AN EVALUATION OF THE POTENTIAL TO INCREASE THE PUMPING CAPACITY OF THE GROUND-WATER SUPPLY FOR THE CITY OF BOTTINEAU USING ADDITIONAL WELLS PHASE I - RESULTS OF TEST DRILLING AND WATER CHEMISTRY SAMPLING

By Robert B. Shaver
North Dakota Water Commission

NORTH DAKOTA GROUND-WATER STUDIES NUMBER 112

Bismarck, North Dakota

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INTRODUCTION

Due to elevated uranium concentrations in municipal wells 2 and 3 (well 3 exceeds USEPA primary contaminant level), the city of Bottineau is exploring options to augment its existing ground-water supply. The city has stopped pumping wells 2, 3, and 5, all of which are hydraulically connected and completed in the same discrete buried channel aquifer (confined aquifer B). Currently, ground water is being pumped from wells 1 and 6 and additional ground water is derived from the flowing "Bittner" and "Noble" wells. The city reports the pumping rate of well 6 at 185 gallons per minute (gpm) and the pumping rate of well 1 at about 70 gallons per minute. The total flowing rate of the three "Bittner" wells was measured at six gpm and the flowing rate of the Noble well was measured at 48 gpm (Keith Fulsebakke, Bottineau Municipal Works Supervisor – verbal communication). According to Mr. Fulsebakke, the current well-field discharge rate is meeting the city's needs but the city needs additional "peaking" well-discharge capacity and back-up wells to ensure meeting current demand.

In a report entitled "A Hydrogeologic Analysis to Determine the Sustained Yield of the Bottineau Municipal Well Field and All Seasons Rural Water Systems I and II Bottineau County, North Dakota" prepared by the North Dakota State Water Commission (North Dakota Ground Water Studies No. 109), the following recommendations were made to increase the pumping capacity of the Bottineau municipal ground-water supply:

1. Install a replacement well for the "Noble" well and install a pump to maximize the discharge rate instead of relying on natural flow.
2. Install a well(s) in the NW1/4 of Section 7.

On August 4, 2003, the city of Bottineau entered into a cooperative agreement with the North Dakota State Water Commission to evaluate the potential to increase the pumping

capacity of the ground-water supply for the city of Bottineau using additional wells. This study was divided into two phases. Phase I consisted of test drilling, observation well (piezometer) construction, and sampling for water-chemistry analysis and was completed in August and September 2003. This report describes the results of Phase I and presents the basic hydrogeologic data.

Phase II of the study will involve installation of a test well(s) and pump testing to determine maximum sustained well yield. Recommendations regarding Phase II are presented in this report.

Lithologic logs of wells and test holes are found in Appendix I. All logs of test holes/wells drilled for this study and logs of test holes/wells used in the two geohydrologic sections prepared for this report are included in Appendix I. Logs of other test holes/wells in the study area are found in North Dakota Ground Water Studies No. 109.

Chemical analyses of 15 ground-water samples collected from four wells and two piezometers are found in Appendix II. The wells and piezometers are completed in confined aquifers C, D, and F.

Location Numbering System

The location-numbering system used in this report is based on the public land classification system used by the U.S. Bureau of Land Management. The system is illustrated in figure 1. 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 test hole is located. The letters A, B, C, and D designate, respectively, the northeast, northwest, southwest, and southeast quarter section, quarter-

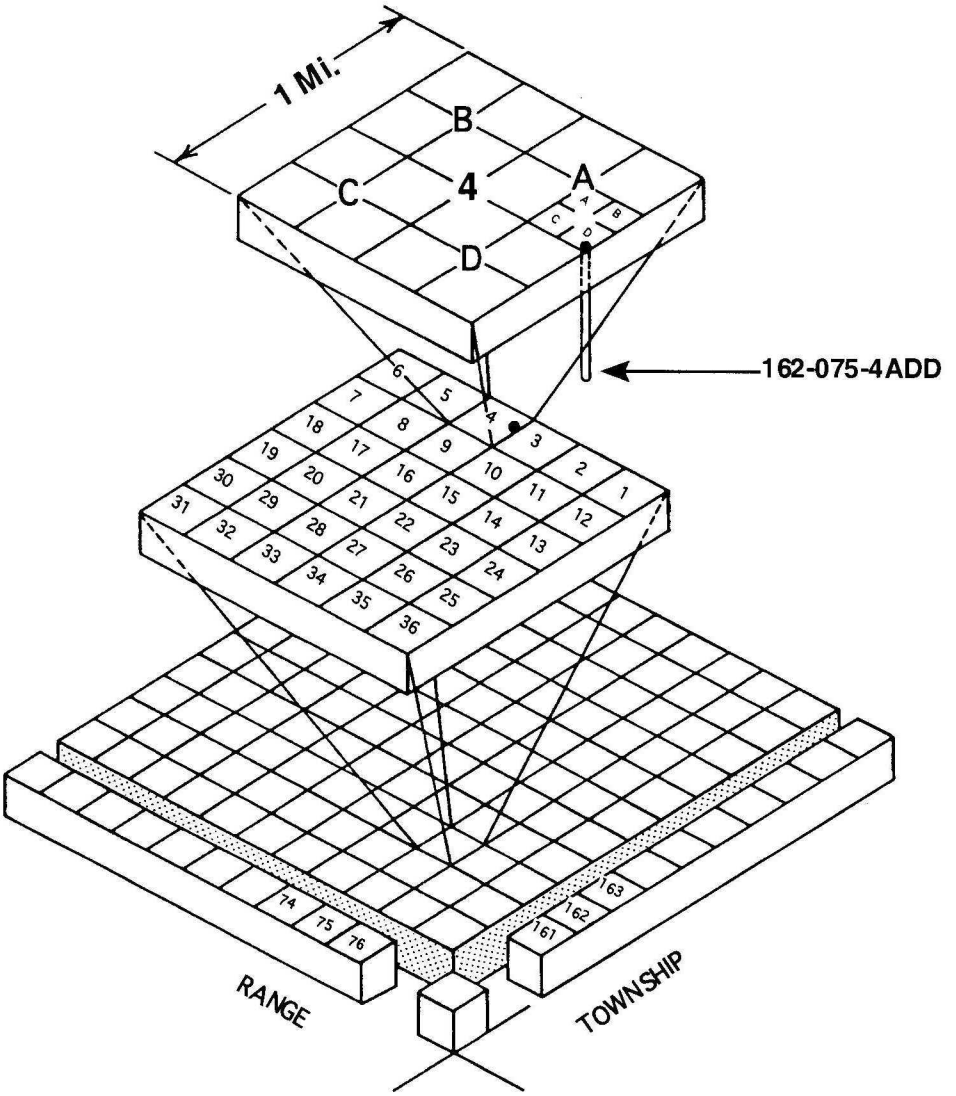

Figure 1.-- Location-numbering system

quarter section, and quarter-quarter-quarter section (10-acre tract). For example, well 162-075-04ADD is located in the SE1/4SE1/4NE1/4 Sec. 4, T. 162 N., R. 75 W. Consecutive terminal numerals are added if more than one well or test hole is located within a 10-acre tract.

Methods

Test holes were drilled using a Failing 1250 forward mud rotary drilling rig. The diameter of the drilling bit was 4 3/4 inches. If a piezometer was not installed at the drilling site, the open hole was plugged with bentonite chips. If a piezometer was constructed, the initial 4 3/4-inch diameter hole was reamed to 6 1/4 inches in diameter to about five feet below the bottom of the proposed well screen. Piezometers were completed using five-foot lengths of 2-inch diameter PVC #12-slot screen with a wash-down valve attached to the bottom. The screen was attached to a 20-foot length of 2-inch diameter PVC casing, which was then inserted into the drill hole. Additional lengths of 2-inch diameter PVC casing were attached onto the casing in the drill hole to set the screen at the desired depth. Casing, screen, and associated fittings were assembled with PVC cement. The PVC well casing was extended about two feet above land surface.

After the well casing and screen were inserted into the drill hole at the desired depth, a 1 1/4-inch diameter PVC tremie pipe was inserted into the well annular space. The bottom of the tremie pipe was set about five feet above the top of the well screen. Silica sand (#10) was washed down the tremie pipe to provide a filter pack around the well screen. After the sand pack was inserted around the well screen, a bentonite slurry was injected through the tremie pipe above the top of the sand pack up to a few feet below land surface to seal the annular

area of the well. The remainder of the annular area to land surface was filled in with solid bentonite chips to provide a surface seal. After completion, the piezometer was pumped with air to ensure the piezometer would pump clean formation water. At a later date, a 4-inch diameter protective casing was installed around the 2-inch piezometer casing above land surface.

Water samples were collected for chemical analysis from three NDSWC piezometers installed for this study and two domestic wells. Four 500-milliliter (ml) samples and one 250-ml sample were collected from the piezometers and domestic wells for chemical analysis. Bicarbonate (HCO_3), carbonate (CO_3), and electrical conductivity were determined using the raw-untreated 500-ml sample. Sulfate (SO_4), fluoride (F), chloride (Cl), and dissolved solids were determined using the filtered (0.45μ) 500-ml sample. Calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), iron (Fe), and manganese (Mn) were determined using the filtered (0.45μ) and acidified (2 ml – nitric acid) 500-ml sample. Trace elements of selenium, lead, mercury, arsenic, lithium, molybdenum, strontium, and uranium were determined on the filtered (0.45μ), acidified (2 ml nitric acid) 500-ml sample using a double acid-rinsed bottle. Nitrate (NO_3) was determined using the raw 250-ml sample that was kept chilled prior to analysis. A Perkin-Elmer Model 4000 atomic-absorption spectrophotometer was used to measure concentrations of Ca, Mg, Na, K, Fe, Mn, lithium (Li), and strontium (Sr). Orion Model 960 and 940 titralyzers were used to measure concentrations of HCO_3, CO_3, and Cl. A gravimetric method was used to measure the concentration of SO_4. Flouride was measured using a specific ion electrode. Nitrate (NO_3) was measured by a cadmium reduction flow-through injection method using a Lachat Quick Chem Model 8000. Uranium (U) was measured using a Perkin-Elmer Elan Model 5000 injection coupled plasma mass-

spectrophotometer. Lead (Pb), arsenic (As), selenium (Se), and molybdenum (Mo) were measured using a Perkin-Elmer Model 4100 ZL graphite furnace. Mercury (Hg) was measured using a Perkin-Elmer Model 3000 cold vapor atomic absorption spectrophotometer.

DESCRIPTION OF THE STUDY AREA

Physiography

The study area is located in the north-central part of North Dakota in the Drift Prairie District of the Central Lowland physiographic province (fig. 2). The study area is situated along the border between the Souris River Valley and Turtle Mountains physiographic divisions. In the Souris River Valley division, that was once occupied by glacial Lake Souris, the land-surface topography is gently undulating. The stagnant glacial features of the Turtle Mountains are hilly. The Bottineau well-field study area (Section 7, T. 162 N., R. 75 W.) is situated along the southwestern flank of the Turtle Mountains. Relief in Section 7 is about 275 feet (fig. 3). Surface runoff occurs in two intermittent streams located in the NW1/4 and SE1/4 of Section 7, T. 162 N., R. 75 W. These two intermittent streams are tributaries to Stone Creek located about two miles south and west of the study area.

Climate

The climate of the study area is semiarid. Based on the period from 1906 through 2000 (Hydrosphere, 2001) the mean annual precipitation is 16.58 inches and the mean annual temperature is 37.6°F. Annual precipitation and the five-year moving average annual precipitation from 1906 and 2000 are shown in figure 4. Most of the precipitation occurs

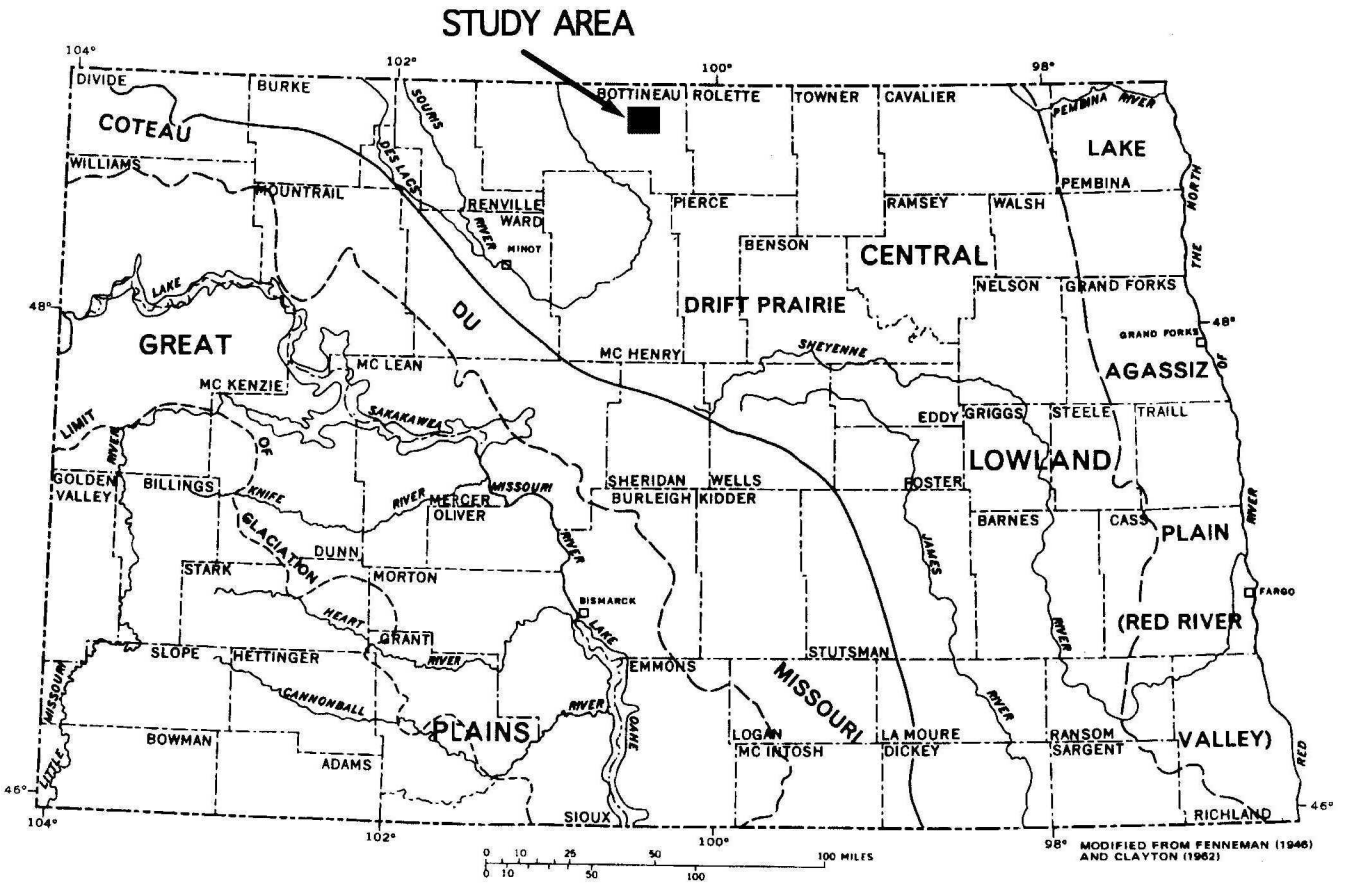

Figure 2. -- Physiographic divisions in North Dakota and location of study area

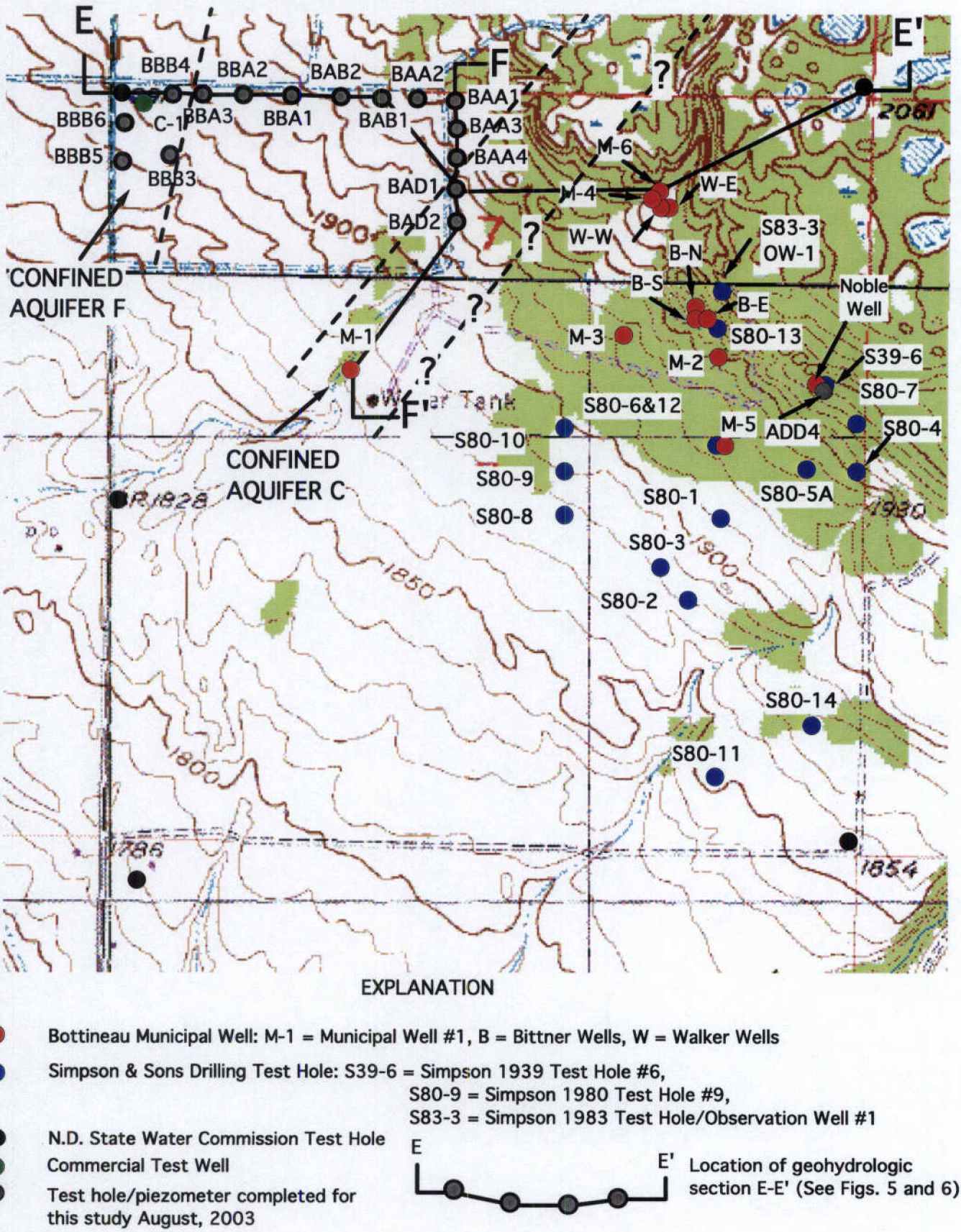

Figure 3. -- Land-surface topography, location of wells, test holes, confined aquifers C and F, and geohydrologic sections E-E' and F-F' in the Bottineau well field area

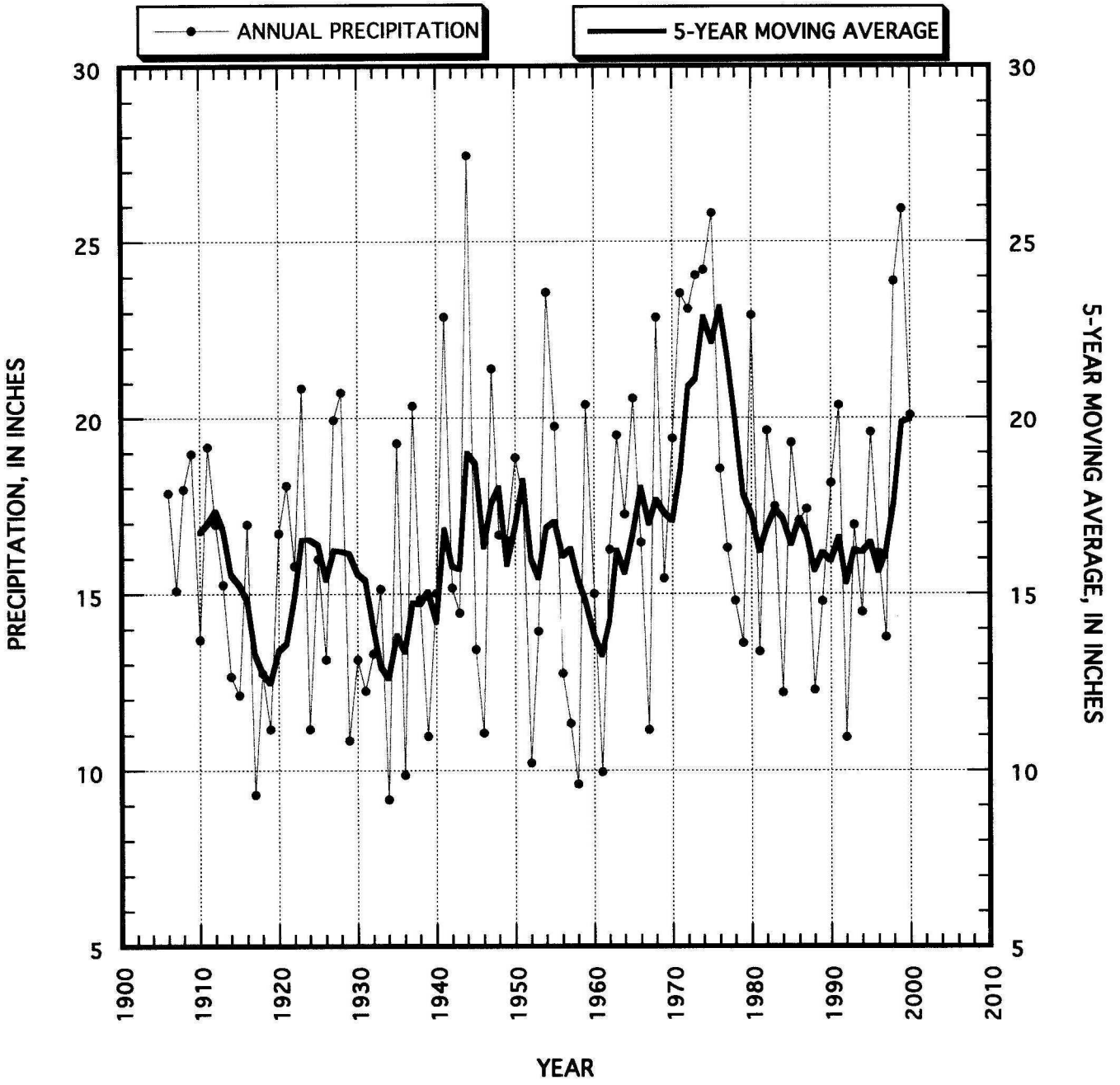

Figure 4. -- Annual precipitation and 5-year moving average at Bottineau from 1906 through 2000

during the growing season, which is the period April through September (Randich and Kuzniar, 1984).

Geology of the Bottineau Aquifer Study Area

Surficial Geology

The study area (Section 7, T. 162 N., R. 075 W.) is characterized by a steeply sloping eroded till deposit of the Coleharbor Group (Bluemle, 1985). The till is an unsorted, unbedded mixture of angular, subangular, and rounded blocks of rock, gravel, and sand, generally in a stiff matrix of silt and clay (Bluemle, 1985). Color varies from yellowish brown (weathered) to olive gray (nonweathered). Discontinuous lenses of sand and gravel are scattered throughout the till (Bluemle, 1985). A well exposed outcrop of the weathered till facies occurs along a trail just south of the observation well located at 162-075-07ADB5.

Subsurface Geology

The Pleistocene Coleharbor Group unconformably overlies the Cretaceous Hell Creek Formation in the study area (Bluemle, 1985). The Coleharbor Group is comprised of a till facies, a sand and gravel facies, and a silt and clay facies. As previously stated, the till facies is a bouldery, cobbly, pebbly mixture of clay, silt, and sand. The till is composed of a heterogeneous mixture of igneous and metamorphic rocks, carbonates (limestone and dolomite), shale, sandstone, and lignite (Bluemle, 1985). Igneous and metamorphic rock fragments were derived from Precambrian rocks of the Canadian Shield and from Tertiary sandstone formations of western North Dakota. Carbonate rock fragments were derived from

Paleozoic rocks in Canada. Shale, sandstone, and lignite were derived from local bedrock formations (Bluemle, 1985).

In the study area, the sand and gravel facies is comprised of fluvial sediment deposited in melt-water stream channels that drape the flanks of the Turtle Mountains. Test drilling, water level, and pumping test data in Section 7, T. 162 N., R. 75 W. indicate at least five and possibly six sand and gravel channels that are hydraulically discrete and appear, for the most part, to occupy different stratigraphic positions (Shaver, ND Ground Water Study No. 109, figs. 6-9). The sand and gravel bodies commonly are overlain and underlain by till. Based on the above, the study area is characterized by a glacial history consisting of a number of ice advances and melting events that gave rise to a complex distribution of sand and gravel units.

For Phase I of this study, 15 test holes were drilled and three piezometers were installed in the NW1/4 of Section 7 (fig. 3). One piezometer was installed about 25 feet southeast of the "Noble" well. Geohydrologic sections E-E' (fig. 5) and F-F' (fig. 6) incorporate much of the new test drilling in the NW1/4 of Section 7. (Note: To maintain continuity and to avoid confusion, North Dakota Ground-Water Study #109 includes geohydrologic sections A-A' through D-D' and this report includes geohydrologic sections E-E' and F-F'). Geohydrologic section E-E' extends from west to east along the N1/2 of Section 7 (fig. 3). Confined aquifers A, C, and F are delineated in geohydrologic section E-E'. Confined aquifer C and possibly a new discrete buried channel are delineated in geohydrologic section F-F'.

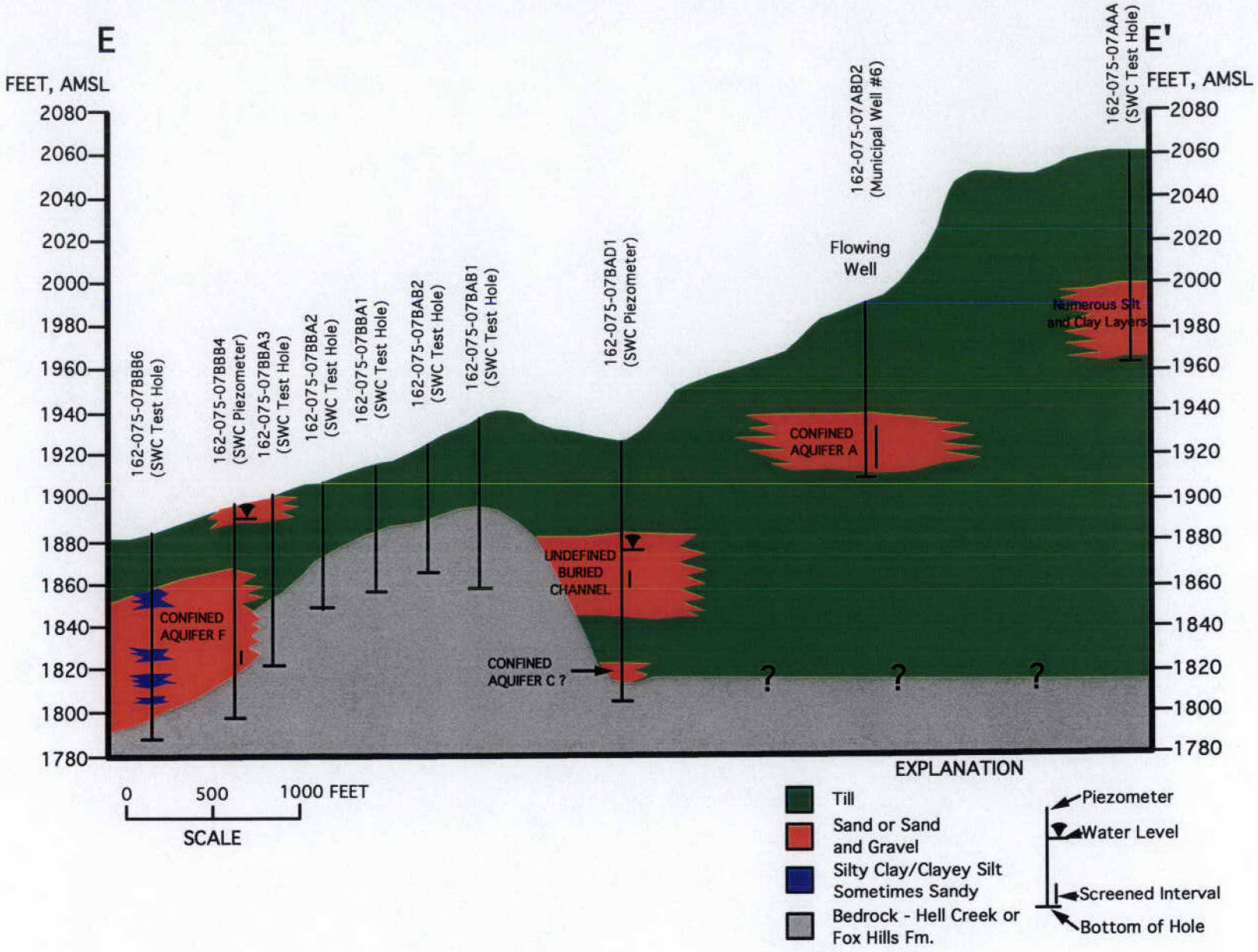

Figure 5. -- Geohydrologic section E-E' showing various buried channels in the Bottineau aquifer

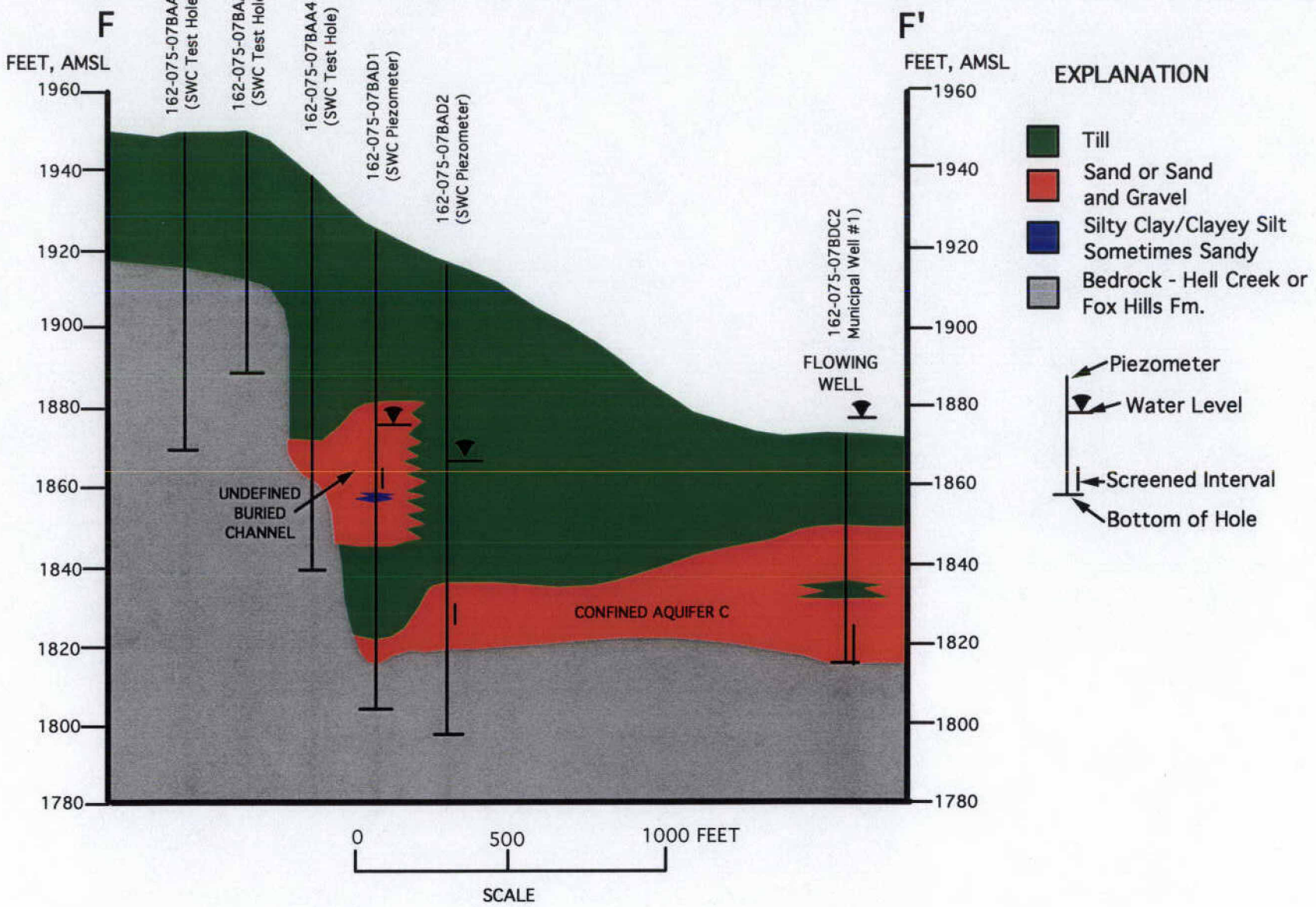

Figure 6. -- Geohydrologic section F-F' showing confined aquifer C and an undefined buried channel in the Botttineau aquifer

CONFINED AQUIFER F

Confined aquifer F appears to be a northeast-southwest trending buried channel comprised of sand and gravelly sand. The width of this buried channel aquifer is unknown, but it is estimated to be at least 450 feet wide in the NW1/4NW1/4 of Section 7. Confined aquifer F was encountered at test holes 7BBB1, 7BBB3, 7BBB4, 7BBB5, and 7BBB6. The unused commercial well located at 7BBB2 and the domestic well (Norman Getzlaff) located at 6CCC also are completed in confined aquifer F.

Confined Aquifer F – Water Chemistry

Based on two ground-water samples collected at well 7BBB2, and one sample each from wells 7BBB4 and 6CCC, ground water in confined aquifer F is a calcium-bicarbonate to calcium-sulfate type (fig. 7). The range and mean values of selected ions, dissolved solids, and hardness and USEPA secondary maximum contaminant levels (SMCL) are shown in table 1. SMCLs are non-enforceable recommended standards. Values exceeding SMCL are not considered a health hazard. Ground water in confined aquifer F exceeds SMCL for sulfate, iron, manganese, and dissolved solids.

Trace element analyses were also conducted on the above four water samples. Each analysis included selenium, lead, mercury, arsenic, lithium, molybdenum, strontium, and uranium. Concentrations of these trace elements and USEPA primary maximum contaminant levels (MCLs) are shown in table 2. None of the trace elements analyzed exceed MCL.

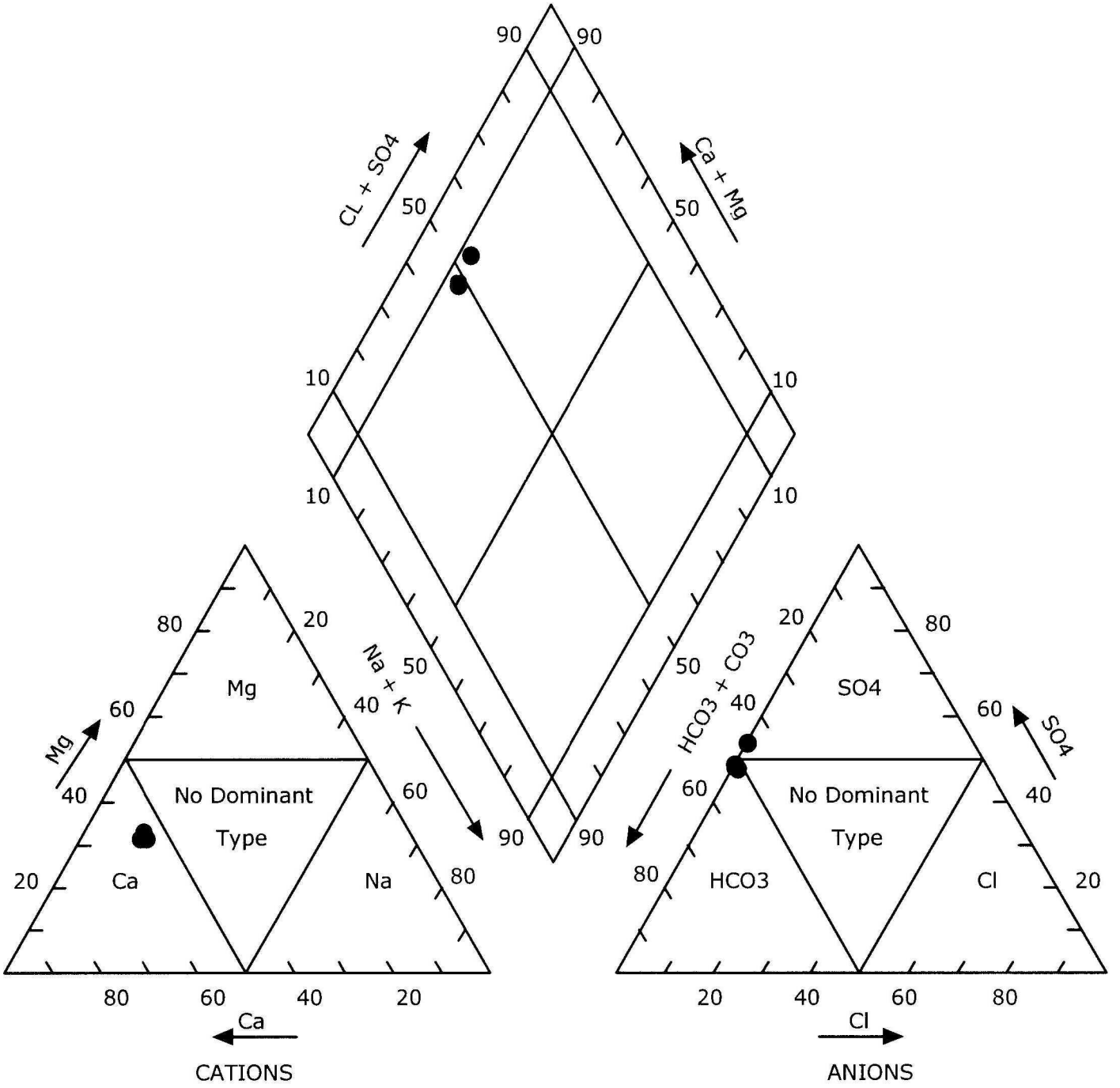

Figure 7. -- Relative distribution of major ions in ground water from confined aquifer F of the Bottineau aquifer system

Table 1. -- Range and mean values of selected ions, dissolved solids, and hardness in confined aquifer F and USEPA secondary maximum contaminant levels.

	Range (mg/L)	Mean (mg/L)	SMCL[1] (mg/L)
Calcium	200-216	211	N/A
Magnesium	75-81	77.9	N/A
Sodium	50-60	55.3	N/A
Potassium	8-8.5	8.3	N/A
Bicarbonate	486-590	564	N/A
Sulfate	437-470	453	250
Chloride	3.7-4.5	4.0	250
Iron	0.71-1.81	1.43	0.3
Manganese	1.31-1.85	1.53	0.05
Dissolved Solids	1050-1120	1090	500
Hardness	810-867	849	N/A

1. USEPA secondary maximum contaminant level.

Table 2. -- Concentrations of selected trace elements from ground water in confined aquifer F and USEPA primary maximum contaminant levels.

Well Location	Selenium	Lead	Mercury	Arsenic	Lithium	Molybdenum	Strontium	Uranium
	micrograms per liter							
162-075-06CCC	<1	<1	<0.2	5.08	152	1.21	1120	3.91
162-075-07BBB2 (10/9/01)	3	2	0	2	130	2	1030	6
162-075-07BBB2 (9/3/03)	<1	<1	<0.2	<1	146	1.66	1060	6.22
162-075-07BBB4	<1	<1	<0.2	<1	148	<1	1080	3.05
USEPA PMCL[1.]	50	15[2.]	2	10	N/A	N/A	N/A	30[3.]

1. U.S. Environmental Protection Agency Primary Maximum Contaminant Level.
2. Lead is regulated by a treatment technique that requires systems to control the corrosiveness of their water. If more than 10% of tap water exceeds an action level of 15 ug/L water, systems must take additional steps.
3. Effective 12/8/03.

Confined Aquifer F – Estimated Well Yield

A piezometer was completed in confined aquifer F at test hole site 162-075-07BBB4. The thickest, coarsest section of confined aquifer F was found at this drilling site. At piezometer 162-075-07BBB4, confined aquifer F consists of very fine to very coarse sands and gravelly sands from 28 to 74 feet below land surface. The aquifer is confined by an upper layer of till from 6 to 28 feet below land surface.

On September 3, 2003, the water level in piezometer 162-075-07BBB4 was measured at 7.30 feet below land surface. Based on an aquifer interval from 28 to 74 feet and a static water level of 7.30 feet, the total head above the base of the aquifer at this site in confined aquifer F is 66.7 feet.

Visual examination of the drill cuttings indicate the bottom 20 feet of the aquifer (54 to 74 feet below land surface) consists primarily of fine sand. This corresponds to a well screen slot size ranging from about 0.010 to 0.012 inches (#10- to #12-slot). The transmitting capacity of 8-inch diameter, pipe size, Johnson High-Q, #10-slot stainless-steel well screen is 14.1 gallons per minute per foot of screen and the transmitting capacity of 8-inch diameter, pipe size, Johnson High-Q, #12-slot, stainless-steel well screen is 16.5 gallons per minute per foot of screen. For 20-foot lengths of #10- and #12-slot screens total transmitting capacity is 282 gallons per minute and 330 gallons per minute, respectively.

Based on previous experience in designing shallow wells in similar aquifer materials in the Oakes aquifer, a well constructed at this site should include a properly designed filter pack to be inserted around the well screen. The well screen slot size should then be increased above the 0.010- to 0.012-slot size to accommodate the coarser texture of the filter pack. Installation

of a properly designed filter pack, in conjunction with appropriate well development procedures, will increase well specific capacity and associated well yield.

Based on test drilling in the NW1/4NW1/4 of Section 7, the limiting factor determining well yield is aquifer geometry. Confined aquifer F was encountered at test holes 7BBB1, 7BBB3, 7BBB4, 7BBB5, and 7BBB6. Confined aquifer F was also encountered at commercial well 7BBB2 and domestic well 6CCC. Test hole 7BBA3 is located 250 feet east of piezometer 7BBB4 (described above). No interval of confined aquifer F was encountered at 7BBA3. Thus, the eastern margin of this buried aquifer is less than 250 feet east of 7BBB4. Test-drilling data is not available west of the NW corner of Section 7 to determine the location of the western margin of confined aquifer F. Therefore, the width of buried channel aquifer F is unknown. Available test-drilling data indicates confined aquifer F is at least 450 feet wide. The narrower the aquifer, the smaller the maximum sustained well yield. The only way to accurately determine long-term sustained well yield is to install a large diameter test well and conduct an aquifer test (pumping test) for two to four days. Based on available data, a long-term sustained well yield of between 50 to 100 gallons per minute appears possible from a properly completed well in confined aquifer F located in the NW1/4NW1/4NW1/4 of Section 7.

CONFINED AQUIFER C

Confined aquifer C appears to be a northeast-southwest trending buried channel comprised of sand and gravelly sand. The width of this buried channel is unknown.

Municipal well #1 is completed in confined aquifer C. Piezometer 7BAD2 also appears to be completed in confined aquifer C (fig. 6). The sand and gravel intervals at

municipal well #1 and 7BAD1 occur at the same elevation. The water level elevation in 7BAD2 measured in September 3, 2003, was 1867.2 feet AMSL. The "static" water level measured in municipal well #1 in November 2001, was 1876.7 feet AMSL. Municipal well #1 had not been pumping for about two months. The water level at piezometer 7BAD2 is 9.5 feet lower than that measured at municipal well #1. However, during the summer of 2003, municipal well #1 was pumped almost continuously prior to measuring the water level in piezometer 7BAD2 on September 3, 2003. As a result, the pumping level in municipal well #1 probably is significantly lower than the water level measured in this well in November 2001 and also significantly lower than the water-level elevation measured in piezometer 7BAD2 on September 3, 2003.

The basal sand and gravel interval from 103 to 109 feet encountered at piezometer 7BAD1 also occurs at the same elevation as the sand and gravel intervals in piezometer 7BAD2 and municipal well #1. Thus, it appears this basal 6-foot interval of sand and gravel is part of confined aquifer C.

Geohydrologic section F-F' indicates upper sand and gravel intervals at test hole 7BAA4 and piezometer 7BAD1 (fig. 6). The water level in piezometer 7BAD1 is 8.7 feet higher than that measured in piezometer 7BAD2 on September 3, 2003. These two piezometers are 200 feet apart. The horizontal hydraulic gradient is 0.044 feet per foot, which is too large if a relatively good hydraulic connection exists between the upper sand and gravel interval at 7BAD1 and the lower sand and gravel interval of 7BAD2. Thus, it appears the upper sand and gravel intervals at 7BAA4 and 7BAD1 are associated with an undefined discrete buried channel aquifer.

Confined Aquifer C – Water Chemistry

Based on chemical analyses of four ground-water samples collected at municipal well #1 (7BDC2) over a period from August 1979 through November 2001 and one ground-water sample collected at piezometer 7BAD2, ground water in confined aquifer C is a calcium-bicarbonate to calcium-sulfate type (fig. 8). The range and mean values of selected ions, dissolved solids, and hardness and USEPA secondary maximum contaminant levels (SMCL) are shown in table 3. SMCLs are non-enforceable recommended standards. Values exceeding SMCL are not considered a health hazard. Ground water in confined aquifer C exceeds SMCL for sulfate, iron, manganese, and dissolved solids.

Trace element analyses were also conducted on one sample collected from municipal well #1 on November 16, 2001 and from piezometer 7BAD2 on September 3, 2003. Each analysis included selenium, lead, mercury, arsenic, lithium, molybdenum, strontium, and uranium. Concentrations of these trace elements and USEPA primary maximum contaminant levels (MCLs) are shown in table 4. None of the trace elements shown in table 4 exceed MCL.

Confined Aquifer C – Estimated Well Yield

A piezometer was completed in what is believed to be confined aquifer C at 162-075-07BAD2. At piezometer 162-075-07BAD2, confined aquifer C consists of about 50 percent medium to very coarse, predominantly coarse to very coarse sand and about 50 percent gravel predominantly 1/8- to 1/4-inch in diameter. The aquifer is confined by an upper layer of till from land surface to a depth of 83 feet.

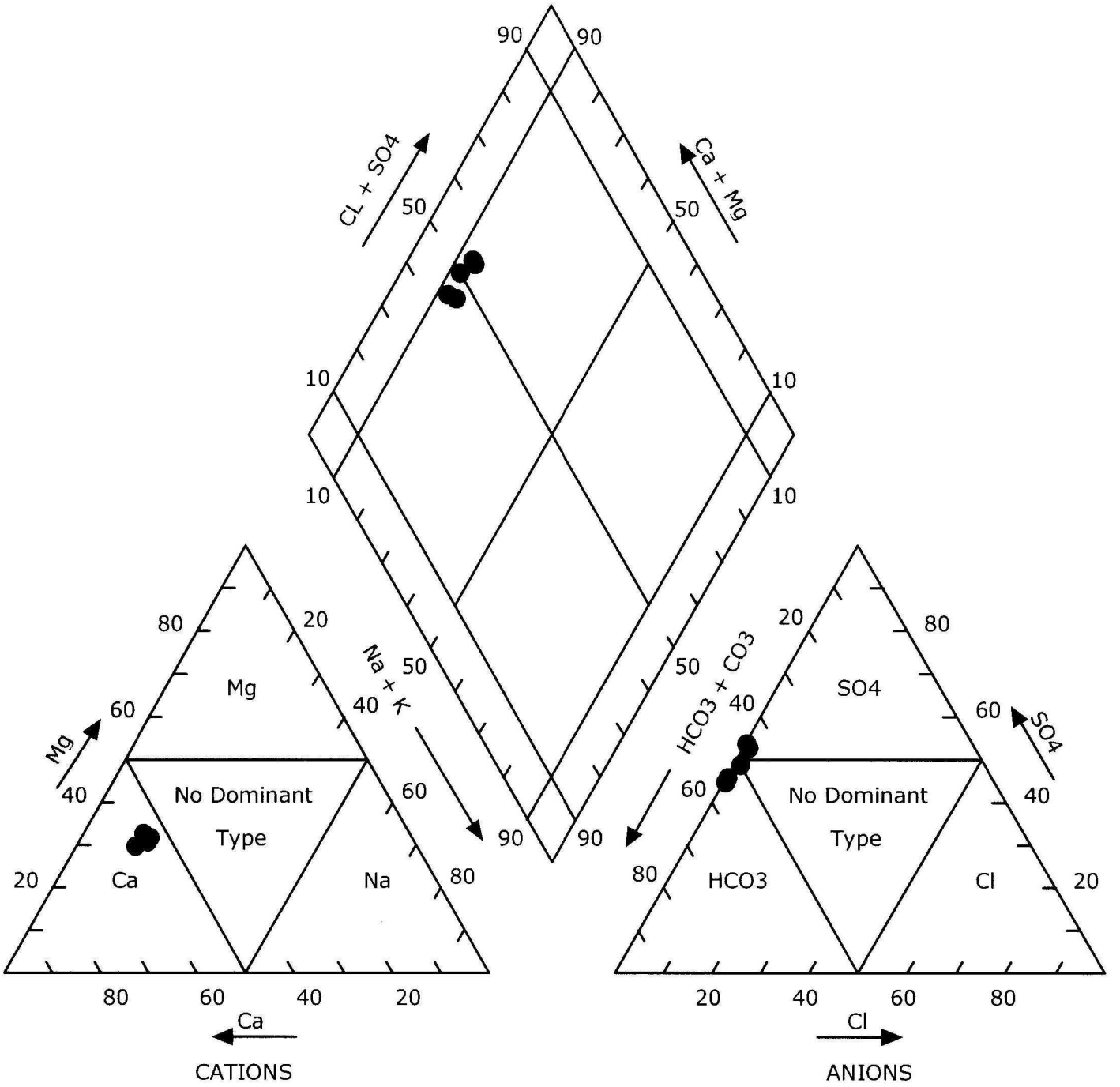

Figure 8. -- Relative distribution of major ions in ground water from confined aquifer C of the Bottineau aquifer system

Table 3. -- Range and mean values of selected ions, dissolved solids, and hardness in confined aquifer C and USEPA secondary maximum contaminant levels.

	Range (mg/L)	Mean mg/L)	SMCL[1] (mg/L)
Calcium	200-210	204	N/A
Magnesium	66-69	73	N/A
Sodium	46-60.6	53	N/A
Potassium	7.3-8.3	8.0	N/A
Bicarbonate	481-613	556	N/A
Sulfate	390-480	443	250
Chloride	0.4-8.9	4.9	250
Iron	0.76-5.4	1.91	0.3
Manganese	1.6-1.9	1.8	0.05
Dissolved Solids	1040-1140	1090	500
Hardness	770-850	809	N/A

1. USEPA secondary maximum contaminant level.

Table 4. -- Concentrations of selected trace elements from ground water in confined aquifer C and USEPA primary maximum contaminant levels.

Well Location	Selenium	Lead	Mercury	Arsenic	Lithium	Molybdenum	Strontium	Uranium
	micrograms per liter							
162-075-07BDC2 (Municipal Well #1) (11/16/01)	1.0	<1	<1	2.0	140	<1	1000	19.0
162-075-07BAD2 (9/3/03)	1.0	1.0	0.2	2.45	147	1.13	1030	12.1
USEPA PMCL[1]	50	15[2]	2	10	N/A	N/A	N/A	30[3]

1. U.S. Environmental Protection Agency Primary Maximum Contaminant Level.

2. Lead is regulated by a treatment technique that requires systems to control the corrosiveness of their water. If more than 10% of tap water exceeds an action level of 15 ug/L water, systems must take additional steps.

3. Effective 12/8/03.

On September 3, 2003, the water level was measured at 49.40 feet below land surface. Given the base of the aquifer at 98 feet and a static water level of 49.40 feet below land surface, the total head above the base of the aquifer at this site in confined aquifer C is 49.4 feet.

Based on a visual examination of the drill cuttings of the aquifer materials from 83 to 98 feet, it appears at least a 50-slot (0.050 inch) screen could be used in the construction of a well at this site. The transmitting capacity of 8-inch diameter, pipe size, Johnson High-Q, #50-slot stainless-steel well screen is 45.6 gallons per foot of screen. For a 15-foot length of screen the total transmitting capacity amounts to 684 gallons per minute.

A production well constructed at this site may require a properly designed filter pack to be inserted around the well screen. Installation of a properly designed filter pack in conjunction with appropriate well development procedures will increase well specific capacity and associated well yield.

Based on test drilling in the NW1/4 of Section 7, the limiting factor determining well yield in confined aquifer C is aquifer geometry (width of the buried channel). Confined aquifer C was encountered at test hole sites 162-075-07BAD1 and BAD2. The location of the southeastern flank of confined aquifer C is not known. As a result, the width of the buried aquifer channel is unknown. It is probably less than about 800 feet in width.

In addition, as previously mentioned, it appears municipal well #1 (near the water tank) is also completed in confined aquifer C. If so, mutual well interference will also be an important constraint on the maximum sustained well yield at the proposed drilling site at 162-075-07BAD2.

The only way to accurately determine long-term sustained well yield at the above site is to install a large diameter test well and conduct an aquifer test (pumping test) for two to four days. Based on available data, a long-term sustained well yield of between 50 to 100 gallons per minute appears possible from a properly completed well at 162-075-07BAD2.

CONFINED AQUIFER D – NOBLE WELL SITE

Confined aquifer D was delineated based on test drilling completed by Simpson and Son Drilling in 1939 and 1980 (see geohydrologic section C-C' and Simpson test holes TH39-6 and TH80-7 in North Dakota Ground Water Study Number 109). In the above study it was inconclusive as to whether the aquifer interval in TH39-6 and the upper aquifer interval in TH80-7 formed a discrete buried confined aquifer (confined aquifer D) or were part of a southeast extension of confined aquifer A. The elevations of the aquifer intervals and estimated water-level elevations in both confined aquifer A and confined aquifer D are about the same. If a test well is installed at piezometer 162-075-07ADD4 (confined aquifer D) and test pumped it will be possible to determine if that aquifer interval is a discrete buried channel aquifer (confined aquifer D) or if it is part of confined aquifer A.

The drilling log for piezometer 162-075-07ADD4 indicates an interval of stratified coarse to very coarse sand (20-30%) and 1/8- to 1/4-inch diameter gravel (70-80%) from 31 to 47 feet. It appears this sand and gravel is the same aquifer interval in which the Noble well is completed. The Noble well is located about 25 feet north of piezometer 162-075-07ADD4. Shortly after installing piezometer 162-075-07ADD4, Mr. Keith Fulsebakke, Bottineau Municipal Works Supervisor, shut-in the flowing Nobel well and measured an almost instantaneous water-level rise in piezometer 162-075-07ADD4. This indicates the Noble

well, for which no driller's log exists, is completed in the same aquifer as piezometer 162-075-07ADD4. Based on available test drilling data in the study area, it is not possible to determine the geometry (in particular, the width) of this buried channel aquifer.

Confined Aquifer D – Water Chemistry

At this point in time, it is assumed the Noble well (162-075-07ADD1) and piezometer 162-075-07ADD4 are both completed in a discrete aquifer (confined aquifer D). Based on chemical analyses of four ground-water samples collected at the Noble well (162-075-07ADD1) and chemical analyses of two ground-water samples collected at piezometer 162-075-07ADD4, ground water in confined aquifer D is a calcium-bicarbonate type (fig. 9). The range and mean values of selected ions, dissolved solids, and hardness and USEPA secondary maximum contaminant levels (SMCL) are shown in table 5. SMCLs are non-enforceable recommended standards. Values exceeding SMCL are not considered a health hazard. Ground water in confined aquifer D exceeds SMCL for sulfate, ion, manganese, and dissolved solids.

Trace element analyses were also conducted on two samples collected from the Noble well and piezometer 162-075-07ADD4. Each analysis included selenium, lead, mercury, arsenic, lithium, molybdenum, strontium, and uranium. Concentrations of these trace elements and USEPA primary maximum contaminant levels (MCLs) are shown in table 6. None of the trace elements shown in table 6 exceed MCL.

On October 29, 2002, a filtered and acidified sample from the Noble well indicated a uranium concentration of 19.6 µg/L. On August 5, 2003, a raw sample collected by Keith Fulsebakke and sent to the ND Department of Health lab indicated a uranium concentration of 17.8 µg/L. A filtered and acidified sample collected on September 3, 2003 from the newly constructed piezometer (162-075-07ADD4) located about 25 feet south of the Noble well

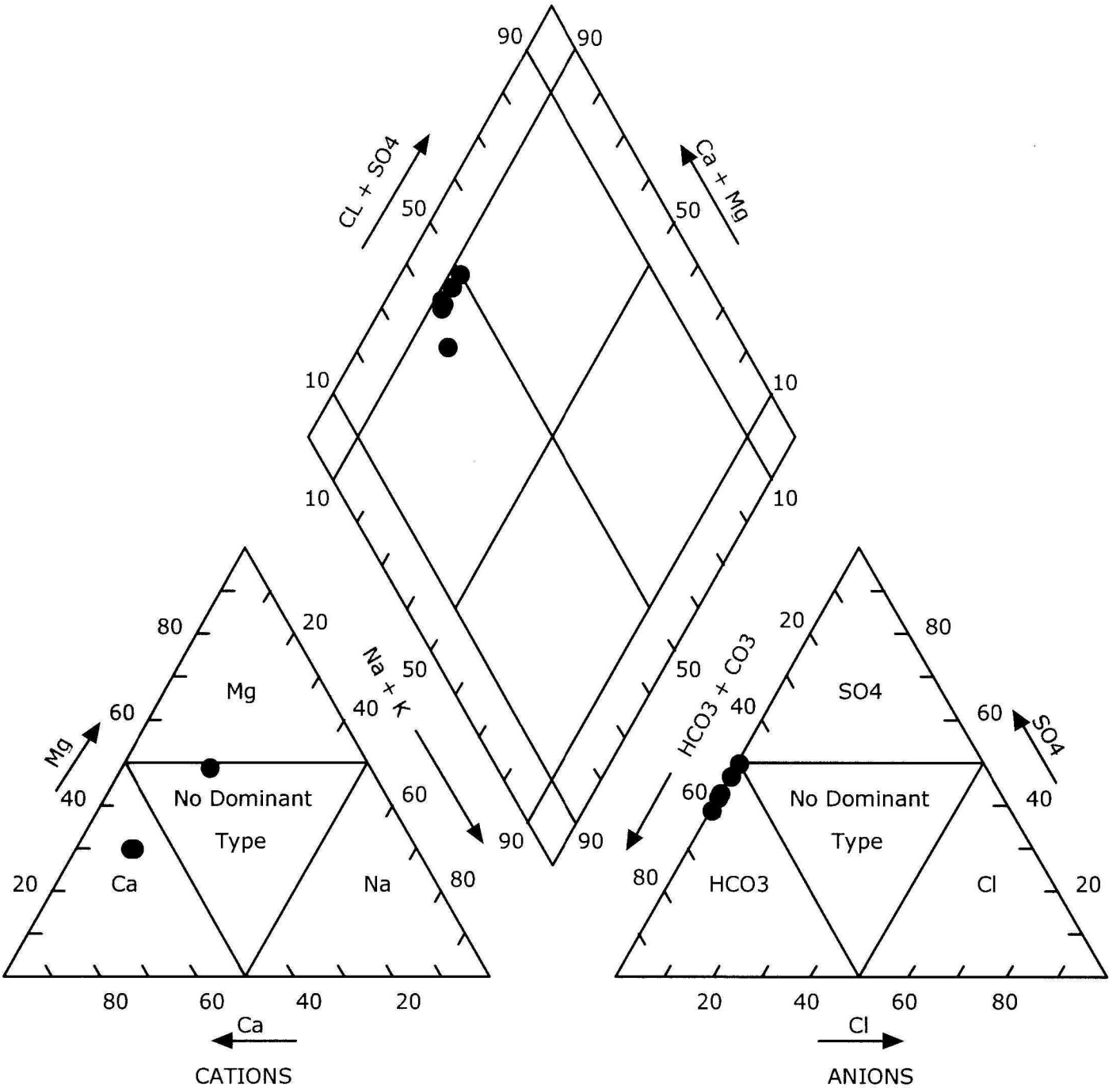

Figure 9. -- Relative distribution of major ions in ground water from confined aquifer D (Noble well area) of the Bottineau aquifer system

Table 5. -- Range and mean values of selected ions, dissolved solids, and hardness in confined aquifer D and USEPA secondary maximum contaminant levels.

	Range (mg/L)	Mean mg/L)	SMCL[1] (mg/L)
Calcium	182-201	191	N/A
Magnesium	58-66	62	N/A
Sodium	41-47	44	N/A
Potassium	7.1-8.3	7.9	N/A
Bicarbonate	460-598	527	N/A
Sulfate	335-370	356	250
Chloride	3.7-4.2	3.9	250
Iron	0.07-1.55	0.80	0.3
Manganese	1.78-1.99	1.88	0.05
Dissolved Solids	920-983	951	500
Hardness	695-775	732	N/A

1. USEPA secondary maximum contaminant level.

Table 6. -- Concentrations of selected trace elements from ground water in confined aquifer D and USEPA primary maximum contaminant levels.

Well Location	Selenium	Lead	Mercury	Arsenic	Lithium	Molybdenum	Strontium	Uranium
	micrograms per liter							
162-075-07ADD1 (Noble Well) (10/29/02)	<1	<1	0.0	<1	110	4	800	19.6
162-075-07ADD1 (Noble Well) (10/ 23/ 03)	1.1	<1	<0.2	4.17	101	3.36	727	19.3 18.3[4]
162-075-07ADD4 (SWC Obs. Well) (9/3/03)	<1	<1	<0.2	<1	128	3.11	899	24.1
162-075-07ADD4 (SWC Obs. Well) (10/23/03)	<1	<1	<0.2	1.31	90	3.26	635	21.2 21.0[4]
USEPA PMCL[1]	50	15[2]	2	10	N/A	N/A	N/A	30[3]

1. U.S. Environmental Protection Agency Primary Maximum Contaminant Level.
2. Lead is regulated by a treatment technique that requires systems to control the corrosiveness of their water. If more than 10% of tap water exceeds an action level of 15 ug/L water, systems must take additional steps.
3. Effective 12/8/03.
4. Uranium analysis performed on a "raw," unfiltered, non-acidified water sample

indicated a uranium concentration of 24.1 µg/L. The smallest uranium concentration is associated with a raw, untreated sample. It is possible that some uranium may have precipitated prior to analysis, thus indicating a lower than actual dissolved uranium concentration.

To evaluate this hypothesis, both the Noble well and piezometer 162-075-07ADD4 were re-sampled on October 23, 2003. For each well both a raw, untreated, and a filtered/acidified sample were collected for uranium analysis to evaluate potential sample bias relating to uranium concentration. The results are shown in table 6. The differences in uranium concentrations between the raw and filtered/acidified samples are small suggesting sample bias is insignificant with regard to the raw, untreated water samples.

Uranium concentrations are larger for ground-water samples collected from piezometer 162-075-07ADD4 as compared to those collected from the nearby Noble municipal well (table 6). It is possible that the differences are due to "chemical stratification" within the buried aquifer channel. The intake area (well screen) of the Noble well probably extends over most, if not all, of the aquifer thickness, whereas the intake area (well screen) for piezometer 162-075-07ADD4 only extends near the bottom five feet of the aquifer from 42 to 47 feet below land surface. The base of the aquifer may be characterized by larger concentrations of uranium.

Confined Aquifer D – Estimated Well Yield

A piezometer was completed in confined aquifer D at 162-075-07BAD2. At this site the aquifer consists of 70 to 80 percent gravel mostly 1/8- to 1/4-inch diameter and about 20

to 30 percent coarse to very coarse sand from 31 to 47 feet below land surface. The aquifer is confined by an upper layer of till from land surface to a depth of 31 feet.

On September 3, 2003, the water level was measured at 11.14 feet below land surface in piezometer 162-075-07ADD4. At the time of measurement, the Noble well located about 25 feet north of this piezometer was flowing into a buried discharge pipe that conveys water to the municipal water tank. The flowing discharge rate was measured by Keith Fulsebakke at 48 gallons per minute. As previously mentioned, the Noble well was temporarily shut-in and the water level began to rise in piezometer 162-075-07ADD4. The "static" water level at piezometer 162-075-07ADD4 is estimated to be at land surface. Given the base of the aquifer at 47 feet and a static water level at land surface, the total head above the base of the aquifer at of this site in confined aquifer D is 47 feet.

Based on a visual examination of the drill cuttings of the aquifer materials from 31 to 47 feet, it appears at least a 50-slot (0.050 inch) screen should be used in the construction of a well at this site. The transmitting capacity of 8-inch diameter, pipe size, Johnson High-Q, #50-slot, stainless-steel well screen is 45.6 gallons per minute per foot of screen. For a 16-foot length of screen, the total transmitting capacity amounts to 730 gallons per minute.

A production well constructed at this site may require a properly designed filter pack to be inserted around the well screen. Installation of a properly designed filter pack in conjunction with appropriate well development procedures will increase well specific capacity and associated well yield.

As with the other two proposed production well sites, the limiting factor determining well yield is aquifer geometry (width of the buried channel). With available data, it is not possible to determine aquifer width and extent. In addition, as previously mentioned, it is not

clear if site 162-075-07ADD4 and the Noble well are completed in a discrete confined aquifer (confined aquifer D) or if the aquifer intervals in which piezometer 162-075-07ADD4 and the Noble well are completed are part of confined aquifer A. If the latter is true, the maximum sustained well yield at 162-075-07ADD4 will be limited somewhat by interference caused by pumping municipal wells #4 and #6.

The only way to accurately determine long-term sustained well yield at 162-075-07ADD4 will be to install a large diameter test well and conduct an aquifer test (pumping test) for two to four days. Based on available data, a long-term sustained well yield of about 75 to 100 gallons per minute appears possible from a properly completed well at 162-075-07ADD4.

RECOMMENDATIONS

The August 2003 test drilling/piezometer installation program completed in the N1/2 of Section 7, Township 162 North, Range 75 West indicated three sites where additional ground-water development is feasible. These areas are:

1. 162-075-07ADD4 – about 25 feet south of the Noble well.
2. 162-075-07BAD2 – north of the Gordon Hall farmstead on the east side of the north-south gravel access road to the farmstead.
3. Near 162-075-07BBB4 – the northwest corner of the NW1/4 of Section 7.

It is estimated that properly completed wells in these three areas could provide long-term sustained yields of at least 50 to 100 gallons per minute. To accurately determine maximum sustained well yields, test wells need to be installed at/near the three sites and two- to four-day pumping tests need to be conducted on each of the three test wells. This can be

accomplished in the next phase of the cooperative study between the city of Bottineau and the State Water Commission.

Chemical analyses of water samples collected at each of the three sites indicate USEPA secondary maximum contaminant levels are exceeded for iron, manganese, sulfate, and dissolved solids. Uranium is below USEPA primary maximum contaminant level at all three sites. It appears the larger uranium concentration at piezometer 162-075-07ADD4 as compared to that from the Noble well may be due to "chemical stratification" within the buried aquifer channel. The intake area (well screen) of the Noble well probably extends over most of the aquifer thickness whereas the intake area (well screen) for piezometer162-075-07ADD4 only extends over the bottom five feet of the aquifer from 42 to 47 feet below land surface. The base of the aquifer may be characterized by larger concentrations of uranium.

It is important to note that increased pumping at each of the above three sites may result in increased concentrations of dissolved solids. The major concern is increased concentrations of uranium, which could exceed the USEPA primary maximum contaminant level of 30 ug/L. However, uranium concentrations at sites 162-075-07BAD2 and 162-075-07BBB4 are well below the USEPA primary maximum contaminant level for uranium. If the uranium primary maximum contaminant level is exceeded in the future from a production well completed at 162-075-07ADD4 (Noble well area) ground water could be blended with ground water pumped from other buried channel aquifers in the area (confined aquifers A, C, and F), which are characterized by smaller uranium concentrations.

Another important consideration in prioritizing the development of production wells at the three recommended sites is distance to existing buried water transmission pipelines that lead to the water tank. Site 162-075-07ADD4 is within about 25 feet from the existing Noble

well and the associated buried pipeline. A well located at 162-075-07BAD2 would be about 900 feet north of the buried pipeline leading to the water tank. A well located at/near 162-075-07BBB4 would be about 2,300 feet northwest of the nearest pipeline leading to the water tank.

Based on well yield, water quality, and construction of additional buried pipelines, a production well located at/near 162-075-07ADD4 (Noble well area) would be the first priority, a production well located at/near 162-075-07BAD2 (just north of the Gordon Hall farmstead) would be the second priority, and a production well located at/near 162-075-07BBB4 (northwest corner of the NW1/4 of Section 7) would be the third priority.

APPENDIX I

Lithologic Logs of Wells, Piezometers and Test Holes

162-075-06CCC
Norman Getzlaff

Date Completed:	05/16/1994	Purpose:	Domestic Well
L.S. Elevation (ft):	N/A	Well Type:	4 in. - Steel
Depth Drilled (ft):	80	Aquifer:	Bottineau
Screen Int. (ft.):	65-69	Data Source:	

Completion Info:

Remarks:

Lithologic Log

Depth (ft)	Unit	Description
0-1	TOPSOIL	
1-15	CLAY	yellow
15-70	CLAY	blue with sand strips
50-70	SAND	coarse, blue, shale
70-80	CLAY	blue

162-075-07AAA
NDSWC 8-738

Date Completed:	05/21/1962	Purpose:	Test Hole
L.S. Elevation (ft):	2061		
Depth Drilled (ft):	94		
		Data Source:	

Completion Info:

Remarks: NDSWC-8 738

Lithologic Log

Depth (ft)	Unit	Description
0-2	TOPSOIL	black
2-26	TILL	clay, silty to gravelly, dark yellowish orange, oxidized, calcareous
26-33	TILL	clay, silty to gravelly, dark yellowish brown, oxidized, calcareous
33-54	TILL	clay, silty to gravelly, dark greenish gray, calcareous
54-58	TILL	as above with layers of fine to coarse sandy gravel
58-63	SILT	dark yellowish brown, partially oxidized, calcareous
63-74	SILT	sandy, olive gray, with layers of very fine to very coarse subrounded sand and fine to coarse subangular gravel
74-82	GRAVEL	fine to medium, clayey to sandy, subrounded
82-91	GRAVEL	fine to medium, clayey to sandy, subrounded
91-94.5	CLAY	very indurated, no samples

162-075-07ABD2
City of Bottineau

Date Completed:	10/18/1983	Purpose:	Municipal Well
L.S. Elevation (ft):	1990	Well Type:	8 in. - Steel
Depth Drilled (ft):	80	Aquifer:	Bottineau
Screen Int. (ft.):	60-80	Data Source:	

Completion Info:

Remarks: Bottineau Municipal well #6

Lithologic Log

Depth (ft)	Unit	Description
0-3	PEAT	sandy
3-5	TOPSOIL	
5-24	CLAY	yellow
24-51	CLAY	blue
51-79	SAND	medium to coarse
79-83	CLAY	blue

162-075-07ADD2
City of Bottineau

Date Completed:	1939	Purpose:	Observation Well
L.S. Elevation (ft):	1985	Well Type:	10 in. - Steel
Depth Drilled (ft):	54	Aquifer:	Bottineau
Screen Int. (ft.):	48-54	Data Source:	Simpson & Sons, Bisbee, ND

Completion Info:

Remarks: Test well installed 10 feet east of Noble house, both of which have been removed. This test well probably is within 25 to 50 feet of existing Noble well and therefore the log of this well is representative of the Noble well site where no log is available.

Lithologic Log

Depth (ft)	Unit	Description
0-2	TOPSOIL	
2-16	CLAY	yellow
16-35	CLAY	gravelly, blue
35-54	SAND & GRAVEL	
54-54.5	CLAY	blue

162-075-07ADD4
NDSWC 15047

Date Completed:	08/28/2003	Purpose:	Observation Well
L.S. Elevation (ft):	1985.5	Well Type:	2 in. - PVC
Depth Drilled (ft):	60	Aquifer:	Bottineau
Screen Int. (ft.):	42-47	Data Source:	

Completion Info:

Remarks:

Lithologic Log

Depth (ft)	Unit	Description
0-16	TILL	clay, silty, sandy, pebbly, soft to mod. hard, plastic, pale yellow-gray-brown, oxidized
16-31	TILL	as above, olive gray, unoxidized
31-47	SAND & GRAVEL	sand (20-30%), cse. to v. cse., and gravel (70-80%), up to 1-inch diam., mostly 1/4-1/8-inch diam., no fines in back of mud tub, clean section, drills as stratified, comprised of silicates, carbonates, shale, quartz, angular to well rounded, mostly well rounded, takes water, mixed 4 bags mud at 40 ft., caving badly
47-58	TILL	clay, as above, olive gray
58-60	SAND & GRAVEL	poor recovery, mud thick, bit slipped fast. * Did not want to drill into deeper aquifer that may have elevated uranium concentrations. This is a test hole for a possible replacement well for the "Noble Well" used by the city of Bottineau

162-075-07BAA1
NDSWC 15041

Date Completed:	08/26/2003	Purpose:	Test Hole
L.S. Elevation (ft):	1950		
Depth Drilled (ft):	80	Data Source:	

Completion Info:

Remarks:

Lithologic Log

Depth (ft)	Unit	Description
0-2	TILL	clay, silty, sandy, pebbly, pale yellow-gray-brown, oxidized, soft, cohesive
2-4	GRAVEL	and cobbles, 1/4 to 2 inches diam., comprised of silicates, carbonates, and shale
4-26	TILL	clay, as above
26-31	TILL	clay, as above, olive gray, unoxidized
31-80	SAND	sequence of silty, clayey, sands, v.fn., silty, sandy, clays and some gray-brown silty, sandy, clays to silty clays, soft to mod. hard, lignite layers from 41 to 42 ft. and 74 to 75 ft., from 60 to 80 ft., mostly greenish-gray sand, v. fn., silty, clayey, soft, cohesive, (Bedrock—Hell Creek – Fox Hills?)

162-075-07BAA2
NDSWC 15031

Date Completed:	08/25/2003	Purpose:	Test Hole
L.S. Elevation (ft):	1950		
Depth Drilled (ft):	140		
		Data Source:	

Completion Info:

Remarks:

Lithologic Log

Depth (ft)	Unit	Description
0-42	TILL	clay, silty, sandy, pebbly, up to 1-inch diam. pebbles, granite, diorite, carbonates, yellow gray-brown with red-yellow stringers, oxidized, cohesive, mod. plastic to sl. brittle, rocks at 26 and 36 ft.
42-61	SAND	v.fn. to fn., silty,clayey,cohesive, pale greenish-gray with some interbedded brown sticky clay (shale), no chatter, no pebbles, good recovery (Bedrock - Hell Creek - Fox Hills?)
61-68	CLAY	greenish-gray to brownish gray, sticky, hard, some ribbon-like cuttings, drills smooth (Bedrock- Hell Creek - Fox Hills?)
68-71	CLAY	dark brown, fissile, softer than above, (Bedrock -- Hell Creek - Fox Hills?)
71-77	SAND	as interval from 61 to 68 ft. (Bedrock -- Hell Creek - Fox Hills?)
77-78	CLAY	as interval from 68 to 71ft. (Bedrock -- Hell Creek - Fox Hills?)
78-81	CLAY	sticky, hard, as interval from 61 to 68 ft. (Bedrock -- Hell Creek - Fox Hills?)
81-82	SAND	v. fn. to fn., silty, clayey, green to grayish green, cohesive, slightly brittle, drills smooth, good recovery, very low k, does not take water. (Bedrock -- Hell Creek - Fox Hills?)
82-83	CLAY	silty, olive gray, sticky, (Bedrock -- Hell Creek - Fox Hills?)
83-103	SAND	as interval from 83 to 103 ft., (Bedrock -- Hell Creek - Fox Hills?)
103-104	LIGNITE	good bit chatter, recovered lignite chips, (Bedrock -- Hell Creek - Fox Hills?)
104-123	CLAY	sequence of olive gray and dark brown sticky hard clays, drills smooth, (Bedrock -- Hell Creek - Fox Hills?)
123-124	LIGNITE	(Bedrock -- Hell Creek - Fox Hills?)
124-128	CLAY	sequence of olive gray and dark brown clays, as from 104 to 123 ft. (Bedrock -- Hell Creek - Fox Hills?)
128-140	CLAY	as interval from 104 to 123 ft., with interbedded v.fn. to fn. clayey, silty, sand, (Bedrock -- Hell Creek - Fox Hills?)

162-075-07BAA3
NDSWC 8/26/03

Date Completed:	08/26/2003	Purpose:	Test Hole
L.S. Elevation (ft):	1950		
Depth Drilled (ft):	60		
		Data Source:	

Completion Info:

Remarks:

Lithologic Log

Depth (ft)	Unit	Description
0-36	TILL	clay, silty, sandy, pebbly, pale yellow-gray-brown, oxidized, soft to mod. hard with depth, cohesive
36-38	CLAY	silty, dark brown, soft, cohesive (Bedrock – Hell Creek - Fox Hills?)
38-60	CLAY	silty, to sl. silty, greenish-gray, hard, sticky, some ribbon-like cuttings, good recovery, (Bedrock –Hell Creek - Fox Hills?)

162-075-07BAA4
NDSWC 15043

Date Completed:	08/26/2003	Purpose:	Test Hole
L.S. Elevation (ft):	1940		
Depth Drilled (ft):	100		
		Data Source:	

Completion Info:

Remarks:

Lithologic Log

Depth (ft)	Unit	Description
0-45	TILL	clay, silty, sandy, pebbly, pale yellow-gray-brown, oxidized, soft to mod. hard with depth
45-68	TILL	clay, as above, olive gray, unoxidized
68-76	SAND & GRAVEL	sand is fn. to v. cse., predom. cse. to v.cse., (40 -50%) and gravel, up to 1-inch diam., mostly 1/4-inch diam., (50-60%), comprised of silicates, carbonates, shale, quartz, angular to well rounded, good clean section, no fines in mud tub, mod. bit chatter, drills as stratified, caving, takes water
76-98	CLAY	silty, to v. sl. silty, greenish-gray, hard, some ribbon-like cuttings, mixed 1 bag mud at 80 ft., upper S&G caving, (Bedrock -- Hell Creek-Fox Hills?)
98-100	SAND	v.fn. to fn., silty, clayey, greenish-gray, soft (Bedrock -- Hell Creek - Fox Hills?)

162-075-07BAB1
NDSWC 15032

Date Completed:	08/25/2003	Purpose:	Test Hole
L.S. Elevation (ft):	1938		
Depth Drilled (ft):	80	Data Source:	

Completion Info:

Remarks:

Lithologic Log

Depth (ft.)	Unit	Description
0-42	TILL	clay, silty, sandy, pebbly, pebbles up to 1-inch diam.,pale yellow-gray-brown, oxidized, yellow stringers, cohesive, mod. plastic, at 27 and 35ft., rocks, from 7 to 8ft., v.fn. to v. cse. sand, predom. cse., sl. gravelly, up to 1/4 -inch diam., yellow stained, oxidized
42-43	CLAY	dark brown, soft to mod. sticky, cohesive, (Bedrock -- Hell Creek - Fox Hills?)
43-55	SAND	v.fn.to fn., silty, clayey, cohesive, pale yellow green to brownish green, soft, oxidized, low k, (Bedrock -- Hell Creek - Fox Hills?)
55-56	CLAY	dark brown, soft, cohesive, mod. sticky, (Bedrock -- Hell Creek -- Fox Hills?)
56-66	CLAY	sequence of oxidized silty clay and v.fn., clayey, silty, sands, yellow green to yellow brown, (Bedrock -- Hell Creek - Fox Hills?)
66-68	CLAY	as interval 55 to 56 ft. (Bedrock -- Hell Creek -- Fox Hills?)
68-69	CLAY	silty, greenish gray, sticky, (Bedrock -- Hell Creek - Fox Hills?)
69-70	SANDSTONE	hard, indurated, yellow stained, oxidized, good bit chatter, (Bedrock -- Hell Creek - Fox Hills?)
70-74	CLAY	as interval from 68 to 69 ft., (Bedrock -- Hell Creek - Fox Hills?)
74-80	SAND	v.fn. to fn., silty, clayey, soft, cohesive, olive gray, low k, (Bedrock -- Hell Creek - Fox Hills?)

162-075-07BAB2
NDSWC 15033

Date Completed:	08/25/2003	Purpose:	Test Hole
L.S. Elevation (ft):	1925		
Depth Drilled (ft):	60		
		Data Source:	

Completion Info:

Remarks:

Lithologic Log

Depth (ft)	Unit	Description
0-18	TILL	clay, silty, sandy, pebbly, pebbles up to 1-inch diam., pale yellow-gray-brown,, yellow stringers, oxidized, cohesive, mod. plastic
18-36	TILL	as above, olive gray, unoxidized
36-38	SAND	v.fn.to fn., silty, clayey, green, soft, cohesive, low k, (Bedrock - Hell Creek - Fox Hills?)
38-60	CLAY	sequence of brown to red-brown clays and olive gray to greenish-gray sandy, silty, clays, (Bedrock -- Hell Creek - Fox Hills?)

162-075-07BAD1
NDSWC 15044

Date Completed:	08/27/2003	Purpose:	Observation Well
L.S. Elevation (ft):	1924.7	Well Type:	2 in. - PVC
Depth Drilled (ft):	120	Aquifer:	Bottineau
Screen Int. (ft.):	61-66	Data Source:	

Completion Info:

Remarks:

Lithologic Log

Depth (ft)	Unit	Description
0-27	TILL	Clay, silty, sandy, pebbly, pale yellow-gray-brown, oxidized, soft, cohesive, mod. plastic, @19ft. rock
27-43	TILL	Clay, as above, olive gray, unoxidized
43-66	SAND	very fine to very cse.,predom. cse., becomes gravelly at aboout 43 to 45 ft., comprised of shale, carbonates, silicates, quartz, subangular to well rounded, very clean section, no fines in back of mud tub, no bit chatter drilled smooth and fast, takes water, mixed 1 bag mud at 45 ft.
66-67	CLAY	or till?, bit slowed , no recovery
67-80	GRAVEL	(70-80%), up to 3/4 inch diam., mostly 1/8 to 1/4 inch, sand cse. to v.cse, good bit chatter, composition as above, subangular to well rounded, no fines in back of mud tub, takes water, caving badly, nice clean section, stratified, mixed 1 bag mud at 70 ft., and 2 bags mud at 80 ft.
80-101	TILL	clay, as above, olive gray, rock at 86 –87ft., upper sand and gravel caving badly, mixed 2 bags mud at 100 ft.
101-103	CLAY	or till?, poor recovery, bit slowed
103-109	SAND & GRAVEL	good bit chatter, large washed cavity above, very poor sample recovery, drilling mud very thick, much into suspension, based on bit chatter this is a coarse, clean section, drills as stratified
109-120	CLAY	very slightly silty, gray brown, hard, sticky, plastic, drills very slow with pull-down, fair sample recovery, (Bedrock -- Hell Creek - FoxHills?)

162-075-07BAD2
NDSWC 15045

Date Completed:	08/27/2003	Purpose:	Observation Well
L.S. Elevation (ft):	1916.6	Well Type:	2 in. - PVC
Depth Drilled (ft):	120	Aquifer:	Bottineau
Screen Int. (ft.):	88-93	Data Source:	

Completion Info:

Remarks:

Lithologic Log

Depth (ft)	Unit	Description
0-25	TILL	clay, silty, sandy, pebbly, pale yellow-gray-brown, oxidized, soft, cohesive
25-83	TILL	clay, as above, unoxidized, sand lens from 27 to 28 ft.
83-98	SAND & GRAVEL	sand (50%), med. to very coarse, predom. cse to v.cse, gravel (50%) up to 1-inch diam., mostly 1/8 to 1/4 inch, comprised of silicates, carbonates, shale, qtz., angular to well rnded, good bit chatter, clean section, takes water, drills as stratified, @ 93-94 ft. bit slowed, clay layer?
98-120	CLAY	Clay, gray brown to greenish gray, hard, greasy, drills slow, some dark brown softer clay at base (Bedrock -- Hell Creek - Fox Hills?)

162-075-07BBA1
NDSWC 15034

Date Completed:	08/25/2003	Purpose:	Test Hole
L.S. Elevation (ft):	1925		
Depth Drilled (ft):	60		
		Data Source:	

Completion Info:

Remarks:

Lithologic Log

Depth (ft)	Unit	Description
0-30	TILL	clay, silty, sandy, pebbly, pale yellow-gray-brown, oxidized, cohesive, mod. plastic, at 2 to 4 ft., sand, v.fn. to v. cse., pred. cse., gravelly, 10-15%, up to 11/2-inch diam., yellow stained, oxidized
30-39	CLAY	sl. silty to silty, olive gray, hard to sl. brittle, to sticky, ribbon-like cuttings, (Bedrock -- Hell Creek - Fox Hills?)
39-41	LIGNITE	moderate bit chatter, good recovery, (Bedrock -- Hell Creek - Fox Hills?)
41-43	CLAY	silty, sl. sticky, hard, olive gray, (Bedrock -- Hell Creek - Fox Hills?)
43-49	CLAY	dark brown, hard, sl. mod. sticky, (Bedrock -- Hell Creek - Fox Hills?)
49-51	CLAY	as interval from 41 to 43 ft., (Bedrock -- Hell Creek - Fox Hills?)
51-60	SAND	v.fn.to fn., silty, clayey, soft, cohesive, low k, does not take water, (Bedrock -- Hell Creek - Fox Hills?)

162-075-07BBA2
NDSWC 15035

Date Completed:	08/25/2003	Purpose:	Test Hole
L.S. Elevation (ft):	1908		
Depth Drilled (ft):	60		
		Data Source:	

Completion Info:

Remarks:

Lithologic Log

Depth (ft)	Unit	Description
0-24	TILL	clay, silty, sandy, pebbly, pale yellow-gray-brown, oxidized, cohesive, moderately plastic, at 2 to 4 ft., sand, v.fn. to v.cse., pred. cse, gravelly, up to 1-inch diam., yellow stained, oxidized, angular to well rounded
24-36	TILL	clay, as above, olive gray, unoxidized
36-50	CLAY	sequence of olive gray to greenish gray silty clays and clayey, silty, sands, clays are sticky, sands are soft, and cohesive, (Bedrock -- Hell Creek - Fox Hills?)
50-51	SANDSTONE	well indurated, very hard drilling, strong chatter, greenish gray chips with green specks, (Bedrock -- Hell Creek - Fox Hills?)
51-60	CLAY	silty, sandy,, sand, v.fn. to fn., olive gray to greenish gray, soft, sl. sticky, (Bedrock -- Hell Creek - Fox Hills?)

162-075-07BBA3
NDSWC 15036

Date Completed:	08/25/2003	Purpose:	Test Hole
L.S. Elevation (ft):	1900		
Depth Drilled (ft):	80	Data Source:	

Completion Info:

Remarks:

Lithologic Log

Depth (ft)	Unit	Description
0-9	SAND	v.fn., v. cse., gravelly, up to 1-inch diam., 10-15% gravel, yellow stained, oxidized, comprised of carbonates, shield silicates, shale, lignite, quartz, sub-angular to well rounded
9-11	TILL	clay, silty, sandy, pebbly, pale yellow-gray-brown, oxidized, soft, cohesive
11-47	TILL	clay, as above, olive gray, unoxidized
47-56	CLAY	silty, dark brown, soft, (Bedrock -- Hell Creek - Fox Hills?)
56-80	CLAY	sequence of interbedded dark brown clays and v. fn to fn., silty, clayey greenish-gray sands, (Bedrock -- Hell Creek - Fox Hills?)

162-075-07BBB1
NDSWC 26-738

Date Completed:	06/19/1962	Purpose:	Test Hole
L.S. Elevation (ft):	1890		
Depth Drilled (ft):	126	Data Source:	

Completion Info:

Remarks: Test Hole 26-738

Lithologic Log

Depth (ft)	Unit	Description
0-3	TOPSOIL	silty, black, organic
3-4	SILT	sandy, olive gray, noncohesive
4-8	GRAVEL	fine to coarse, sandy yellowish brown, subangular to rounded
8-10	TILL	clay, silty, yellowish brown, oxidized, slightly calcareous
10-15	TILL	clay, silty to pebbly, moderate olive brown, oxidized, sligtly calcareous
15-18	SAND	fine to coarse with fine gravel, well rounded
18-32	TILL	clay, silty, grayish olive, cohesive and plastic, slightly calcareous
32-48	SILT	clayey, dark greenish gray, smooth
48-52	GRAVEL	fine to coarse, subangular to subrounded, clean
52-62	SAND	fine to coarse, silty and clayey, angular to subrounded
62-74	SANDSTONE	fine, grayish olive, subangular to rounded, highly indurated, calcareous cement
74-93	CLAY	moderate olive brown, smooth, soapy
93-104	SAND	fine, grayish olive, rounded, well sorted, slightly indurated
104-126	SHALE	silty, dark brown, oily, high organic content, slightly indurated

162-075-07BBB2
Other

Date Completed:	4/1996	Purpose:	Domestic Well
L.S. Elevation (ft):	1892	Well Type:	5 in. - PVC
Depth Drilled (ft):	74	Aquifer:	Bottineau
Screen Int. (ft.):	54-74	Data Source:	

Completion Info:

Remarks: Open casing, drilled for retirement home that is not yet built.

Lithologic Log

Depth (ft)	Unit	Description
0-1	TOPSOIL	
1-3	CLAY	and stones
3-14	SAND & GRAVEL	
14-33	CLAY	yellow
33-55	CLAY	blue
55-57	LIGNITE	and stones
57-71	SAND	coarse, and fines
71-74	CLAY	dark

162-075-07BBB3
NDSWC 15038

Date Completed:	08/26/2003	Purpose:	Test Hole
L.S. Elevation (ft):	1880		
Depth Drilled (ft):	80	Data Source:	

Completion Info:

Remarks:

Lithologic Log

Depth (ft)	Unit	Description
0-6	TILL	clay, silty, sandy, pebbly, pale yellow-gray-brown, oxidized, soft, cohesive
6-29	CLAY	as above, olive gray, unoxidized
29-36	SAND	v.fm., to fn., silty,good recovery, drills fairly slow, smooth, appears yellow brown, oxidized.
36-37	SAND	as above, but med. to cse.
42-71	CLAY	sequence of brown silty clays, greenish gray, clayey, sandy, v.fn., silty, and harder greenish-gray silty clays, (Bedrock -- Hell Creek - Fox Hills?)
71-77	LIGNITE	small black chips, good recovery
77-80	CLAY	silty, greenish-gray, (Bedrock -- Hell Creek - Fox Hills?)

162-075-07BBB4
NDSWC 15037

Date Completed:	08/26/2003	Purpose:	Observation Well
L.S. Elevation (ft):	1894.9	Well Type:	2 in. - PVC
Depth Drilled (ft):	100	Aquifer:	Bottineau
Screen Int. (ft.):	69-74	Data Source:	

Completion Info:

Remarks:

Lithologic Log

Depth (ft)	Unit	Description
0-6	SAND	(50%), v.f. to v. cse. and gravel (50%) up to 1-inch diam., subangular to well rounded, comprised of carbonates, shale, silicates, quartz, yellow stained, oxidized
6-13	TILL	clay, silty, sandy, pebbly, up to 1-inch diam. pebbles, pale yellow-grray-brown, soft, oxidized
13-28	TILL	clay, as above, olive gray, unoxidized
28-40	SAND	v. fn. to v. cse., predom. medium, subangular to well rounded, comprised of silicates, carbonates, shale, quartz, lignite, no bit chatter, drilled smooth and fast, good recovery, no fines in back of mud tub
40-46	SAND	v.fn. to v. cse., predom. med. to cse, gravelly (5-10%), up to 1/4-inch diam., mostly less than 1/8-inch diam., drills smooth and fast, no bit chatter, good recovery, composition as above, no fines in back of mud tub
46-51	SAND	as in interval from 40 to 46 Ft., possibly a little coarser section, slight to moderate bit chatter, drills as stratified
51-74	SAND	v.fn to v.cse., predom. fn. to med. no gravel, composition as above, drills smooth and fast, no fines in back of mud tub
74-82	SAND	as in interval from 51 to 74, but possibly interbedded with silty, sandy, clays, poor clay recovery, bit still moved relatively fast, occas. slower interval
82-88	SAND	v.fn. to fn., silty, clayey, greenish gray, soft, poor sample recovery, bit slowed somewhat (Bedrock -- Hell Creek - Fox Hills?)
88-100	CLAY	silty, dark brown, soft, sl. greasy, bit slowed, good sample recovery (Bedrock -- Hell Creek - Fox Hills?)

162-075-07BBB5
NDSWC 15039

Date Completed:	08/26/2003	Purpose:	Test Hole
L.S. Elevation (ft):	1878		
Depth Drilled (ft):	60	Data Source:	

Completion Info:

Remarks:

Lithologic Log

Depth (ft)	Unit	Description
0-2	TILL	clay, silty, sandy, pebbly, yellow-gray-brown, soft, cohesive
2-4	SAND	v.fn., to v.cse., predom. med. to cse., gravelly, up to 1-inch diam.
4-11	TILL	clay, as above
11-14	TILL	clay, as above, olive gray, unoxidized
14-21	TILL	clay, as above, olive gray to gray brown
21-49	SAND	v.fn.to med., predom. fn. to v.fn., soupy intervals, possible interbedded silty, sandy, clay layers, poor recovery, good sand recovery, does not take water, not a very clean section
49-55	SAND	v.fn., to cse., predom. fn. to med., clean section, bit moved faster, comprised of carbonates, shale, and silicates
55-60	CLAY	silty, dark brown, (Bedrock -- Hell Creek - Fox Hills?)

162-075-07BBB6
NDSWC 15040

Date Completed:	08/25/2003	Purpose:	Test Hole
L.S. Elevation (ft):	1883		
Depth Drilled (ft):	100		
		Data Source:	

Completion Info:

Remarks:

Lithologic Log

Depth (ft)	Unit	Description
0-14	TILL	clay, silty, sandy, pebbly, yellow-gray-brown, oxidized, soft
14-17	TILL	as above, olive gray
17-18	SAND	v.fn. to v. cse., predom. med., yellow stained, oxidized
18-26	TILL	as above, olive gray
26-36	CLAY	silty, sandy to sand, v.fn.to fn., clay, silty, soft, cohesive, yellow-gray-brown to greenish-gray, looks like bedrock
36-40	SAND	v.fn. to cse., predom. fn., clean, sl. gravelly, at 40 ft., comprised of quartz, shale, carbonates, silicates, lignite, subangular to well rounded
40-51	SAND	as above, but coarser section, predom. med. to cse., 5% gravel < 1/4-inch diameter, lots of rounded detrital shale, very light to smooth bit chatter
51-55	SAND	interbedded with gravel, sand as above, sandstone layers?, lots of angular greenish-gray sandstone chips, possibly some interbedded silty clay, moderate bit chatter
55-61	CLAY	silty, sandy, brown, looks like bedrock
61-67	SAND	v.fn. to v.cse., predom. medium, comprised of shale, quartz, silicates, carbonates, bit moved mod. fast, no chatter, good recovery appears to be a clean section
67-77	CLAY	silty, sandy? greenish-gray, bit slowed, looks like bedrock
77-78	SANDSTONE	light greenish-gray, hard, indurated, hard bit chatter, good recovery of sandstone chips
78-80	CLAY	silty, brown, soft, appears like bedrock
80-82	SANDSTONE	as from 77 to 78 ft.
82-89	SAND	v.fn. to med., pedom. fn. to med., clean, good recovery, bit moved moderately fast, composition as from 61 to 67 ft., glaciofluvial not bedrock
89-100	CLAY	silty, dark brown, soft, good recovery, (Bedrock -- Hell Creek - Fox Hills)

162-075-07BDC2
City of Bottineau

Date Completed:	04/25/1968	Purpose:	Municipal Well
L.S. Elevation (ft):	N/A	Well Type:	10 in. - Steel
Depth Drilled (ft):	0	Aquifer:	Bottineau
Screen Int. (ft.):	54.3-63.3	Data Source:	

Completion Info:

Remarks: Bottineau Municipal well #1
MP is top of 1-inch diameter pvc pipe extending 1.28 feet above top of well seal inside manhole.

Lithologic Log

Depth (ft)	Unit	Description
0-0.5	TOPSOIL	
0.5-4.5	ROCK	gray, clay
4.5-5.5	CLAY	gravelly, yellow, rocks
5.5-21	CLAY	sandy, gray, rocks
21-24	ROCK	
24-26	CLAY	gravelly, gray
26-38	SAND & GRAVEL	very clayey
38-40	SAND	fine, clayey
40-44	CLAY	blue, very gravelly
44-46	GRAVEL	clayey, with water
46-57	SAND & GRAVEL	somewhat clayey

APPENDIX II

Chemical Analyses of Ground-Water Samples

Appendix II. — Chemical analyses from wells and piezometers completed in confined aquifers C, D, and F.

Location	Screened Interval (ft)	Date Sampled	(milligrams per liter) SiO_2	Fe	Mn	Ca	Mg	Na	K	HCO_3	CO_3	SO_4	Cl	F	NO_3	B	TDS	Hardness as $CaCO_3$	NCH	% Na	SAR	Spec Cond (µmho)	Temp (°C)	pH
162-075-06CCC	65-69	09/03/03	30.8	1.81	1.35	214.	80.7	59.6	8.4	590.	<1	458.	4.00	0.212	<0.09		1120	867.	384.	12.8	0.88	1525		
162-075-07ADD1	?	04/01/99		1.22	1.99	190	61.9	43.1	8.3	462	0	335	4	0.28			920	729				1300		
162-075-07ADD1	?	07/01/99		1.55	1.78	182	58.3	40.8	7.1	460	0	370	3.7	0.3			938	695				1210		
162-075-07ADD1	?	10/29/02		0.35	1.9	190	62	44	7.9	588	0	360	4.2	0.2	0.1		961	730	250	11	0.7	1324		7.39
162-075-07ADD1	?	10/23/03	29.4	0.334	2.04	203.	66.2	48.2	8.1	581.	<1	354.	3.15	0.191	<0.09		971.	780.	303.	11.7	0.75	999		
162-075-07ADD4	42-47	09/03/03	29.4	0.066	1.86	201.	66.2	47.3	8.1	598.	<1	360.	3.81	0.184	0.22		983.	775.	285.	11.5	0.74	1347		
162-075-07ADD4	42-47	10/23/03	30.0	0.146	2.03	212.	69.2	45.1	8.2	585.	<1	359.	3.61	0.195	<0.09		987.	815.	335.	10.6	0.69			
162-075-07BAD2	88-93	09/03/03	31.5	1.02	1.90	206.	75.2	60.6	8.3	606.	<1	425.	3.66	0.192	<0.09		1080	824.	328.	13.6	0.92	1456		
162-075-07BBB2	54-74	10/09/01		0.71	1.6	200	75	50	8	486	0	470	4.5	0.2	0.1		1050	810	410	12	0.8	1453	7	
162-075-07BBB2	54-74	09/03/03	31.2	1.43	1.85	216.	78.4	54.5	8.5	590.	<1	448.	3.68	0.206	<0.09		1100	863.	379.	11.9	0.81	1453		
162-075-07BBB4	69-74	09/03/03	30.2	1.78	1.31	214.	77.4	57.1	8.4	590.	<1	437.	3.81	0.200	<0.09		1090	854.	370.	12.5	0.85	1516		
162-075-07BDC2	54.3-63.3	08/16/79	30	0.95	1.6	200	66	46	7.3	595	0	390	0.4	0.2	0.3	0.:	1040	770	280	11	0.7	1400	7.5	7.6
162-075-07BDC2	54.3-63.3	04/01/99		5.4	1.79	202	72.3	56.7	8.1	483	0	450	6.7	0.3			1090	802				1510		
162-075-07BDC2	54.3-63.3	07/09/99		1.44	1.74	200	72.5	52.7	7.8	481	0	470	4.8	0.29			1100	798				1360		
162-075-07BDC2	54.3-63.3	11/16/01		0.76	1.9	210	79	50	8.3	613	0	480	8.9	0.2	0.1		1140	850	350	11	0.7		7	