INVESTIGATION TO IDENTIFY A WATER SUPPLY FOR A RURAL WATER ASSOCIATION IN BOTTINEAU COUNTY, NORTH DAKOTA

by

Alan Wanek

North Dakota Ground-Water Studies
Number 101
North Dakota State Water Commission
David Sprynczynatyk, State Engineer

Prepared by the
North Dakota State Water Commission
In cooperation with the
Bottineau County Water Resource District

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INTRODUCTION

General Statement

On 18 March 1991 Mark Bollinger, Manager for the All Seasons Rural Water Association contacted the North Dakota State Water Commission requesting a study be undertaken to find a supplemental water supply for the rural water association. At a meeting on 27 March 1991 two areas were selected for further study (fig. 1).

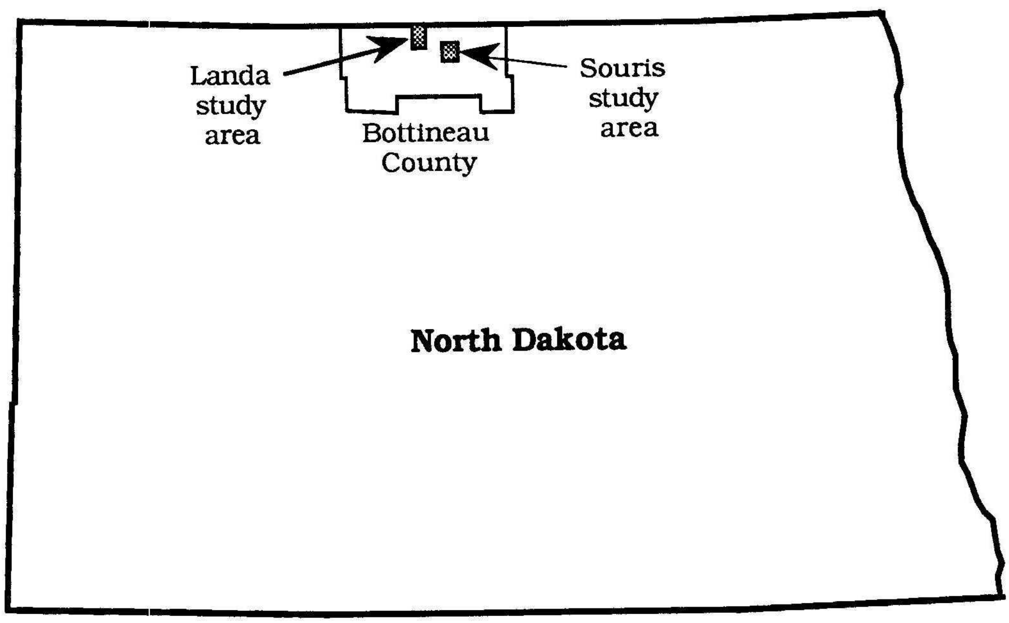

Figure 1 - Location of study areas

An agreement dated 24 July 1991 was signed by the North Dakota State Water Commission and by the Bottineau County Water Resource District. The agreement calls for the Water Commission to conduct an investigation of the ground-water resources of the two selected areas. Costs of the study are to be paid jointly by the two parties. This report is in partial fulfillment of the agreement.

Study Areas

The Souris area is located between Bottineau and Souris, along a surficial sand and gravel deposit (fig 2). The Landa area is located northeast of Westhope and north of Landa, along the southwestward projection of a buried glacial valley which has been identified between three and nine miles north of the Canada-United States border.

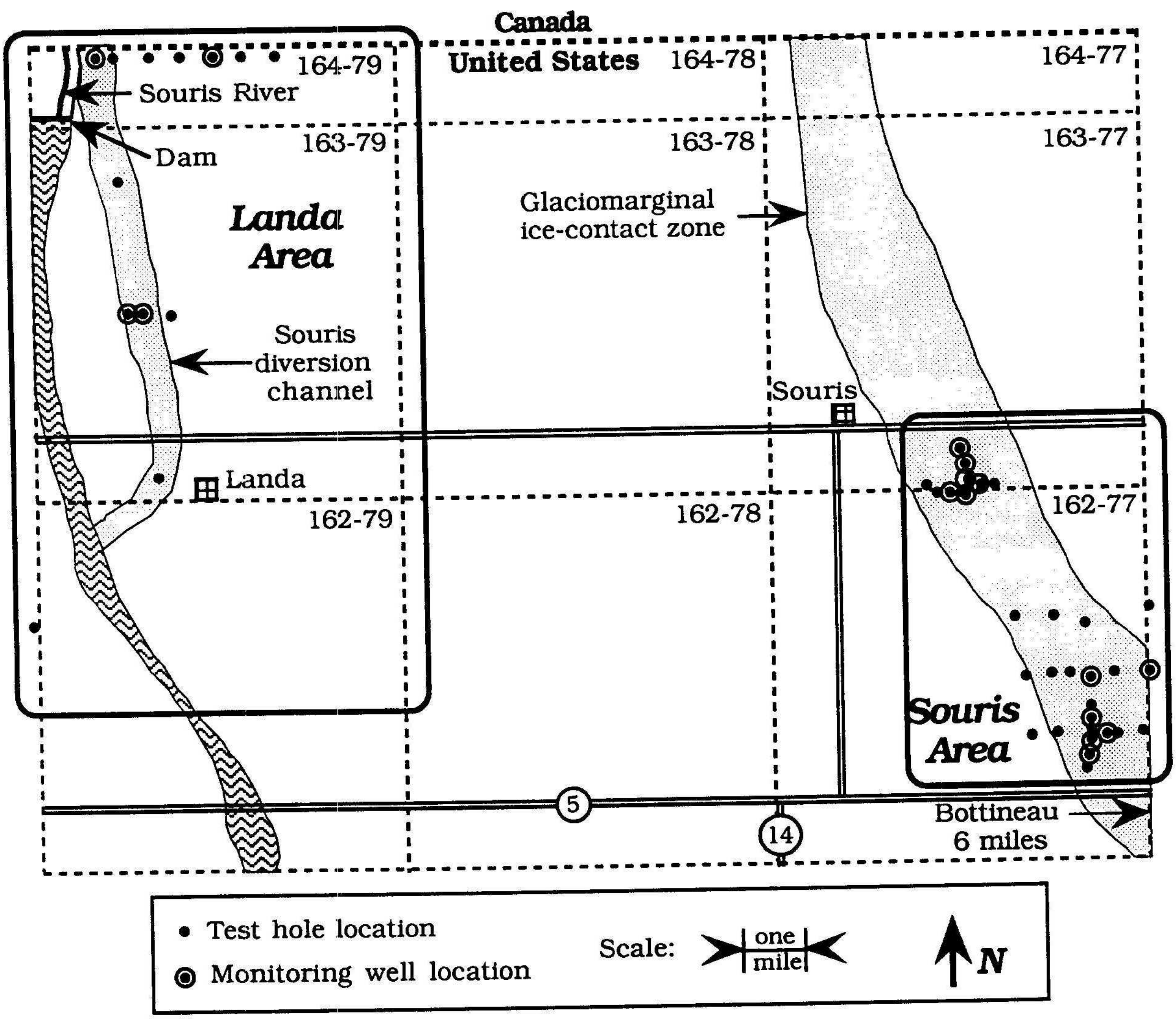

Figure 2 - Test hole and monitoring well locations in Bottineau Co.

Previous Investigations

The geology of Bottineau County was described by Bluemle (1985) as part of the county ground-water studies program. Kuzniar and Randich (1982) compiled the ground-water data of Bottineau and Rolette Counties and Randich and Kuzniar (1984) described the ground-water resources of Bottineau and Rolette Counties.

Field Methods

As part of the investigation, 33 test holes were drilled totaling 3394 feet of drilling, using a forward, mud-rotary drilling rig. Test holes were drilled through glacial drift until the underlying bedrock was encountered.

Sixteen monitoring wells were installed using two-inch diameter, polyvinyl chloride casing and five feet of slotted screen for each well. The monitoring wells were developed by collapsing *in situ* sand and gravel against the screen. The annular space between the casing and the wall of the drilled hole was filled with granular bentonite and drill cuttings. Elevations of the tops of the monitoring wells were determined by horizontal leveling. Water levels in the wells were measured in August and November 1991 and in April and November 1992 using a chalked steel tape. Lithologic descriptions of sediments encountered in the test holes and monitoring well completion details are included in Appendix 1.

Water samples were collected from the monitoring wells to determine the quality of the water. The samples were analyzed for common ions. Five samples were analyzed for trace concentrations of metallic elements. The analyses were performed by the North Dakota State Water Commission Laboratory.

Location-Numbering System

The number and letter designation used to describe the location of a monitoring well or test hole is based upon the federal system of rectangular surveys of public land, the township and range system, (fig. 3). In the designation, 162-78-4ADD, the first number is the township north of a base line, the second number is the range west of the fifth principal meridian, and the third number is the section in which the well is located. The first letter is the quarter section, the second letter is the quarter-quarter section, and the third letter is the quarter-quarter-quarter section (10 acre tract) in which the well is located. The letter "A" designates the northeast subdivision, the letter "B" the northwest subdivision, the letter "C" the southwest subdivision, and the letter "D" the southeast subdivision.

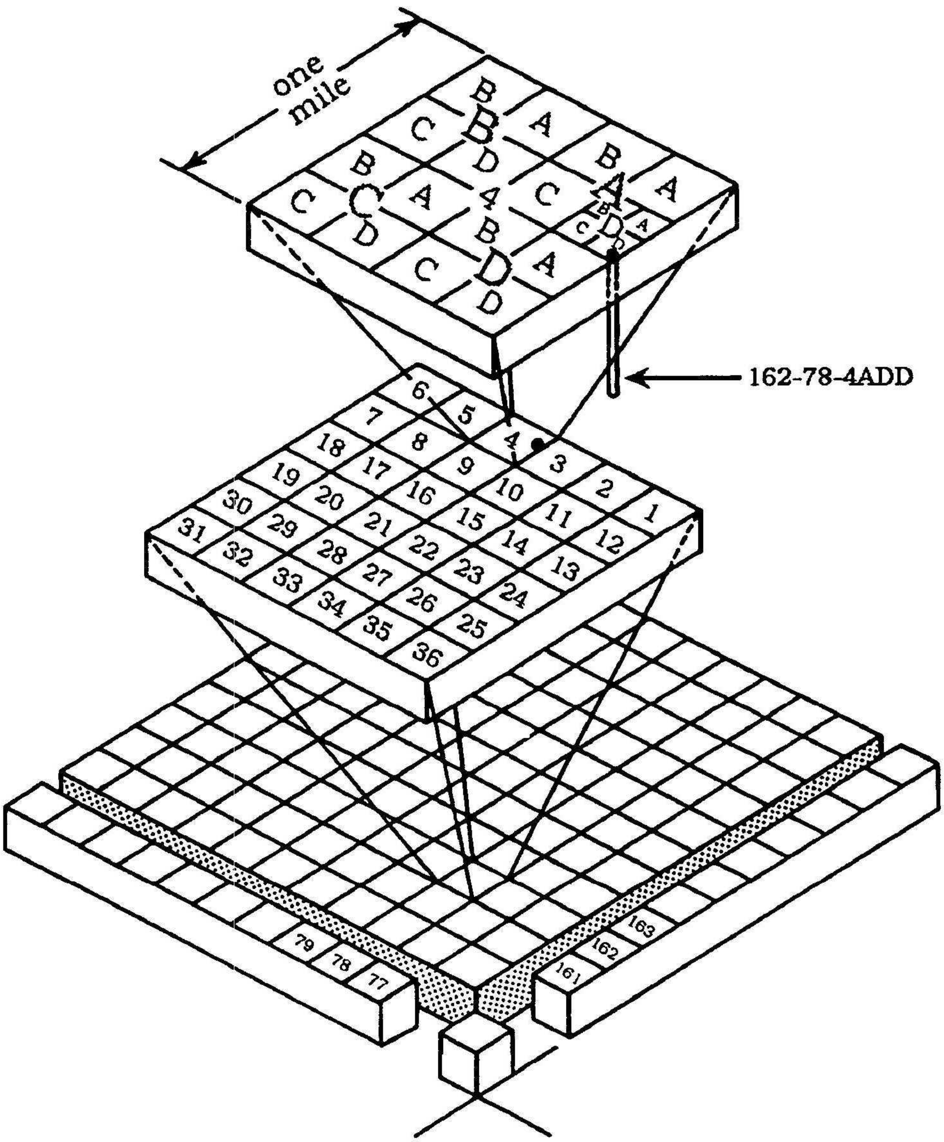

Figure 3 - Location-numbering system

SOURIS STUDY AREA

Geologic Setting

The area investigated near Souris is along a belt of land which includes kames and eskers, which are ice-contact fluvial deposits. The belt of land parallels the west side of the Turtle Mountains about four miles west of the base of the escarpment (fig. 4). The ice-contact deposit consists about 2/3 sand and 1/3 gravel.

East of the ice-contact belt the land surface is covered by 20 to 40 feet of glacial drift, primarily till, overlying bedrock. West of the ice-contact belt the land surface is covered by fine sandy, silty and argillaceous lacusterine sediments deposited in glacial Lake Souris. West of the northern part of the study area is a slough which is nearly dry. Southwest of the southern part of the study area are two lakes. The slough and lakes are probably hydraulically interconnected with the adjacent ice-contact deposits.

Geometry of the Ice-contact Deposits

Thirty test holes were drilled in the area to outline two deposits of ice-contact sand and gravel. The two deposits are four miles apart. Additional lithologic information was gained from the well driller's reports of three water supply wells located at the northern end of the Souris area. The water supply wells belong to the City of Souris and to All Seasons Rural Water Association. No other information is available from test holes or wells in the study area.

Test holes were drilled until bedrock was encountered. Bedrock in the area consists of fine grained to silty and clayey sand (Wentworth grain size scale, Wentworth, 1922) of the Hell Creek and Fox Hills Formations.

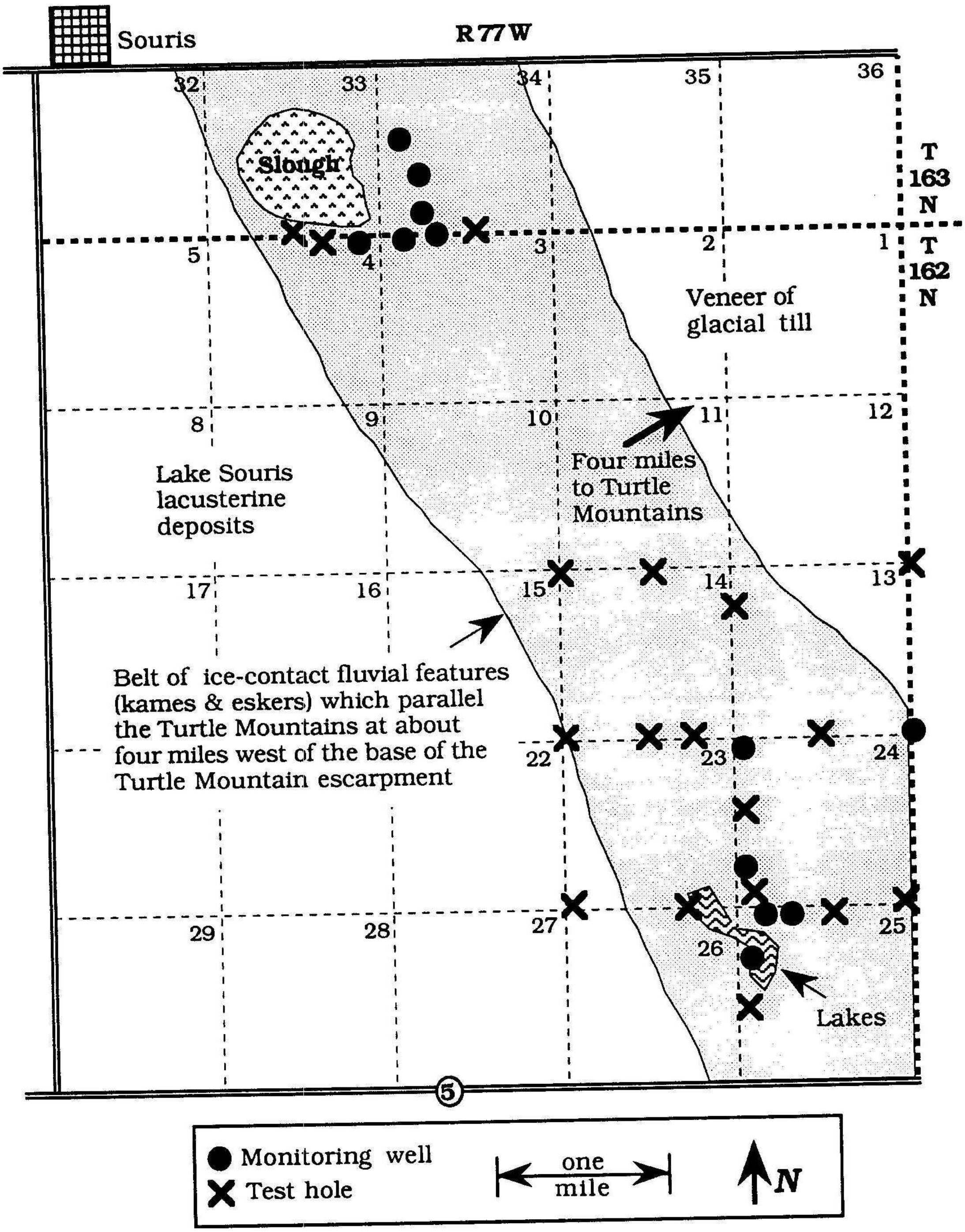

Figure 4 - Geology of the Souris area with test hole and well locations

The thickness of sand and gravel below the water table was determined from test hole lithologic information and from monitoring well water-level information (fig. 5). Each of the two outwash deposits identified in the Souris area is slightly more than one mile long and about 1/3 of a mile wide. The thickest part of each

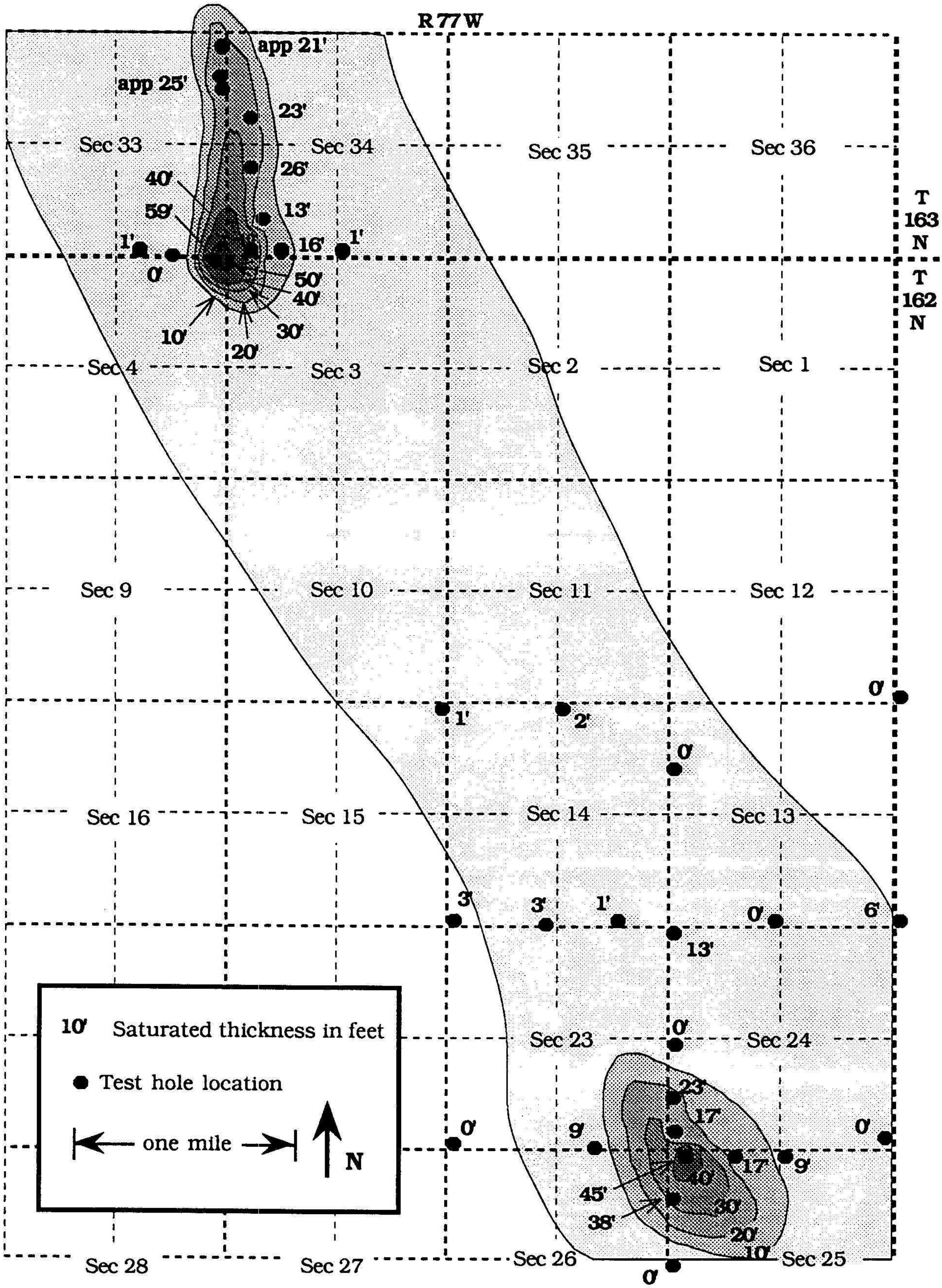

Figure 5 - Saturated thickness of sand and gravel in the Souris area

ice-contact deposit is at its southern end. Test drilling indicates sand and gravel is present from land surface to a depth of up to 64 feet.

In the northern ice-contact deposit of the Souris area, the southern extent of the deposit was not clearly defined. The land south of the township line was under cultivation and was not drilled. Judging by the relationship between surface topography and test drilling in the southern ice-contact deposit of the Souris area, the northern ice-contact deposit probably ends not far south of the township line between Sections 33 & 34 and Sections 3 & 4; however, because the area has not been drilled, the aquifer may extend farther south than has been indicated on figure 5.

Geohydrology of the Ice-contact Deposits

Six geohydrologic sections, a - a' through f - f', were constructed using information gathered from the test holes and monitoring wells installed in the Souris area. An index to the geohydrologic sections is shown in figure 6.

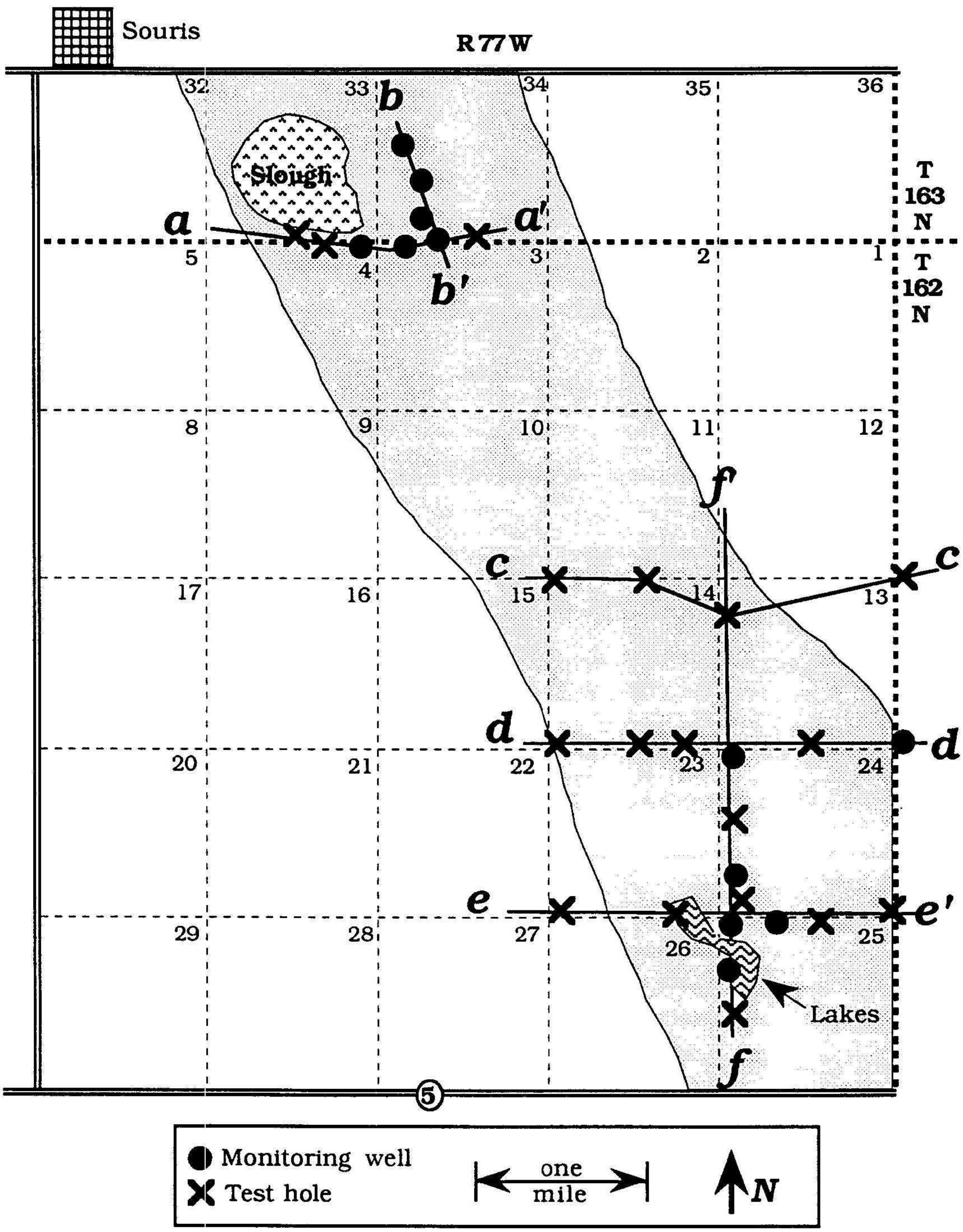

Figure 6 - Location of geohydrologic sections in the Souris area

Geohydrologic section a - a' is a west to east section of six test holes. The section includes the thickest portion of sand and gravel found in the northern ice-contact deposit. Three monitoring wells were installed along section a - a', (fig. 7).

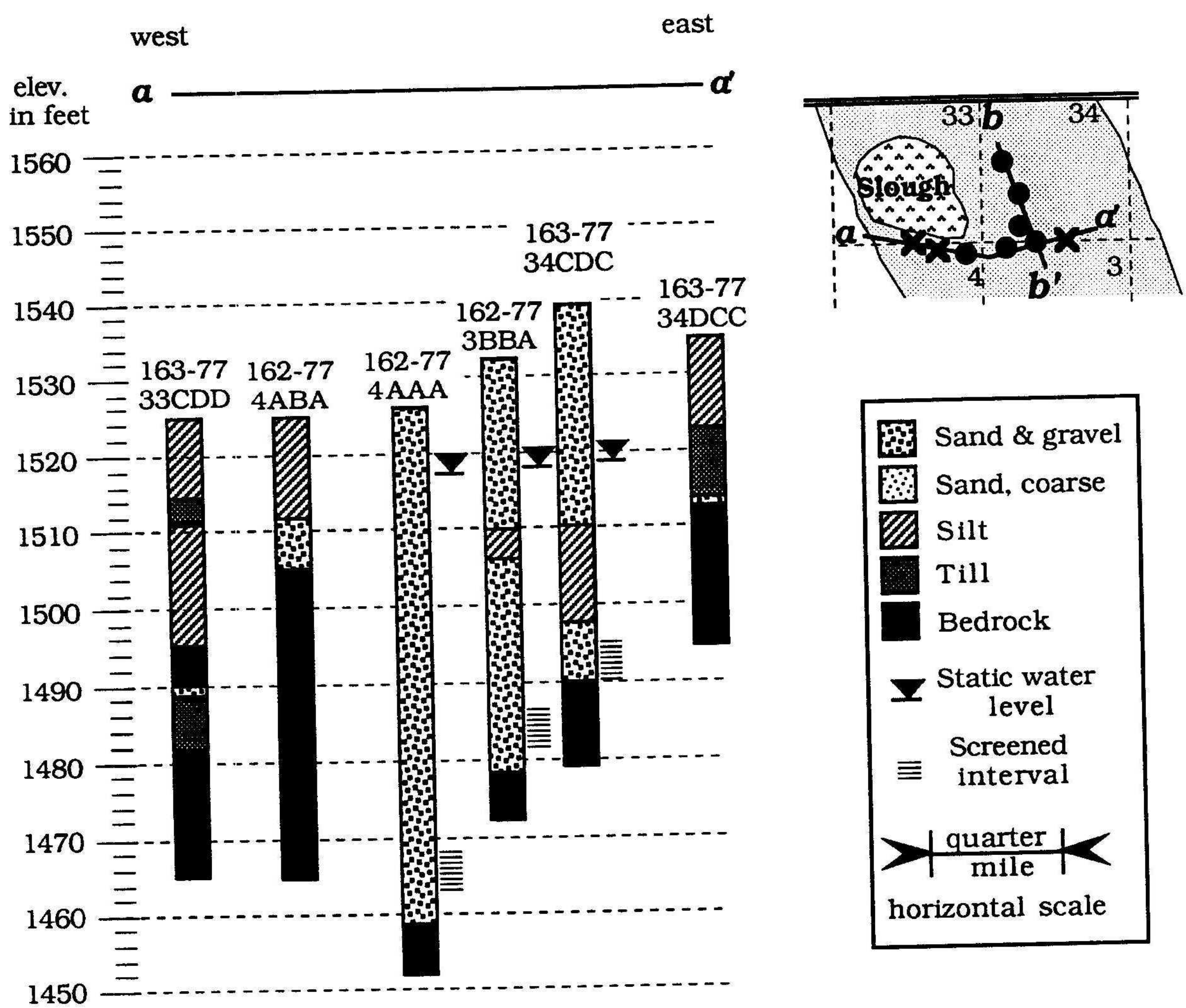

Figure 7 - **Geohydrologic section a - a' showing the northern ice-contact deposit in the Souris area**

Geohydrologic section b - b' is a north to south-southeast section of four test holes along the long axis of the northern ice-contact deposit (fig. 8). Monitoring wells were installed in all of the test holes.

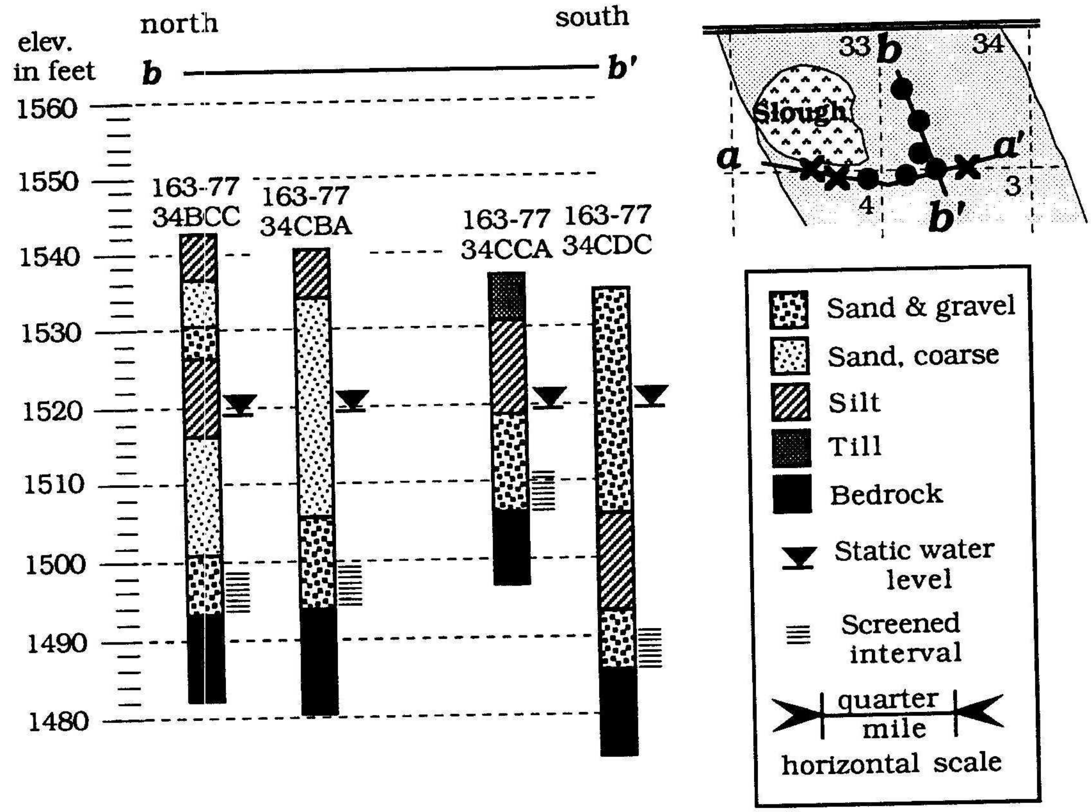

Figure 8 - **Geohydrologic section b - b' showing the northern ice-contact deposit in the Souris area**

Geohydrologic section c - c' is a west to east section north of the southern ice-contact deposit (fig. 9). Till is present to the east and lacusterine silt and clay is present to the west along section c - c'. Little sand and gravel was found in the test holes along section c - c'.

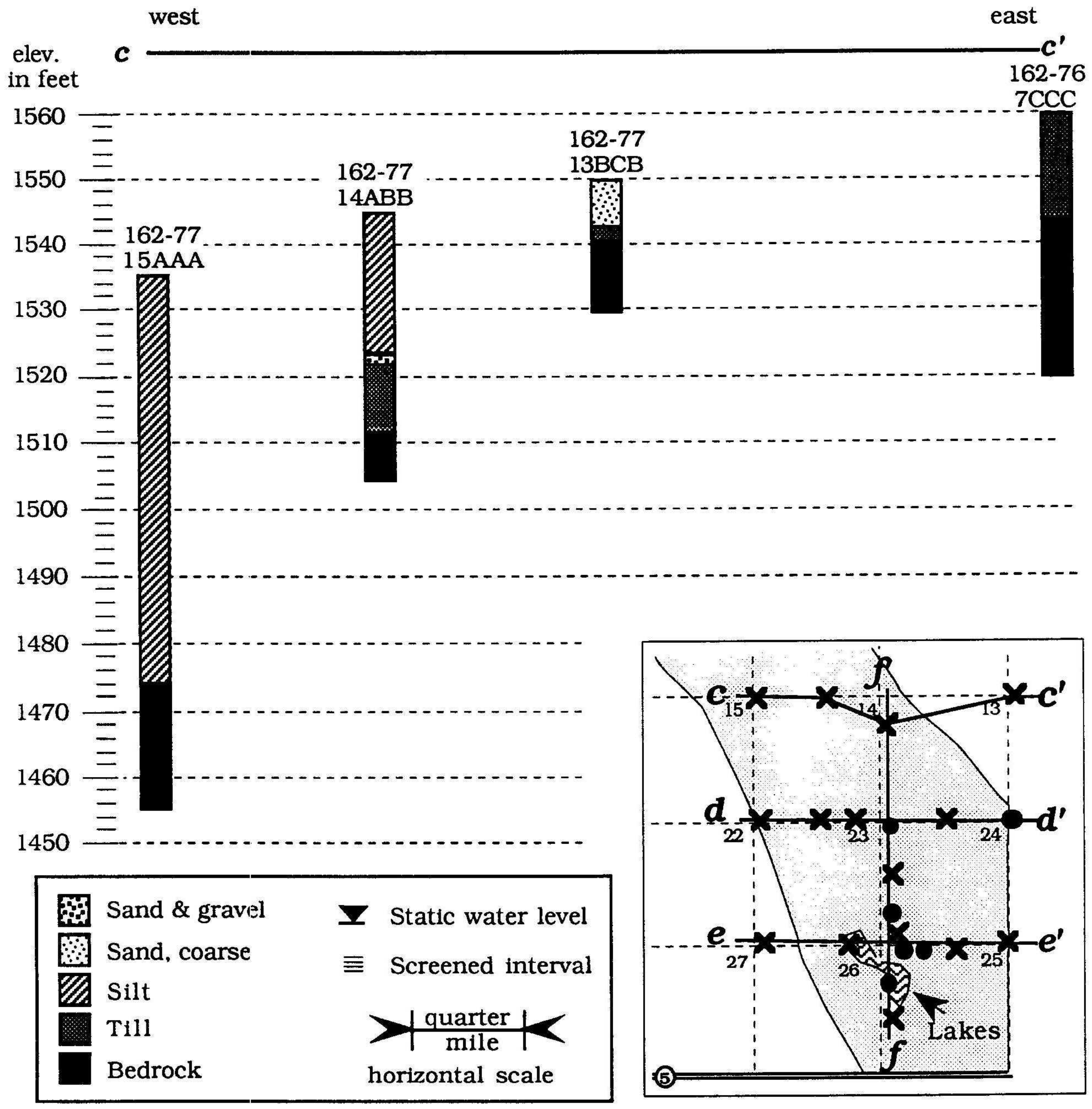

Figure 9 - **Geohydrologic section c - c' showing the far northern limit of the southern ice-contact deposit in the Souris area**

Geohydrologic section d - d' occurs one mile south of section c - c', (fig. 10). Two monitoring wells were completed in sand and gravel found along the section. Water levels in the two wells were about 20 and 50 feet higher than water levels in the sand and gravel found near the lakes at the south end of the study area. The differences in water level elevation indicate a poor hydraulic interconnection between the sand and gravel deposits along d - d' and the deposits near the lakes.

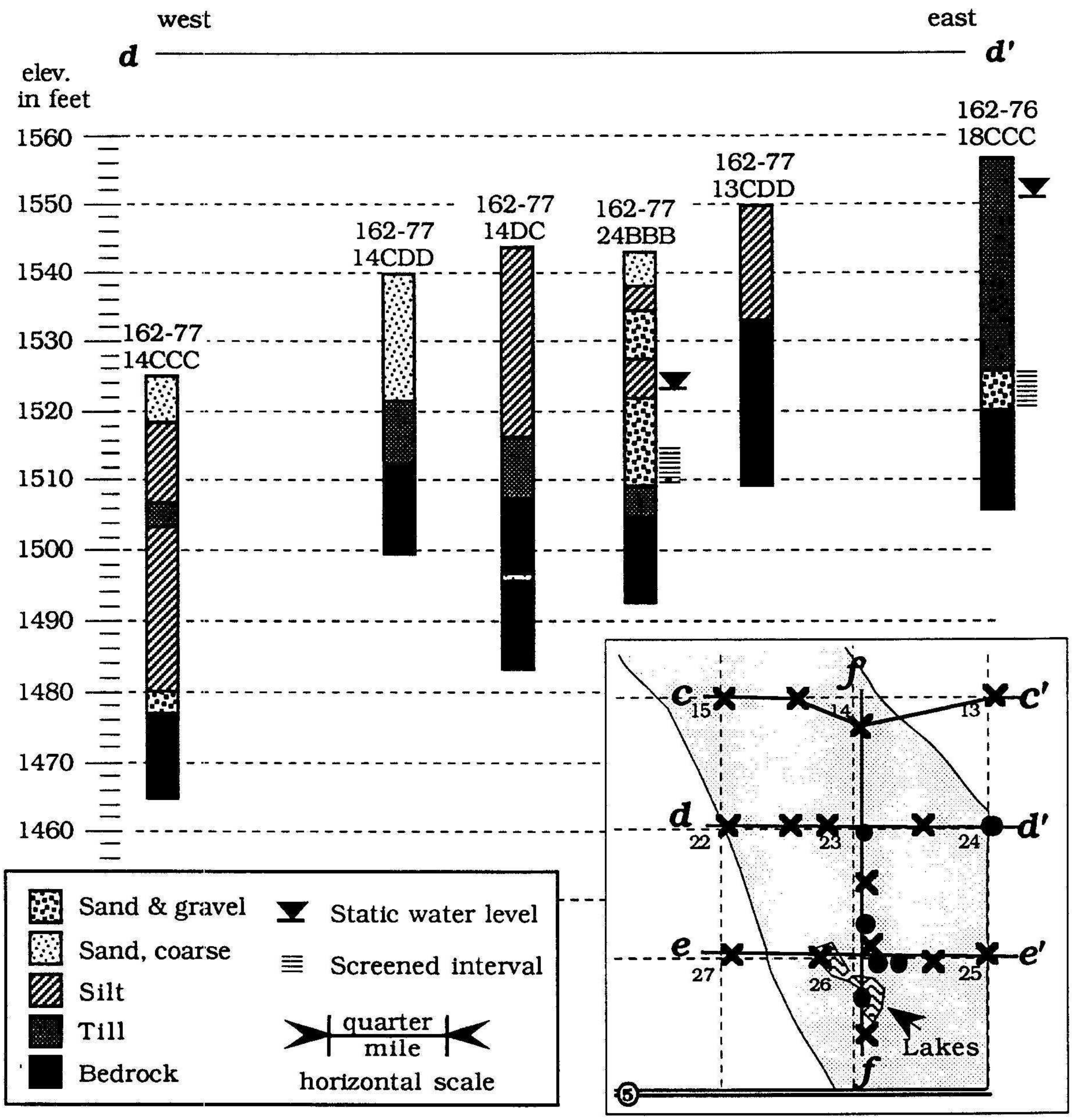

Figure 10 - **Geohydrologic section d - d' showing the northern limit of the southern ice-contact deposit in the Souris area**

Geohydrologic section e - e' is located one mile south of section d - d', along the two small lakes which are present on the southwest side of the southern ice-contact deposit, (fig. 11).

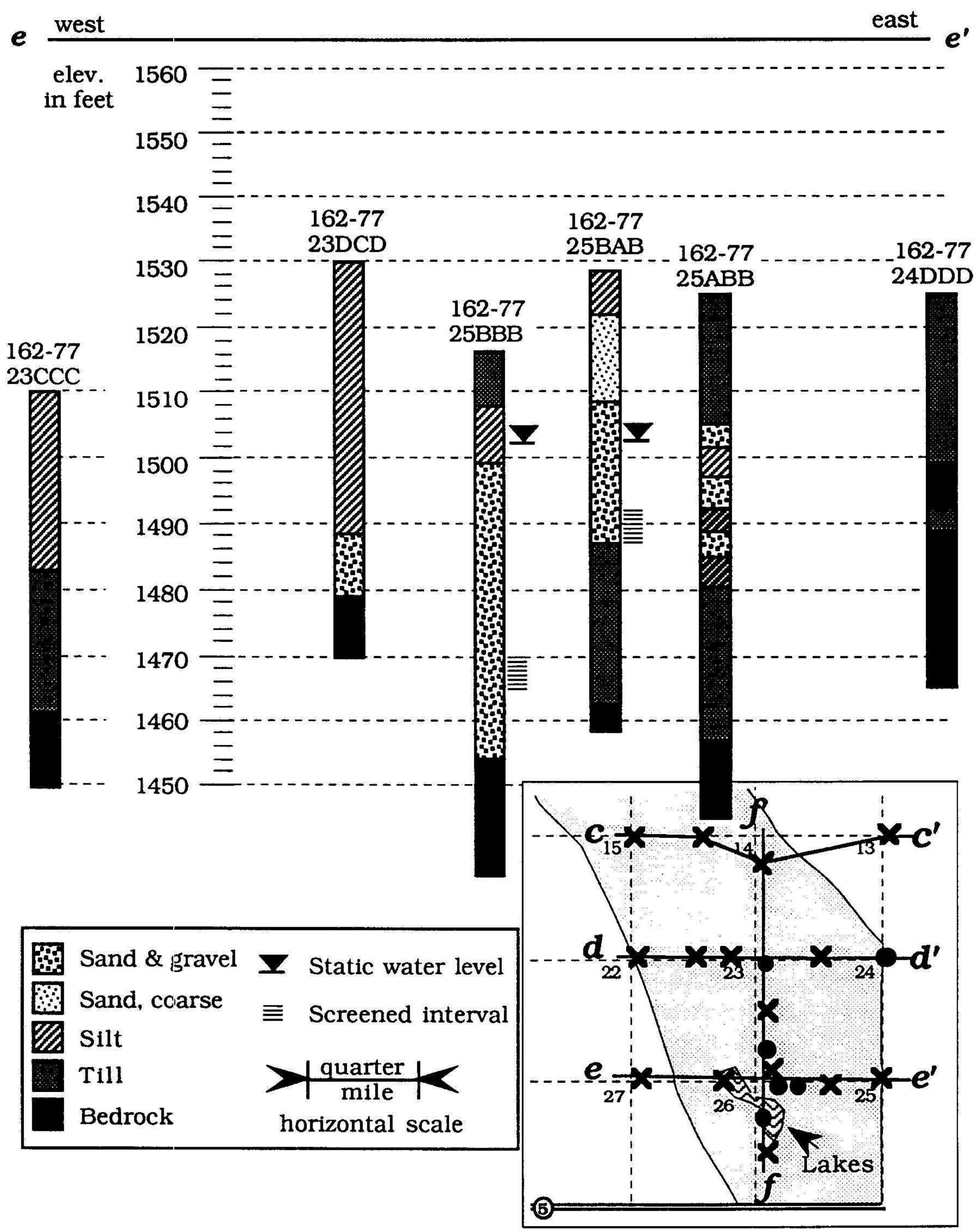

Figure 11 - **Geohydrologic section e - e' showing the southern part of the southern ice-contact deposit in the Souris area**

Geohydrologic section f - f' is a south to north section drawn through the southern ice-contact deposit, (fig. 12).

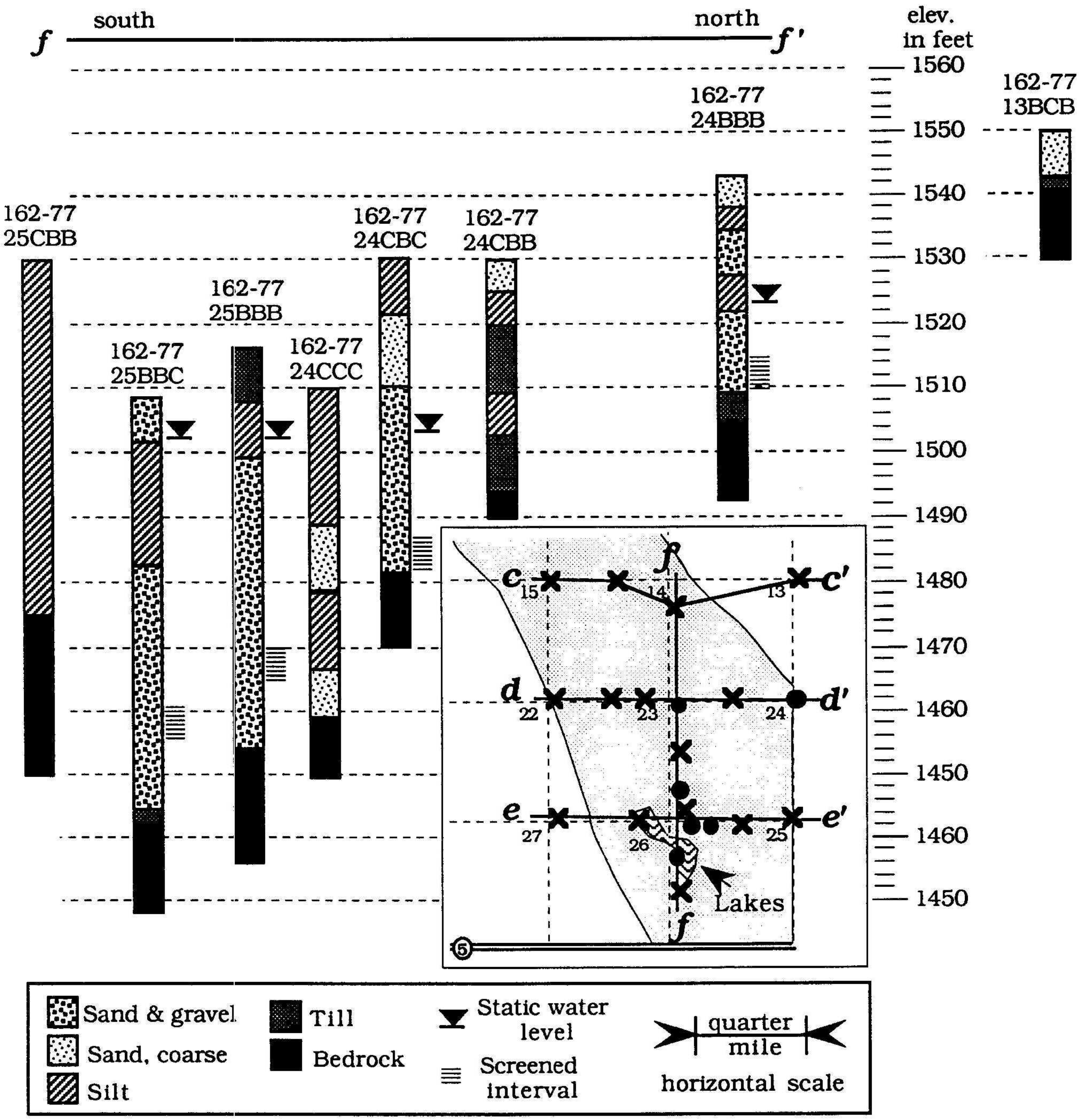

Figure 12 - Geohydrologic section f - f' showing a south to north view of the southern ice-contact deposit in the Souris area

Water levels were measured in the monitoring wells on 20-21 August 1991, 18 November 1991, 27 April 1992, and 17 November 1992. A hydrograph made from the four measurements indicates the relative water level elevations between the two ice-contact deposits (fig. 13).

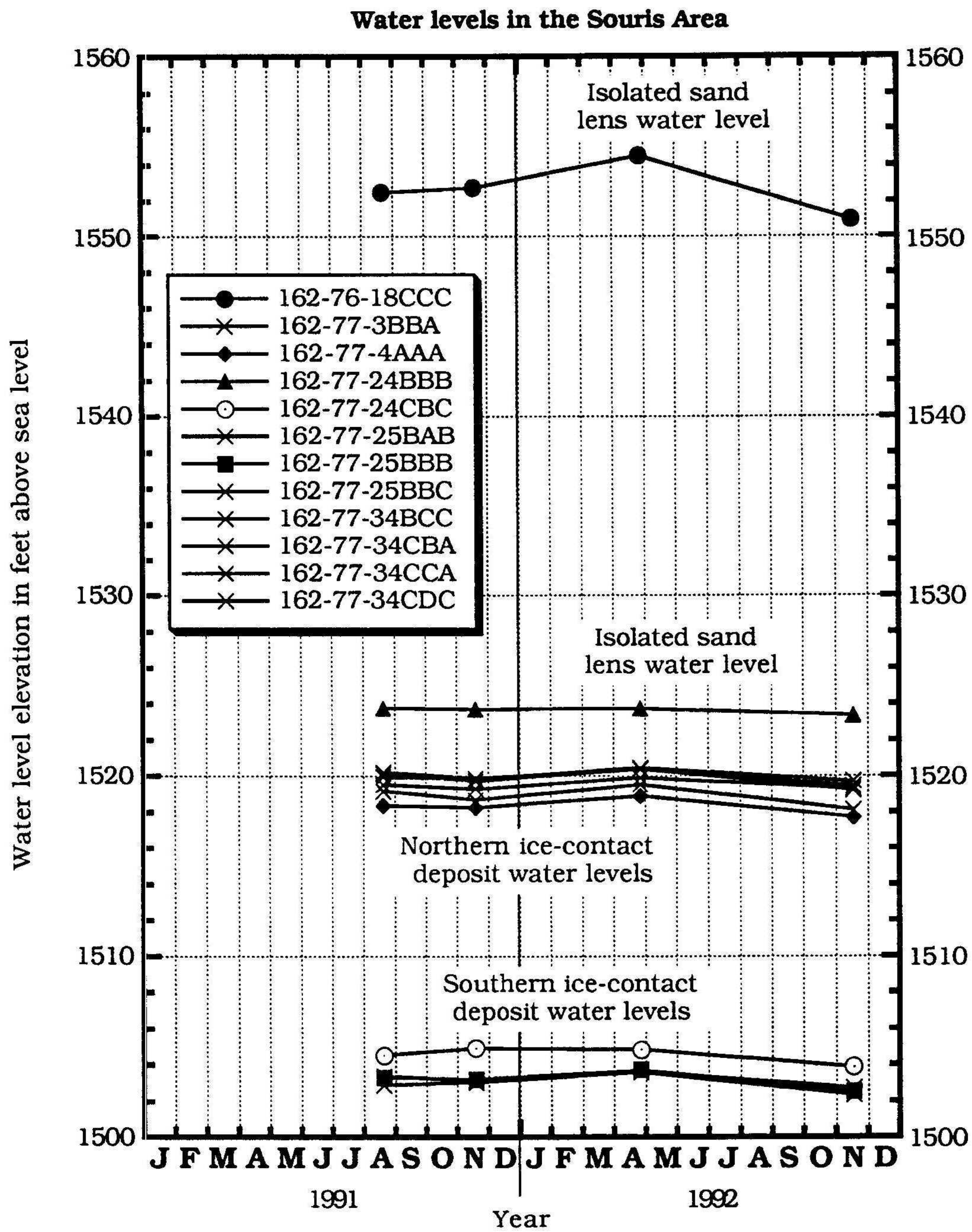

Figure 13 - **Hydrograph from monitoring wells in the Souris area**

A hydrograph of the six wells in the northern ice-contact deposit of the Souris area (fig. 14) indicates seasonal water level changes and water level changes in response to precipitation. The seasonal water level change indicated in the hydrograph seems to be about one foot, which is typical of an unstressed surficial aquifer. Precipitation measured at Bottineau in 1991 was 22 inches, 4.22 inches above average. Precipitation measured during the first half of 1992 was 4.09 inches, 4.13 inches below average. The water level decline of about one half foot between November 1991 and November 1992 may be indicative of the aquifer response to less infiltration from precipitation in 1992 than in 1991.

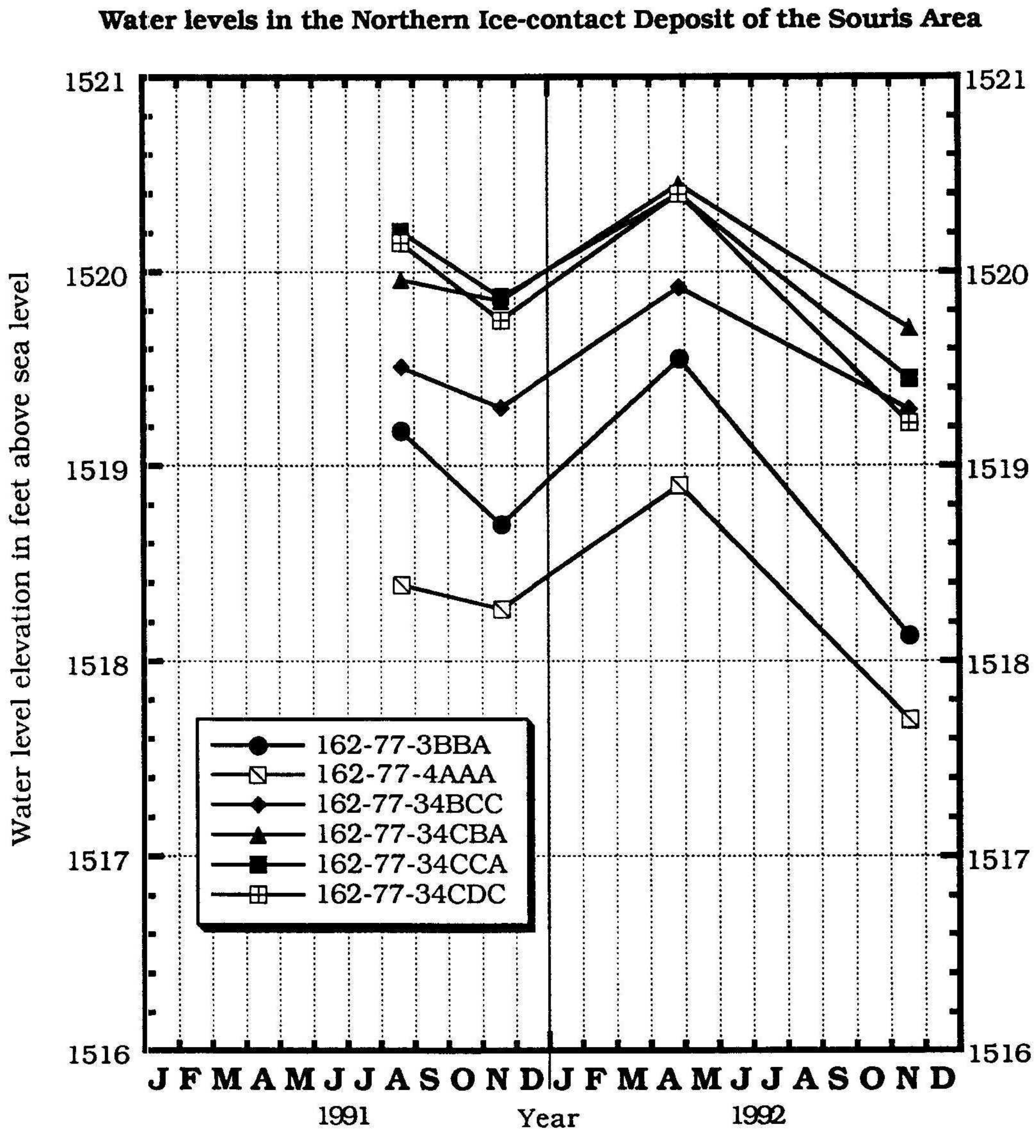

Figure 14 - **Hydrograph from wells in the northern Souris area**

A hydrograph of the four wells in the southern ice-contact deposit of the Souris area (fig. 15) indicates water level responses to seasonal changes and to precipitation similar to those in the northern ice-contact deposit.

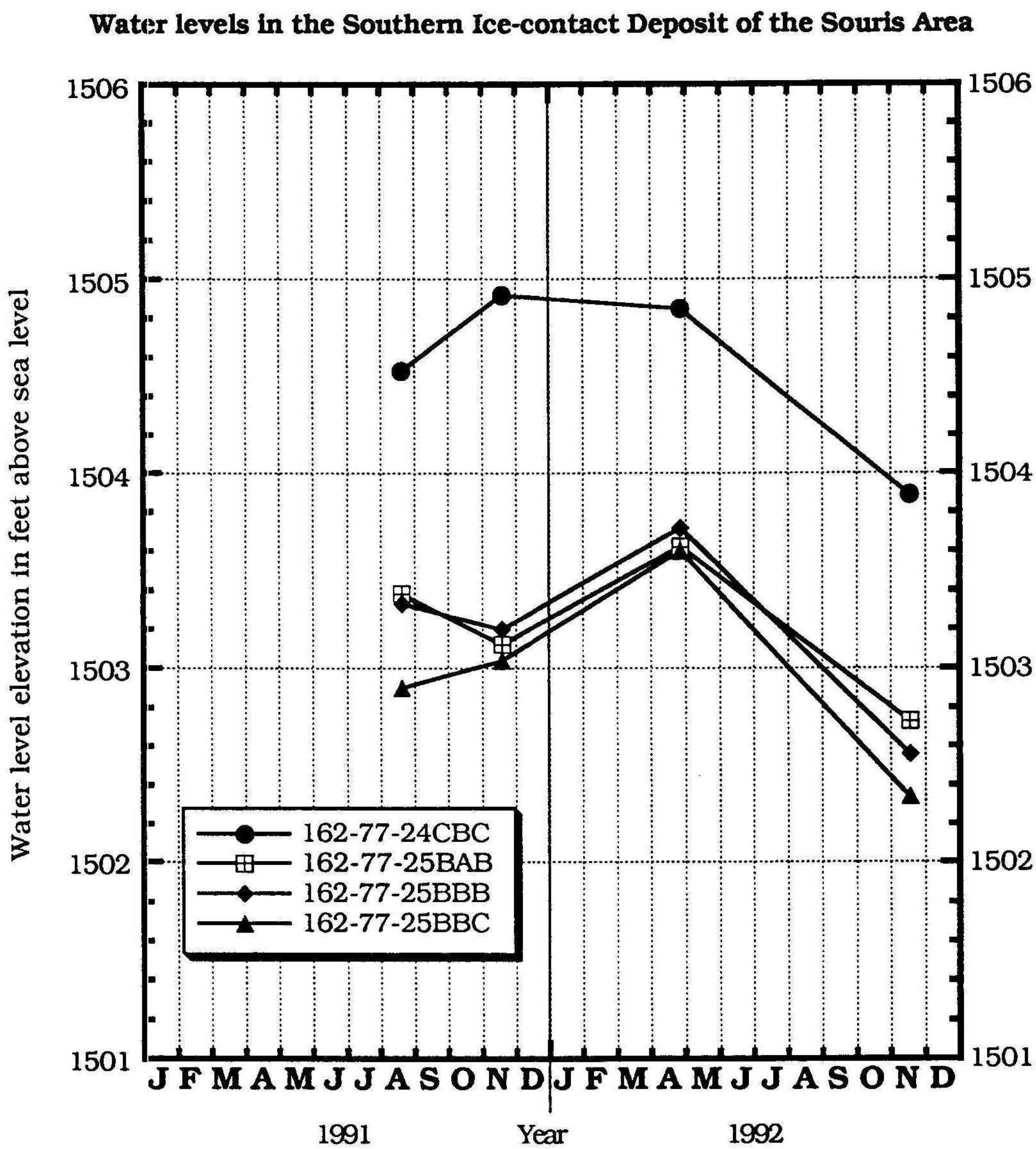

Figure 15 - **Hydrograph from wells in the southern Souris area**

Water-level elevations as measured in monitoring wells on 17 November 1992 indicate a water-table gradient of about four feet per mile to the southwest, in the direction of the Souris Lake plain (fig. 16). The slightly lower water level in the 163-77-34BCC well may be due to pumping in the northern portion of the ice-contact deposit by All Seasons Water Users and by the City of Souris.

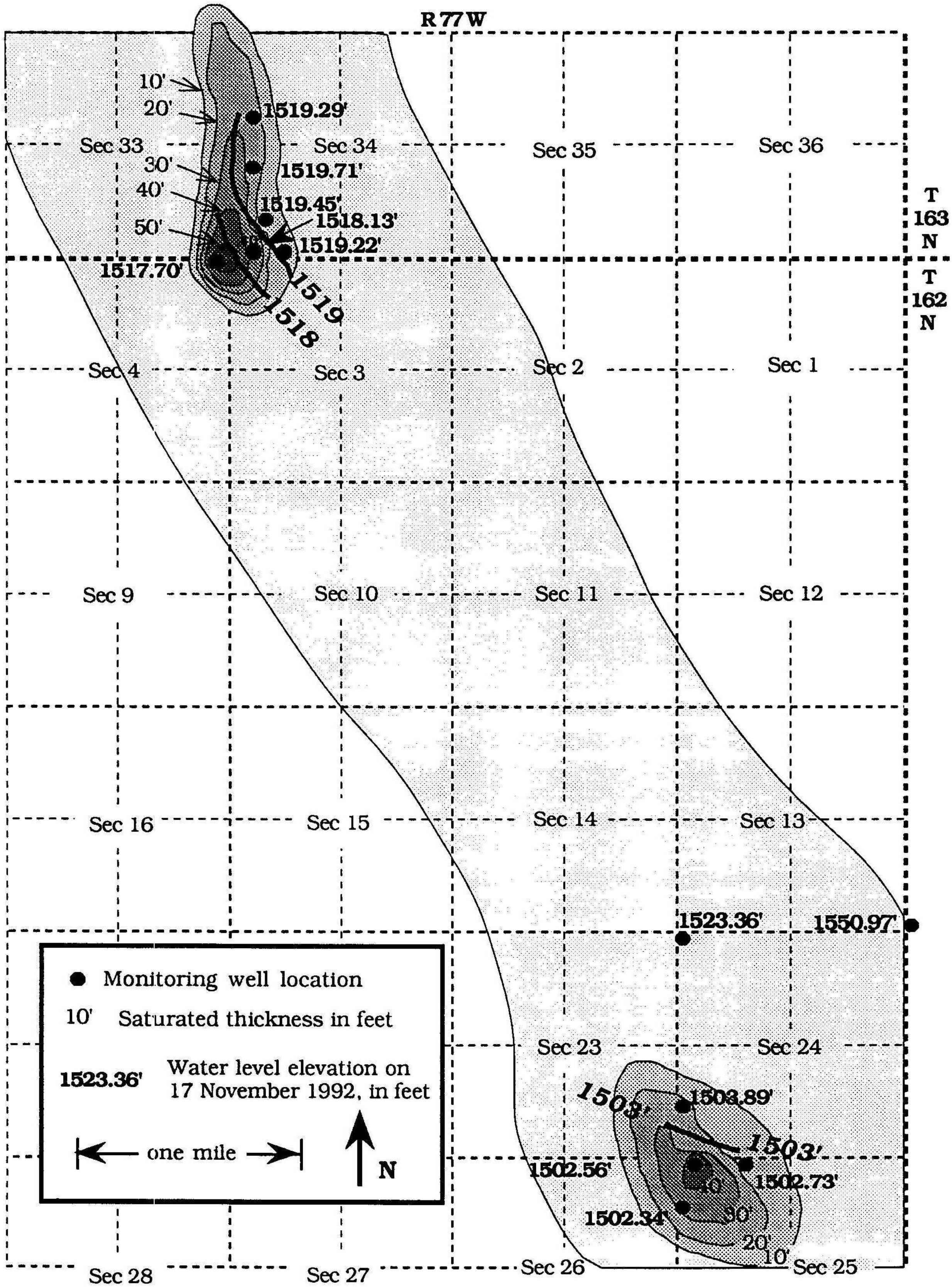

Figure 16 - Water-level elevations in the Souris area - 17 November 1992

Properties and Characteristics of Water

Thirteen water samples were collected and analyzed from the Souris area. The physical properties and mineral constituents of water reported include those that have a practical bearing on the value of the water for most purposes. The analyses include determinations of:

Specific conductance
pH
Temperature
Hardness
Sodium-adsorption ratio
Residual sodium carbonate
Percent sodium

and dissolved mineral concentrations of:

<u>CATIONS:</u>
Silica
Calcium
Magnesium
Potassium
Sodium
Iron
Manganese

<u>ANIONS:</u>
Fluoride
Bicarbonate
Carbonate
Sulfate
Chloride
Nitrate
Boron

and total dissolved solids.

Five samples were analyzed for 'trace' dissolved mineral concentrations of:

Selenium
Lead
Mercury
Arsenic
Lithium
Molybdenum
Strontium

The water samples obtained during the study were collected in polyethylene bottles, and the analyses were made by the North Dakota State Water Commission Laboratory in Bismarck.

Dissolved mineral constituents in water are usually reported in milligrams per liter (mg/l) or micrograms per liter (μg/l). A milligram per liter is one-thousandth (0.001) of a gram of dissolved material per liter of solution. A microgram per liter is one millionth (0.000001) of a gram of dissolved material per liter of solution. Milligrams per liter can be converted to grains per gallon by dividing milligrams per liter by 17.12 (Hem, 1970, p.81).

Equivalents per million (epm) is the unit chemical combining weight of a constituent in a million weights of water. These units are usually not reported, but are used to calculate percent sodium, the sodium-adsorption ratio, or to check the accuracy of a chemical analysis.

Specific conductance (micromhos per centimeter at 25^{o} Celsius): Specific conductance is a measure of the ability of water to conduct an electric current. Approximately 65 to 70 percent of the specific conductance (in micromohs) is an estimate of the amount of dissolved solids (in milligrams per liter) in water; however, this relation is not constant and will vary with the chemical composition of the water (Hem, 1970).

Hydrogen-ion concentration (pH): Hydrogen-ion concentration (activity) is expressed in terms of pH units. The values of pH often are used as one measure of the solvent capacity of water. The hydrogen-ion concentrations affect the corrosiveness of water. A pH of 7.0 indicates the water is neutral, neither acidic nor basic. Readings progressively lower than 7.0 denote increasing acidity, and those progressively higher than 7.0 denote increasing alkalinity.

Temperature: Temperature is important for its influence upon concentrations of dissolved gases and mineral matter in water. Water temperatures given in the tables are expressed in degrees Celsius (Centigrade). Degrees Celsius can be converted to degrees Fahrenheit using the following equation:

$$\text{Degrees Fahrenheit} = (9/5) \text{ degrees Celsius} + 32.$$

Hardness:: Calcium and magnesium are the principal cause of hardness. Hardness exhibits the characteristic of requiring greater quantities of soap to produce a lather as the hardness increases. Hard water also can contribute to the formation of scale in boilers, water heaters, radiators, and pipes, with a resultant decrease in the rate of water flow and/or heat transfer.

The hardness that is equivalent to the alkalinity is called carbonate hardness, and any excess is called noncarbonate hardness. The carbonate hardness is the quantity that will contribute scale on heating, and the noncarbonate hardness is the quantity of hardness that will remain after removal of the carbonate hardness. As a general reference, the U. S. Geological Survey often uses the following classification of water hardness (Hem, 1970).

Calcium and magnesium hardness, as CaCO3 (mg/l)

0-60	soft
61-120	moderately hard
121-180	hard
more than 180	very hard

Sodium-adsorption ratio (SAR): The term "sodium-adsorption ratio" was introduced by the U. S. Salinity Laboratory Staff (1954). Their experiments shown that the SAR relates to the degree water enters into cation-exchange reactions with soil. Sodium-adsorption ratio as expressed by the equation:

$$SAR = \frac{Na^{+}}{\sqrt{\frac{[Ca^{++}] + [Mg^{++}]}{2}}}$$

where the concentrations of the ions are expressed in milli-equivalents per liter. The U. S. Salinity Laboratory Staff (1954) divided water into 16 classes, depending upon the SAR and specific conductance. The classifications indicate the usefulness of water for irrigation of different crops on different types of soil.

Residual sodium carbonate (RSC): Residual sodium carbonate is twice the amount of carbonate or bicarbonate a water would contain after subtracting an amount equivalent to the calcium plus the magnesium, that is, RSC = $2(HCO_3 + CO_3 - CA - Mg)$, in milliequivalents per liter.

Percent sodium: The percent sodium is the percentage of sodium to all cations, with the cations in milliequivalents per liter. The displacement of calcium and magnesium by sodium in soils is slight unless the percent sodium is considerably higher than 50.

Silica (SiO_2): Weathering processes dissolve silica from practically all rocks. Silica affects the usefulness of water because it can contribute to the formation of scale in pipes, water heaters, and boilers in the presence of calcium and magnesium.

Calcium and Magnesium (Ca and Mg): Limestone and similar rocks are the principal source of calcium and magnesium in natural water. Calcium and magnesium cause water hardness and, with anions, can form scale on utensils and in water heaters, boilers, and pipes.

Sodium and Potassium (Na and K): Sodium and potassium are present in many rocks. Sodium dissolves readily and when brought into solution it tends to remain in solution. Potassium is dissolved with greater difficulty and exhibits a stronger tendency to be reincorporated into solid weathering products, especially clay minerals. In most natural water, the concentration of potassium is much lower than the concentration of sodium. Water that contains a large proportion of sodium salts may be unsatisfactory for irrigation on certain types of poorly drained soils. The presence of several hundred milligrams per liter of sodium in water can make it unsuitable for use in sodium-restricted diets (North Dakota State Department of Health, 1962).

Iron (Fe): Iron is a widespread constituent in rocks and is easily leached by ground water under reducing conditions or in acidic water. Water containing more than 300 μg/l of iron, after exposure to air, may become discolored. Reddish-brown stains on porcelain or enamelware and fixtures and on fabrics washed in the water result from the iron.

Manganese (Mn): Manganese in concentrations as low as 200 µg/l may cause a dark-brown or black stain on fabrics and porcelain fixtures. Ground water that contains high concentrations of iron may also have considerable amounts of manganese.

Fluoride (F): Fluoride in the ground water probably is derived from solution of fluorite, apatite, and hornblende minerals. High fluoride content (depending on annual average maximum daily air temperature) may cause mottling of tooth enamel in children's teeth during calcification.

Bicarbonate and Carbonate (HCO_3 and CO_3): Bicarbonate and carbonate ions are the major cause of alkalinity in most water. The significance of alkalinity to the domestic, agricultural, and industrial user is usually dependent upon the nature of the cations (Ca, Mg, Na, and K) associated with it. However, moderate amounts of alkalinity do not adversely affect most uses. Alkalinity can be calculated from the analyses by using the formula:

$$\text{Alkalinity (as } CaCO_3) = 0.82\ (HCO_3) + 1.67\ (CO_3)$$

Sulfate (SO_4): Metallic sulfide minerals may be converted to sulfates upon weathering or with bacterial action. Sulfate also may be dissolved from beds of gypsum and deposits of sodium sulfate and other sulfosalts.

Chloride (Cl): Chloride is present in all natural waters, but the concentrations usually are low. Important sources of chloride are sedimentary rocks that were deposited under marine conditions. Chloride concentrations of 400 mg/l impart a noticeable salty taste for most people.

Nitrate (NO_3): The occurrence of high nitrate concentrations is shallow ground water has been attributed to leaching in feedlots or to fertilizer from irrigated fields where nitrogen compounds have been applied. High nitrate content is undesirable in drinking water because of its bitter taste and it has been reported to cause methemoglobinemia (blue babies) in infants (Comly, 1945).

Boron (B): Boron is a constituent of the mineral tourmaline and may be present in biotite and amphiboles. In small quantities, boron is essential for plant growth.

Excessive concentrations in soil and in irrigation water are harmful for some plants.

(Total) dissolved solids: (TDS): The concentration of total dissolved solids (TDS) is calculated from the weight of residue on evaporation at 180° Celsius from a known volume of water.

Trace elements: The metallic elements selenium, lead, mercury, arsenic, lithium, molybdenum, and strontium may be found in low ("trace") concentrations in water supplies. Maximum allowable concentrations for drinking water have been established for the elements selenium, lead, mercury and arsenic.

Water Quality in the Ice-contact Deposits

Water samples were collected from the 12 monitoring wells completed in ice-contact deposits in the Souris area and from a lake at 162-77-26AAA, downgradient of the southern ice-contact deposit. The samples were collected on 20-21 August 1991 and on 8 October 1991.

The water is generally a calcium-bicarbonate or sodium-bicarbonate type. Total dissolved solids concentrations ranged between 381 mg/l and 1,700 mg/l, with a median of 649 mg/l, that is one half the samples had concentrations higher than 649 mg/l and one half the samples had concentrations lower than 649 mg/l. Hardness ranged between 112 mg/l (as $CaCO_3$) and 519 mg/l, with a median of 289 mg/l. Iron concentration ranged between 0.01 mg/l and 0.49 mg/l, with a median of 0.07 mg/l.

The quality of the water from three of the samples analyzed is not thought to be typical of the water to be found in the two ice-contact deposits. The well at 162-76-18CCC is completed in what is probably an isolated pocket of gravel. The sample from 162-76-18CCC has a TDS of 1,490 mg/l. The well at 162-77-25BBC is downgradient of the two lakes at the south end of the southern outwash area and has a TDS of 1,420 mg/l. Sample 162-77-26AAA is from one of the two lakes and has a TDS of 1,290 mg/l. The lakes probably have elevated dissolved solids concentrations because of evaporation from the lake surface.

Results of the analyses are summarized in table 1. Included under the column labeled "Standard" are the Environmental Protection Agency's "non-mandatory guidelines" which are concentration limits recommended for drinking and other domestic water use (U. S. Environmental Protection Agency, 1973b). The guidelines shown for selenium, lead, mercury, and arsenic are maximum permissible limits. The permissible limits for selenium, lead, mercury, and arsenic were not exceeded in the five samples analyzed for those elements. Limits have not been set for lithium, molybdenum, and strontium. Concentrations of lithium, molybdemun, and strontium determined for the samples from the Souris area seem to be in the normal range of North Dakota ground water samples.

Table 1. Water quality analyses in the Souris area

	Standard	162-76-18CCC	162-77-3BBA	162-77-4AAA	162-77-24BBB	162-77-24CBC	162-77-25BAB	162-77-25BBB	162-77-25BBC	162-77-26AAA	163-77-34BCC	163-77-34CBA	163-77-34CCA	163-77-34CDC
Date sampled		Aug 91	Aug 91	Aug 91	Aug 91	Aug 91	Aug 91	Aug 91	Aug 91	Oct 91	Aug 91	Aug 91	Aug 91	Aug 91
Screen depth (ft)		31'-36'	26'-51'	58'-63'	29'-34'	44'-49'	37'-42'	47'-52'	48'-53'	Lake	44'-49'	42'-47'	26'-31'	44'-49'
Depth to water (ft)		4.01'	13.22'	7.64'	19.49'	26.56'	25.16'	13.07'	5.29'	1'	23.26'	20.59'	7.14'	19.74'
Cond. (µmhos)		2200	907	826	682	759	963	615	2180	0	2290	1190	906	1480
pH		7.9	7.66	7.59	7.9	7.56		7.14	7.97	8.7	7.45	7.83	7.58	7.68
Temp. (^{o}C)		15	11	10	9	9	10	10	9	9	11	10	10	10
Hardness (CaCO3)		112.11	231.73	244.24	297.80	337.34	342.84	289.29	383.38	282.28	518.52	209.71	318.32	238.24
SAR		20	3.2	2.4	0.8	0.9	1.9	0.5	8.7	9.6	6.7	6.0	1.9	7.0
RSC		10	2	1	0	0	0	0	13	11	0	4	0	5
% Sodium		90	50	43	18	19	33	13	67	70	59	67	35	69
Silica (mg/l)		27	25	29	25	26	25	23	30	34	21	27	27	26
Calcium (mg/l)		30	55	60	78	84	78	68	38	19	130	51	78	56
Magnesium (mg/l)	125	9.0	23	23	25	31	36	29	70	57	47	20	30	24
Potassium (mg/l)		6.1	3.1	3.6	4.4	3.1	7.7	3.0	28	43	6.6	4.4	4.9	5.1
Sodium (mg/l)		480	110	85	30	37	79	21	390	370	350	200	80	250
Iron (mg/l)	0.3	0.07	0.09	0.07	0.02	0.08	0.01	0.07	0.14	0.03	0.05	0.01	0.49	0.02
Manganese (mg/l)	0.05	0.13	0.28	0.15	0.01	0.23	0.04	0.28	0.03	0.02	0.39	0.19	0.21	0.07
Fluoride (mg/l)	1.5	0.3	0.2	0.2	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.1	0.2
Bicarbonate (mg/l)		763	379	348	344	418	322	326	1290	950	444	474	408	570
Carbonate (mg/l)		0	0	0	0	0	0	0	0	45	0	0	0	0
Sulfate (mg/l)	250	540	170	160	59	84	240	72	200	210	890	280	170	340
Chloride (mg/l)	250	19	13	12	2.9	6.8	8.5	2.4	28	40	36	11	8	14
Nitrate (mg/l)	45	3.2	1	0.3	59	1	16	1	1	0.9	1.9	0.8	1	1
Boron (mg/l)	1	0.61	0.14	0.12	0.05	0.05	0.1	0.08	0.49	0.5	0.28	0.23	0.10	0.27
TDS (mg/l)	500	1490	589	542	456	475	662	374	1430	1320	1700	809	599	988
Selenium (µg/l)	10		1					1	1	1		1		
Lead (µg/l)	50		0					0	0	0		0		
Mercury (µg/l)	2		0					0	0	0		0		
Arsenic (µg/l)	50		1					1	2	1		3		
Lithium (µg/l)			40					30	150	30		60		
Molybdenum (µg/l)			1					0	0	0		0		
Strontium (µg/l)			320					230	470	230		340		

LANDA STUDY AREA

Geologic Setting

The Landa area is located near Westhope, 14 miles west of the Souris area (fig. 17). The Landa area was selected along the projection of a buried glacial channel, the Medora-Waskada channel, which has been mapped in the Waskada oil field located between three and nine miles north of the Canada - U. S. border.

The Landa area was once inundated by glacial Lake Souris. Land surface is generally covered with wave washed glacial till. A surficial channel, about 30 feet lower than the surrounding topography, traverses the area. The channel was likely formed as a temporary, presumably late Pleistocene, diversion of the Souris River. About eight feet of sand and gravel occur immediately below land surface along the channel.

Geometry of the Buried Valley Deposit

Thirteen test holes were drilled in the Landa area. Test drilling penetrated a buried valley near the Canada - U. S. border and also four miles farther south. In both cases the buried valley coincides with the surficial channel. The two southern locations where the buried channel was encountered, 163-79-17DCC and 163-79-20BAB, are also along the southern projection of the Medora-Waskada channel into the U. S. near the Canada-U. S. border.

The sand and gravel encountered in the buried valley deposit is about 1/4 gravel and 3/4 sand. The composition of the sand and gravel is shale, sandstone (probably of Fox Hills or Hell Creek origin), lignite, and quartz. The composition of the sand and gravel in the deposit 1/4 mile south of the Canada-U. S. border was similar to that found four miles farther south. The thickest section of buried sand and gravel was found in the 163-79-20BAB test hole where the sand and gravel was encountered between 101 and 217 feet below land surface.

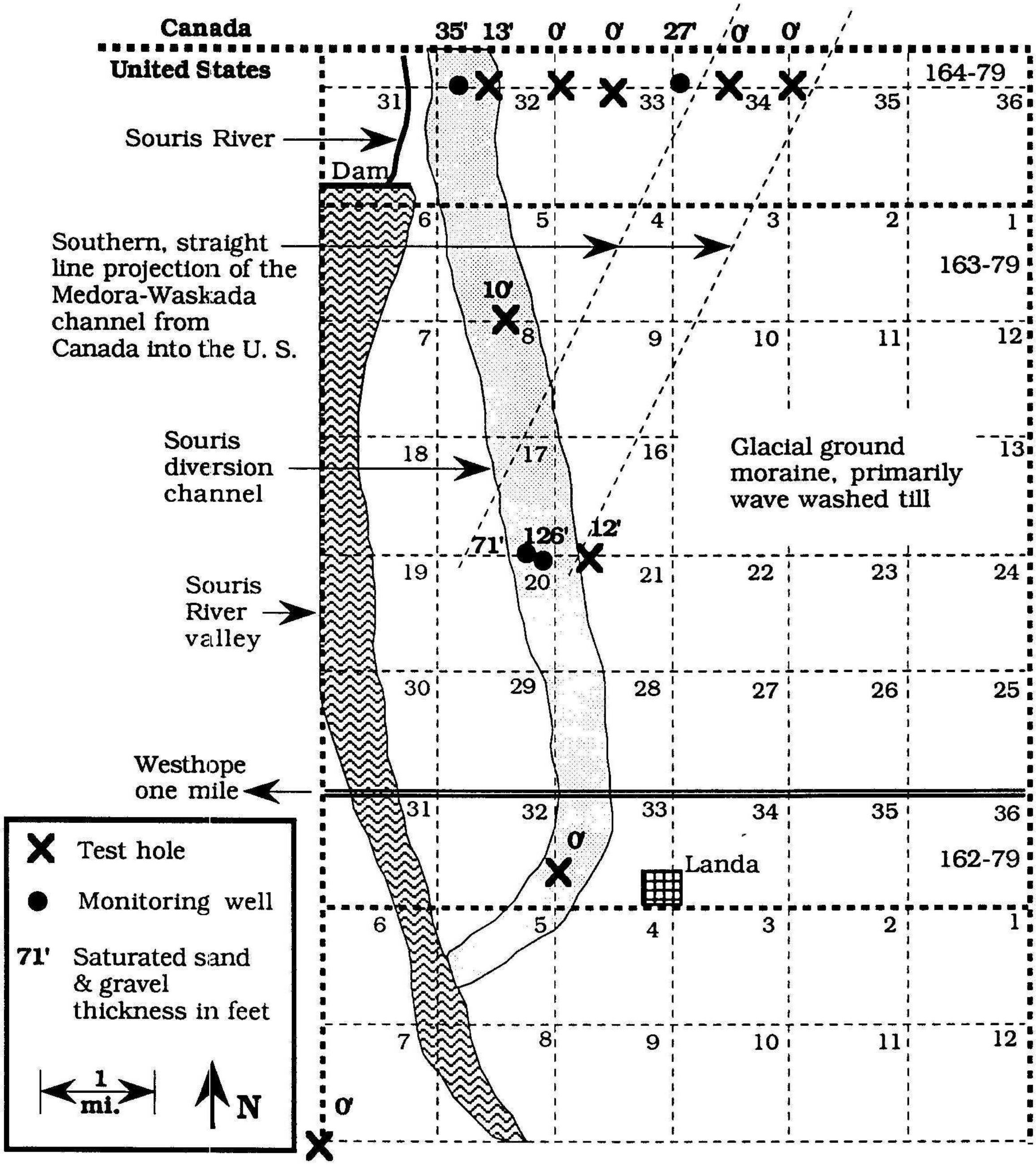

Figure 17 - Geology of the Landa area with test hole and well locations

The buried valley deposit 1/4 mile south of the Canada - U. S. border and the buried valley deposit four miles farther south are probably part of the same channel; however, added test drilling would be necessary to determine the point conclusively. A test hole drilled between the two areas and along the surficial channel failed to penetrate the buried valley. The surficial diversion channel may have formed by following a topographically low-lying, partially sediment filled, abandoned valley. Alternatively, the buried deposits may not be part of the same valley. Further investigation of the subsurface glacial geology of the area is beyond the scope of the present investigation.

Geohydrology of the Buried Valley Deposit

Three geohydrologic sections, g - g' through i - i', were constructed using information gathered from the test holes and monitoring wells installed in the Landa area. An index to the geohydrologic sections is shown in figure 18.

Geohydrologic section g - g' shows the lithology penetrated in the test holes drilled 1/4 mile south of the Canada - U. S. border (fig. 19). A buried channel deposit was found two miles west of the projected Medora-Waskada channel. The buried channel was filled mostly with till and silty clay.

The sand penetrated in test hole 164-79-27CCC, 1.5 miles east of the buried channel and shown on section g - g', is apparently an isolated sand lens. The sand in 164-79-27CCC is composed mostly of Canadian shield silicates. Sand and gravel from the buried channel deposit has more shale, lignite and sandstone. A well installed in the sand at 164-79-27CCC pumped dry during development and was slow to recover. The water level in the sand is 55 feet higher than the water level in the buried channel.

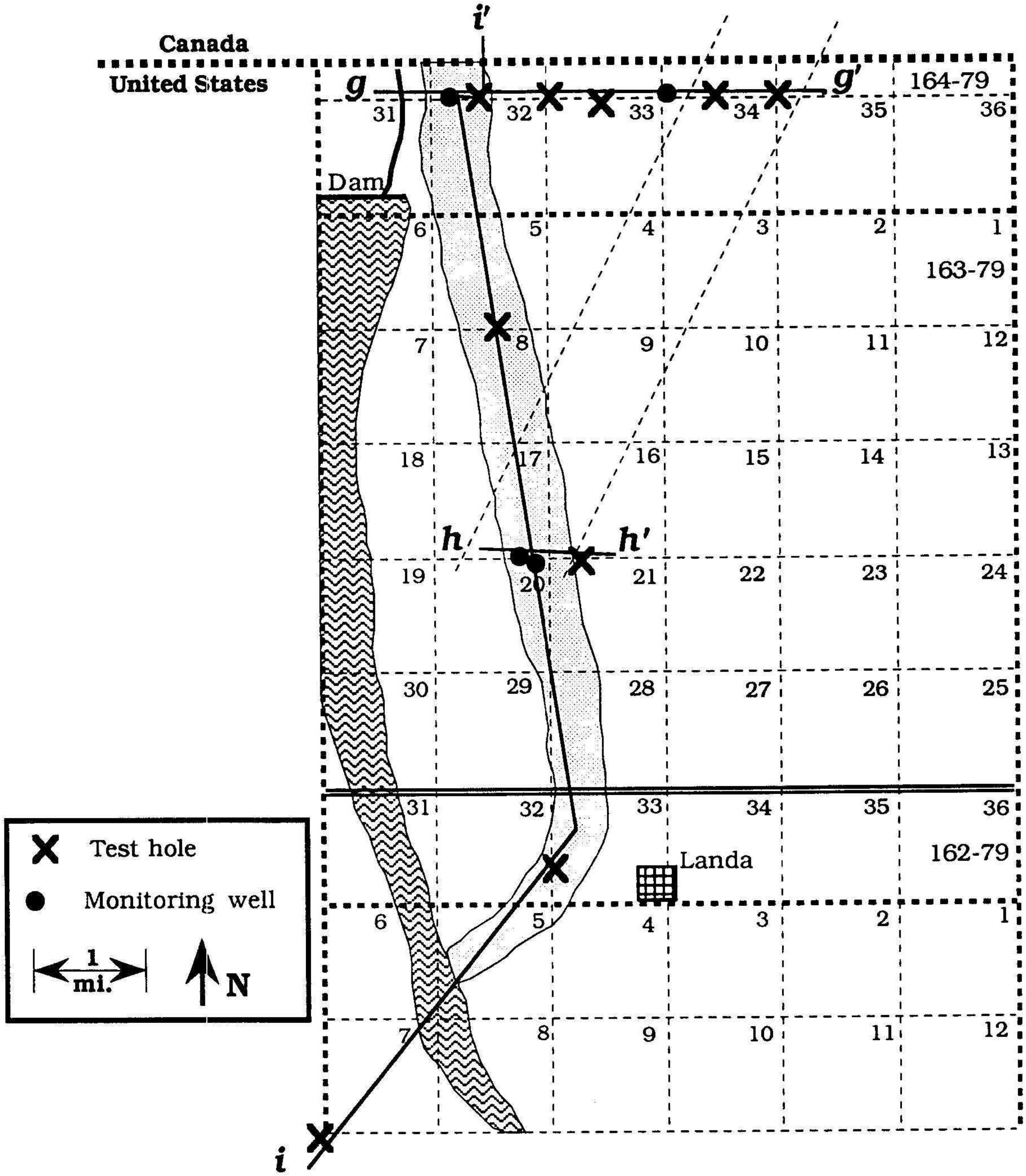

Figure 18 - Location of geohydrologic sections in Landa area

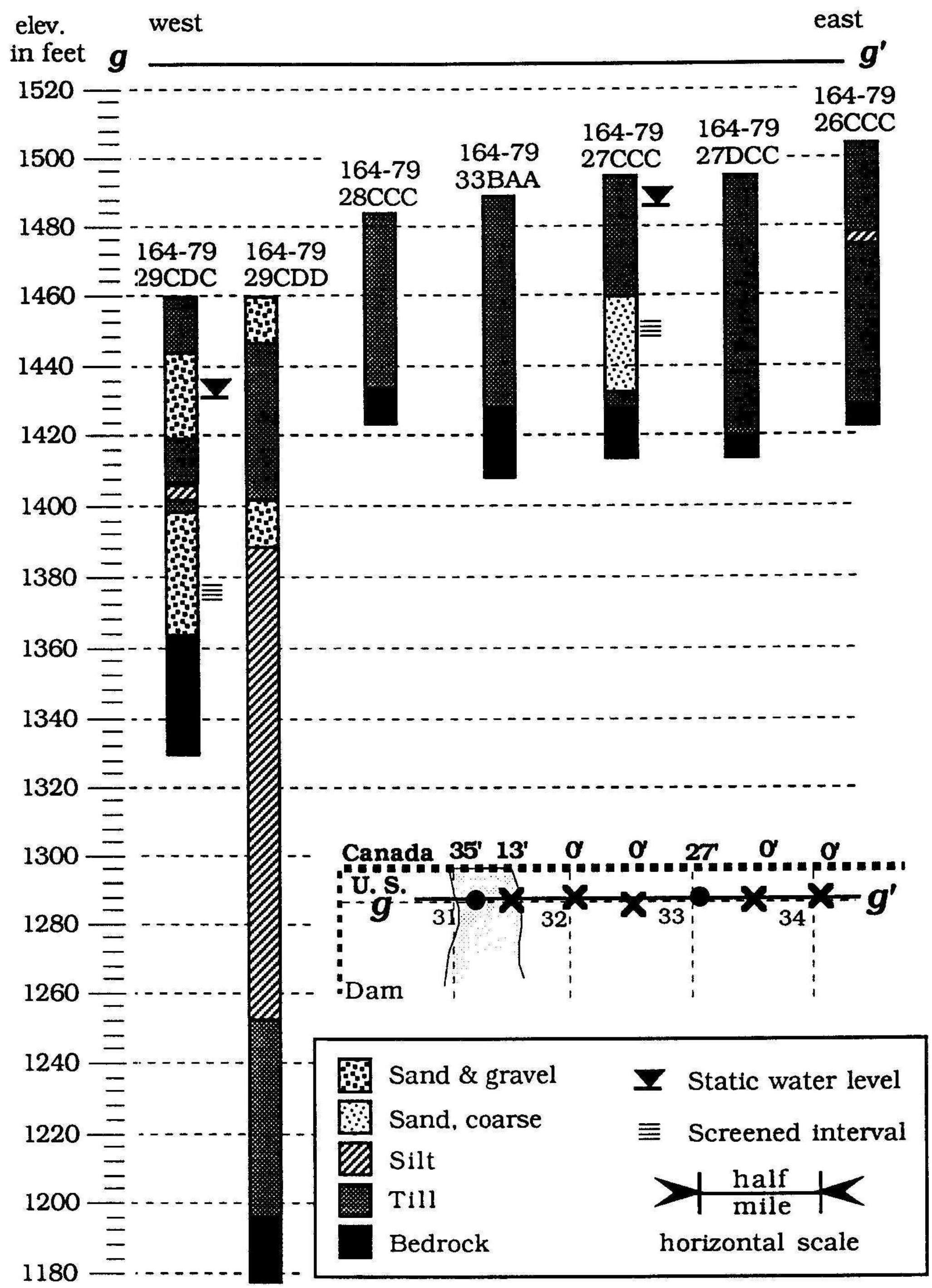

Figure 19 - Geohydrologic section g - g' showing the buried channel deposit in the northern Landa area

Geohydrologic section h - h' shows the lithology penetrated in test holes drilled four miles south of section g - g' (fig. 20). A buried channel deposit of sand and gravel (primarily sand) was penetrated. The gravel is composed of granules of Pierre shale, lignite, and sandstone of the Fox Hills and Hell Creek Formations as well as lesser amounts of Canadian shield silicates. The composition of the sand and gravel found along section h - h' is similar to the composition of the sand and gravel found in 164-79-29CDC, 1/4 mile south of the Canada - U. S. border.

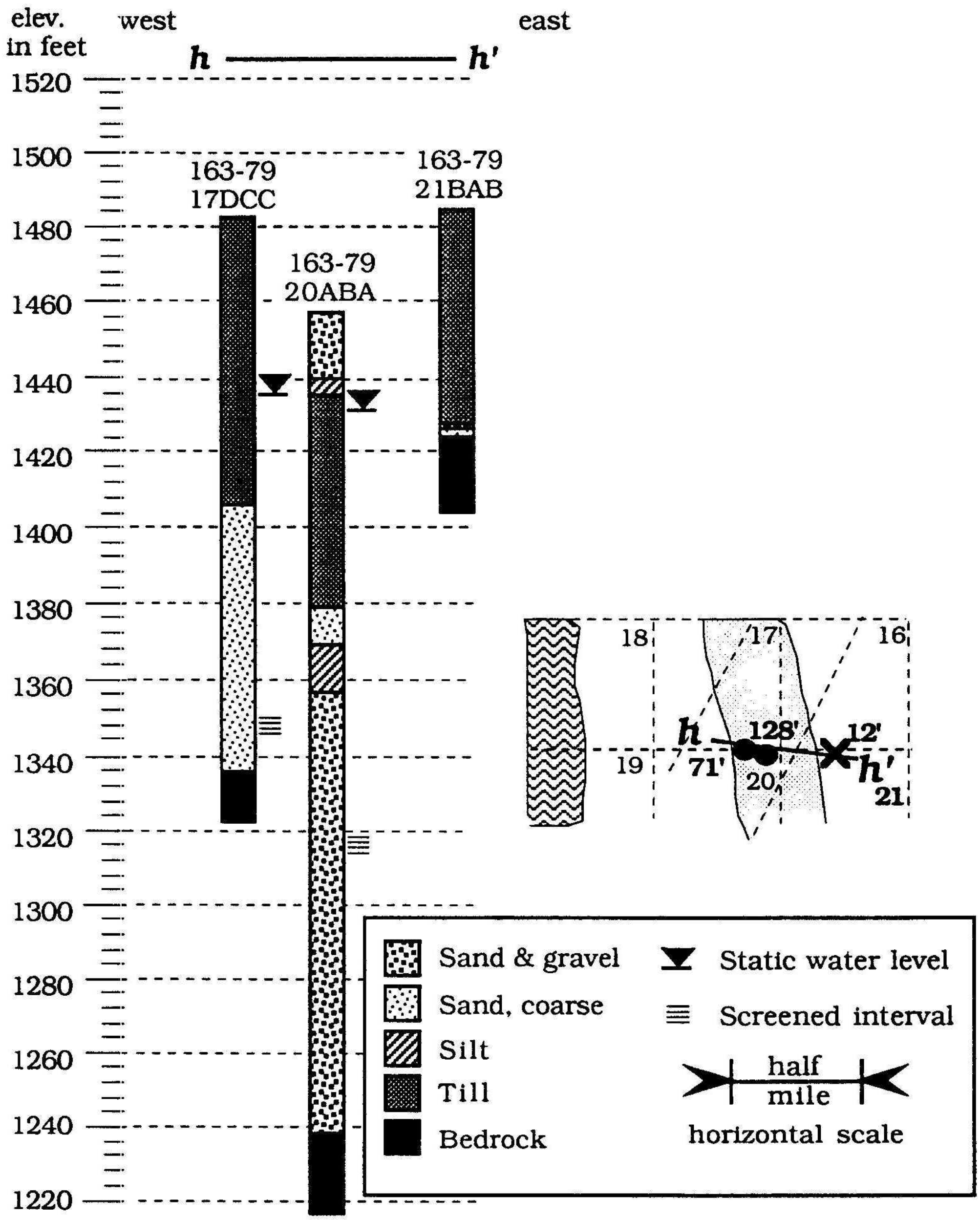

Figure 20 - **Geohydrologic section h - h' showing the buried channel deposit in the central Landa area**

Geohydrologic section i - i' is oriented south to north and follows the surficial channel (fig. 21). A comparison can be made of the lithology and water levels in the buried channel deposit near the Canada U. S. border and four miles farther south.

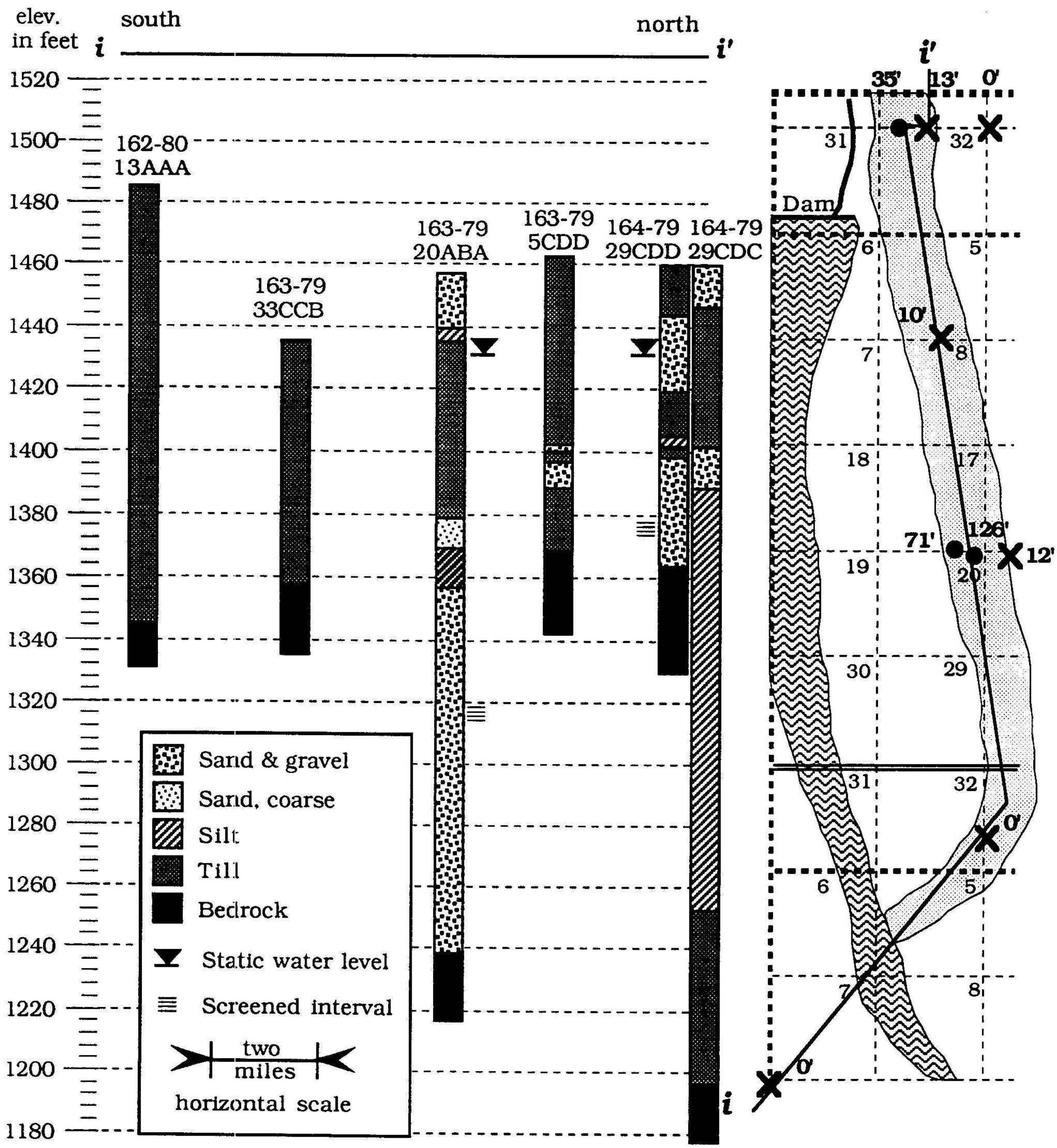

Figure 21 - **Geohydrologic section i - i' comparing the buried channel deposits found at two locations four miles apart**

Water levels were measured in the four monitoring wells on 21 August 1991, 18 November 1991, 27 April 1992, and 17 November 1992. A hydrograph made from the four measurements indicates the relative water level elevation in the buried valley deposit and in the isolated sand lens (fig. 22). Well surface elevations were not surveyed, but were instead estimated from topographic maps (due to the costs involved) and may be in error as much as five feet.

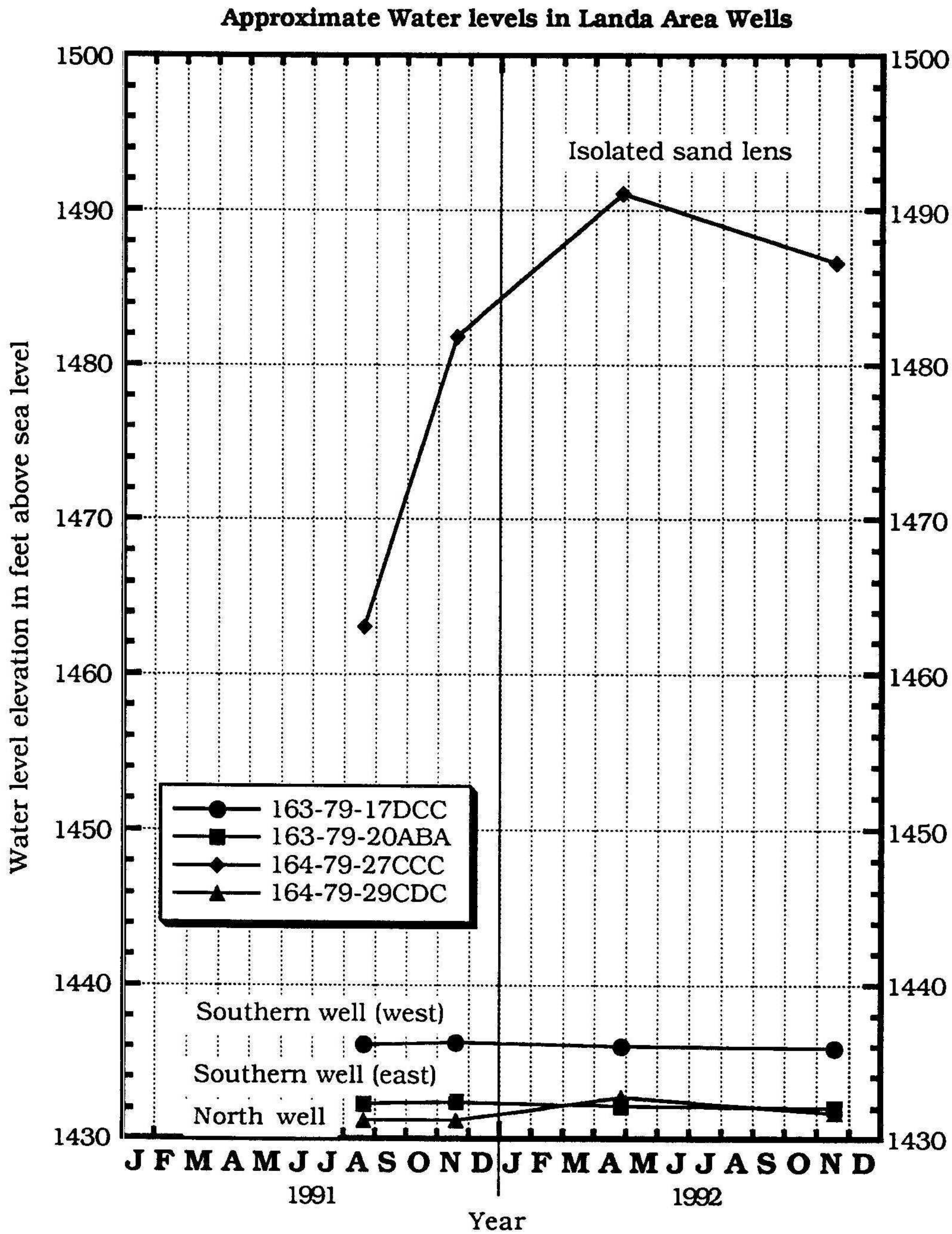

Figure 22 - **Hydrograph from wells in the Landa area**

Eliminating the graph of the well completed in the isolated sand lens enables the relative water level changes of the three wells completed in the buried valley deposit to be compared more closely (fig. 23). Because the well top elevations are based on topographic map estimates, the water level elevations in the three wells are all within the margin of error of one another.

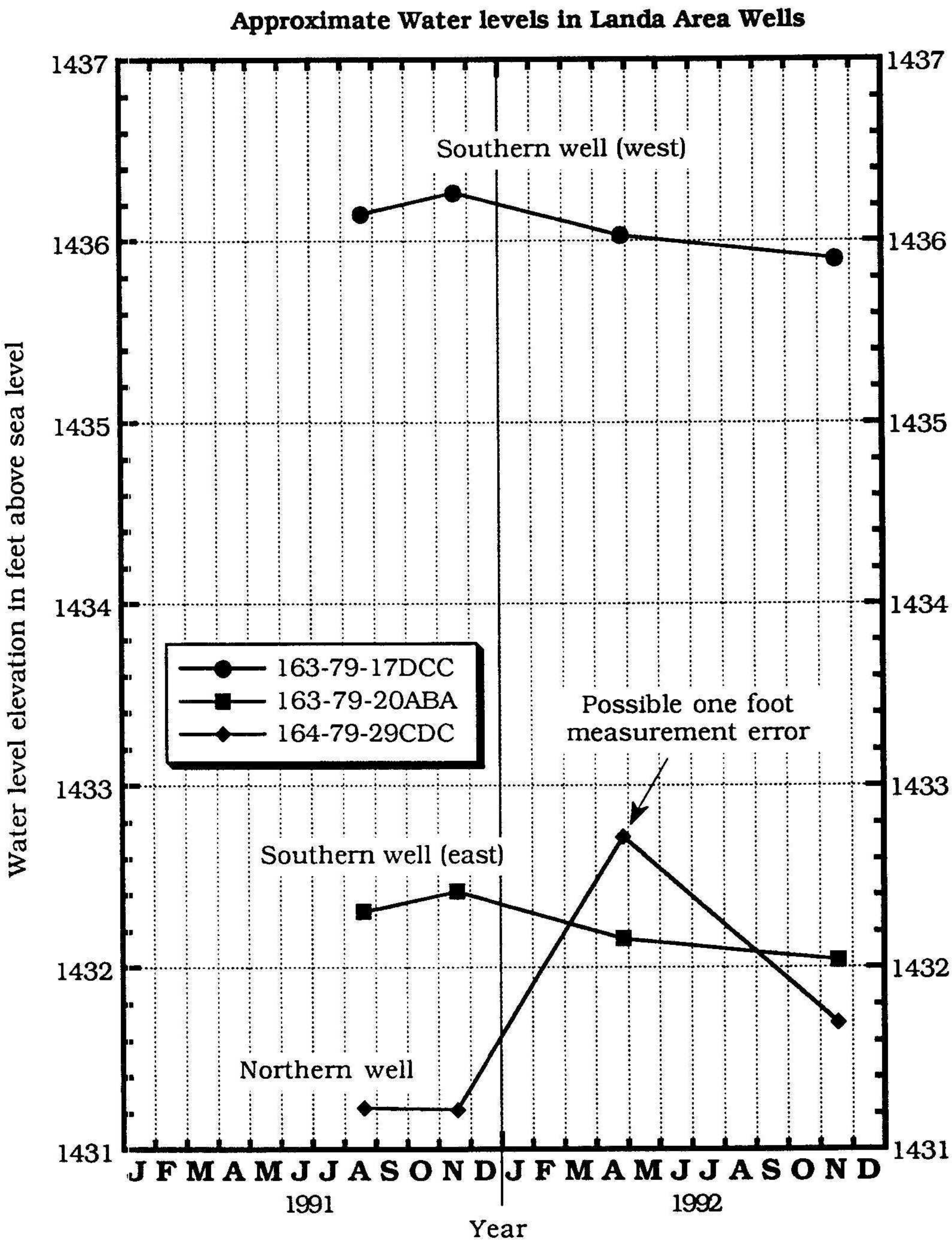

Figure 23 - Hydrograph from the buried valley wells in the Landa area

Approximate water level elevations in the Landa area are shown in figure 24. The water level in buried channel aquifer in the Landa area, about 1433 feet above sea level, is about 17 feet above the spillway of the dam on the Souris River, which is at 1416 feet above sea level.

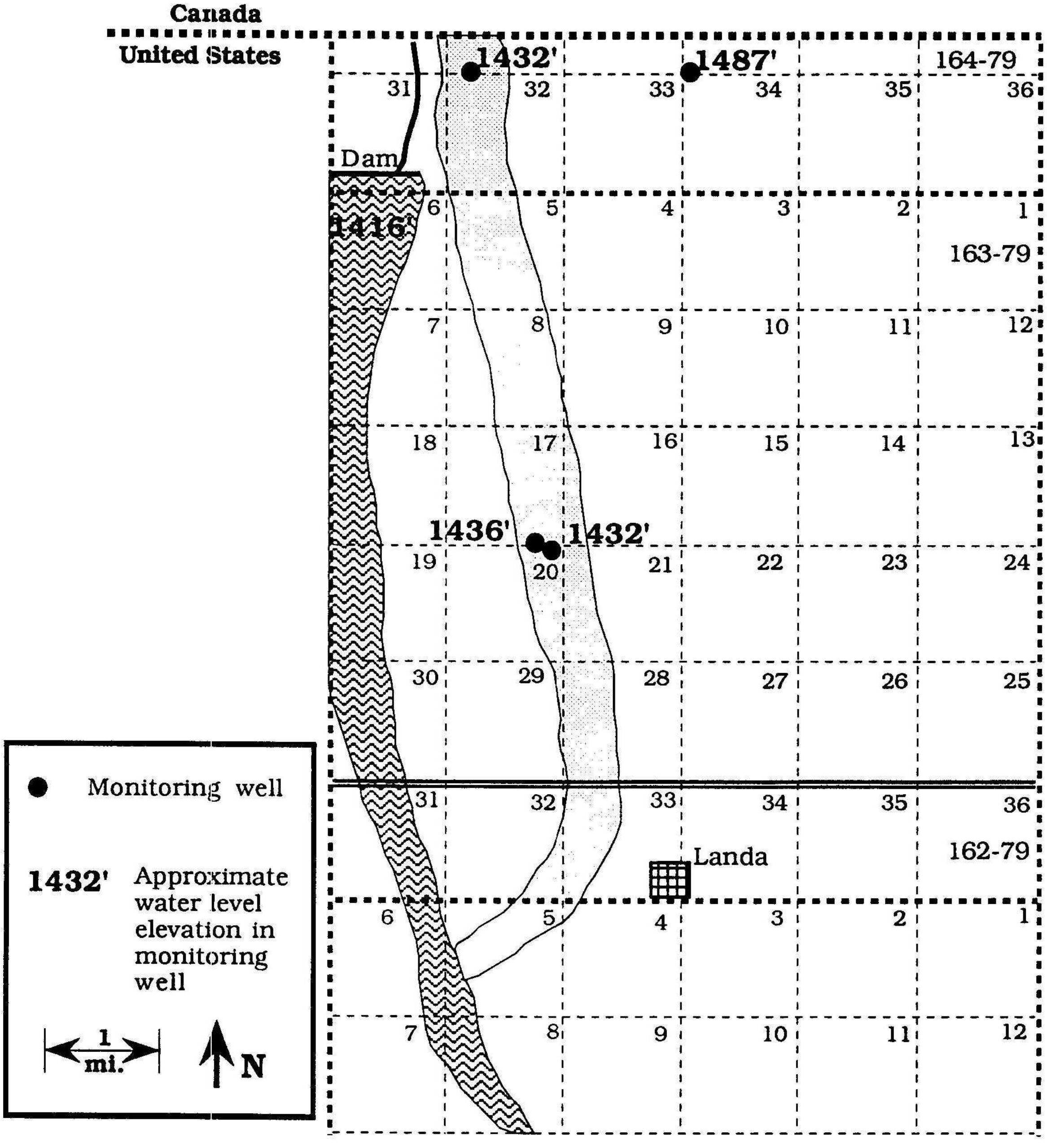

Figure 24 - Approximate water-level elevations in the Landa area, 7 November 1992

Water quality in the Buried Valley Deposit

Water samples were collected from the four monitoring wells and from one shallow private well in the Landa area on 20-21 August 1991. The water samples were analyzed for dissolved chemicals. The analyses are summarized in table 2. Water samples obtained during the study were collected in polyethylene bottles, and the analyses were made by the North Dakota State Water Commission Laboratory.

Table 2. Water quality analyses in of the Landa area

	Standard	163-79-17DCC *	163-79-17DDC	163-79-20ABA *	163-79-27CCC	163-79-29CDC *
Date sampled		Aug 91	Aug 91	Aug 91	Aug 91	Aug 91
Screen depth (ft)		132-137	9'-12'	138-143	42'-47'	82'-87'
Depth to water (ft)		46.85'	8.15'	24.69'	31.96'	28.77'
Cond. (μmhos)		2310	547	2080	2760	3070
pH	6.8 - 8.5	7.71	7.65	7.91	7.68	7.45
Temp. (^{o}C)		10	11	10	9	9
Hardness ($CaCO_3$)		691.69	258.26	514.01	572.57	1170.67
SAR		4.8	0.3	5.6	8.0	4.0
RSC		0	0	0	0	0
% Sodium		47	8	55	62	37
Silica (mg/l)		38	27	36	20	40
Calcium (mg/l)		160	64	120	150	340
Magnesium (mg/l)	125	71	24	52	48	78
Potassium (mg/l)		11	7.4	8.9	12	9.4
Sodium (mg/l)		290	10	290	440	320
Iron (mg/l)	0.3	0.79	0.03	0.03	0.05	0.11
Manganese (mg/l)	0.05	0.09	0.37	0.05	0.41	0.28
Fluoride (mg/l)	1.5	0.2	0.1	0.2	0.2	0.1
Bicarbonate (mg/l)		583	263	584	538	478
Carbonate (mg/l)		0	0	0	0	0
Sulfate (mg/l)	250	880	85	600	1100	1400
Chloride (mg/l)	250	18	8.2	76	14	67
Nitrate (mg/l)	45	1	1	0.3	0.3	1
Boron (mg/l)	1	0.59	0.02	0.51	0.71	0.32
TDS (mg/l)	500	1780	368	1500	2090	2660

* Analyses from wells completed in the Landa area buried channel

The well sampled at 163-79-17DDC is 12 feet deep and is completed in surficial sand and gravel found along the temporary diversion channel of the

Souris River. The private well was used as a source for make-up water in the drilling program and was sampled for that reason. Water from the shallow source is of good quality, but is limited in the quantity which can be pumped from an individual well.

The well sampled at 163-79-27CCC is probably completed in an isolated sand lens and therefore is not of significance in evaluating the water quality of the buried channel deposit in the Landa area.

The quality of the Landa area water, as determined from the three wells completed in the buried channel, is generally a sodium-sulfate type with secondary calcium bicarbonate. The total dissolved solids concentration in the three buried channel wells is 1500 mg/l, 1780 mg/l and 2660 mg/l. Hardness in the three buried channel wells is 514 mg/l (as $CaCO_3$), 691 mg/l and 1,171 mg/l. The iron concentration in the three buried channel wells is 0.03 mg/l, 0.11 mg/l and 0.79 mg/l.

The water in the Landa area buried channel is of a poor quality, or at least poorer than that found in the monitoring wells in the Souris area. The water is hard, high in sodium, high in manganese, and high in sulfate. Because of the relatively high concentration of dissolved minerals, the source was not investigated more thoroughly as a potential water supply.

ESTIMATING THE EFFECT OF GROUND-WATER WITHDRAWALS ON WATER LEVELS IN THE SOURIS AREA

A Theis analytical model was made to project the effect of withdrawing water from either of the two Souris area water sources. The following assumptions were made:

Aquifer transmissivity: 5,000 ft^2/day and 10,000 ft^2/day
(based on an average thickness of 30 feet and a hydraulic conductivity of either 166 feet/day or 333 feet/day)

Aquifer storage coefficient: 0.2 and 0.1

Impermeable boundaries: 1,320 feet to the east and west of the pumping well (the model assumes the aquifer continues in a north-south direction.)

No recharge

Pumping rate: 31 gpm (50 acre-feet/year) and 62 gpm

Pumping time: 25 years

The projected water-level decline at one foot from the pumped well after 25 years of pumping is shown for different values of transmissivity, storativity and pumping rate (table 3).

Table 3. Estimated water-level decline corresponding to different aquifer properties and pumping rates

Transmissivity	Storativity	Pumping rate	estimated water level decline
10,000 ft^2/day	0.2	31 gpm	3.3 feet
5,000 ft^2/day	0.2	31 gpm	5.0 feet
10,000 ft^2/day	0.2	62 gpm	6.6 feet
5,000 ft^2/day	0.2	62 gpm	10.0 feet
5,000 ft^2/day	0.1	62 gpm	13.2 feet

A water-level decline of about ten feet is projected at a distance of one foot from the pumped well after 25 years of pumping at a rate of 100 acre-feet of water each year. The analysis leads to the conclusion that aquifer depletion is not likely to become a problem if either of the two Souris area water sources is developed by All Seasons Rural Water Association.

RECOMMENDATION

The Souris area seems to be a suitable location in which to develop a water supply for a rural water system. The thickest saturated sand and gravel section is found near the southern part of the each of the two ice-contact deposits.

In the northern ice-contact deposit the thickest saturated sand and gravel section is found near the township line separating Townships 162 and 163. It is recommended that a water source well or wells in the northern ice-contact deposit in the Souris area be located slightly north of the thickest section of aquifer.

In the southern ice-contact deposit the thickest saturated sand and gravel section is found near the two lakes. The water quality slightly downgradient of the two lakes has an elevated dissolved solids concentration. It is therefore recommended that a water source well or wells in the southern ice-contact deposit in the Souris area be located slightly upgradient of the lakes. The general area recommended for developing a water source is shown in figure 25.

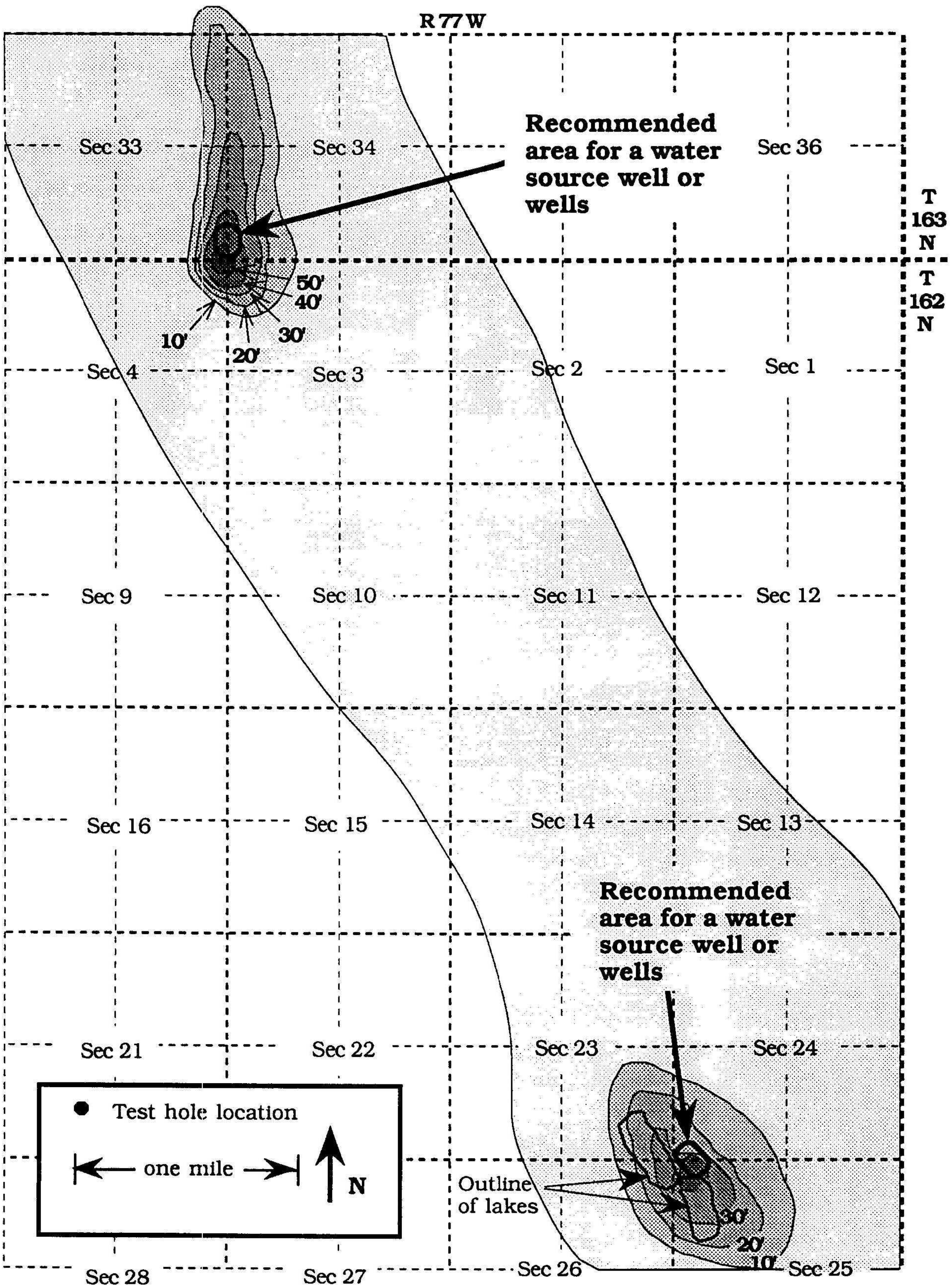

Figure 25 - Recommended locations for water source well(s)

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APPENDIX 1 - LITHOLOGIC LOGS

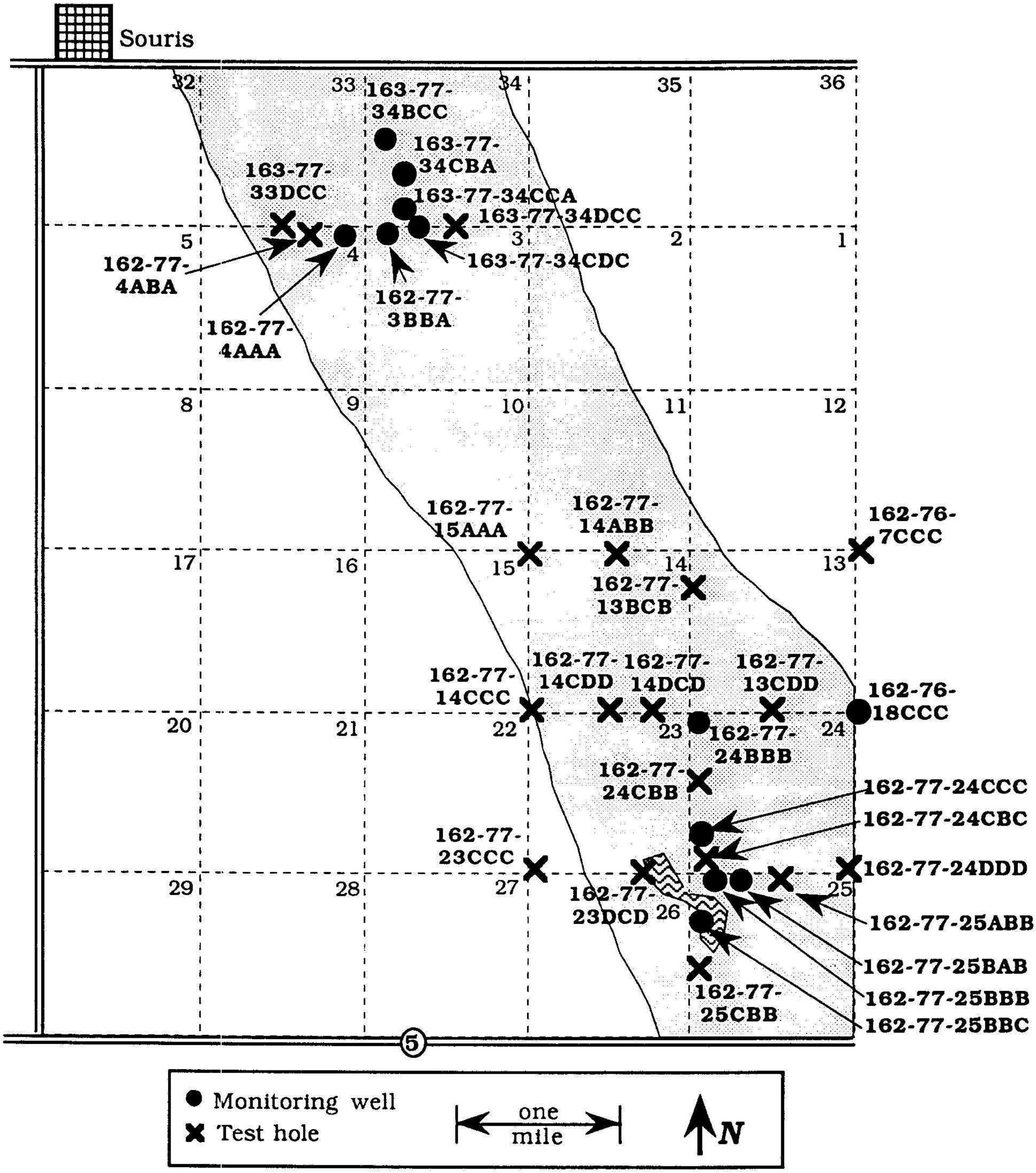

Figure 26 - Well and test hole designations, Souris area

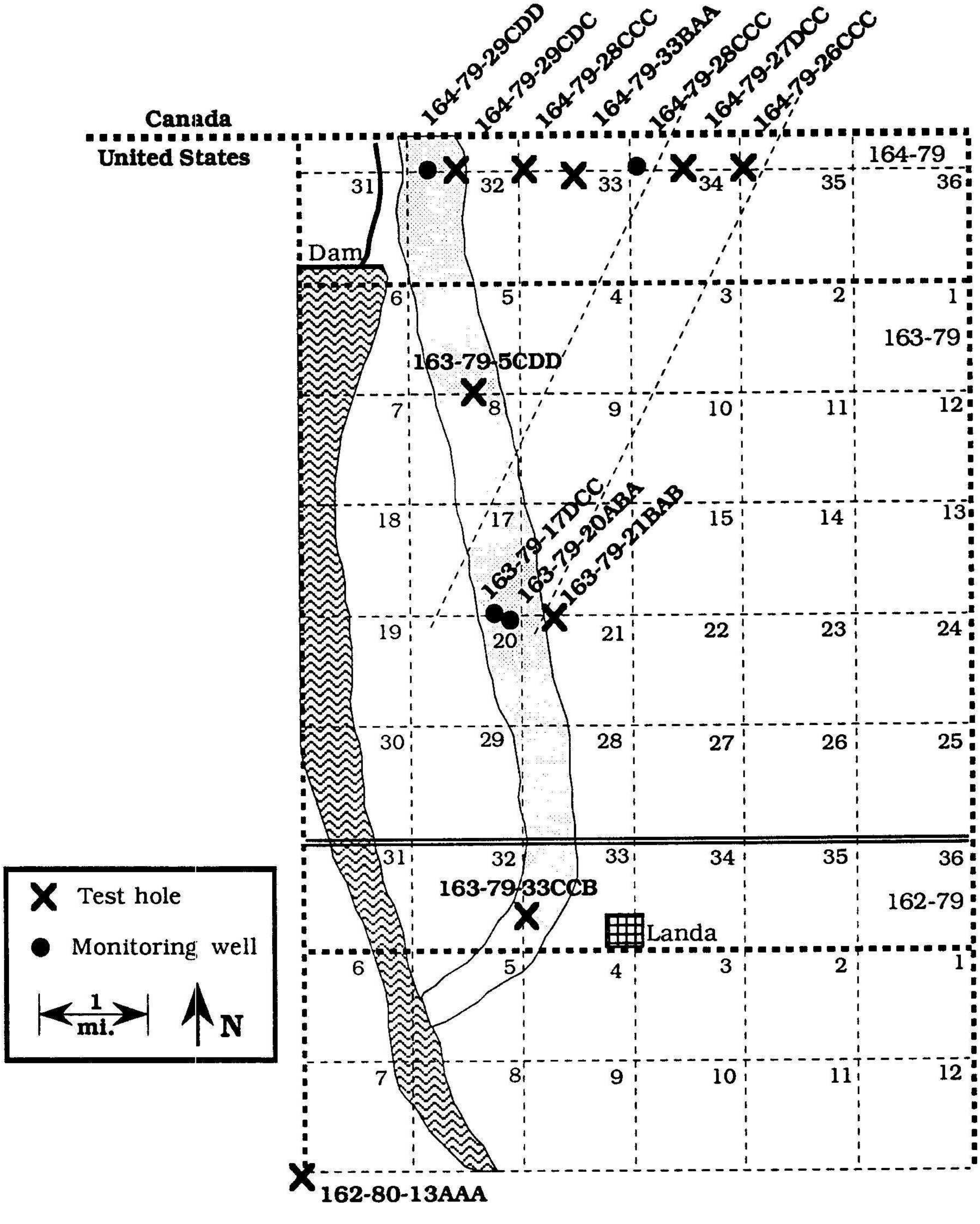

Figure 27 - Well and test hole designations, Landa area

162-076-07CCC

Test Hole # 12813	
Date Completed:	6 Aug 91
Depth Drilled (ft):	40
L.S. Elevation (ft)	1560

Lithologic Log

Description	Depth (ft)
TOPSOIL	0-2
CLAY, dark yellowish brown, 30% with silt, sand, & gravel (oxidized till)	2-12
CLAY, olive gray, 30% with silt, sand, & gravel (till)	12-16
SAND, dark greenish gray, well sorted, subrounded, with interstitial clay, interbedded with carbonaceous silt, (bedrock - Hell Creek Formation)	16-40

162-076-18CCC

Test Hole # 12812			
Date Completed:	6 Aug 91	Well Type:	2 inch PVC
Depth Drilled (ft):	50	Screened Interval (ft):	30-35
L.S. Elevation (ft)	1556.52		

Lithologic Log

Description	Depth (ft)
TOPSOIL	0-2
CLAY, dark yellowish brown, 25%, with silt, sand, & gravel (oxidized till)	2-15
CLAY, olive gray, 25%, with silt, sand, & gravel; 20'-25' clastic fraction mostly Pierre Shale (till)	15-30
SAND & GRAVEL, granules, moderately well sorted, 50% gravel, subangular, silicates & carbonates	30-36
SILT, olive gray, with sand, argillaceous, (bedrock - Hell Creek Formation)	36-50

162-077-03BBA

Test Hole # 12832			
Date Completed:	8 Aug 91	Well Type:	2 inch PVC
Depth Drilled (ft):	60	Screened Interval (ft):	46-51
L.S. Elevation (ft)	1532.4		

Lithologic Log

Description	Depth (ft)
TOPSOIL	0-1
SAND & GRAVEL, well graded, 40% gravel, subangular, silicates, carbonates, sandstone, shale	1-22
SILT, olive gray, sandy	22-26
SAND & GRAVEL, as above	26-54
SAND, fine to medium grained, well sorted, subrounded, quartzose with glauconite, interstitial clay, dark greenish gray, (bedrock - Fox Hills Formation)	54-60

162-077-04AAA

Test Hole # 12833			
Date Completed:	8 Aug 91	Well Type:	2 inch PVC
Depth Drilled (ft):	74	Screened Interval (ft):	58-63
L.S. Elevation (ft)	1526.03		

Lithologic Log

Description	Depth (ft)
TOPSOIL	0-2
SAND & GRAVEL, well graded, 45% gravel, subrounded to subangular, silicates & carbonates	2-44
SAND & GRAVEL, as above, interbedded with silt and very fine grained olive gray to greenish gray sand	44-55
SAND & GRAVEL, as above	55-67
SAND, fine grained, well sorted, subrounded, semi-indurated, quartz, glauconite, interstitial clay, indurated at 74 feet, (bedrock - Fox Hills Formation)	67-74

162-077-04ABA

Test Hole # 12835
Date Completed: 8 Aug 91
Depth Drilled (ft): 60
L.S. Elevation (ft) 1525

Lithologic Log

Description	Depth (ft)
TOPSOIL	0-2
SILT, dark yellowish brown	2-7
SAND & GRAVEL, well graded, 40% gravel, silicates	7-8
SILT, dark yellowish brown	8-9
SILT, olive gray	9-12
SAND & GRAVEL, as above	12-15
CLAY, olive gray to olive black, silty	15-17
SAND & GRAVEL, as above	17-20
CLAY, dark greenish gray, silty, some indurated zones, (disturbed bedrock block)	20-28
SAND, fine grained to silty, quartz and glauconite, semi-indurated with dark greenish gray clay, (disturbed bedrock block)	28-53
SILT, olive gray, (bedrock - Hell Creek Formation)	53-60

162-077-13BCB

Test Hole # 12816
Date Completed: 6 Aug 91
Depth Drilled (ft): 20
L.S. Elevation (ft) 1550

Lithologic Log

Description	Depth (ft)
TOPSOIL	0-2
SAND, coarse grained, poorly sorted, subrounded, quartz	2-7
CLAY dark yellowish brown, with silt, sand, & gravel, (oxidized till)	7-9
SAND, fine grained, silty, with interstitial dark greenish gray clay, (bedrock - Hell Creek or Fox Hills Formation)	9-20

162-077-13CDD

Test Hole # 12814
Date Completed: 6 Aug 91
Depth Drilled (ft): 40
L.S. Elevation (ft) 1550

Lithologic Log

Description	Depth (ft)
TOPSOIL	0-2
CLAY, dark yellowish brown, 25%, with silt, sand, & gravel, (oxidized till)	2-16
SILT, dark yellowish brown, sandy, (bedrock - Hell Creek Formation)	16-17
SAND, fine grained, silty, quartzose, with interstitial dark greenish gray, (bedrock - Hell Creek Formation)	17-40

162-077-14ABB

Test Hole # 12817
Date Completed: 6 Aug 91
Depth Drilled (ft): 40
L.S. Elevation (ft) 1545

Lithologic Log

Description	Depth (ft)
TOPSOIL	0-2
SILT, medium yellowish brown, argillaceous, sandy	2-17
SILT, olive gray, sandy	17-21
SAND & GRAVEL, 40% gravel, silicates, carbonates	21-23
CLAY, olive gray, 30%, with silt, sand, & gravel, gravel lenses at 30' & 32' (till)SAND, f	23-33
SAND, fine grained, subrounded, well sorted, with interstitial dark greenish gray clay, (bedrock - Hell Creek Formation)	33-40

162-077-14CCC

Test Hole # 12820
Date Completed: 6 Aug 91
Depth Drilled (ft): 60
L.S. Elevation (ft) 1525

Lithologic Log

Description	Depth (ft)
TOPSOIL	0-2
SAND, medium grained, moderate sorting, subrounded, quartz	2-6
SILT, dark yellowish brown, argillaceous, (lacusterine)	6-18
CLAY, olive gray, 30%, with silt, sand, & gravel (till)	18-22
SILT, olive gray, (lacusterine)	22-45
SAND & GRAVEL, 40% gravel, moderate sorting, silicates, carbonates	45-48
SAND, fine to very fine grained to silty, with interstitial olive gray to dark greenish gray clay, (bedrock - Hell Creek or Fox Hills Formation)	48-60

162-077-14CDD

Test Hole # 12819
Date Completed: 6 Aug 91
Depth Drilled (ft): 40
L.S. Elevation (ft) 1540

Lithologic Log

Description	Depth (ft)
TOPSOIL	0-2
SAND, medium grained, well sorted, subrounded, quartz	2-17
SAND & GRAVEL, 25% gravel	17-18
CLAY, dark yellowish brown, 30%, with silt, sand, & gravel, (oxidized till)	18-22
CLAY, olive gray, 30%, with silt, sand, & gravel (till)	22-27
SILT, medium gray, argillaceous, sandy, sand from 37' to 40', (bedrock - Hell Creek Formation)	27-40

162-077-14DCD

Test Hole # 12851
Date Completed: 14 Aug 91
Depth Drilled (ft): 60
L.S. Elevation (ft) 1544

Lithologic Log

Description	Depth (ft)
TOPSOIL	0-2
SILT, dark to medium yellowish brown, argillaceous	2-27
CLAY, olive gray, with shale pieces (till)	27-36
SAND, fine grained, with interstitial dark greenish gray clay, (bedrock block)	36-46
SAND & GRAVEL, lens, silicates & carbonates	46-47
CLAY, dark greenish gray, (bedrock - Hell Creek Formation)	47-60

162-077-15AAA

Test Hole # 12818
Date Completed: 6 Aug 91
Depth Drilled (ft): 80
L.S. Elevation (ft) 1535

Lithologic Log

Description	Depth (ft)
TOPSOIL	0-2
SILT, medium yellowish brown, sandy to argillaceous	2-21
SILT, olive gray, sandy to argillaceous	21-36
SAND & GRAVEL, 40% gravel, silicates, carbonates	36-37
SILT, olive gray, as above	37-61
SAND, fine grained, well sorted, subrounded, quartz, glauconite, dark silicates, (bedrock - Hell Creek or Fox Hills Formation)	61-80

162-077-23CCC

Test Hole # 12823
Date Completed: 6 Aug 91
Depth Drilled (ft): 60
L.S. Elevation (ft) 1510

Lithologic Log

Description	Depth (ft)
TOPSOIL	0-2
SILT, medium yellowish brown, sandy to argillaceous, (lacusterine)	2-27
CLAY, olive gray, 30%, with silt, sand, & gravel (till)	27-49
SAND, very fine grained, argillaceous, with interstitial olive gray clay, (bedrock - Hell Creek Formation)	49-60

162-077-23DCD

Test Hole # 12828
Date Completed: 7 Aug 91
Depth Drilled (ft): 60
L.S. Elevation (ft) 1530

Lithologic Log

Description	Depth (ft)
TOPSOIL	0-2
SILT, dark yellowish brown, slightly sandy	2-22
SILT, olive gray, argillaceous, (lacusterine)	22-42
SAND & GRAVEL, 40% gravel, well graded, silicates, carbonates, shale, with interbedded till layers	42-51
SAND, fine grained, quartz, glauconite, with interstitial dark greenish gray clay, (bedrock - Fox Hills Formation)	51-60

162-077-24BBB

Test Hole # 12815

Date Completed:	6 Aug 91	Well Type:	2 inch PVC
Depth Drilled (ft):	50	Screened Interval (ft):	29-34
L.S. Elevation (ft)	1543.26		

Lithologic Log

Description	Depth (ft)
TOPSOIL	0-2
SAND, coarse grained, poorly sorted, subrounded, quartz, silicates, carbonates, shale	2-5
CLAY, dark yellowish brown, silty	5-8
SAND, very coarse, 15% gravel, well graded, subangular, silicates, carbonates, shale	8-15
CLAY, dark yellowish brown, silty	15-21
SAND, coarse grained, as above	21-34
CLAY, olive gray, 30%, with silt, sand, & gravel (till)	34-38
SAND, fine grained, semi-indurated, quartz, glauconite, (bedrock - Hell Creek or Fox Hills Formation)	38-50

162-077-24CBB

Test Hole # 12821

Date Completed:	6 Aug 91
Depth Drilled (ft):	40
L.S. Elevation (ft)	1530

Lithologic Log

Description	Depth (ft)
TOPSOIL	0-2
SAND, fine to medium grained, moderately sorted, subrounded, quartz	2-5
SILT, medium gray	5-9
SAND & GRAVEL, (Oxidized)	9-10
CLAY, dark yellowish brown, 30%, with silt, sand, & gravel (till)	10-21
SAND, very fine grained, argillaceous	21-27
CLAY, olive gray, 30%, with silt, sand, & gravel (till)	27-36
SAND, fine grained, subrounded, quartz, glauconite, dark silicates, indurated in places, (bedrock - Fox Hills Fm.)	36-40

162-077-24CBC

Test Hole # 12825			
Date Completed:	7 Aug 91	Well Type:	2 inch PVC
Depth Drilled (ft):	60	Screened Interval (ft):	44-49
L.S. Elevation (ft)	1531.09		

Lithologic Log

Description	Depth (ft)
TOPSOIL	0-2
SILT, dark yellowish brown, sandy	2-9
SAND, coarse grained, poorly sorted, subrounded, silicates, carbonates	9-20
SAND & GRAVEL, 25% gravel, well graded, subangular to subrounded, silicates, carbonates	20-49
SAND, fine grained, quartz, glauconite, with interstitial dark greenish gray clay, (bedrock - Fox Hills Formation)	49-60

162-077-24CCC

Test Hole # 12852	
Date Completed:	14 Aug 91
Depth Drilled (ft):	60
L.S. Elevation (ft)	1510

Lithologic Log

Description	Depth (ft)
TOPSOIL	0-2
SILT, olive gray to olive black, argillaceous	2-7
	7-8
CLAY, dark yellowish brown to olive gray, silty	8-22
SAND, coarse to very coarse grained, fair sorting, quartz, dark silicates, carbonates	22-32
SAND, very fine to fine grained, with interstitial dark greenish gray clay	32-44
SAND, very coarse, as above	44-51
CLAY, olive gray, (bedrock - Hell Creek or Fox Hills Formation)	51-60

162-077-24DDD

Test Hole # 12811

Date Completed:	5 Aug 91
Depth Drilled (ft):	60
L.S. Elevation (ft)	1525

Lithologic Log

Description	Depth (ft)
TOPSOIL	0-2
CLAY, dark yellowish brown, 25%, with silt, sand, & gravel, (oxidized till)	2-17
CLAY, olive gray, 25%, with silt, sand, & gravel	17-26
SAND, fine to medium grained, moderately well sorted, subrounded, quartz, dark grains, with interstitial medium gray clay, (bedrock block)	26-33
CLAY, as above (till)	33-37
SAND, as above, indurated zone at 44', (bedrock- Hell Creek or Fox Hills Formation)	37-53
CLAY, olive green to olive black, sandy, (bedrock)	53-55
SAND, as above, dark greenish gray, (bedrock)	55-60

162-077-25ABB

Test Hole # 12824

Date Completed:	7 Aug 91
Depth Drilled (ft):	80
L.S. Elevation (ft)	1525

Lithologic Log

Description	Depth (ft)
TOPSOIL	0-2
SILT, dark yellowish brown, with some larger grains (oxidized till)	2-20
SAND & GRAVEL, 30% gravel, moderate sorting, subangular, quartz, silicates, carbonates	20-24
SILT, dark yellowish brown	24-28
SAND & GRAVEL, as above, with interbedded silt	28-33
SILT, olive gray	33-36
SAND & GRAVEL, as above, with interbedded silt	36-40
SILT, as above	40-45
CLAY, olive gray, 30% with silt, sand, & gravel (till)	45-68
SAND, fine to medium grained, fair sorting, subrounded, quartz, glauconite, (bedrock - Fox Hills Formation)	68-80

162-077-25BAB

Test Hole # 12829			
Date Completed:	7 Aug 91	Well Type:	2 inch PVC
Depth Drilled (ft):	70	Screened Interval (ft):	37-42
L.S. Elevation (ft)	1528.54		

Lithologic Log

Description	Depth (ft)
TOPSOIL	0-2
SILT, dark yellowish brown, sandy	2-7
SAND, coarse grained, fair to moderate sorting, subrounded to subangular, quartz, dark silicates, carbonates	7-20
SAND & GRAVEL, 25% gravel, subangular, silicates, carbonates	20-42
CLAY, olive gray, 30%, with silt, sand, & gravel (till)	42-66
SAND, fine grained, well sorted, quartz, with interstitial dark greenish gray clay, (bedrock - Hell Creek or Fox Hills Formation)	66-70

162-077-25BBB

Test Hole # 12822			
Date Completed:	6 Aug 91	Well Type:	2 inch PVC
Depth Drilled (ft):	80	Screened Interval (ft):	47-52
L.S. Elevation (ft)	1516.4		

Lithologic Log

Description	Depth (ft)
TOPSOIL	0-2
CLAY, dark yellowish brown, 25%, with silt, sand, & gravel, (oxidized till)	2-8
SILT, medium yellowish brown	8-17
SAND & GRAVEL, 30% gravel, well graded, subangular, (oxidized to 29 feet), silicates, carbonates, some shale & Fox Hills granules & pebbles, occasional silt, 55' - 62' is intermixed with bedrock clay	17-62
SAND, fine grained, silty, argillaceous, with interstitial dark greenish gray clay, (bedrock - Hell Creek Formation)	62-80

162-077-25BBC

Test Hole # 12826			
Date Completed:	7 Aug 91	Well Type:	2 inch PVC
Depth Drilled (ft):	80	Screened Interval (ft):	48-53
L.S. Elevation (ft)	1508.44		

Lithologic Log

Description	Depth (ft)
TOPSOIL	0-2
SAND & GRAVEL, 30% gravel, well graded	2-7
SILT, dark to medium yellowish brown	7-15
SILT, olive gray, sand lens at 16 feet	15-26
SAND & GRAVEL, 30% gravel, well graded but predominantly very coarse sand and gravel granules, silicates, carbonates, granules & pebbles of Fox Hills sandstone and Pierre shale	26-64
CLAY, olive gray, 30%, with silt, sand, & gravel (till)	64-66
SAND, very fine grained, moderate sorting, with interstitial dark greenish gray clay, (bedrock - Fox Hills Formation)	66-80

162-077-25CBB

Test Hole # 12827	
Date Completed:	7 Aug 91
Depth Drilled (ft):	80
L.S. Elevation (ft)	1530

Lithologic Log

Description	Depth (ft)
TOPSOIL	0-2
SILT, medium yellowish brown, mottled, sandy	2-37
SILT, olive gray, (lacusterine)	37-55
CLAY, olive gray, 30%, with silt, sand, & gravel (till)	55-75
SILT, olive gray, sandy, (bedrock - Hell Creek or Fox Hills Formation)	75-80

162-080-13AAA

Test Hole # 12850
Date Completed: 14 Aug 91
Depth Drilled (ft): 160
L.S. Elevation (ft) 1485

Lithologic Log

Description	Depth (ft)
TOPSOIL	0-2
CLAY, dark yellowish brown, 30%, with silt, sand, & gravel (oxidized till)	2-38
CLAY, olive gray, 30%, with silt, sand, & gravel, gravel lenses at 121', 131' (till)	38-146
CLAY, olive gray to dark greenish gray, silty, (bedrock - Fox Hills or Pierre Formation)	146-160

163-077-33DCC

Test Hole # 12834
Date Completed: 8 Aug 91
Depth Drilled (ft): 60
L.S. Elevation (ft) 1525

Lithologic Log

Description	Depth (ft)
TOPSOIL	0-2
SILT, dark yellowish brown, sandy	2-11
CLAY, olive gray, 30%, with silt, sand, & gravel (till)	11-14
SILT, olive gray, argillaceous, (may be block of bedrock)	14-30
SANDSTONE, fine to medium grained, fair sorting, subrounded, quartz, dark silicates, glauconite, partially indurated, (bedrock block)	30-35
SAND & GRAVEL, 30% gravel, silicates etc.	35-36
CLAY, 30%, with silt, sand, & gravel (till)	36-44
SILT, olive gray, argillaceous, (bedrock - Hell Creek or Fox Hills Formation)	44-60

163-077-34BCC

Test Hole # 12830			
Date Completed:	6 Aug 91	Well Type:	2 inch PVC
Depth Drilled (ft):	60	Screened Interval (ft):	44-49
L.S. Elevation (ft)	1542.77		

Lithologic Log

Description	Depth (ft)
TOPSOIL	0-2
SILT, medium yellowish brown	2-6
SAND, coarse grained, poorly sorted, subangular, quartz, silicates, carbonates, shale, sandstone	6-12
SAND & GRAVEL, 30% gravel, well graded, subangular, silicates, carbonates, shale, sandstone	12-16
SILT, medium yellowish brown, sandy	16-22
SILT, olive gray, sandy	22-26
SAND, coarse grained, moderate sorting, silicates, carbonates, shale, sandstone	26-42
SAND & GRAVEL, 30% gravel, as above	42-49
SILT, olive gray, sandy, (bedrock - Hell Creek or Fox Hills Formation)	49-60

163-077-34CBA

Test Hole # 12830A			
Date Completed:	7 Aug 91	Well Type:	2 inch PVC
Depth Drilled (ft):	60	Screened Interval (ft):	42-47
L.S. Elevation (ft)	1540.55		

Lithologic Log

Description	Depth (ft)
TOPSOIL	0-2
SILT, dark yellowish brown	2-9
SAND, medium grained, moderate sorting, subrounded, mostly quartz	9-35
SAND & GRAVEL, 50% gravel, well graded, silicates, sandstone, siltstone, shale, carbonates	35-47
SILT, dark greenish gray to olive gray, sandy, (bedrock - Fox Hills Formation)	47-60

163-077-34CCA

Test Hole # 12831			
Date Completed:	7 Aug 91	Well Type:	2 inch PVC
Depth Drilled (ft):	40	Screened Interval (ft):	26-31
L.S. Elevation (ft)	1527.35		

Lithologic Log

Description	Depth (ft)
TOPSOIL	0-2
CLAY, light gray to olive gray to dark yellowish brown, 40% with silt, sand, & gravel (oxidized till)	2-6
SILT, dark yellowish brown	6-12
SILT, olive gray	12-18
SAND, coarse grained, poorly sorted, subrounded, quartz	18-22
SAND & GRAVEL, 30% gravel, well graded, silicates, etc. SILT, o	22-31
SILT, olive gray, sandy, (bedrock - Hell Creek or Fox Hills Formation)	31-40

163-077-34CDC

Test Hole # 12837			
Date Completed:	8 Aug 91	Well Type:	2 inch PVC
Depth Drilled (ft):	60	Screened Interval (ft):	44-49
L.S. Elevation (ft)	1539.89		

Lithologic Log

Description	Depth (ft)
TOPSOIL	0-2
SAND & GRAVEL, 40% gravel, well graded, subrounded to subangular, silicates, et. al.	2-11
SAND & GRAVEL, as above, with interbedded dark yellowish brown silt	11-20
SAND & GRAVEL, 30% gravel, well graded	20-29
SILT, dark yellowish brown	29-42
SAND & GRAVEL, as above	42-49
SILT, dark greenish gray to olive gray, (bedrock - Hell Creek or Fox Hills Formation)	49-60

163-077-34DCC

Test Hole # 12836
Date Completed: 8 Aug 91
Depth Drilled (ft): 40
L.S. Elevation (ft) 1535

Lithologic Log

Description	Depth (ft)
TOPSOIL	0-2
SILT, dark to medium yellowish brown, sometimes mottled	2-12
CLAY, 30% dark yellowish brown, with silt, sand, & gravel, (oxidized till)	12-16
CLAY, olive gray, 30%, with silt, sand, & gravel (till)	16-21
SAND & GRAVEL, 30% gravel, well graded, silicates, et. al.	21-22
SILT, dark greenish gray, sandy, (bedrock - Hell Creek or Fox Hills Formation)	22-40

163-079-05CDD

Test Hole # 12848
Date Completed: 14 Aug 91
Depth Drilled (ft): 120
L.S. Elevation (ft) 1462

Lithologic Log

Description	Depth (ft)
TOPSOIL	0-2
CLAY, dark yellowish brown, 30%, with silt, sand, & gravel (oxidized till)	2-24
CLAY, olive gray, 30%, with silt sand, & gravel (till)	24-60
SAND & GRAVEL, 30% gravel, well graded, subangular, silicates predominate	60-62
CLAY, olive gray, as above (till)	62-66
SAND & GRAVEL, as above	66-74
CLAY, olive gray, as above, with pieces of bedrock (till)	74-94
CLAY, olive black, consolidated, drills slow, (bedrock - Fox Hills or Pierre Formation)	94-120

163-079-17DCC

Test Hole # 12839			
Date Completed:	9 Aug 91	Well Type:	2 inch PVC
Depth Drilled (ft):	160	Screened Interval (ft):	132-137
L.S. Elevation (ft)	1483		

Lithologic Log

Description	Depth (ft)
TOPSOIL	0-2
CLAY, dark yellowish brown, 30%, with silt, sand, & gravel (oxidized till)	2-51
CLAY, olive gray, 30-35%, cohesive, with silt, sand, & gravel (till)	51-76
SAND, very coarse grained, some gravel, poor to moderate sorting, subangular, shale, quartz, lignite, silicates, carbonates, 101'-120' has pieces of Fox Hills sandstone, abundant lignite, coarser below 123',	76-147
CLAY, olive gray, consolidated, (bedrock - Fox Hills or Pierre Formation)	147-160

163-079-20ABA

Test Hole # 12838			
Date Completed:	8 Aug 91	Well Type:	2 inch PVC
Depth Drilled (ft):	240	Screened Interval (ft):	138-143
L.S. Elevation (ft)	1457		

Lithologic Log

Description	Depth (ft)
TOPSOIL	0-2
SAND & GRAVEL, 40% gravel, well graded, subangular, silicates, carbonates, sandstone, shale	2-17
SILT, olive gray to dark yellowish brown, sandy, argillaceous	17-22
CLAY, olive gray, 30% with silt, sand & gravel, sandier below 70' (till)	22-78
SAND, very coarse grained, fair sorting, subangular, shale, lignite, quartz	78-88
SAND, fine grained, silty, argillaceous, overall dark greenish gray color	88-101
SAND & GRAVEL, 25% gravel, subrounded to subangular, shale, sandstone, lignite, drills choppy, clay lenses at 105', 111', 154-158', rocky at 215-217'	101-217
CLAY, olive gray, slightly silty, drills slow, (bedrock - Pierre or Fox Hills Formation)	217-240

163-079-21BAB

Test Hole # 12840
Date Completed: 12 Aug 91
Depth Drilled (ft): 80
L.S. Elevation (ft) 1485

Lithologic Log

Description	Depth (ft)
TOPSOIL	0-2
CLAY, 30%, dark yellowish brown, cohesive, with silt, sand, & gravel (oxidized till)	2-32
CLAY, 30%, olive gray, cohesive, with silt, sand & gravel (till)	32-56
SILT, olive gray, argillaceous, drills slow	56-58
SAND, very coarse grained, fair sorting, subrounded to subangular, silicates	58-60
SANDSTONE, medium to fine grained, well sorted, indurated, grains are dark greenish gray, green, black, & clear, interstitial clay, (bedrock - Fox Hills Formation)	60-80

163-079-33CCB

Test Hole # 12849
Date Completed: 14 Aug 91
Depth Drilled (ft): 100
L.S. Elevation (ft) 1435

Lithologic Log

Description	Depth (ft)
TOPSOIL	0-2
CLAY, dark yellowish brown, 30%, with silt, sand & gravel, (oxidized till)	2-14
CLAY, olive gray, 30%, with silt, sand & gravel, sand lenses at 31', 34', 44-46' (till)	14-78
CLAY, olive gray, (bedrock - Hell Creek Formation)	78-82
SAND, fine grained, with interstitial dark greenish gray clay, (bedrock - Hell Creek Formation)	82-100

164-079-26CCC

Test Hole # 12843
Date Completed: 13 Aug 91
Depth Drilled (ft): 80
L.S. Elevation (ft) 1505

Lithologic Log

Description	Depth (ft)
TOPSOIL	0-2
CLAY, dark yellowish brown, 30%, with silt, sand, & gravel, (oxidized till)	2-25
SILT, dark yellowish brown	25-29
CLAY, dark yellowish brown, as above	29-36
CLAY, olive gray, 30% with silt, sand & gravel (till)	36-74
CLAY, medium gray, (bedrock - Hell Creek Formation)	74-80

164-079-27CCC

Test Hole # 12841
Date Completed: 13 Aug 91
Depth Drilled (ft): 80
L.S. Elevation (ft) 1495

Lithologic Log

Description	Depth (ft)
TOPSOIL	0-2
CLAY, dark yellowish brown, 30%, cohesive, with silt, sand, & gravel (oxidized till)	2-17
CLAY, olive gray, 30%, cohesive, with silt, sand, & gravel (till)	17-35
SAND, very coarse grained, poorly sorted, subrounded to subangular, primarily silicates & carbonates	35-62
CLAY, as above (till)	62-66
SAND, fine grained, quartz, interstitial olive to medium gray clay, (bedrock - Hell Creek or Fox Hills Formation)	66-80

164-079-27DCC

Test Hole # 12842
Date Completed: 13 Aug 91
Depth Drilled (ft): 80
L.S. Elevation (ft) 1500

Lithologic Log

Description	Depth (ft)
TOPSOIL	0-2
CLAY, dark yellowish brown, 30%, with silt, sand, & gravel (oxidized till)	2-30
CLAY, olive gray, 30%, with silt, sand, & gravel (till)	30-74
SAND, very fine to fine grained, well sorted, subrounded, quartz with interstitial medium gray to dark greenish gray clay, (bedrock - Fox Hills Formation)	74-80

164-079-28CCC

Test Hole # 12845
Date Completed: 13 Aug 91
Depth Drilled (ft): 60
L.S. Elevation (ft) 1485

Lithologic Log

Description	Depth (ft)
TOPSOIL	0-2
CLAY, dark yellowish brown, 30%, with silt, sand & gravel, (oxidized till)	2-28
CLAY, olive gray, 30%, with silt, sand, & gravel (till)	28-49
SAND, very fine grained, with interstitial medium gray clay, (bedrock - Hell Creek or Fox Hills Formation)	49-60

164-079-29CDC

Test Hole # 12847			
Date Completed:	13 Aug 91	Well Type:	2 inch PVC
Depth Drilled (ft):	130	Screened Interval (ft):	82-87
L.S. Elevation (ft)	1460		

Lithologic Log

Description	Depth (ft)
TOPSOIL	0-2
CLAY, dark yellowish brown, 30%, with silt, sand, & gravel (oxidized till)	2-16
SAND & GRAVEL, 25% gravel, well graded, subangular, silicates, carbonates, some sandstone	16-41
CLAY, olive gray, 30%, with silt, sand, & gravel, sand lenses at 43' & 48' (till)	41-54
SILT, olive gray	54-58
CLAY, olive gray, as above (till)	58-61
SAND & GRAVEL, 20% gravel, primarily very coarse sand, moderate sorting, subrounded, quartz, shale, sandstone, silicates, carbonates, lignite, some interbedded clay	61-96
CLAY, olive gray, with interbedded lignite & some interbedded sandstone, (bedrock - Hell Creek Formation)	96-130

164-079-29CDD

Test Hole # 12846	
Date Completed:	13 Aug 91
Depth Drilled (ft):	280
L.S. Elevation (ft)	1460

Lithologic Log

Description	Depth (ft)
TOPSOIL	0-2
SAND & GRAVEL, 30% gravel, well graded, subangular, silicates, carbonates	2-13
CLAY, dark yellowish brown, 30%, with silt, sand, & gravel, (oxidized till)	13-15
CLAY, olive gray, 30%, with silt, sand, & gravel (till)	15-58
SAND & GRAVEL, 25% gravel, well graded, subangular, silicates, carbonates, shale, & sandstone	58-71
SAND, very fine grained, silty, with olive to dark greenish gray silt	71-206
CLAY, olive gray, 30%, cohesive, with silt, sand, & gravel	206-262
SAND, fine grained, with interstitial dark to medium greenish gray clay, interbedded with clay, olive gray, (bedrock - Fox Hills Formation)	262-280

164-079-33BAA

Test Hole # 12844
Date Completed: 13 Aug 91
Depth Drilled (ft): 80
L.S. Elevation (ft) 1490

Lithologic Log

Description	Depth (ft)
TOPSOIL	0-2
CLAY, dark yellowish brown, 30%, cohesive, with silt, sand, & gravel, (oxidized till)	2-29
CLAY, olive gray, 30%, with silt, sand, & gravel, 57' to 60' is gravely (till)	29-60
CLAY, dark greenish gray, blocky/fissile, (bedrock - Hell Creek or Fox Hills Formation)	60-71
SAND, fine to medium grained, argillaceous, (bedrock - Hell Creek or Fox Hills Formation)	71-80