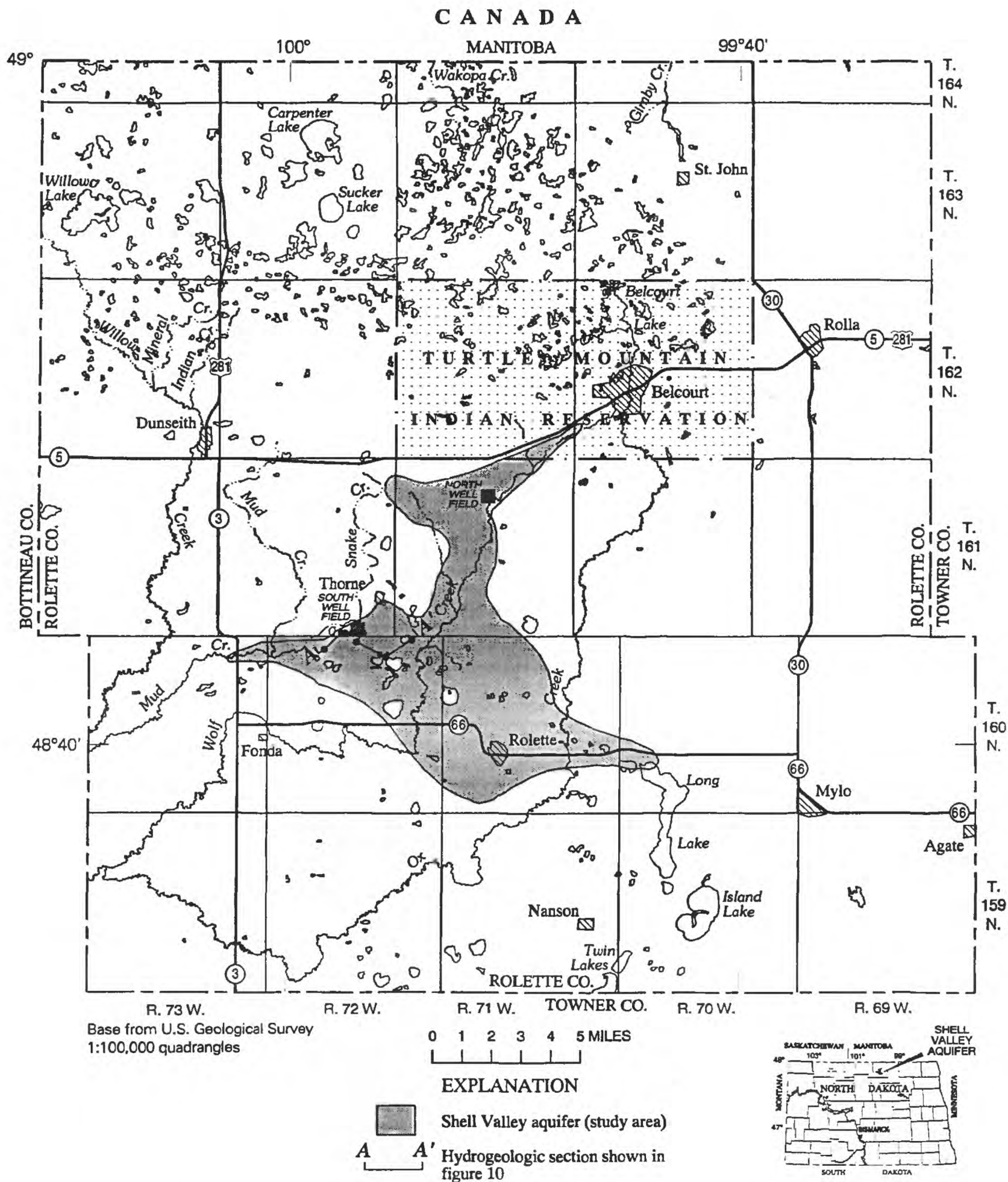


Figure 1. Location of the Turtle Mountain Indian Reservation and the Shell Valley aquifer, Rolette County, North Dakota.

The Shell Valley aquifer, which consists mainly of surficial and buried glacial-outwash deposits, is the sole source of water for the city of Belcourt and the primary source of water for most of the rural areas within and adjacent to the Turtle Mountain Indian Reservation. The Turtle Mountain Band of Chippewa Indians obtains water from the north and south well fields (fig. 1) in the Shell Valley aquifer and is concerned about the long-term viability of water in the area. Increases in the population of the Reservation and areas adjacent to the Reservation and concurrent increases in water use have prompted the Turtle Mountain Band of Chippewa Indians to apply to the State of North Dakota for a third permit to increase withdrawals from the Shell Valley aquifer.

The Turtle Mountain Band of Chippewa Indians also is concerned about possible water-quality degradation. Because most of the land overlying the Shell Valley aquifer is farmed, the aquifer may be susceptible to contamination from agricultural chemicals (fertilizer nutrients and pesticides). The many small lakes and wetlands in the central and southern parts of the aquifer also potentially may contribute to contamination because some of the water bodies may be directly connected to the aquifer and may be sources of focused recharge. Industries located near the northeastern part of the aquifer near the city of Belcourt and along Wolf Creek also may be potential sources of contamination.

Because of the concerns about the viability of water and possible water-quality degradation, the U.S. Geological Survey conducted a study during 1995 in cooperation with the Turtle Mountain Indian Reservation to describe the hydrogeology of the Shell Valley aquifer and to assess the potential for contamination from agricultural chemicals and industrial hydrocarbons. The study area is the area underlain by the Shell Valley aquifer (fig. 1). Specific objectives of the study were to (1) determine ground-water flow directions and velocities and describe recharge and discharge to the aquifer; (2) determine the distribution and concentration of major ions, selected trace elements, and agricultural chemicals (selected nutrients and pesticides) and the occurrence of industrial hydrocarbons in the aquifer; and (3) evaluate the susceptibility of the aquifer to contamination. Results of the study will contribute to improved understanding of the Shell Valley aquifer and similar hydrogeologic settings.

Purpose and Scope

This report presents results of the study and describes the hydrogeology, water quality, and susceptibility of the Shell Valley aquifer to contamination. Existing observation wells were used to obtain water-level and water-quality data, and additional shallow observation wells were completed to obtain ground-water samples from the uppermost part of the aquifer. The additional wells were screened across the water table. Surface-water samples were collected and analyzed for agricultural chemicals and industrial hydrocarbons.

The location-numbering system used to identify the ground- and surface-water sampling sites used in this report is based on the Federal system of rectangular surveys of the public lands (fig. 2). The first number denotes the township north of a base line, the second number denotes the range west of the fifth principal meridian, and the third number denotes the section in which the well or sampling site is located. The letters A, B, C, and D designate, respectively, the northeast, northwest, southwest, and southeast quarter section, quarter-quarter section, and quarter-quarter-quarter section (10-acre tract); thus, well 160-072-02AAA would be located in the NE1/4NE1/4NE1/4 sec. 2, T. 160 N., R. 72 W. Consecutive terminal numbers are added if more than one well or sampling site is located within a 10-acre tract.

Previous Work

Until 1976, water for the city of Belcourt was obtained from Belcourt Lake, which is located about 2 miles north of Belcourt. In 1973, the U.S. Geological Survey conducted a study in cooperation with the

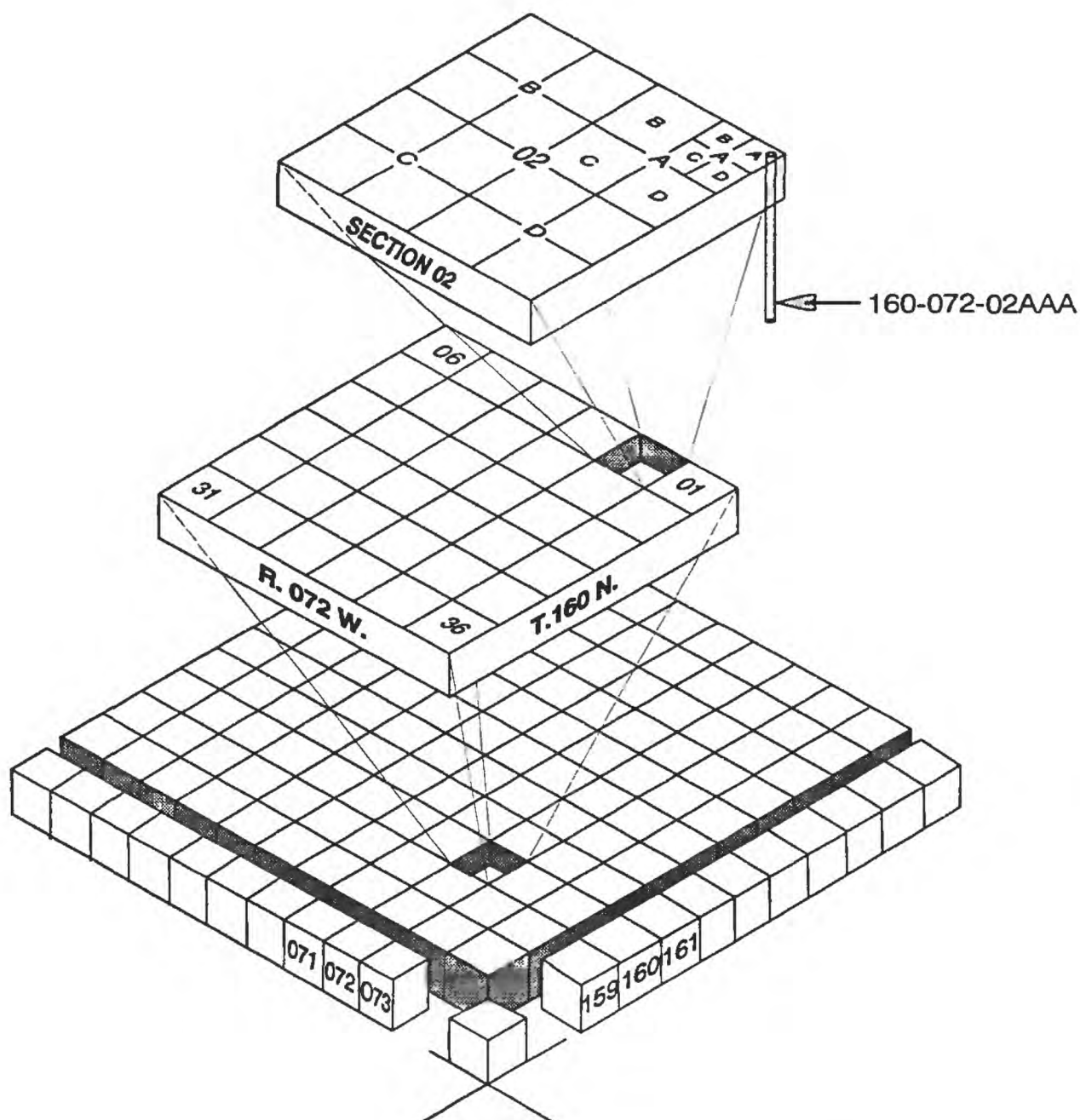


Figure 2. Township-range location-numbering system used to identify ground- and surface-water sampling sites.

U.S. Public Health Service to evaluate ground-water availability in the area. Results of the study indicated that neither the Fox Hills Sandstone nor the Pierre Shale (bedrock units underlying the glacial deposits) would yield substantial quantities of good-quality water to wells drilled on or near the Reservation (Randich, 1975). Drillers' reports indicated that wells completed in the Fox Hills Sandstone in the Turtle Mountains west and north of Belcourt yielded from 10 to 100 gallons of water per minute, but the water quality generally was poor. Wells completed in the fractured upper part of the Pierre Shale had small yields. Many private wells on the Reservation were completed mainly in thin, isolated lenses of silt, sand, and gravel within the glacial till and yielded only small quantities of poor-quality water. Generally, these wells ranged from about 20 to 400 feet in depth.

Because of the limited quantities of good-quality ground water in the area, the study was expanded to include evaluation of nearby glacial deposits, and test holes were drilled in the northeastern part of the Shell Valley aquifer immediately south of the Reservation. In the area investigated, the surficial and buried glacial-outwash aquifer consists of mixed sand and gravel deposits as much as 50 feet thick (Randich and Ghering, 1975). During 1976, three production wells were completed in the northern part of the aquifer (fig. 1). These wells, known as the north well field, are located 5 miles southwest of Belcourt and 1 mile south of the Reservation boundary.

During 1979-81, the Shell Valley aquifer was investigated by Randich and Kuzniar (1984) as part of a cooperative study among the U.S. Geological Survey, the North Dakota State Water Commission, the North Dakota Geological Survey, and the Bottineau and Rolette County Water Management Districts. Results of the study indicated that the aquifer underlies about 56 square miles in central Rolette County. The aquifer has two potential high-yield (100 to 500 gallons of water per minute) areas that are separated by an area that is less than 25 feet thick and that directly overlies the bedrock (Randich and Kuzniar, 1984). The northern high-yield area consists of surficial outwash deposits of sand and gravel interbedded with lenses of silt, clay, and till. The southern high-yield area consists of outwash deposits in a narrow meltwater valley and in other scattered areas that in some places are overlain by clays and tills.

During 1983, three additional production wells were completed in the southern part of the Shell Valley aquifer (fig. 1). These wells, known as the south well field, were completed to supply water for a rural water-distribution system for the entire Reservation and adjacent areas. After completion of the distribution system, most of the private domestic and stock wells on the Reservation and adjacent trust lands were abandoned.

Water levels have been measured routinely for about 40 of the observation wells completed during 1979-81. Many of the water levels have declined steadily during the period of record (1980-95). The greater-than-normal precipitation and flooding during 1993 did little to reverse the downward trend in water levels near the south well field. Water-level declines in measured wells in the south well field range from about 2 to 17 feet during the 16-year period of record. Water levels in the north well field also declined during the period of record, but some recovery occurred because of wet periods during 1987-88 and 1993-95.

HYDROGEOLOGY

Geology

The study area is underlain by Pleistocene-age sediments that consist mainly of surficial-outwash deposits but also consist of some glacial tills and stratified silt, sand, and gravel deposits that were in contact with melting glacial ice (Randich, 1975). These sediments will be referred to collectively herein as "the outwash deposit." Sediments in the northeastern part of the outwash deposit, near the city of Belcourt, consist of large limestone and granitic gravels and cobbles with little clay and silt; sediments in the central part of the outwash deposit consist mainly of medium sand; and sediments in the southern part of the outwash deposit consist of fine sands and silts with numerous clay and silt lenses. The outwash deposit generally is bounded laterally by clay-rich till.

The sediments generally are less than 40 feet thick except in one area in the northern part of the outwash deposit and within a west-northwest- to southeast-trending buried valley in the southern part (fig. 3). Thickness in the buried valley exceeds 120 feet in some places. The outwash deposit terminates rather abruptly against the adjacent till along parts of the northeastern and southeastern boundaries.

The lower and upper boundaries of the outwash deposit vary spatially. Most of the northern and southern parts overlie clay-rich till, whereas much of the central, southeastern, and southwestern parts directly overlie the Cretaceous-age Fox Hills Sandstone (fig. 4). Generally, the outwash deposit extends to land surface, but parts are overlain at the land surface by clay or till deposits (fig. 5) that generally are less than 5 feet thick.

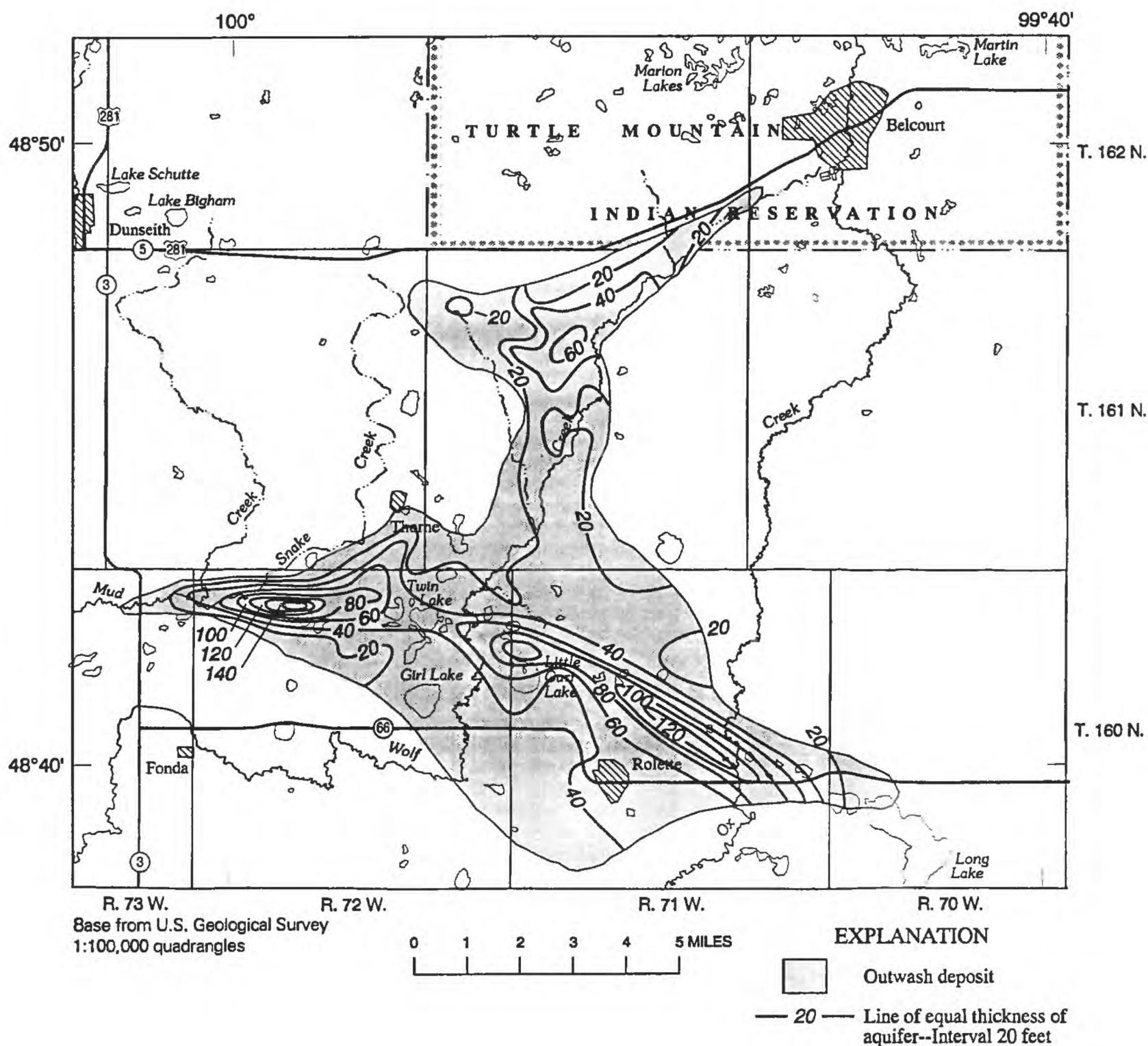


Figure 3. Thickness of the outwash deposit.

Hydrology of the Aquifer

Data from 85 test holes indicate that the Shell Valley aquifer ranges from 6 to 117 feet in thickness and has an average saturated thickness of about 35 feet (Randich and Kuzniar, 1984). Water levels in 47 wells measured monthly during April through September 1995 range from less than 1 foot below land surface to more than 41 feet below land surface. Ground-water flow in the aquifer is predominantly from northeast to southwest (fig. 6). The potentiometric surface generally conforms with the topographic surface. A ground-water divide exists in the southern part of the aquifer, and water in that part of the aquifer flows either to the southeast or to the southwest. Although the outwash deposits are overlain by clay or till deposits in some areas (fig. 5), the aquifer is confined only in locations where the potentiometric surface is within or above the clay or till deposits. These conditions can vary seasonally. Most of the aquifer is unconfined.

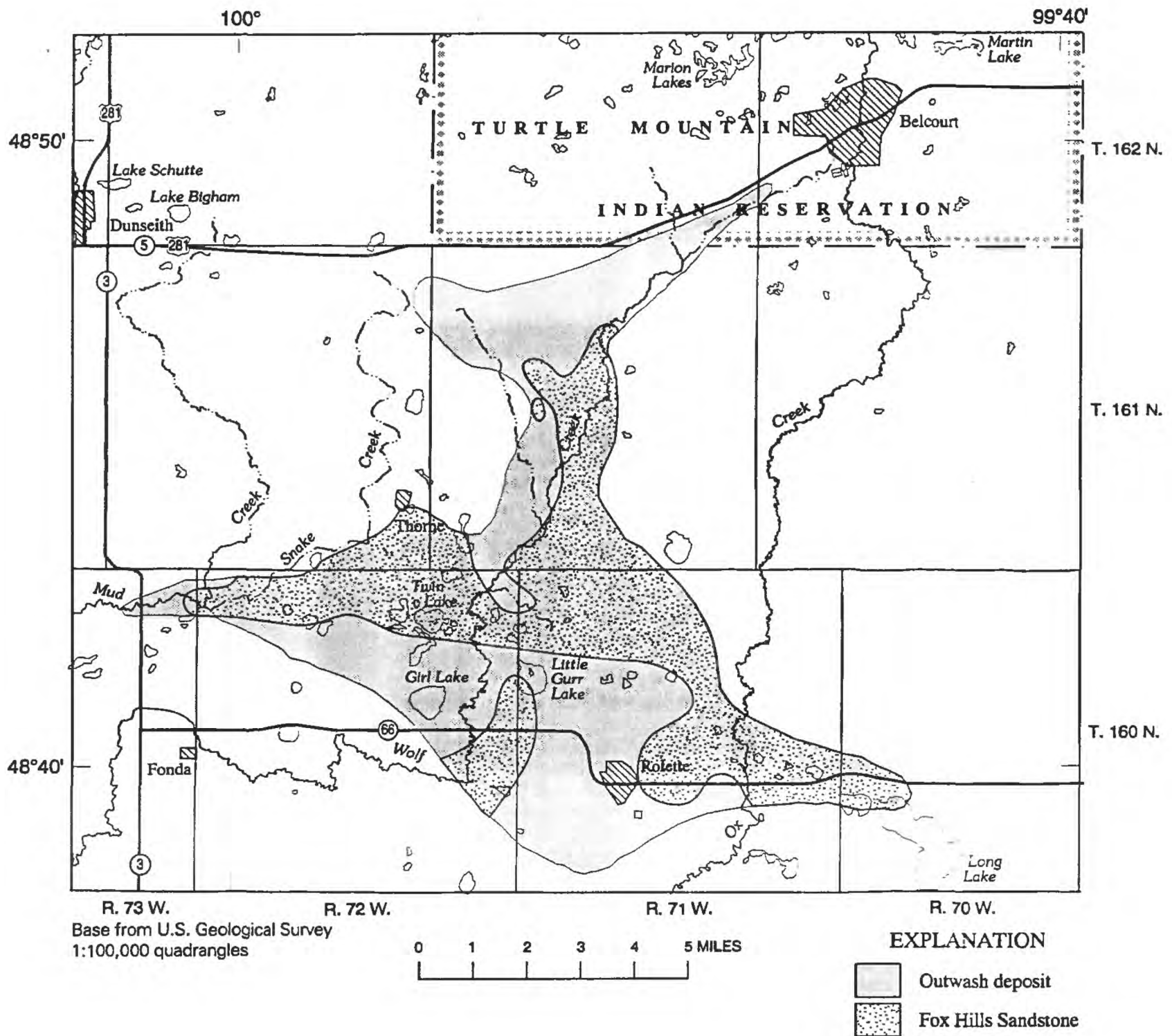


Figure 4. Areas where the Fox Hills Sandstone underlies the outwash deposit.

Ground-water velocities in the Shell Valley aquifer vary spatially because of variations in the physical properties of the aquifer. Hydraulic conductivity, porosity, and hydraulic gradient vary from north to south across the aquifer because of variations in grain size and land-surface slope.

Ground-water velocities in the northern part of the Shell Valley aquifer were calculated as average linear velocity, which is the average distance a particle of water travels over some unit of time. Average linear velocity, V_x , is defined by Fetter (1994) as

$$V_x = \frac{-K}{Ne} \frac{dh}{dl}, \quad (1)$$

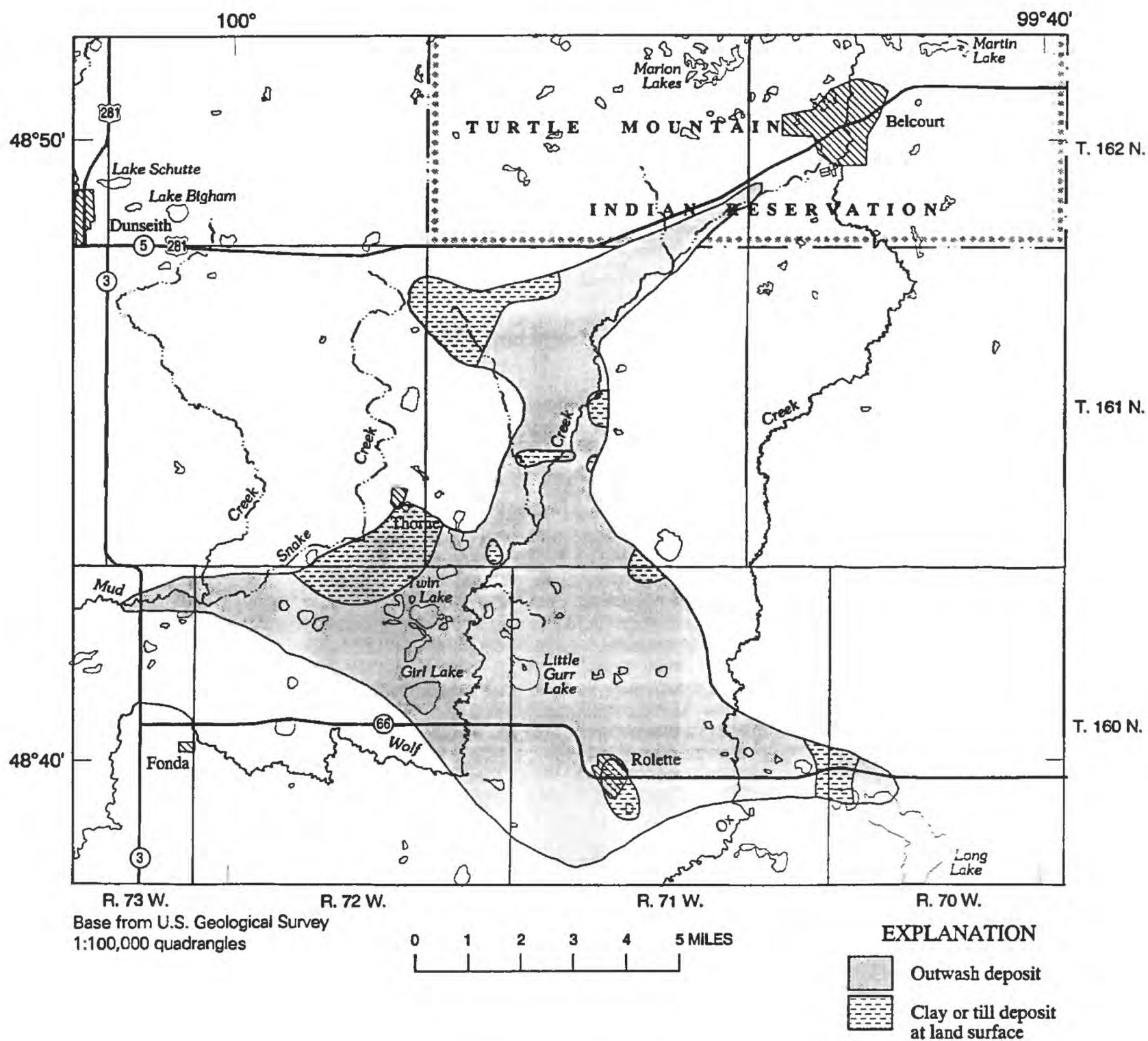


Figure 5. Areas where clay or till overlies the outwash deposit.

where

K is the hydraulic conductivity,

Ne is the effective porosity, and

$\frac{dh}{dl}$ is the hydraulic gradient.

Ground-water velocities in the central and southern parts of the aquifer were not determined because hydraulic conductivity and porosity have not been estimated for those areas.

Randich and Kuzniar (1984) used transmissivity and average saturated thickness to calculate a hydraulic conductivity of 222 feet per day for the northern part of the Shell Valley aquifer. Based on that

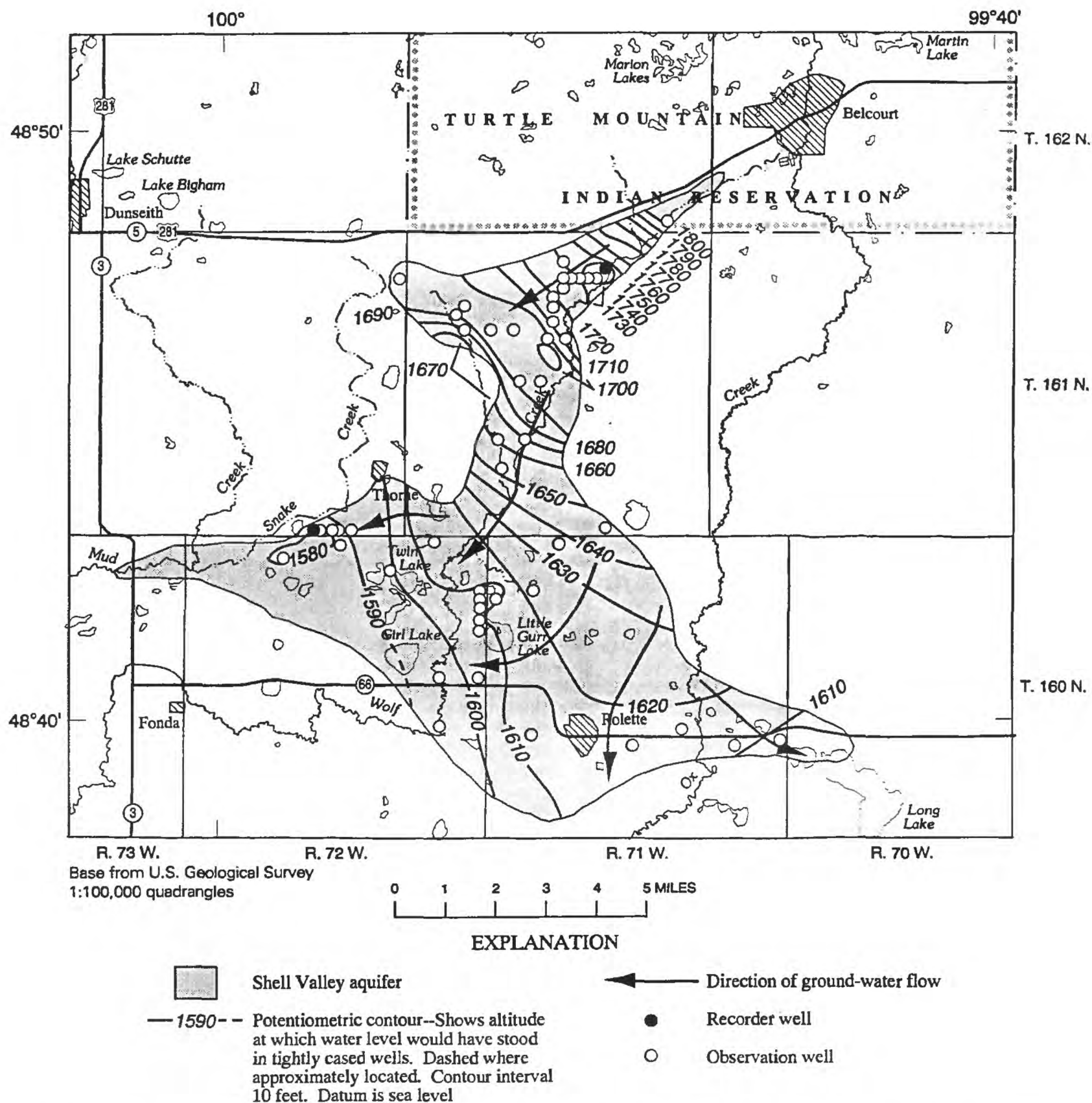


Figure 6. Potentiometric surface of the Shell Valley aquifer and direction of ground-water flow in the aquifer, July 1995.

hydraulic conductivity, an estimated effective porosity of 0.30 (Freeze and Cherry, 1979), and an average hydraulic gradient of 30 feet per mile, average linear velocity in the northern part of the aquifer is 4.2 feet per day. The average linear velocity decreases southward across the aquifer along with grain size and hydraulic gradient.

Recharge to the Shell Valley aquifer is mainly from infiltration of precipitation, which falls as rain or snow. Recharge occurs more readily in unconfined areas of the aquifer than in confined areas of the

aquifer. Numerous lakes and wetlands in the southern part of the study area, which has more surface relief than the northern part, collect surface runoff and may act as areas of focused recharge. Recharge to the aquifer also occurs along Wolf and Ox Creeks (fig. 1). Wolf Creek transects the study area from the northeast to the southwest, and Ox Creek transects the southeastern part of the study area. Both creeks are ephemeral where they cross the study area. In the spring, streamflow in the creeks exceeds inflow through the streambed into the outwash deposit, resulting in continuous streamflow along the length of the stream across the study area. During most of the year, however, the streambed losses into the outwash deposit exceed streamflow, and all flow in the creeks across the outwash deposit becomes recharge to the aquifer. The creeks usually flow across the study area during the spring, but, at other times, stop flowing as they intersect the outwash deposit and the surface water infiltrates and recharges the aquifer. Additional recharge to the aquifer may occur as subsurface inflow from the adjacent and underlying Fox Hills aquifer. Contributions from the Fox Hills Sandstone may occur in the buried valley in the southern part of the study area and near pumped wells where the hydraulic head in the aquifer has been lowered.

Discharge from the Shell Valley aquifer occurs mainly by evapotranspiration. The depth to water is less than 10 feet in much of the area (fig. 7). Withdrawals from the north and south well fields and by the city of Rolette, All Seasons Water Users (the county water supplier), and two irrigation wells account for some of the discharge. Variable amounts of discharge also occur along the southern edge of the aquifer to Wolf and Ox Creeks, and some discharge possibly may occur to bedrock units.

During the past 17 years, variations in precipitation have caused water-level fluctuations in the Shell Valley aquifer. Hydrographs for 7 of the 40 routinely measured observation wells are shown in figure 8. Some water-level declines may have been caused partly by withdrawals from the north and south well fields, but the largest water-level declines occurred during the drought of 1988-92 and the largest water-level rises occurred during the wet conditions of 1993-95. In many of the 40 wells, the 1995 water levels are the highest for the period of record.

A generalized hydrologic budget was prepared to evaluate the effects of various factors on groundwater conditions in the Shell Valley aquifer. Although the accuracy of the budget is limited by uncertainty associated with many of the factors, the budget provides a conceptual model for examining the effects of various inputs and outputs. Based on a specific yield of 15 percent and an average saturated thickness of 35 feet, an estimated 190,000 acre-feet of water is available from storage in the Shell Valley aquifer. Water levels across most of the aquifer, except around the north and south well fields, fluctuate with variations in precipitation but generally are stable, indicating near-steady-state conditions.

Recharge to the Shell Valley aquifer is mainly from direct infiltration of precipitation or snowmelt and from stream loss from Wolf and Ox Creeks during the spring. Recharge from precipitation and snowmelt is water that percolates through the unsaturated zone overlying most of the aquifer. The average precipitation at Rolla (fig. 1) during 1961-90 is about 17.8 inches per year (Owenby and Ezell, 1992), which is equal to about 53,160 acre-feet per year. Reed (1997) used an area-weighted average recharge of 4.5 inches per year for the Warwick aquifer, which is about 70 miles to the southeast of the Shell Valley aquifer and has similar hydrogeologic conditions. Using this value for average recharge, about 13,500 acre-feet of water per year is recharged to the Shell Valley aquifer. Recharge from Wolf and Ox Creeks is highly variable throughout the year. In April 1995, streamflow measurements made near the area where each stream begins to transect the outwash deposit indicated discharge in Wolf Creek was about 8 cubic feet per second and discharge in Ox Creek was about 3 cubic feet per second. Generally, however, little to no flow occurs throughout most of the year. Using an estimated annual discharge of 0.5 cubic foot per second for each stream and assuming that all streamflow becomes recharge to the aquifer, recharge from the two streams is about 725 acre-feet per year. Whether adjacent or underlying bedrock aquifers supply water to the Shell Valley aquifer, accept water from the aquifer, or have little or no hydrologic

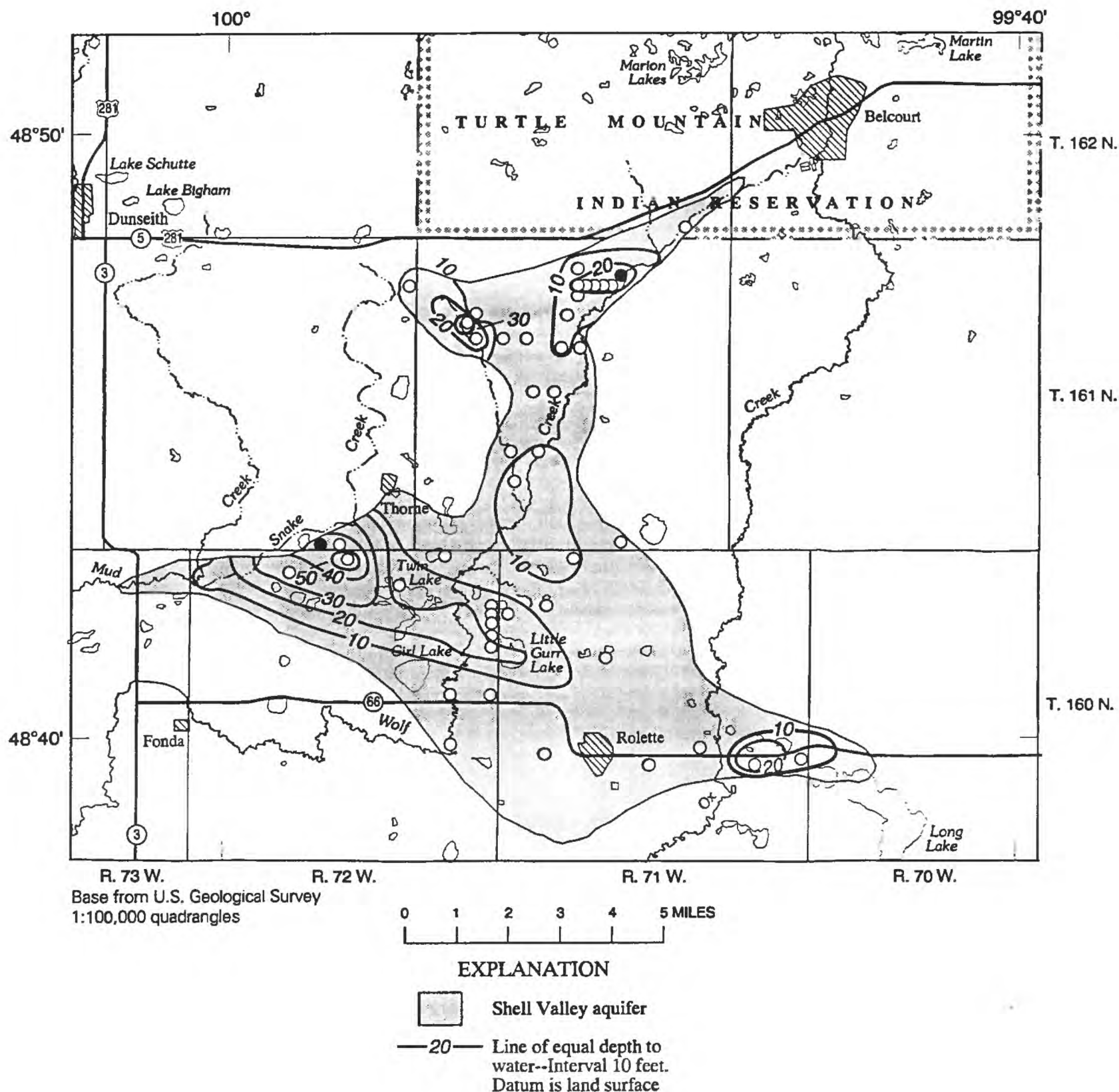


Figure 7. Depth to water in the Shell Valley aquifer, July 11, 1995.

interaction with the aquifer is uncertain. Therefore, that component of the budget was assumed to be zero for the purpose of this analysis.

Discharge or loss from the aquifer occurs by evapotranspiration, ground-water flow into adjacent or underlying bedrock aquifers, discharge to Wolf and Ox Creeks along the southern edge of the aquifer, and withdrawals from wells completed in the aquifer. Evapotranspiration is a function of the potential evapotranspiration rate and depth to the water table in relation to the maximum depth at which evapotranspiration occurs. Because of near-steady-state conditions in the aquifer, the depth to water in the Shell Valley aquifer on July 11, 1995 (fig. 7), is assumed to be representative of typical long-term conditions. The maximum depth at which evapotranspiration occurs is the approximate depth of the base of the rooting zone for

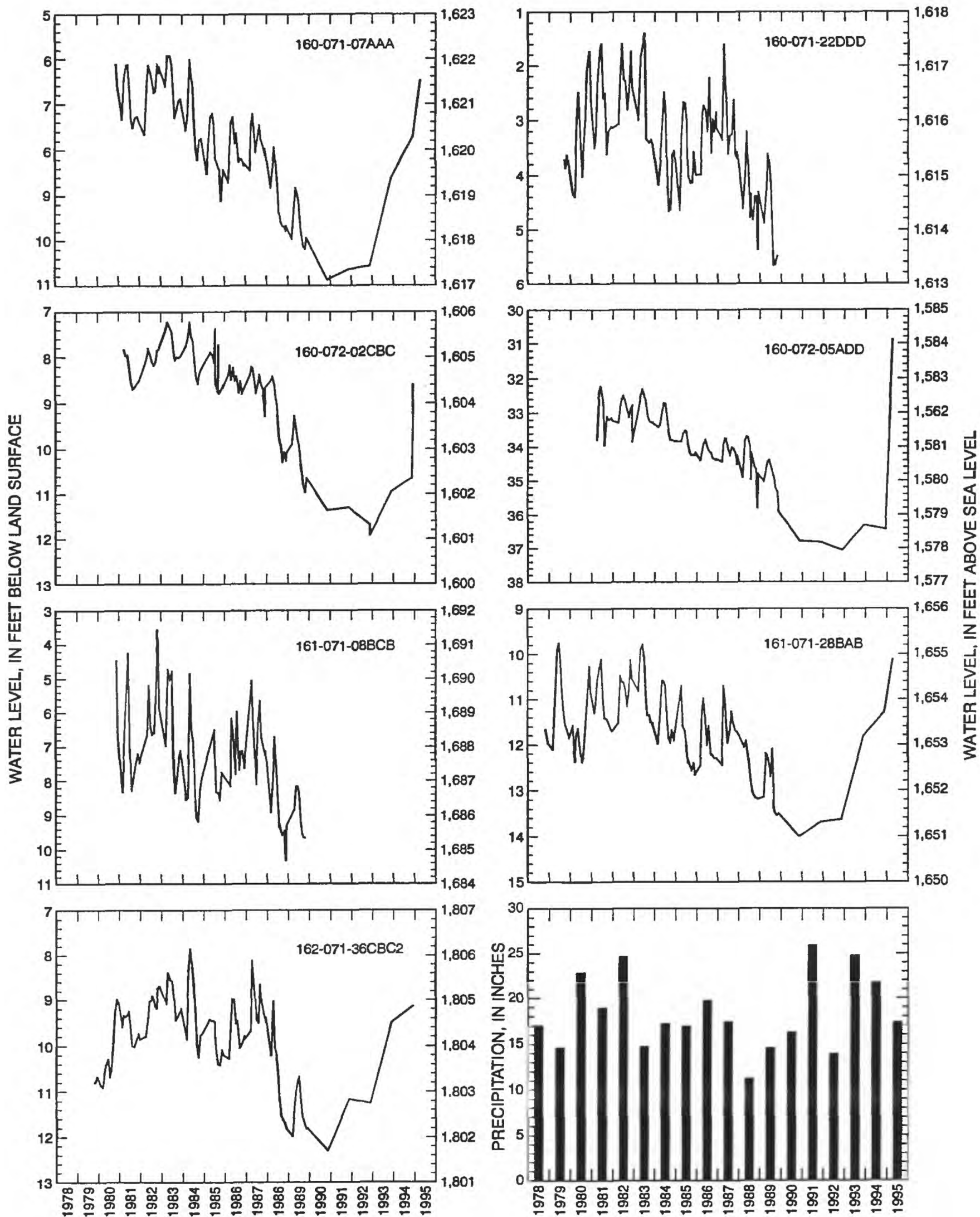


Figure 8. Water levels in selected wells completed in the Shell Valley aquifer and precipitation at Rolla, 1978-95.

overlying vegetation. The vegetation overlying much of the Shell Valley aquifer is native and introduced grasses. Using a maximum depth of evapotranspiration of 10 feet (Reed, 1997), about 32.5 square miles of the Shell Valley aquifer is affected by evapotranspiration. The volume of water discharged from the aquifer to adjacent or underlying bedrock aquifers and to Wolf and Ox Creeks along the southern edge of the aquifer is uncertain but is assumed to be negligible. During 1990-94, average withdrawals from wells completed in the aquifer were about 1,175 acre-feet per year (fig. 9).

Assuming near-steady-state conditions in the aquifer, about 190,000 acre-feet of water is available from storage in the aquifer. About 14,200 (13,500 plus 725) acre-feet of water per year recharges the aquifer from precipitation, snowmelt, and streamflow losses from Wolf and Ox Creeks, and about 1,175 acre-feet of water per year leaves the aquifer through well withdrawals. Therefore, about 13,000 (14,200 minus 1,175) acre-feet of water per year is lost to evapotranspiration. However, uncertainty in all of the estimates presented, as well as the lack of information on the interaction between the Shell Valley aquifer and the bedrock aquifer and on the possible discharges to Wolf and Ox Creeks along the southern edge of the aquifer, limit the accuracy of the estimates of recharge and discharge.

Hydrology Near the North and South Well Fields

The north and south well fields account for most of the withdrawals from the Shell Valley aquifer. Withdrawals from the north well field decreased slightly during 1976-95, but withdrawals from the south well field increased during 1983-95 (fig. 9). The slight decrease in withdrawals from the north well field during 1989-93 may be associated with generally increased withdrawals from the south well field during that period.

Water levels in the north well field declined substantially during 1979-81 as the result of groundwater withdrawals (fig. 9). Generally, equilibrium conditions prevailed during about 1982-88. The water-level fluctuations during 1982-95 reflect variations in precipitation (fig. 9). During 1988-92, the water levels declined because of drought, and during 1993-95, the water levels rose because of wet conditions. Ground-water withdrawals from the north well field decreased slightly during 1982-95 and probably did not account for the water-level fluctuations during that period (fig. 9).

Water levels in well 161-072-35CDC near the south well field declined more than 18 feet during 1982-95 (fig. 9). The average decline during the last 8 years was about 1.75 feet per year. The water levels were affected slightly by variations in precipitation, but the variations did not alter the generally declining trend (fig. 9). The declining water levels correlate with increasing withdrawals from the south well field (fig. 9), and the large decline probably is caused by a combination of increased withdrawals and possible locally confined conditions. Results of aquifer tests in the Shell Valley aquifer indicate similar values of transmissivity for confined and unconfined areas of the aquifer. However, the calculated storage coefficient for confined areas was 3.5×10^{-4} , whereas the coefficient for unconfined areas was 1.4×10^{-1} (Randich and Kuzniar, 1984). Along section A-A' (fig. 10), the water table is below the bottom of the overlying cover of clays or tills, and, therefore, the aquifer is unconfined in that area.

Water levels in observation wells around the south well field are shown in figure 10 along with water levels estimated for the south well field on the basis of the geometry of the cone of depression. The water level has reached the well screen in at least one well. If present (1995) withdrawal rates are continued, at least one well, and possibly two, could go dry. Also, once water levels are drawn down below the top of the well screen, the quantity of water available at present withdrawal rates decreases.

Withdrawals from the north and south well fields probably have little effect on most of the aquifer. Water levels in most observation wells in the aquifer have been relatively steady during the last few years,

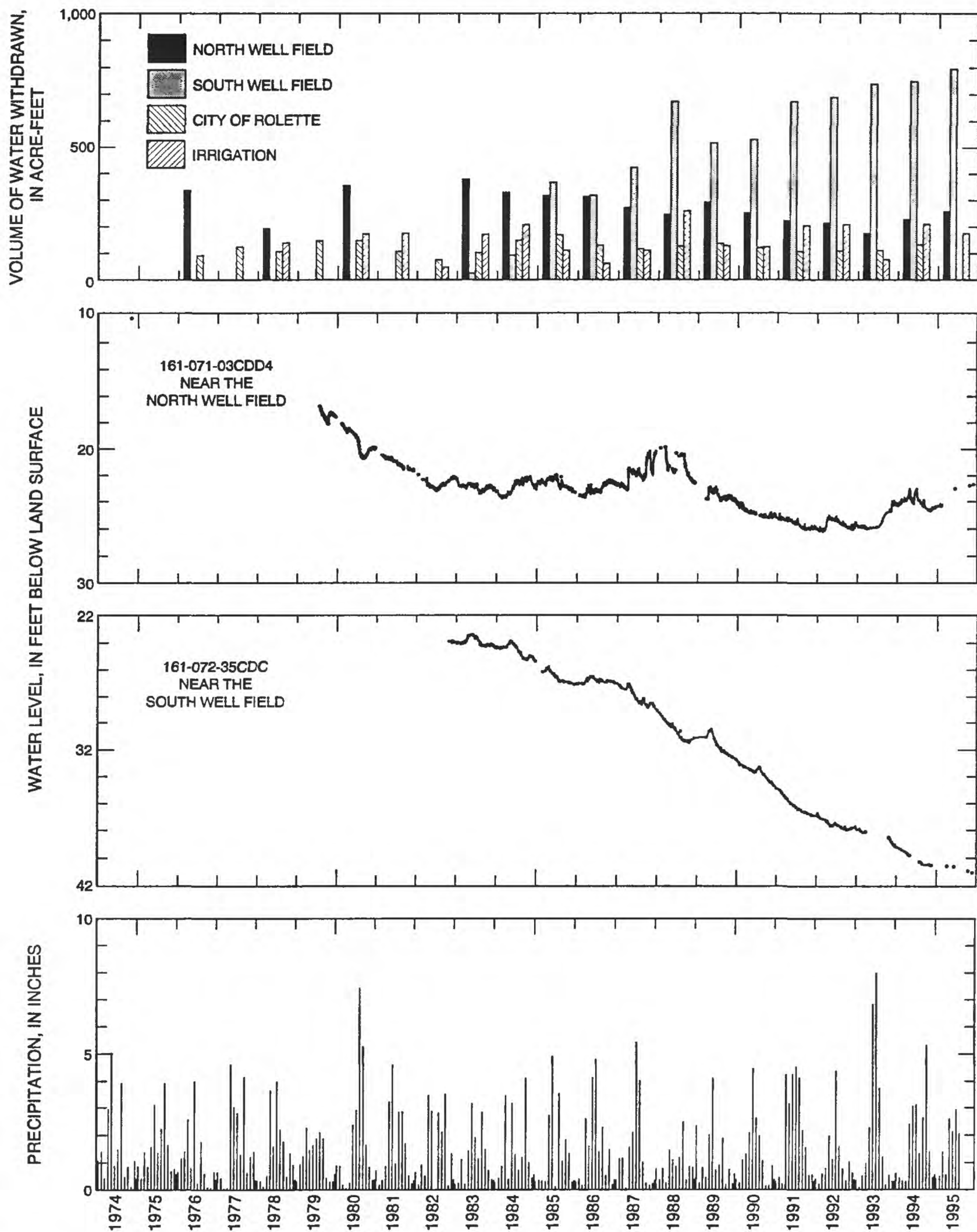


Figure 9. Volume of water withdrawn from the Shell Valley aquifer, water levels in observation wells completed near the north and south well fields, and precipitation at Rolla, 1974-95.

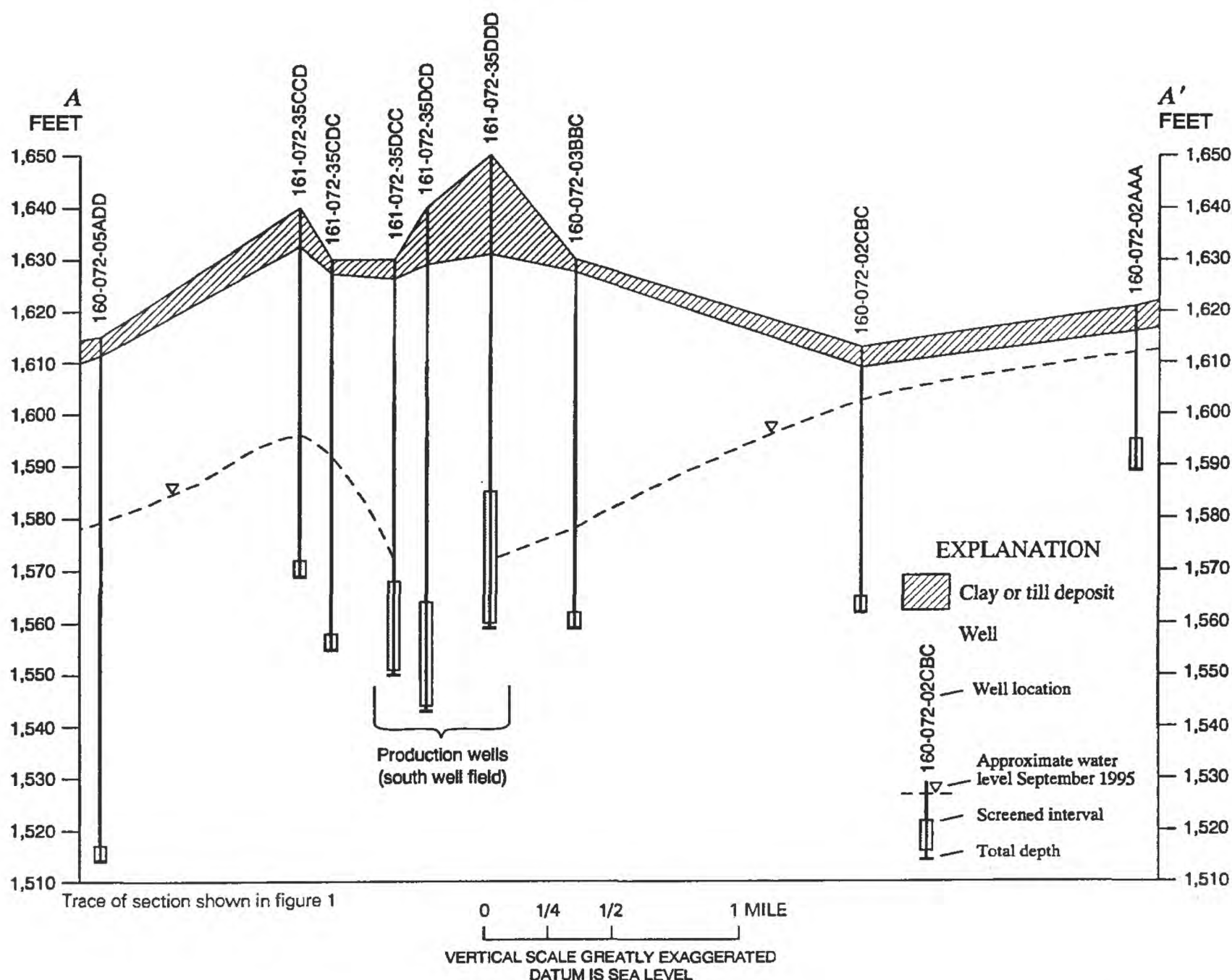


Figure 10. Water levels in observation wells completed near the south well field and approximate water levels in the production wells, September 1995.

and, as indicated from the hydrologic budget of the aquifer, recent annual withdrawals account for only about 0.6 percent of the total water stored in the aquifer and about 8.7 percent of the annual recharge to the aquifer.

WATER QUALITY

Ground- and surface-water samples were collected during July and September 1995 to determine the water quality of the Shell Valley aquifer. Locations of the sampling sites are given in table 1 along with the type of sampling. Numerous lakes, wetlands, and ponded water along the drainage channels of Wolf and Ox Creeks generally represent areas where the water table intersects the land surface. These areas, therefore, provide access to water typically occurring in the aquifer. The eight ground-water samples and six surface-water samples collected during July, and the six ground-water samples and nine surface-water samples collected during September were analyzed for major ions, selected trace elements, agricultural chemicals, and selected hydrocarbons. Data for the major ions, trace elements, and agricultural chemicals are published in a report by Harkness and others (1996).

Table 1. Locations of ground- and surface-water sampling sites in the Shell Valley aquifer and type of sampling

Sampling location	Sampling site	Sampled for major ions		Sampled for hydrocarbons
		July 1995	September 1995	
160-071-05BAA	A	Yes	No	Yes
160-071-16BBB2	B	No	Yes	Yes
160-071-18BBB	C	No	Yes	Yes
160-071-24DCC	D	Yes	Yes	Yes
160-071-24DDD	E	Yes	No	Yes
160-071-26BAB	F	Yes	Yes	Yes
160-071-28AAA2	G	No	Yes	Yes
160-072-02AAA	H	Yes	No	Yes
160-072-02AAB	I	Yes	Yes	Yes
160-072-02CBC2	J	No	Yes	Yes
160-072-02CCD	K	No	Yes	Yes
160-072-04CCC	L	Yes	Yes	Yes
160-072-13CCC2	M	No	Yes	Yes
160-072-13CCD	N	Yes	Yes	Yes
160-072-14CBB	O	Yes	Yes	Yes
160-072-24CCB	P	Yes	No	Yes
161-071-03CDD4	Q	Yes	No	Yes
161-071-08BCB2	R	No	Yes	Yes
161-071-16AAB1	S	Yes	No	Yes
161-071-29DAD	T	Yes	No	Yes
162-071-35DCC	U	No	Yes	Yes
162-071-36CBC2	V	Yes	Yes	Yes

Major Ions and Trace Elements

The locations of ground- and surface-water sampling sites for July are shown in figure 11. Samples collected during September were not analyzed for alkalinity or trace elements, and the major-ion concentrations for the two sampling periods were similar. Therefore, the September samples will not be discussed in this section.

Ground-water samples from the southern part of the Shell Valley aquifer had a bicarbonate type water, and samples from the northern part of the aquifer had a calcium magnesium bicarbonate type water. One sample (from well 162-071-36CBC2) had a calcium sodium sulfate bicarbonate type water. Dissolved-solids concentrations ranged from 479 to 1,510 milligrams per liter. The secondary maximum contaminant level for dissolved solids is 500 milligrams per liter (U.S. Environmental Protection Agency, 1995).

Hardness is a characteristic of water that corresponds to the water's ability to precipitate soap. The two cations mostly associated with precipitating soap are calcium and magnesium. Hardness typically is reported in milligrams per liter of calcium carbonate (CaCO_3). A more generic method of reporting hardness is to classify the water as soft through very hard. The following table relates hardness in milligrams

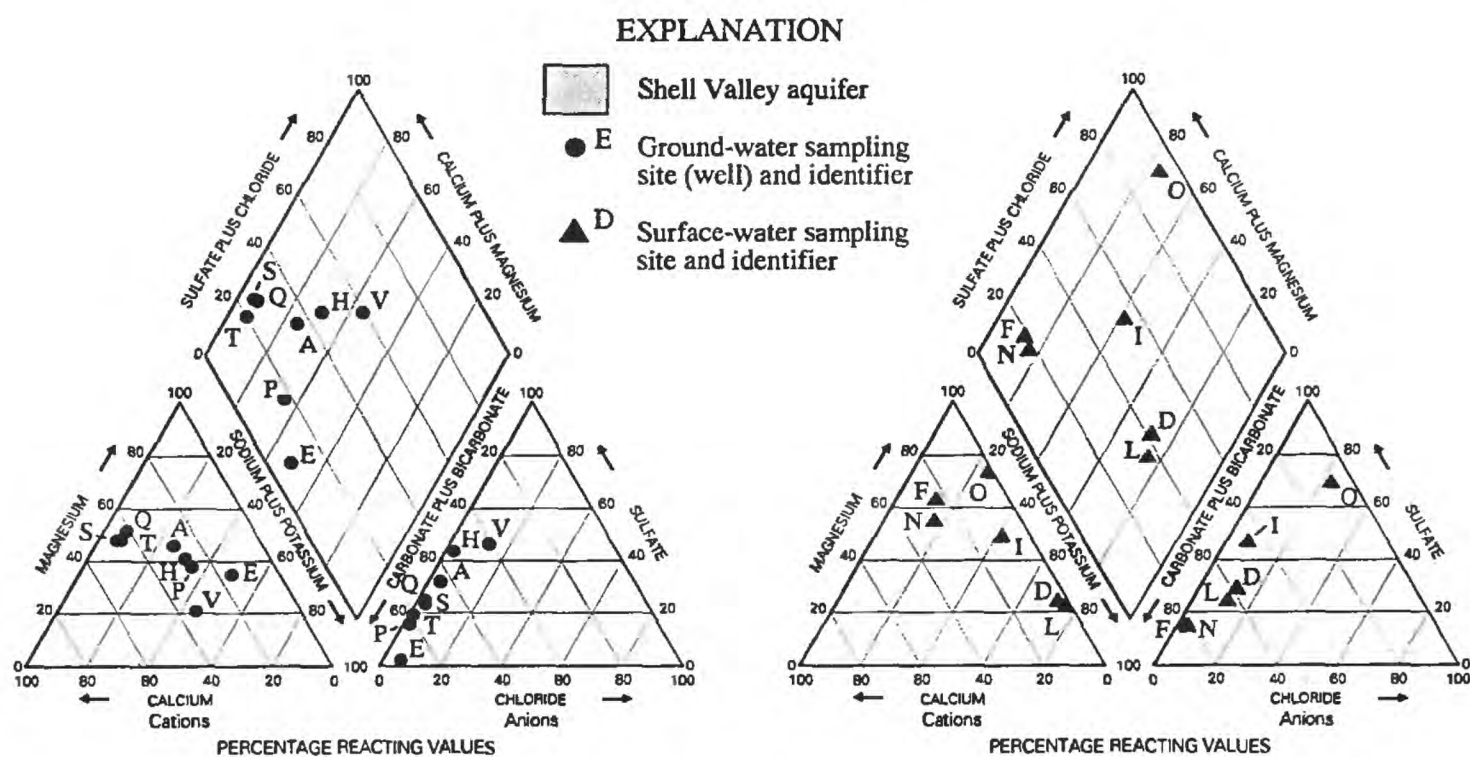
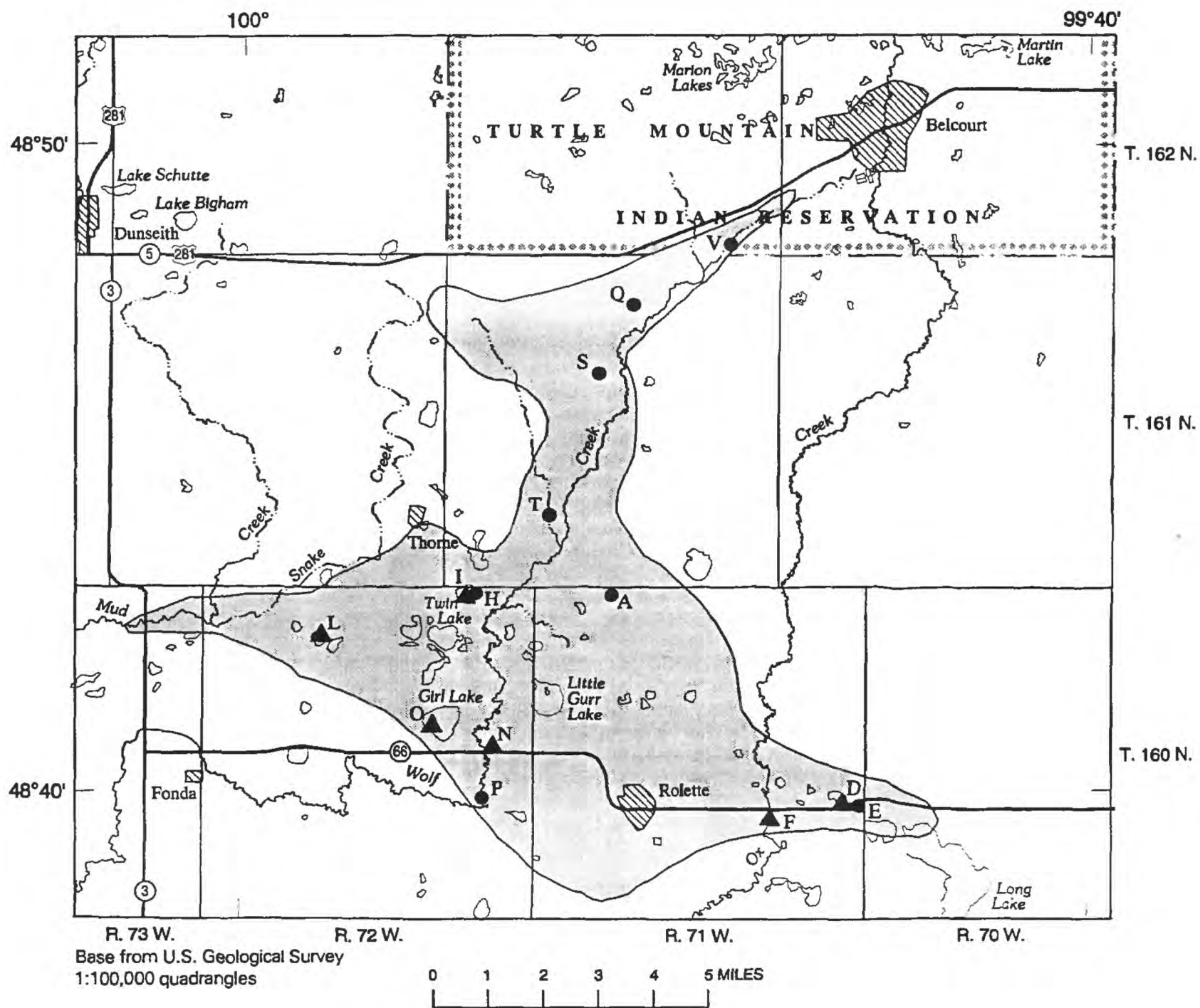


Figure 11. Locations of sites sampled for major ions and major-ion composition of the water, July 1995.

per liter of CaCO_3 to the classification term. The hardness of water in the Shell Valley aquifer ranges from 230 to 760 milligrams per liter of CaCO_3 , which is in the very hard class.

Classification of hardness (Durfor and Becker, 1964, p. 27)

Hardness range (milligrams per liter of CaCO_3)	Classification
0-60	Soft
61-120	Moderately hard
121-180	Hard
More than 180	Very hard

The ground-water samples also were analyzed for arsenic, iron, manganese, and selenium because these trace elements have been identified in other ground water in North Dakota. Arsenic concentrations ranged from below the detection limit of 1 microgram per liter to 46 micrograms per liter. The maximum contaminant level for arsenic in drinking water is 50 micrograms per liter (U.S. Environmental Protection Agency, 1995). Iron concentrations ranged from below the detection limit of 3 micrograms per liter to 9,500 micrograms per liter. The secondary maximum contaminant level for iron in drinking water is 300 micrograms per liter (U.S. Environmental Protection Agency, 1995). Iron concentrations were above that level in five of the eight ground-water samples. Manganese and selenium concentrations were small or undetected in all of the samples.

Sodium and magnesium were the dominant cations in surface-water samples from the study area, and bicarbonate was the dominant anion except in the sample from Girl Lake (fig. 11). That sample was dominant in sulfate. pH ranged from 7 to 8 in most of the samples but was 10.1 in the sample from Girl Lake. Dissolved-solids concentrations generally ranged from 511 to 1,880 milligrams per liter but were 4,650 milligrams per liter in the sample from Girl Lake. The major-ion composition of water in ponds along Wolf Creek was similar to that in ponds along Ox Creek.

Arsenic concentrations in surface-water samples ranged from below the detection limit of 1 microgram per liter to 37 micrograms per liter, and iron concentrations ranged from below the detection limit of 3 micrograms per liter to 40 micrograms per liter. Both arsenic and iron concentrations were below their primary or secondary maximum contaminant levels for drinking water.

Agricultural Chemicals

The ground- and surface-water samples collected during July and September were analyzed for 39 pesticides (table 2), nitrite plus nitrate, and orthophosphate. The samples were analyzed using solid-phase extraction followed by gas chromatography/mass spectroscopy. None of the samples analyzed had detectable concentrations of pesticides. Concentrations of nitrite plus nitrate and orthophosphate were below or near the detection limits in all of the samples. Thus, agricultural chemicals have little effect on the water quality of the Shell Valley aquifer.

Hydrocarbons

The ground- and surface-water samples collected during July and September also were analyzed for benzene, toluene, ethylbenzene, and xylene (BTEX), polycyclic aromatic hydrocarbons (PAH), polychlori-

Table 2. Pesticides for which water samples were analyzed, July and September 1995

[µg/L, micrograms per liter]

Chemical	Detection limit (µg/L)	Chemical	Detection limit (µg/L)
Acifluorfen	0.03	Fluometuron	0.03
Aldicarb	0.02	Linuron	0.02
Aldicarb sulfone	0.02	MCPA	0.05
Aldicarb sulfoxide	0.02	MCPB	0.03
Amiben	0.01	Methiocarb	0.03
Bentazon	0.01	Methomyl	0.02
Bromacil	0.03	Neburon	0.02
Bromoxynil	0.03	Norflurazon	0.02
Carbaryl	0.01	Ocresol 4, 6 dinitro	0.03
Carbofuran	0.03	Oryzalin	0.02
Clopyralid	0.05	Propham	0.03
Chlorothalonil	0.03	Propoxur	0.03
Dacthal monoacid	0.02	Silvex	0.02
Dicamba	0.03	Triclopyr	0.05
Dichlobenil	0.02	1-Naphthol	0.01
Dichlorprop	0.03	2,4-D	0.03
Dinoseb	0.03	2,4-DB	0.03
Diuron	0.02	2,4,5-T	0.03
Esfenvalerate	0.02	3-Hydroxy carbofuran	0.01
Fenuron	0.01		

nated biphenyls (PCB), and pentachlorophenol (PCP). The samples were analyzed using the immunoassay technique, which detects the occurrence of hydrocarbons but does not quantify the concentrations (W.R. Berkas, U.S. Geological Survey, oral commun., 1995).

BTEX is a suite of aromatic hydrocarbons that typically are associated with fuels and additives to boost octane (Fetter, 1993). BTEX detection may indicate that one or more of the individual hydrocarbons are present. Benzene is associated with detergents, solvents, and antiknock gasoline. Toluene is associated with adhesive solvents in plastics, solvents, aviation and high-octane fuels, diluents and thinners, explosives, and detergents. Ethylbenzene often is an intermediate state for the hydrocarbons and is associated with solvents and gasoline. Xylene is associated with aviation fuel, protective coatings, solvents, synthesis of organic chemicals, and gasoline. PAH is associated with the combustion of fossil fuels, asphalt, bituminous coal, and naturally occurring petroleum and may be associated with forest fires, burning grasses, or, possibly, industrial chemicals. PCB is associated with industrial chemicals that do not break down easily, such as those in electrical transformers, heat-exchange and insulating fluids, lubrications and cutting oils, and some pesticides, paints, and inks. PCP is associated with agricultural uses, such as insecticides, fungicides, bactericides, algicides, herbicides, and wood preservatives.

Many hydrocarbons are less dense than water and generally float on the water table. Because the eight ground-water wells sampled during July are screened below the top of the water table, the samples collected from those wells may not contain the hydrocarbons that possibly are floating on the water table. Therefore, six new wells with screens that intersected the water table were completed in August 1995.

Samples from those wells would more accurately represent the occurrence of hydrocarbons in the Shell Valley aquifer.

Hydrocarbons were detected in one of the eight ground-water samples collected during July and in five of the six surface-water samples (table 3; fig. 12). During September, hydrocarbons were detected in five of the six ground-water samples, five of which were from the newly completed wells, and in all nine surface-water samples (table 3; fig. 13). Thus, sampling ground water from the water-table surface was successful in the detection of hydrocarbons.

Table 3. Hydrocarbon detections in the Shell Valley aquifer, July and September 1995

[BTEX, benzene, toluene, ethylbenzene, and xylene; PAH, polycyclic aromatic hydrocarbons; PCB, polychlorinated biphenyls; PCP, pentachlorophenol; --, not sampled]

Sampling site	Detection							
	July 1995				September 1995			
	BTEX ¹	PAH ²	PCB ³	PCP ⁴	BTEX ¹	PAH ²	PCB ³	PCP ⁴
Ground water								
A	No	No	No	No	--	--	--	--
B	--	--	--	--	No	Yes	No	No
E	No	No	No	No	--	--	--	--
G	--	--	--	--	No	Yes	No	No
H	No	No	No	No	--	--	--	--
J	--	--	--	--	No	No	No	No
M	--	--	--	--	No	Yes	No	No
P	No	No	No	No	--	--	--	--
Q	No	No	No	No	--	--	--	--
R	--	--	--	--	No	Yes	No	No
S	Yes	No	No	No	--	--	--	--
T	No	No	No	No	--	--	--	--
V	No	No	No	No	No	Yes	No	No
Surface water								
C	--	--	--	--	No	Yes	No	No
D	No	Yes	No	Yes	No	Yes	No	Yes
F	Yes	Yes	Yes	No	No	Yes	Yes	Yes
I	No	No	No	No	No	Yes	No	No
K	--	--	--	--	No	Yes	No	Yes
L	Yes	Yes	No	No	No	Yes	No	No
N	No	Yes	No	Yes	No	Yes	No	Yes
O	Yes	Yes	No	No	No	Yes	No	Yes
U	--	--	--	--	No	Yes	No	No

¹Detection limit of 0.03 milligram per liter.

²Detection limit of 0.9 microgram per liter.

³Detection limit of 0.2 microgram per liter.

⁴Detection limit of 0.06 microgram per liter.

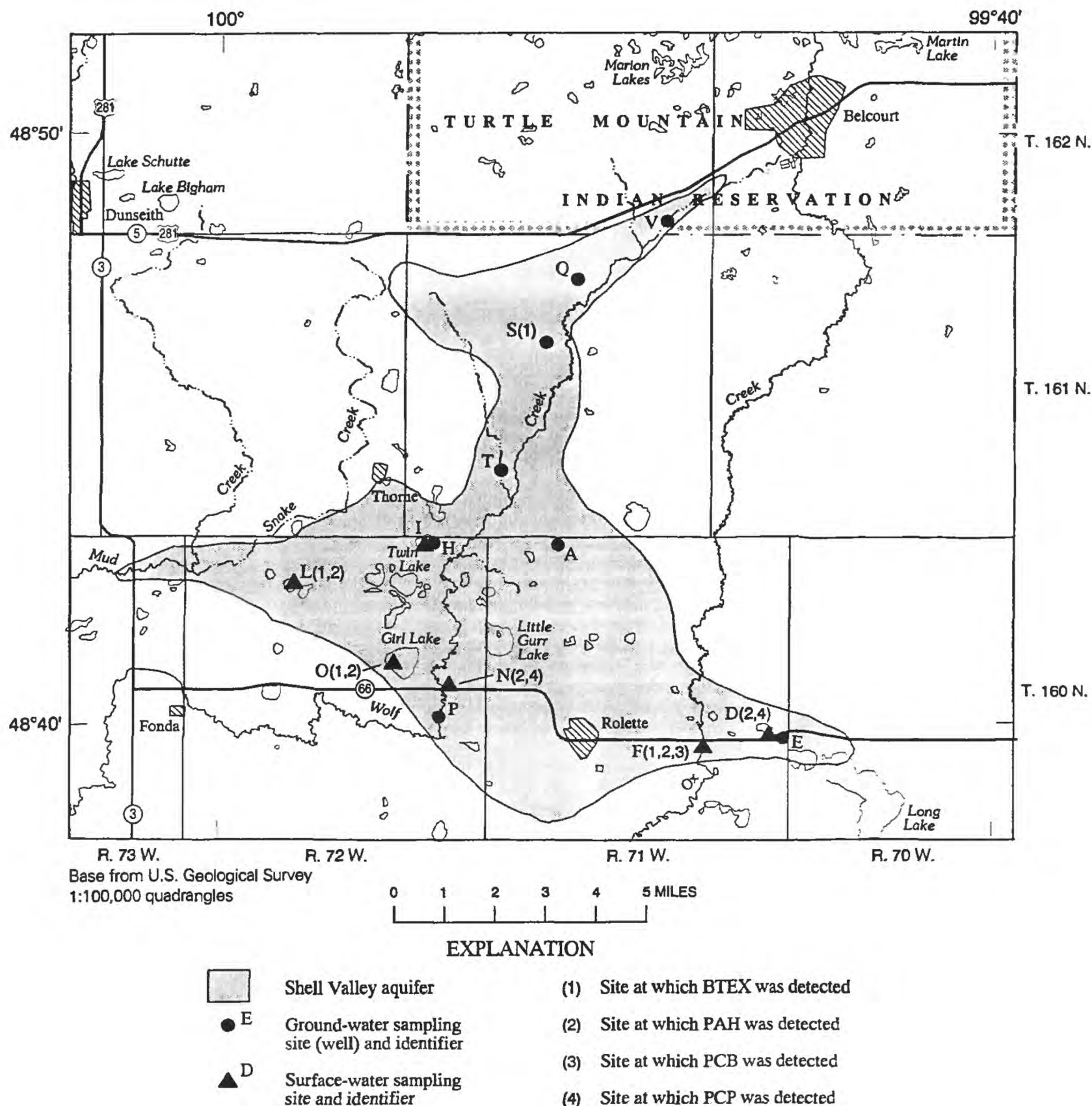


Figure 12. Locations of sites sampled for BTEX, PAH, PCB, and PCP, July 1995.

During July, BTEX was detected in one ground-water sample collected from the northern part of the Shell Valley aquifer and in three surface-water samples (fig. 12). PAH was not detected in any ground-water samples but was detected in five surface-water samples. PCB was not detected in any ground-water samples but was detected in one surface-water sample. PCP was not detected in any ground-water samples but was detected in two surface-water samples.

During September, BTEX was not detected in any ground- or surface-water samples (fig. 13). PAH was detected in five ground-water samples and in all of the surface-water samples. PCB was not detected

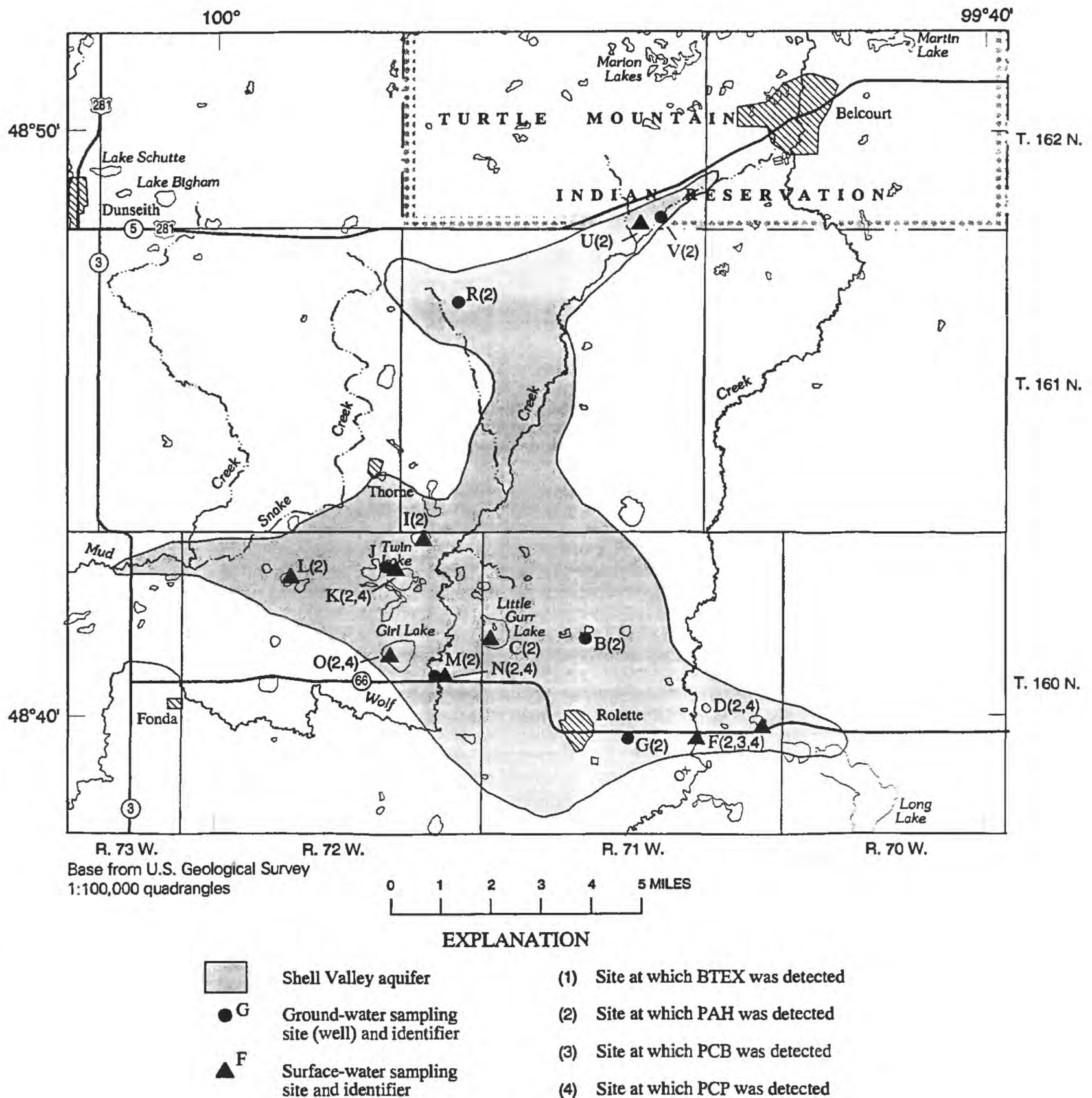


Figure 13. Locations of sites sampled for BTEX, PAH, PCB, and PCP, September 1995.

in any ground-water samples but was detected in one surface-water sample. PCP was not detected in any ground-water samples but was detected in five surface-water samples.

Too few data are available to make conclusions about the distribution and sources of hydrocarbons in the aquifer. Also, the immunoassay technique used to analyze the samples detects certain groups of hydrocarbons but does not allow for individual detection of specific species. Therefore, only general conclusions can be drawn from the data.

BTEX found in the Shell Valley aquifer probably was derived from gasoline and solvents and may have come from fuel spills. However, the BTEX may have entered the aquifer upgradient from the

sampling sites and may have been transported to the sampling sites by ground-water flow or surface runoff.

PAH was distributed throughout the study area and was the most frequently detected hydrocarbon in the study area. The PAH may have come from coal and organic materials in the glacial sediments or from asphalt on paved roads in the area and from burned fields and ditches.

Both PCB detections were in samples collected from the same site on Ox Creek. The PCB may have come from industrial chemicals, oils, pesticides, paints, or a damaged electrical transformer. The detections of PCB in Ox Creek probably indicate contamination upstream from the sampling site.

The PCP in surface-water samples may be the result of aerial spraying or runoff from agricultural fields. Also, if any of the lakes and wetlands have wooden docks, the wood preservative may account for the presence of PCP in the samples.

LAND USE AND SUSCEPTIBILITY OF THE AQUIFER TO CONTAMINATION

Land use in the area underlain by the Shell Valley aquifer is mainly agricultural. Most of the land is used for grasslands to produce hay and crops such as wheat, barley, and oats. Occasionally, the land is used to raise sunflowers, beans, and corn. Pastureland used for cattle production is scattered across the study area but is only a minor component of land use.

The only major residential area overlying the Shell Valley aquifer is the city of Rolette. Farmsteads that occur across the entire area generally are located at least one-half mile apart and usually are located farther apart.

Industries located near the northeastern part of the area may be potential sources of contamination to the aquifer. Municipal sources of contamination (such as small businesses, car washes, and airport and automotive maintenance shops) and domestic sources of contamination (such as septic tanks, garbage dumps, and fuel and oil spills) are rare and generally are present in the southern part of the area.

The Shell Valley aquifer is most susceptible to contamination in areas where it is unconfined and in areas where water levels are near the land surface (fig. 7). Contaminants that are spilled on the land surface will reach the aquifer most easily where the vertical flow path has the least resistance and is the shortest. Recharge to the aquifer occurs from infiltration of precipitation, from collection of water in wetlands and subsequent infiltration, and from Wolf and Ox Creeks. Therefore, potential contaminants can be transported to the aquifer along those flow paths. Because most of the aquifer is unconfined (fig. 5), precipitation easily enters the aquifer across most of the land surface. The infiltration occurs more readily in the northern part of the area, which has coarser aquifer materials and a larger hydraulic conductivity than the southern part of the area.

The surface relief and the length of flow paths vary more in the southern part of the area, where numerous wetlands occur, than in the northern part (fig. 1). The surface depressions occupied by wetlands may result in focused recharge, and contaminants present at land surface in those areas may enter the aquifer through the wetlands. Water levels across much of the aquifer generally are within 10 feet of land surface, except in areas that have large surface relief. In those areas, water levels can be deep near hilltops but at land surface in nearby depressions.

Most of the Shell Valley aquifer is susceptible to contamination. The northern part is susceptible because of shallow water levels and large hydraulic conductivities and because of recharge from Wolf and

Ox Creeks. The southern part is susceptible because wetlands that recharge the aquifer are present where the water table intersects the land surface. These wetlands may be preferential flow paths to the aquifer. The aquifer is least susceptible to contamination where it is confined by overlying clay or till (fig. 5).

SUMMARY AND CONCLUSIONS

The Shell Valley aquifer is the sole source of water for the city of Belcourt and the primary source of water for most of the Turtle Mountain Indian Reservation. The Turtle Mountain Band of Chippewa Indians is concerned about the quantity and quality of water in the Shell Valley aquifer, which underlies about 56 square miles in central Rolette County and has an average saturated thickness of about 35 feet.

Water levels across most of the Shell Valley aquifer fluctuate with variations in precipitation but generally are stable. Withdrawals from the north well field decreased slightly during 1976-95, but withdrawals from the south well field increased during 1983-95. Water levels in the north well field declined during 1979-81 as the result of ground-water withdrawals. During 1988-92, the water levels declined because of drought, and during 1993-95, the water levels rose because of wet conditions. Ground-water withdrawals from the north well field decreased slightly during 1982-95. Water levels in the south well field declined as withdrawals increased. The average decline during the last 8 years was about 1.75 feet per year. The water level has reached the well screen in at least one of the production wells.

Ground- and surface-water samples were collected during July and September 1995 to determine the water quality of the Shell Valley aquifer. The samples were analyzed for major ions, selected trace elements, agricultural chemicals, and selected hydrocarbons. Most of the water in the aquifer is a bicarbonate type and has dissolved-solids concentrations ranging from 479 to 1,510 milligrams per liter. None of the samples analyzed had detectable concentrations of pesticides, but hydrocarbons were detected in both ground- and surface-water samples. Polycyclic aromatic hydrocarbons (PAH) were the most frequently detected hydrocarbons. Benzene, toluene, ethylbenzene, and xylene (BTEX), polychlorinated biphenyls (PCB), and pentachlorophenol (PCP) also were detected. However, too few data are available to make conclusions about the distribution and sources of hydrocarbons in the aquifer.

Generally, the Shell Valley aquifer is an adequate source of water for current needs, but evaluation of withdrawals in relation to a knowledge of aquifer hydrology would be important in quantifying sustainable water supplies. Water quality in the aquifer generally is good; the Turtle Mountain Band of Chippewa Indians filters the water to reduce concentrations of dissolved constituents. Hydrocarbons, although present in the aquifer, have not been quantified and may not pose a general health risk. Further analysis of the quantity and distribution of the hydrocarbons would be useful to understand their sources and implications for water use.

REFERENCES

- Durfor, C.M., and Becker, Edith, 1964, Public water supplies of the 100 largest cities in the United States, 1962: U.S. Geological Survey Water-Supply Paper 1812, 364 p.
- Fetter, C.W., 1993, Contaminant hydrogeology: New York, Macmillan Publishing Company, 458 p.
- Freeze, A.R., and Cherry, J.A., 1979, Groundwater: Englewood Cliffs, New Jersey, Prentice-Hall, Inc., 604 p.
- Harkness, R.E., Haffield, N.D., Berkas, W.R., Norbeck, S.W., and Strobel, M.L., 1996, Water resources data, North Dakota, water year 1995: U.S. Geological Survey Water-Data Report ND-95-1, 534 p.

- Heath, R.C., 1983, Basic ground-water hydrology: U.S. Geological Survey Water-Supply Paper 2220, 85 p.
- Owenby, J.R., and Ezell, D.S., 1992, Monthly station normals of temperature, precipitation, and heating and cooling degree days, 1961-90 (by State): U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Climatic Data Center, Asheville, North Carolina, Climatology of the United States No. 81, unpaginated.
- Randich, P.G., 1975, Ground-water availability in the Belcourt area, Rolette County, North Dakota: U.S. Geological Survey Open-File Report 75-104, 36 p.
- Randich, P.G., and Ghering, G.E., 1975, Results of aquifer testing in the Belcourt area, Rolette County, North Dakota: U.S. Geological Survey Open-File Report 75-396, 31 p.
- Randich, P.G., and Kuzniar, R.L., 1984, Ground-water resources of Bottineau and Rolette Counties, North Dakota: North Dakota State Water Commission County Ground-Water Studies 35, pt. III, and North Dakota Geological Survey Bulletin 78, pt. III, 41 p.
- Reed, T.B., 1997, Digital simulation of ground-water flow in the Warwick aquifer, Fort Totten Indian Reservation, North Dakota: U.S. Geological Survey Water-Resources Investigations Report 97-4114, 50 p.
- U.S. Environmental Protection Agency, 1995, Drinking water regulations and health advisories: Office of Water, USEPA, Washington D.C., 11 p.