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

By Robert B. Shaver
North Dakota Water Commission

NORTH DAKOTA GROUND-WATER STUDIES NUMBER 109

Bismarck, North Dakota

2002

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

By Robert B. Shaver
North Dakota Water Commission

NORTH DAKOTA GROUND-WATER STUDIES NUMBER 109

Bismarck, North Dakota
2002

TABLE OF CONTENTS

LIST OF FIGURES

Page

Page

LIST OF TABLES

Page

APPENDIX

INTRODUCTION

On May 18, 2001, the North Dakota State Water Commission received a letter from Mr. Douglas Marsden, Mayor, city of Bottineau; Mr. Dave Caroline, Utility Committee Chairman, city of Bottineau; and Mr. Dan Schaefer, General Manager, All Seasons Water Users District (ASWU). The letter requested that the State Water Commission provide a cost estimate and project timeline to complete a test drilling and aquifer capacity study for the Bottineau municipal water supply and the All Seasons Systems I and II water supply in the "Twin Lakes" aquifer (Souris aquifer). Due to existing and potential water-quality problems in the city's ground-water supply and the inability of the city of Bottineau to be served by Northwest Area Water Supply (NAWS) project in the near future, the city of Bottineau and ASWU are participating in studies to evaluate their water supply and treatment systems.

A publication entitled, "Water Supply and Treatment Facility Plan Report" was prepared for the city of Bottineau and ASWU by Advanced Engineering and Environmental Services, Inc. in association with Wold Engineering, P.C. (October 2000). The study indicated for a 20-year planning period ending in 2022, the projected annual raw water demands for the city of Bottineau and the ASWU Systems I and II are 697.9 acre-feet. Three water treatment options are presented in the study. These are:

1) Iron and manganese treatment facility,
2) Lime/soda ash softening treatment facility, and
3) Reverse osmosis treatment facility.

Peak raw ground-water demand using the iron and manganese treatment option is estimated at 800 gallons per minute. Peak raw ground-water demand using the lime/soda ash softening option is estimated at 850 gallons per minute, which includes 50 gallons per minute as waste. Peak raw ground-water demand using the reverse osmosis treatment option is estimated at 1300 gallons per minute, which includes 300 gallons per minute as waste.

To provide a basis for developing a work plan for this study, on June 5 and 6, 2001, Mr. Robert Shaver, Hydrologist Manager, North Dakota State Water Commission, conducted a field inspection of the city of Bottineau and ASWU Systems I and II well fields. Mr. Shaver also met with Mr. Keith Fulsebakke, Municipal Works Superintendent for the city of Bottineau, and obtained from his files historical information on the Bottineau well field. The historical information included:

1) test-drilling logs
2) pumping-test data
3) water-level data
4) water-quality data
5) well maintenance records

In addition, Mr. Shaver met with Mr. Richard Foster, P.E., Wold Engineering, Bottineau, ND and received copies of maps showing locations of wells and test holes completed in the city well-field area north of Bottineau.

On July 11, 2001, Mr. Milton O. Lindvig, Director, Water Appropriation Division, North Dakota State Water Commission sent a letter to Douglas Marsden, Dave Caroline, and Dan Schaefer outlining a ground-water study proposal including a work plan and associated cost estimate as requested in their May 14, 2001 letter. The proposal recommended the ground-water study be conducted in three phases (Shaver, 2001). Phase I consisted of an evaluation of existing hydrogeologic data in the Bottineau well-field area and All Seasons Systems I and II areas located west of Bottineau. Phase II involved systematic pump testing/evaluation of selected production wells comprising the Bottineau municipal water supply. The goals of Phases I and II were to determine if a peak pumping capacity of 1300 gallons per minute is possible from the existing well fields (City of Bottineau and All Seasons Systems I and II) and that an annual withdrawal of 697.9 acre-feet of ground water is sustainable. If this determination cannot be made, Phase III will be recommended to explore for additional ground-water resources in the area. This would be accomplished by test drilling, observation well construction, collection of water samples for chemical analyses, water-level measurements, and aquifer testing.

On August 21, 2001, the State of North Dakota, acting through the State Water Commission, through its Secretary, Dale Frink; and the city of Bottineau, North Dakota, acting through its Mayor, Douglas Marsden, entered into an agreement to study an unnamed aquifer (north of Bottineau) to determine the availability of water for the city of Bottineau and to evaluate the yield capability of the All Seasons Systems I and II areas west of Bottineau.

Purpose and Scope

The purpose of this study is to determine if the existing Bottineau municipal well field and the All Seasons Systems I and II are capable of a maximum instantaneous ground-water withdrawal of 1300 gallons per minute and a sustained annual ground-water withdrawal of 697.9 acre-feet over a 20-year period. Specific objectives of this investigation in the Bottineau well-field area are to determine (1) the occurrence and movement of ground water in the unnamed aquifer that currently provides the water supply for Bottineau, (2) aquifer geometry and hydraulic continuity, (3) aquifer hydraulic parameters and well yields, and (4) aquifer water quality. Occurrence and movement of ground water and aquifer geometry/hydraulic continuity were determined by evaluating test-drilling data, water-level data, and pumping-test data. Aquifer hydraulic properties were determined using standard analytical methods applied to pumping-test data. Water quality (common ions and selected trace elements) was determined by analyzing water samples collected from municipal wells, observation wells, and commercial wells.

Wanek (1993) provides a detailed hydrogeologic analysis of the Souris aquifer where All Seasons Systems I and II are located. Specific objectives of this investigation in the All Seasons Systems I and II areas were to (1) summarize the hydrogeologic setting, (2) determine aquifer hydraulic parameters and maximum sustained well yields, and (3) evaluate aquifer water quality. Russel Drilling and LTP Drilling provided data from pumping tests conducted on 4 of the 5 All Seasons Systems I and II production wells. The pumping–test data were used to estimate aquifer hydraulic parameters and maximum sustained well yields. Dan Schaefer, Manager, All Seasons Water Users, provided static/pumping-level data and water quality analyses from the Systems I and II production wells.

Acknowledgements

Thanks are extended to the following North Dakota State Water Commission personnel: Rex Honeyman for assistance in conducting pumping tests on the municipal wells, Kelvin Kunz for logistical support throughout the investigation, Garvin Muri and Mary Osborn for chemical analyses of water samples, and Royce Cline for technical review of this manuscript. Thanks are also extended to Keith Fulsebakke, Bottineau Municipal Works Supervisor and his staff for their timely assistance and patience throughout the pumping-test phase of the study. Mr. Dan Schaefer, Manager, All Seasons Water Users District, provided important water-level, pumping-level, and water-quality data from the Systems I and II production wells. Finally, recognition is due C.A. Simpson and Son Drilling, Bisbee, ND for providing comprehensive documentation of historical test-drilling and pumping-test data from the Bottineau municipal well field.

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-quarter section, and

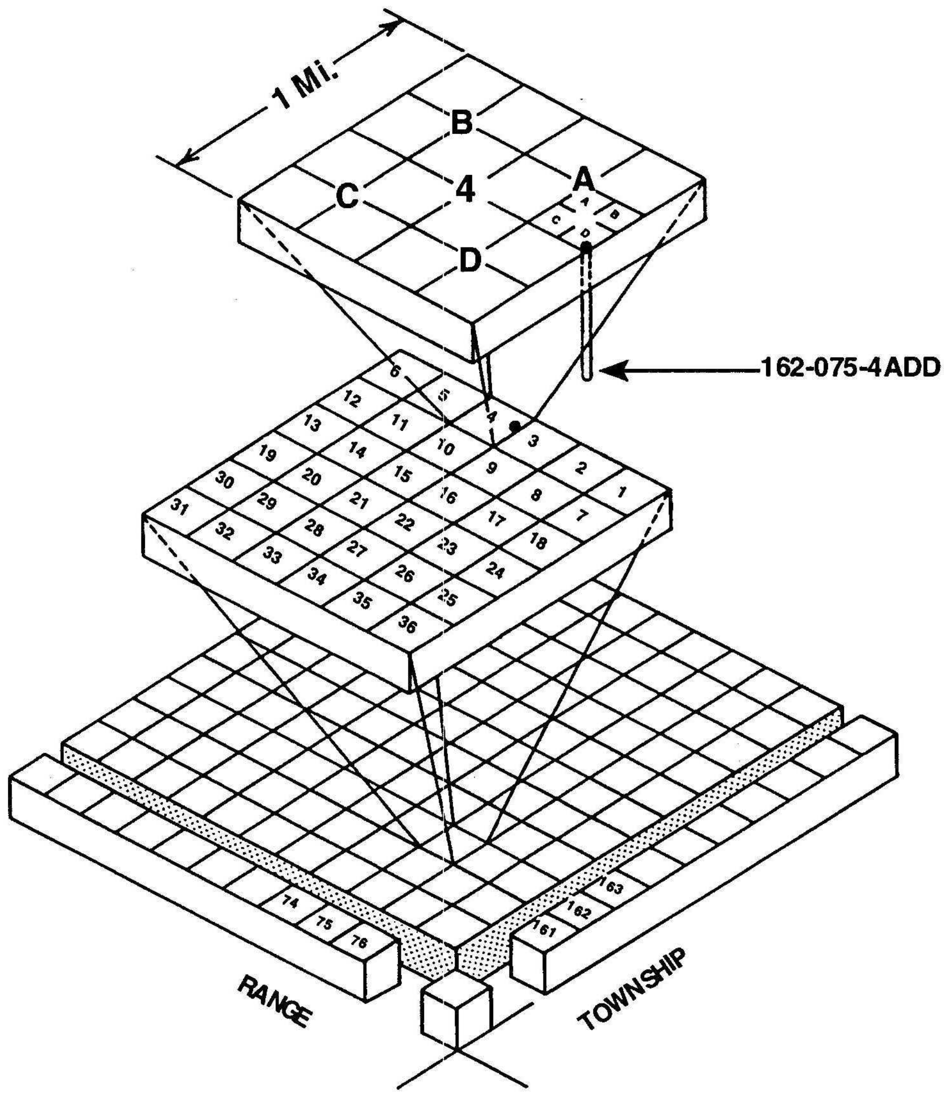


Figure 1.-- Location-numbering system

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., Range 75 W. Consecutive terminal numerals are added if more than one well or test hole is located within a 10-acre tract.

Previous Work

Simpson (1929) provides a general study of the geology and ground-water resources of Bottineau county. Abbott and Voedisch (1938) inventoried municipal water supplies throughout North Dakota, and includes well descriptions and chemical analyses of ground water from four Bottineau municipal wells. The North Dakota State Department of Health (1961) determined water quality in five of the Bottineau municipal wells and an analysis of a sample collected from the distribution system at the Bottineau Armory. Froelich (1963) describes the geology and ground-water resources of the Bottineau area. The North Dakota State Department of Health (1964) includes a chemical analysis of a ground-water sample collected from the "Noble Well."

The geology and ground-water resources of Bottineau county are described in a three-part report. Part I (Bluemle, 1985) describes the geology of Bottineau county, Part II (Kuzniar and Randich, 1982) presents the ground-water data, and Part III (Randich and Kuzniar, 1984) describes the ground-water resources.

The soils of Bottineau county, including the study areas, are described by Des Lauriers (1982). Wanek (1993) provides a report of an investigation to identify a water supply for All Seasons Water Users District (Systems I and II) in Bottineau county.

Advanced Engineering and Environmental Services, Inc., in association with Wold Engineering, P.C. (2001), completed a cooperative study to examine various interim, as well as long-term, solutions to the water supply and treatment concerns in the Bottineau area.

Methods

Wells and test holes in the study area were drilled using cable tool and forward mud-rotary methods. Geologist and drillers' logs of wells and test holes are provided in Appendix I. Except for the older flowing wells (Noble, Walker, and Bittner wells) for which completion data are not available, the municipal wells are completed with steel casing and stainless-steel screen.

Water levels were measured in this study to the nearest 0.01 foot using a chalked steel tape or electric tape. Also continuous water-levels were monitored using Keck electrical water-level sensors coupled with Stevens Type F recorders.

During the pumping tests, discharge was measured using a Panametrics Model PT868 sonic flow meter. The flow meter was attached to a trailer mounted, 3-inch diameter steel measuring pipe equipped with gate valves to control discharge and a petcock to collect water samples.

Near the end of each pumping test, four 500-milliliter (ml) samples and one 250-ml sample were collected for chemical analysis. Bicarbonate (HCO_3), carbonate (CO_3), and electrical conductivity were determined using the rawuntreated 500-ml sample. Sulfate (SO_4), fluoride (F), chloride (Cl), and dissolved solids were determined using the filtered (0.45m) 500-ml sample. Calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), iron (Fe), and manganese (Mn) were determined using the filtered (0.45m) and acidified (2 ml - nitric acid) 500-ml sample. Trace elements of selenium, lead, mercury, arsenic, lithium, molybdenum, strontium, and uranium were determined using the filtered (0.45m), acidified (2 ml - nitric acid) 500-ml sample, the bottle of which was double acid rinsed. 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 spectrophotmeter was used to measure concentrations of Ca, Mg, Na, K, Fe, and 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.

DESCRIPTIOPN 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 whereas 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 a southwestern flank of the Turtle Mountains (fig. 3). Relief in Section 7 is about 275 feet (fig. 4). 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.

The ASWU Systems I and II well fields are respectively located about 6 miles west and 10 miles northwest of Bottineau along a belt of land characterized by ice-contact fluvial deposits (kames and eskers) (fig. 3). Local relief is up to about 75 feet. Surface drainage is lacking in the kame and esker areas because soil infiltration capacities are large. A few small lakes occupy depressions adjacent to the kames/eskers.

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

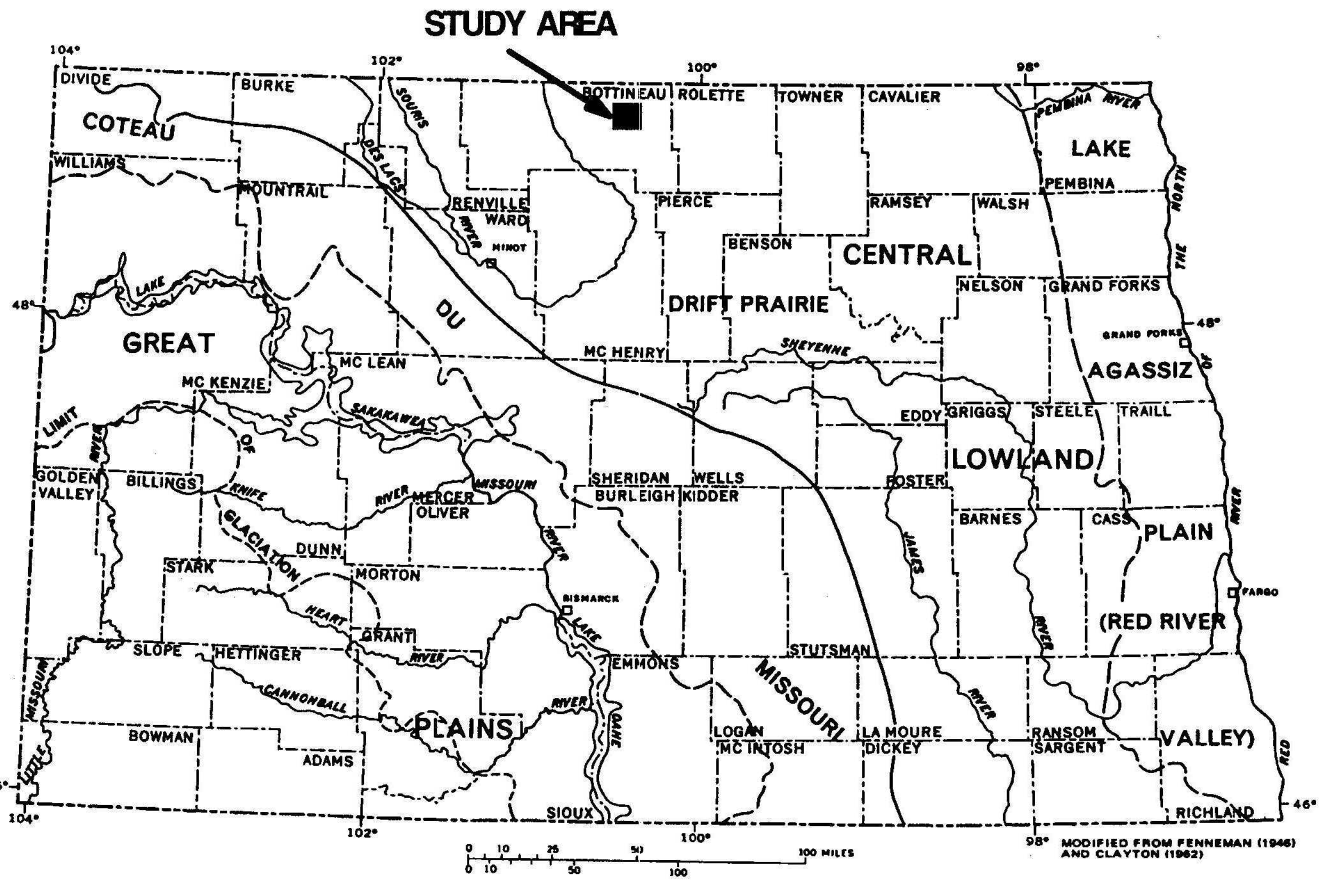


Figure 2. -- Physiographic divisions in North Dakota and location of study area

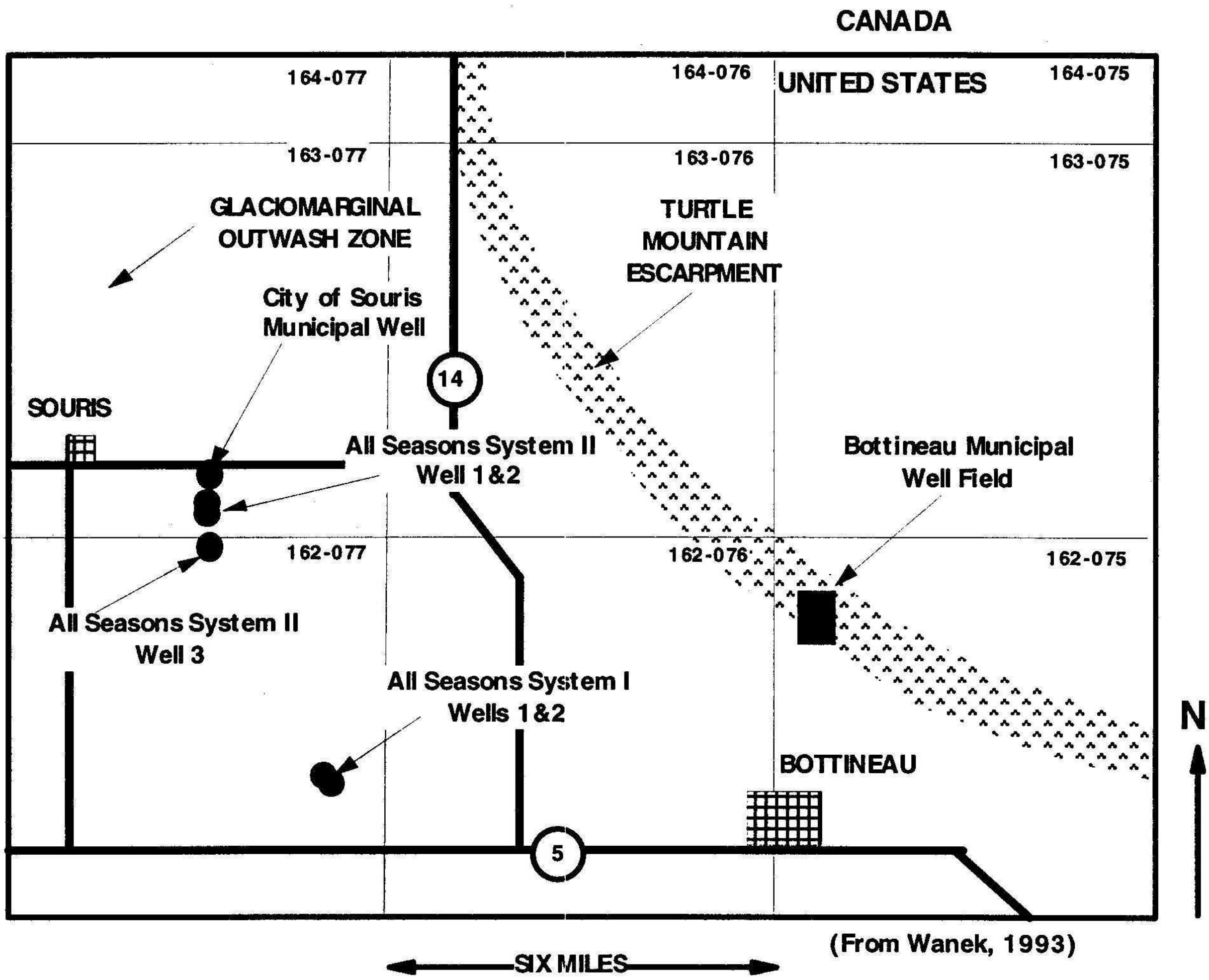
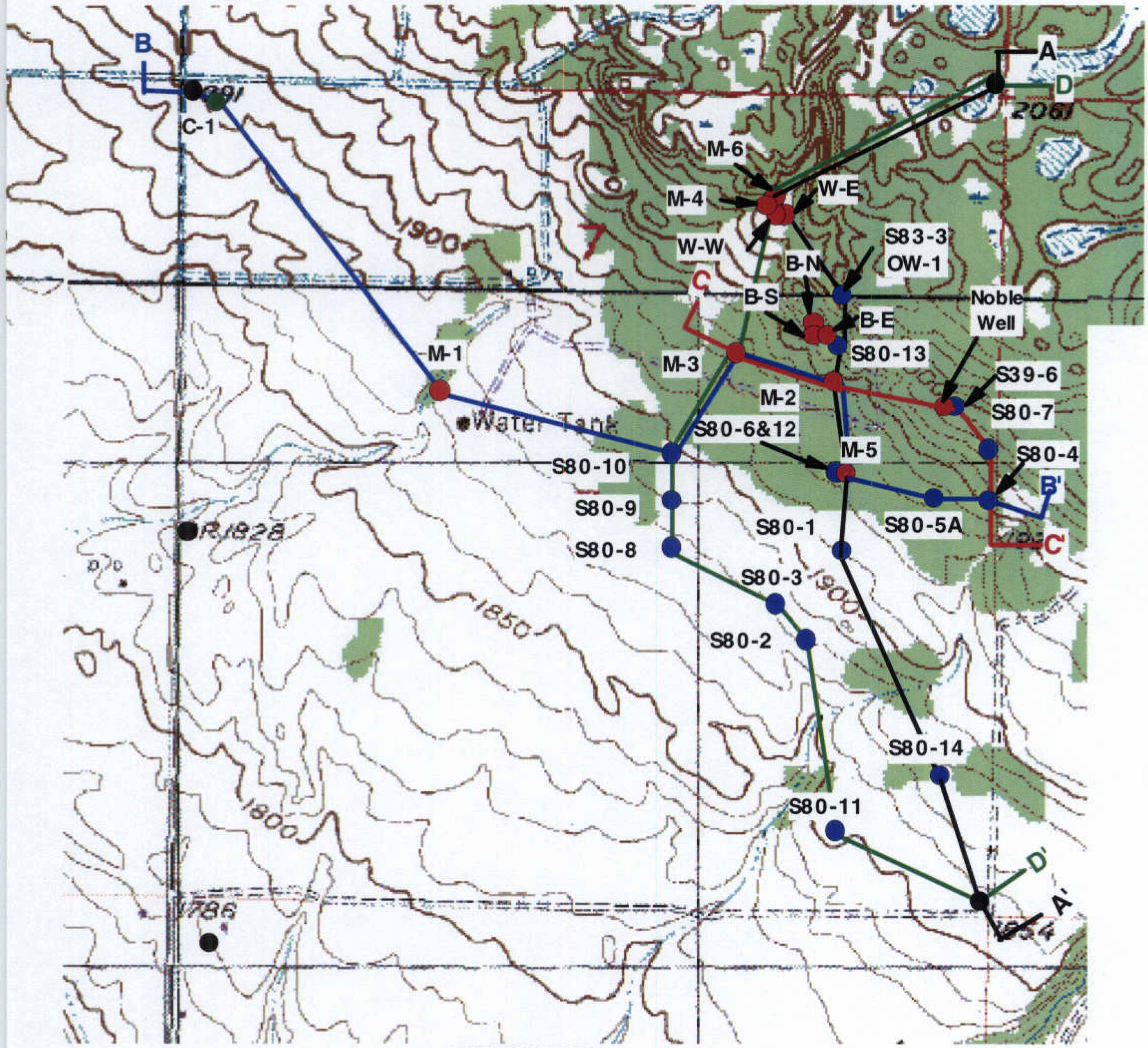


Figure 3. -- Location of Bottineau and All Seasons Systems I and II well field study areas

TOWNSHIP 162 NORTH, RANGE 75 WEST, SECTION 7



EXPLANATION

Bottineau Municipal Well: M-1 = Municipal Well #1, B = Bittner Wells, W = Walker Wells

Simpson & Sons Drilling Test Hole: S39-6 = Simpson 1939 Test Hole #6,
S80-9 = Simpson 1980 Test Hole #9,
S83-3 = Simpson 1983 Test Hole/Observation Well #1

N.D. State Water Commission Test Hole

Commercial Test Well

Location of Geohydrologic Section C-C' (See Figs. 6-9)

Figure 4. -- Land-surface topography, location of wells, test holes, and geohydrologic sections A-A' through D-D' in the Bottineau well field area

and the mean annual temperature is 37.6°F. Annual precipitation and the five-year moving average annual precipitation from 1906 through 2000 are shown in figure 5. Most of the precipitation occurs 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 heterogenous mixture of igneous and metamorphic rocks, carbonates (limestone and dolomite), shale, sandstone, and

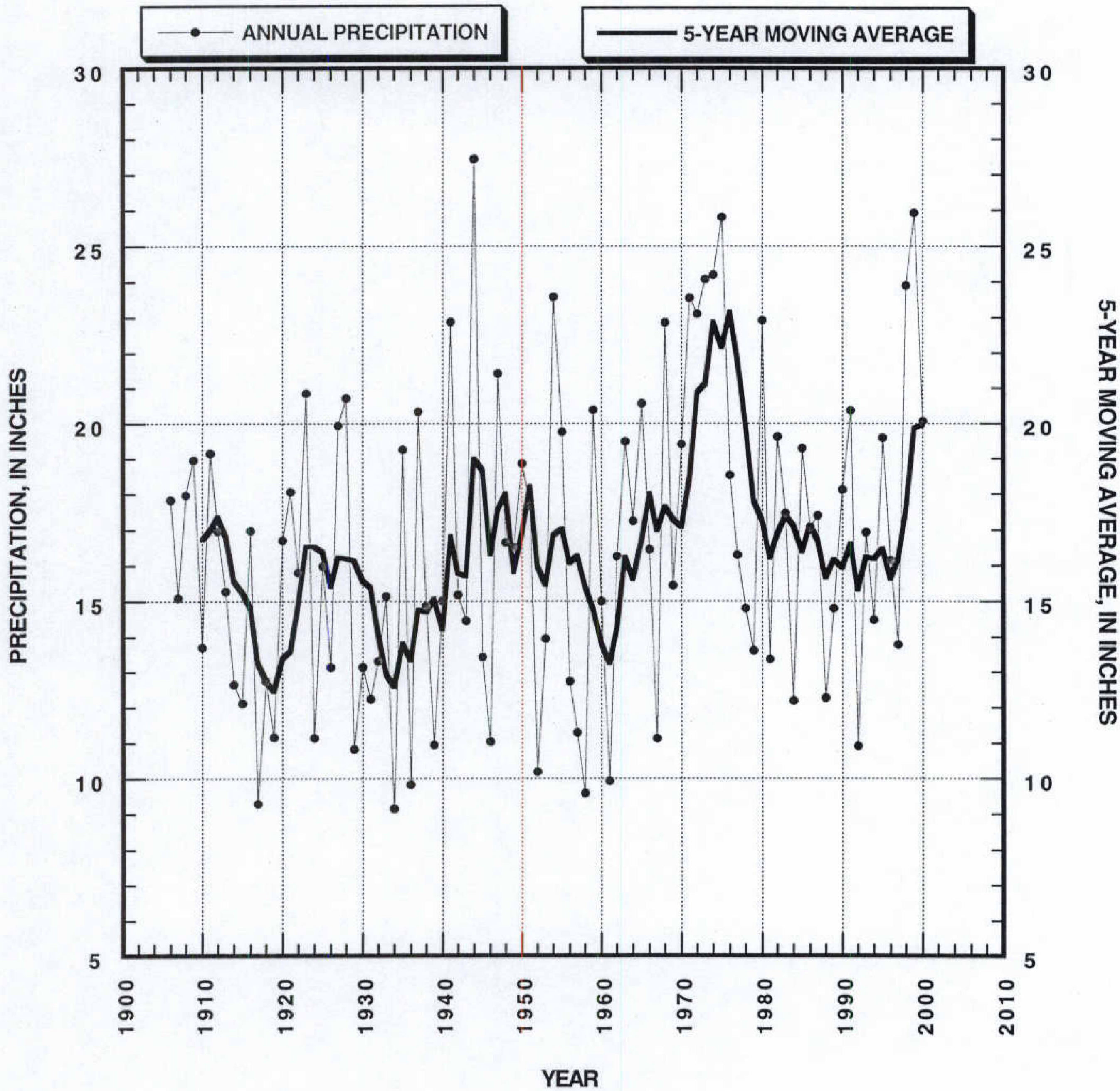


Figure 5. -- Annual precipitation and 5-year moving average at Bottineau from 1906 through 2000

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 (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.

During the well pump-testing phase of this study, casing failures occurred and liners were inserted inside the original casing to prevent sand and gravel from collapsing into the well screens. During the well re-development process, sand and gravel were bailed from inside the wells. Examination of the bailed material indicated the sand and gravel was subrounded to rounded with a mineralogic composition similar to that of the till as previously described.

Bluemle (1985) describes the silt and clay facies of the Coleharbor Group as being deposited in lakes. These lake deposits are, for the most part, associated with glacial Lake Souris (Bluemle, 1985). The silt and clay deposits reported on

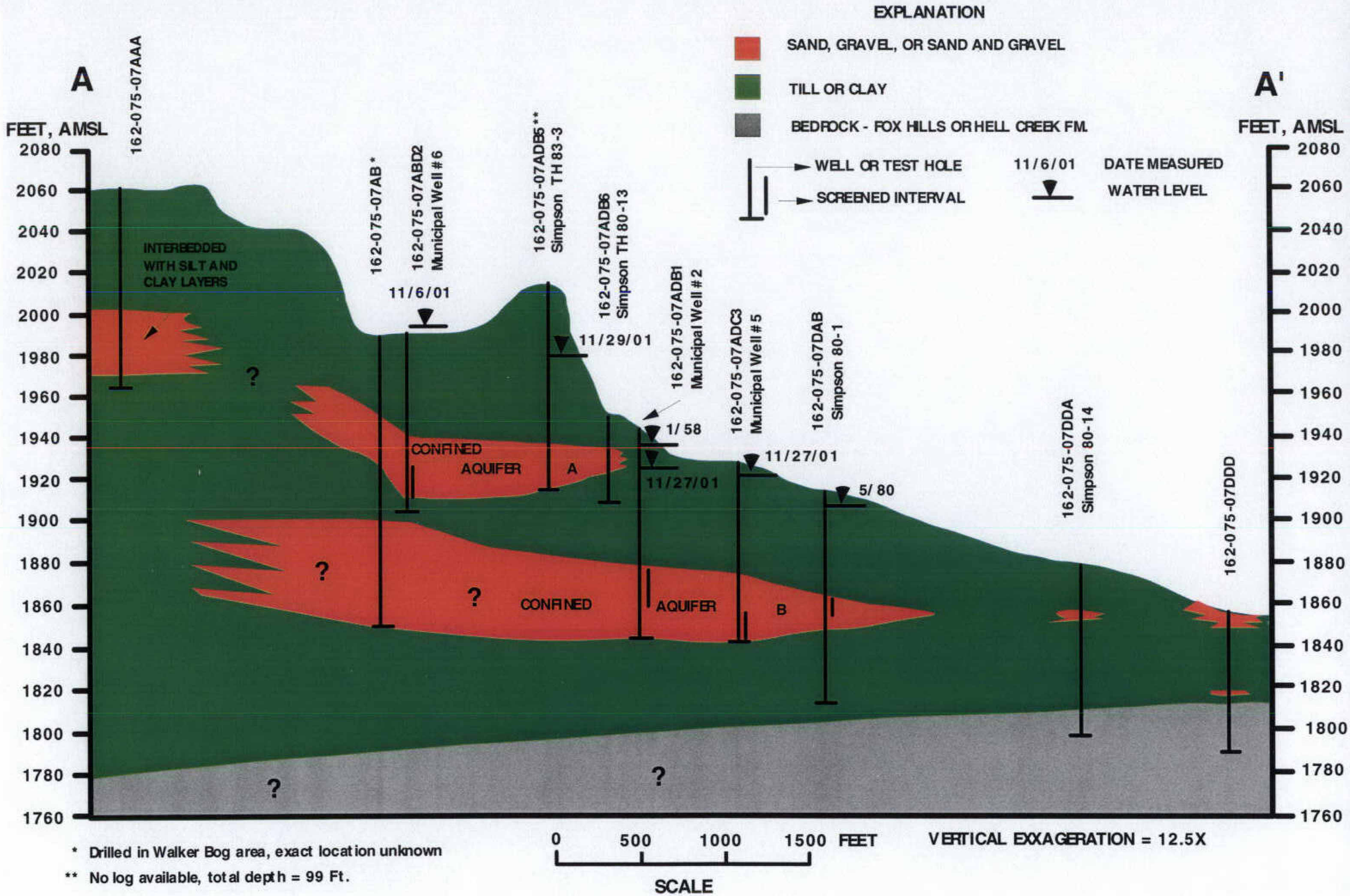


Figure 6. -- Geohydrologic section A-A' showing confined aquifers A and B of the Bottineau aquifer

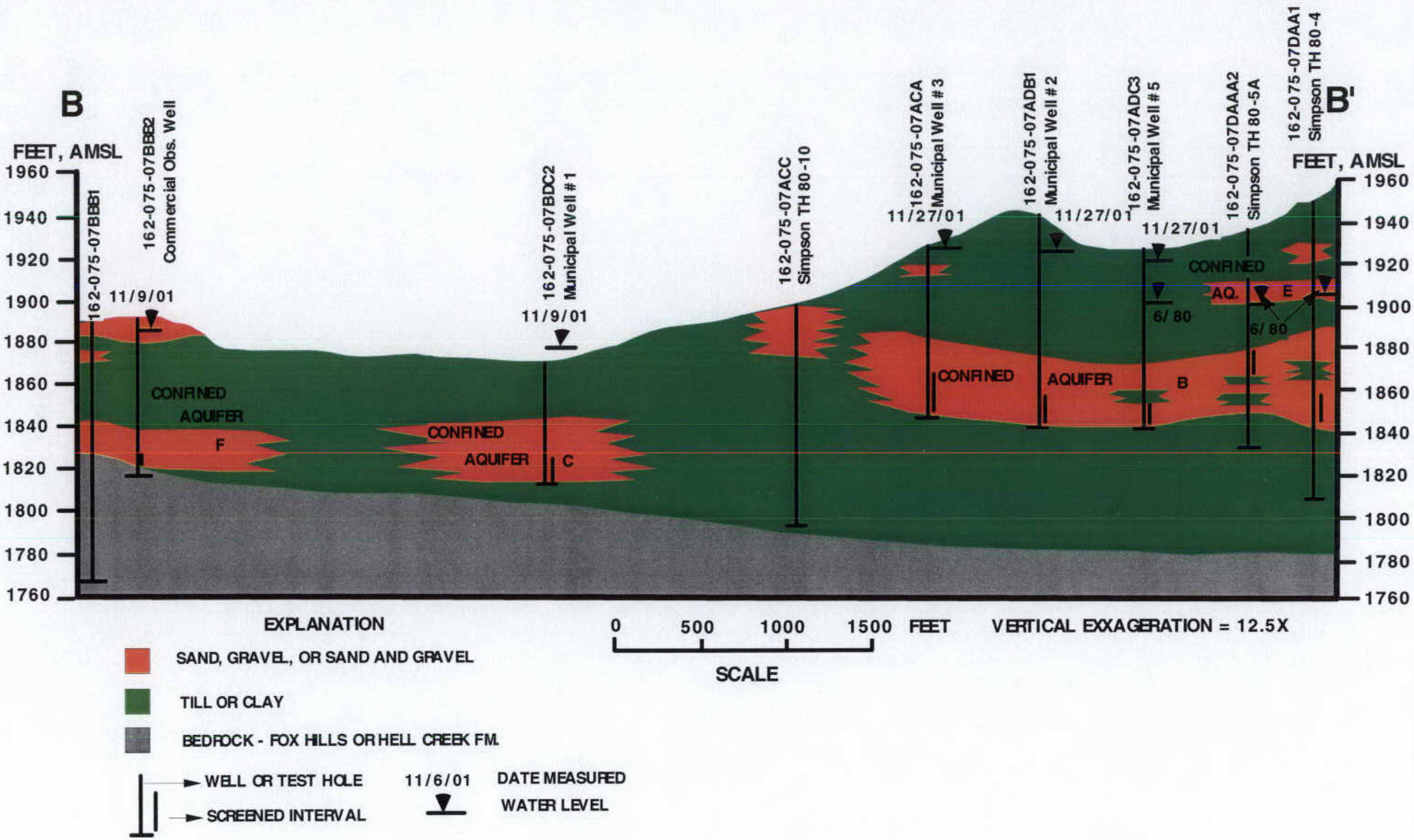


Figure 7. -- Geohydrologic section B-B' showing confined aquifers B. C, E, and F of the Bottineau aquifer

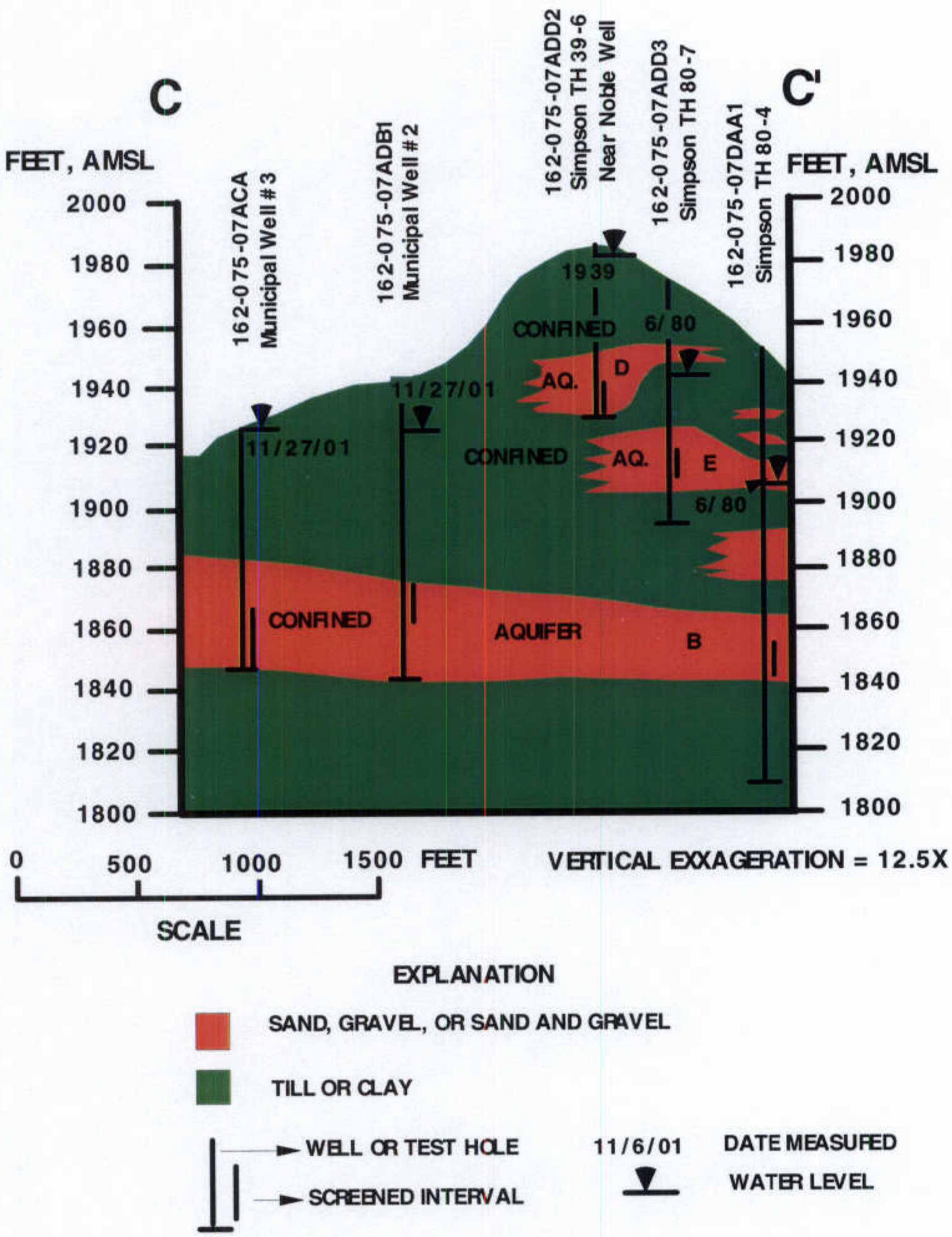


Figure 8. -- Geohydrologic section C-C' showing confined aquifers B, D, and E of the Bottineau aquifer

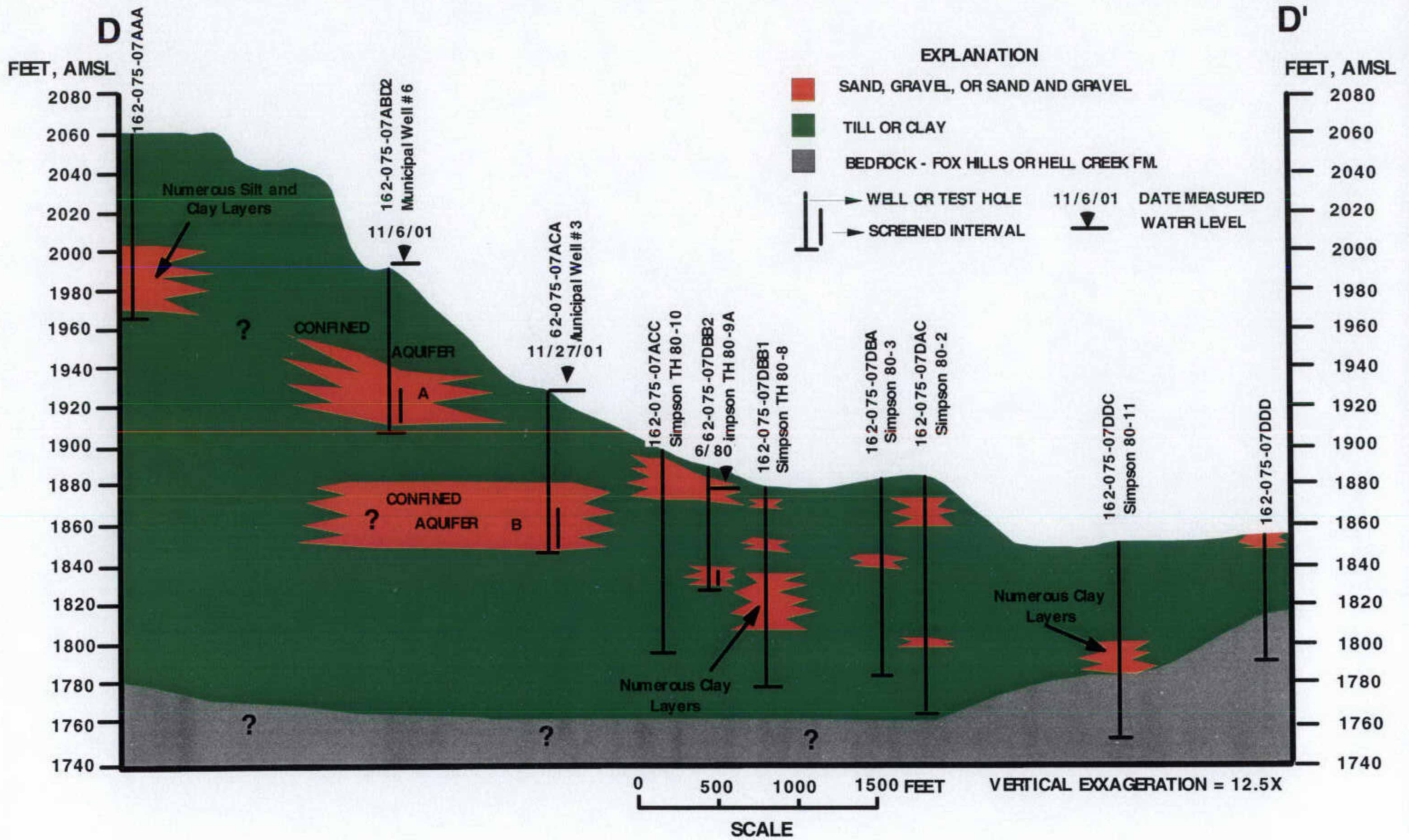


Figure 9.-- Geohydrologic section D-D' showing confined aquifers A and B of the Bottineau aquifer

drillers logs from test holes completed in Section 7, T. 162 N., R. 75 W. probably are fluvial in origin and not of lacustrine origin. These deposits probably formed from low-energy fluvial events associated with ice melting in the Turtle Mountains.

GROUND-WATER HYDROLOGY OF THE BOTTINEAU AQUIFER

Occurrence and Movement of Ground Water

Randich and Kuzniar (1984) outline an undifferentiated buried glaciofluvial aquifer that occurs in the study area. No effort was made to present a detailed hydrogeologic description of this undifferentiated aquifer. Henceforth, this undifferentiated aquifer will be referred to as the Bottineau aquifer.

The Bottineau aquifer consists of at least six discrete hydrogeologic units comprised of sand and gravel. Water occurs under confining conditions within the six discrete hydrogeologic units. Confined aquifer units A and B are shown in figure 6, confined aquifer units B, C, E, and F are shown in figure 7, confined aquifer units B, D, and E are shown in figure 8, and confined aquifer units A and B are shown in figure 9. It is inconclusive as to whether confined aquifers A and D are hydraulically connected. The discrete hydrogeologic units were differentiated based primarily on water-level elevations, response to pumping, and to a much lesser extent, position (elevation) within the stratigraphic column and water chemistry.

Water levels were measured periodically in all wells in the study area from September 26 to December 4, 2001. Hydrographs of selected wells completed in confined aquifers A, B, and C are shown in figures 10 through 16.

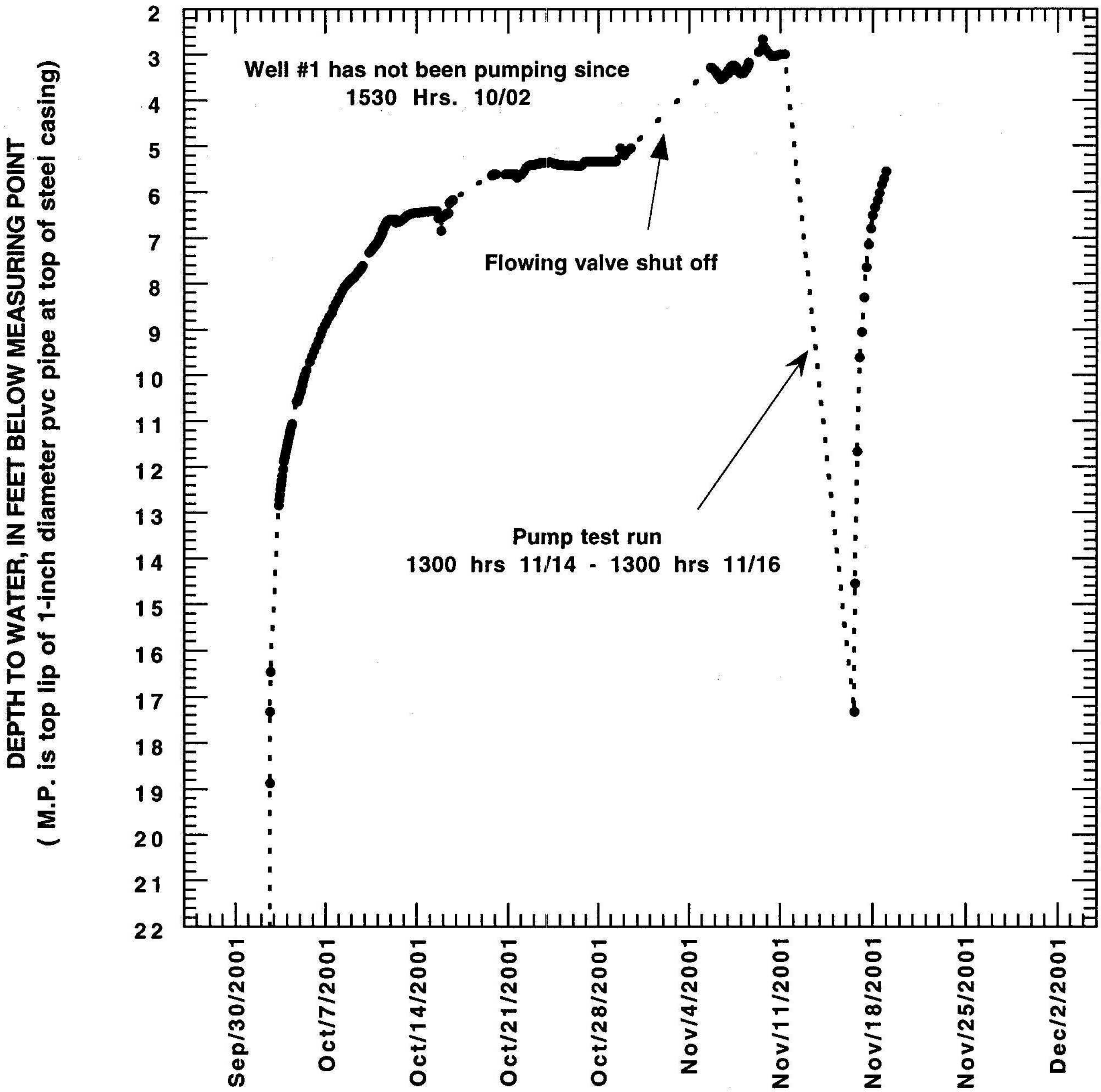


Figure 10. -- Water-level hydrograph municipal well #1 (162-075-07BDC2)

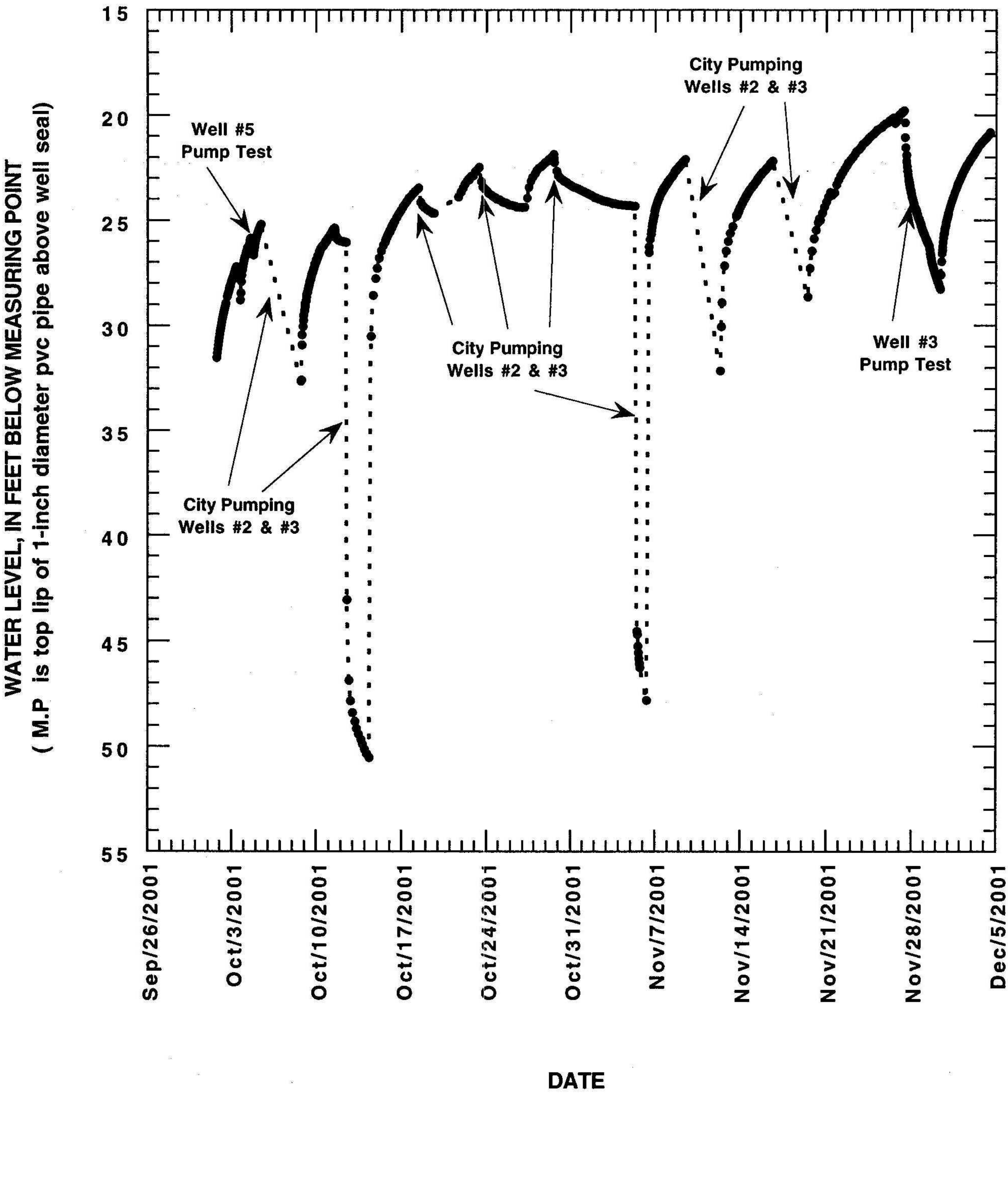


Figure 11. -- Water-level hydrograph municipal well #2 (162-075-07ADB1)

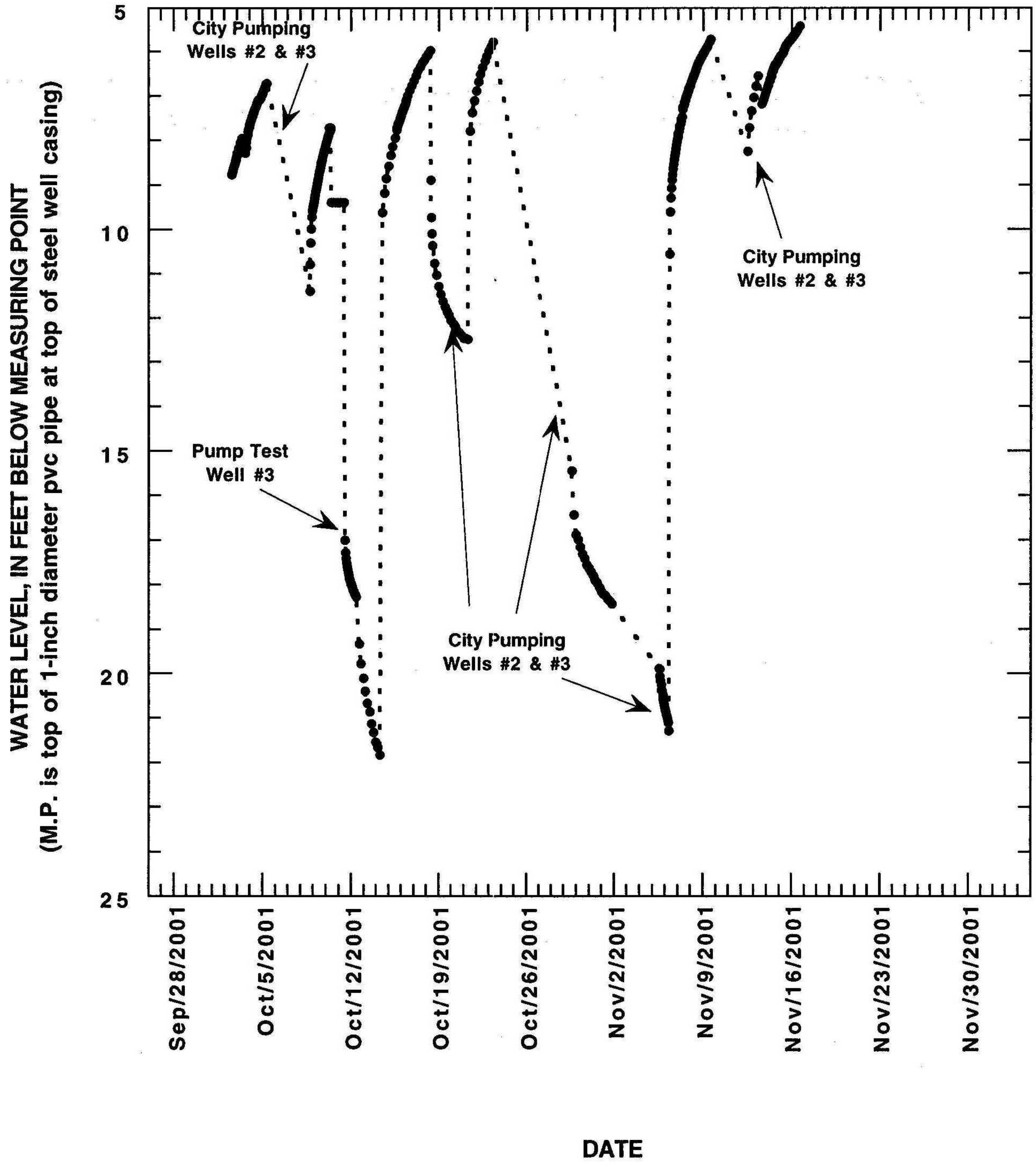


Figure 12. -- Water-lever hydrograph municipal well #3 (162-075-07ACA)

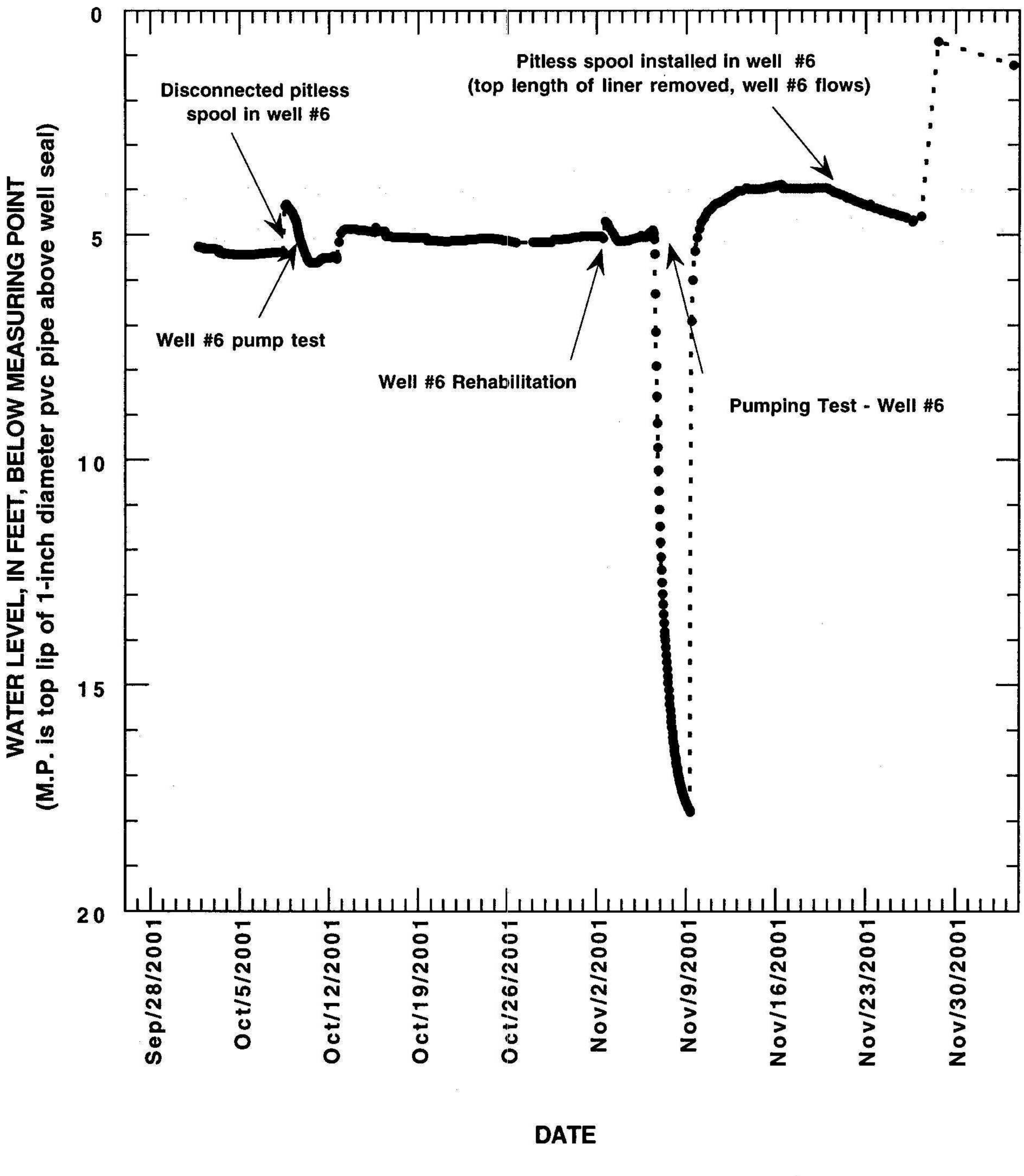


Figure 13. -- Water-level hydrograph municipal well #4 (162-075-07ABD1)

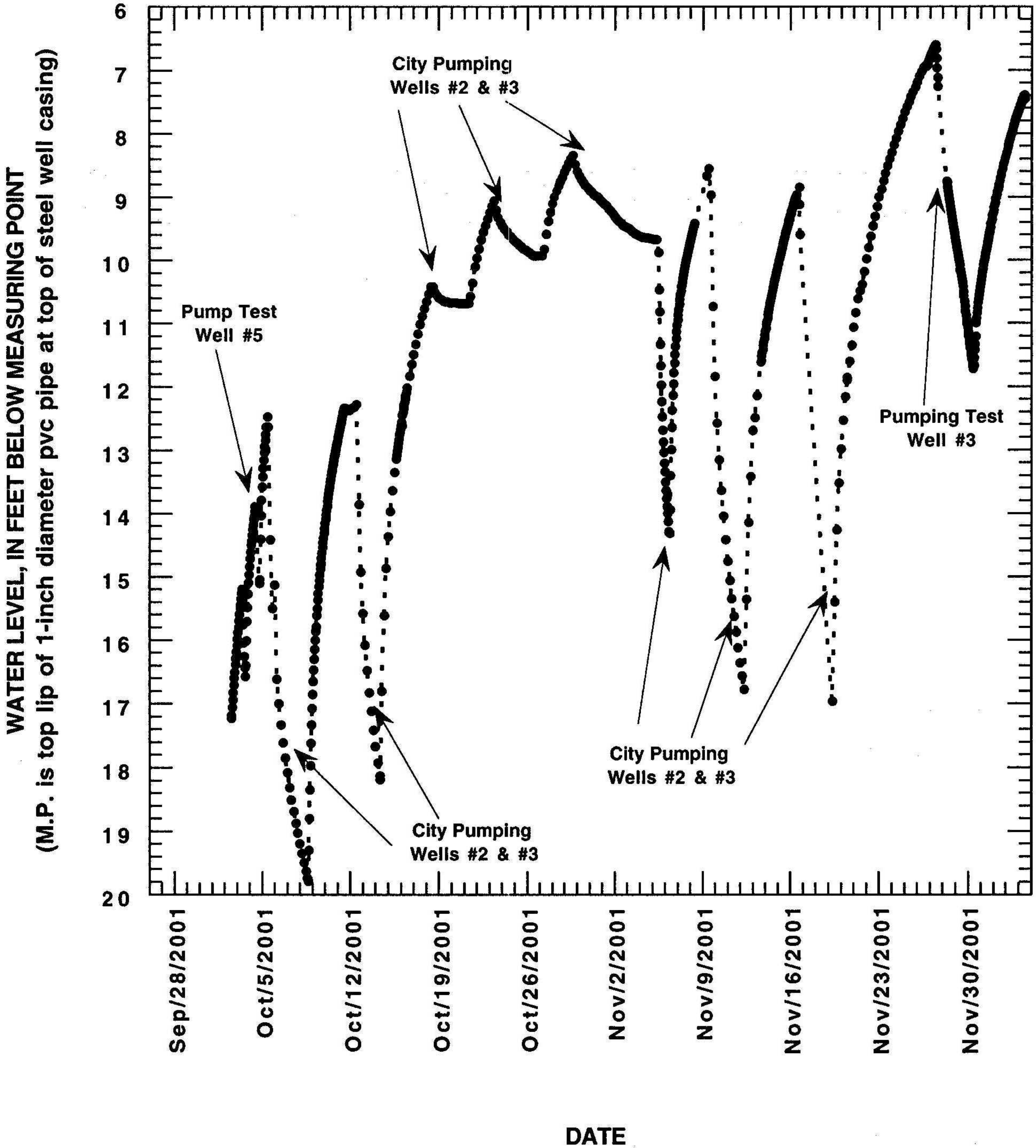


Figure 14. -- Water-level hydrograph municipal well #5 (162-075-07ADC3)

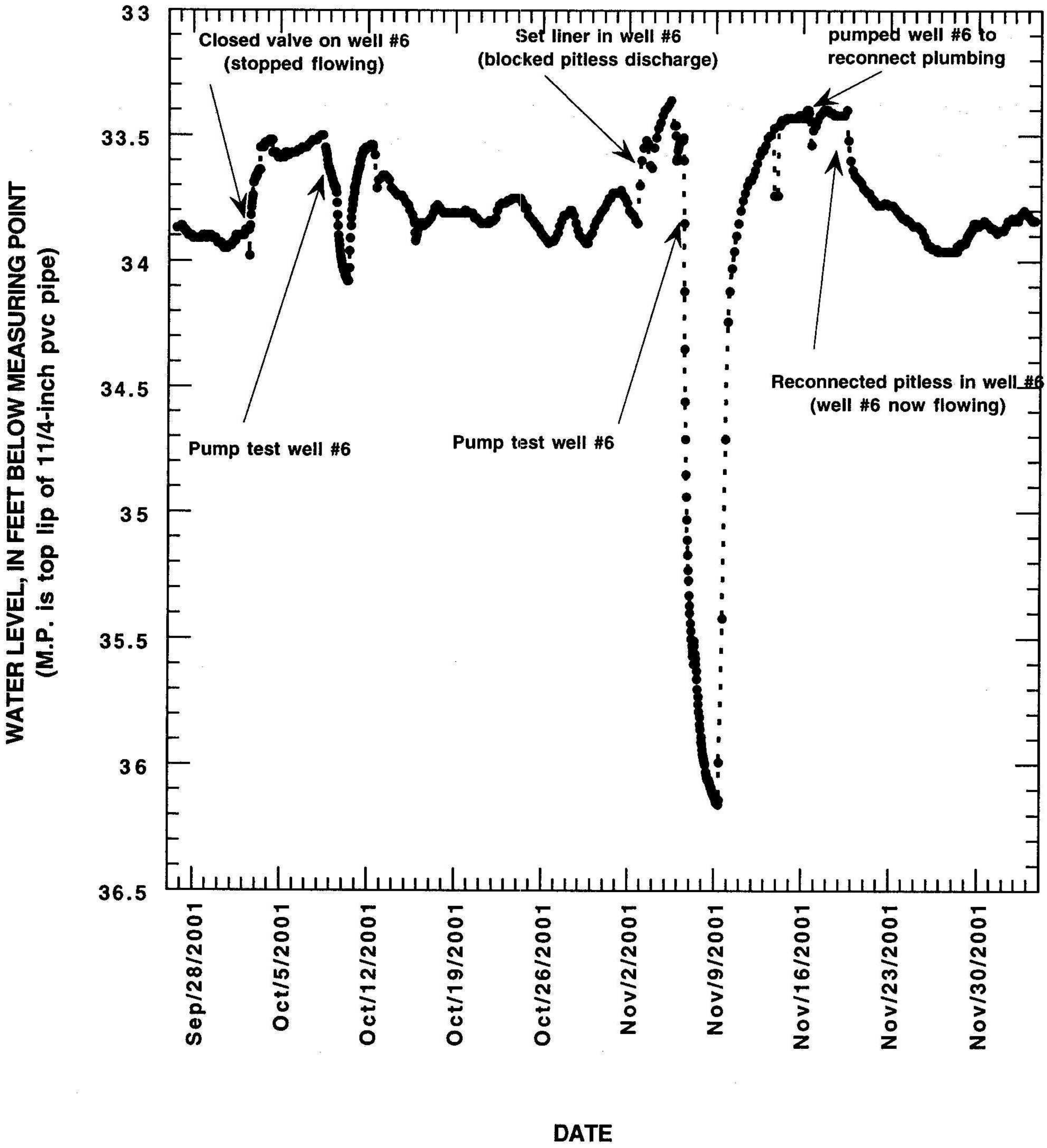
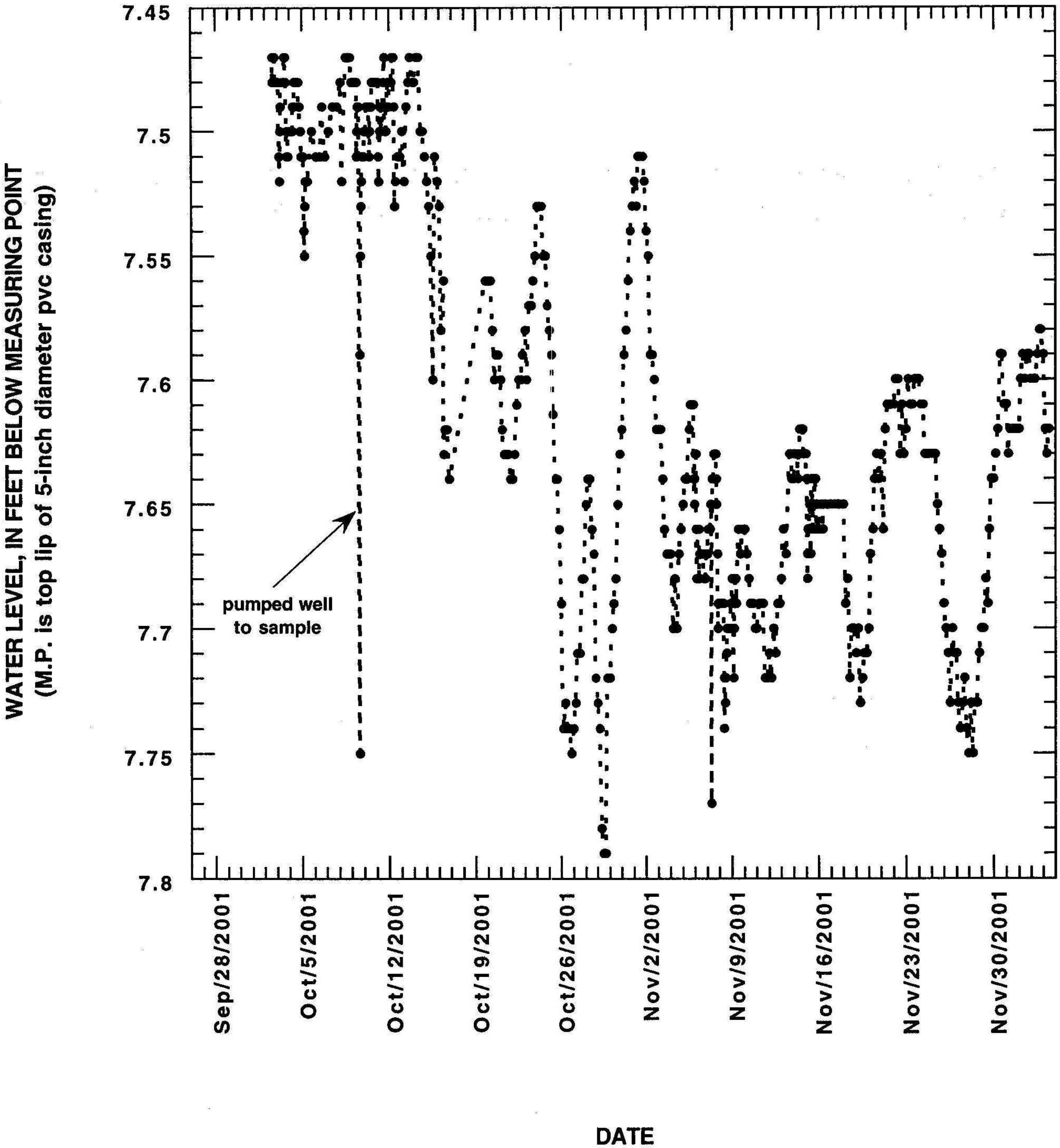


Figure 15. -- Water-level hydrograph Simpson observation well 162-075-07ADB5



igure 16. -- Water-level hydrograph commercial observation well 162-075-07BBB2

Municipal wells #2, #3, and #5 and Simpson observation well 80-1 and possibly Simpson observation wells 80-4 and 80-5A are completed in confined aquifer B (figs. 6-8). Confined aquifer B occurs from about 1840 to 1880 feet above mean sea level. Water levels are about 1920 to 1925 feet above mean sea level (figs. 6-9).

During the pump testing phase of the study, drawdown was measured in municipal wells #2 and #5 when municipal well #3 was pumped, drawdown was measured in municipal wells #3 and #5 when municipal well #2 was pumped, and drawdown was measured in municipal wells #2 and #3 when municipal well #5 was pumped. These responses indicate the sand and gravel intervals in which municipal wells #2, #3, and #5 are completed are hydraulically connected. In addition, Simpson (1980) indicates drawdown was measured in observation well 80-1 during a pumping test conducted on municipal well #5 shortly after construction. Thus, the sand and gravel interval in which well 80-1 is completed is hydraulically connected to the sand and gravel intervals in which municipal wells #2, #3, and #5 are completed.

Municipal wells #4, #6, the two Walker wells, the three Bittner wells and observation well 162-075-07ADB5 (Simpson observation well 83-3) are completed in confined aquifer A (figs. 6 and 9). Confined aquifer A occurs from about 1910 to 1940 feet above mean sea level. Water levels in confined aquifer A are between 40 and 60 feet higher in elevation than those measured in confined aquifer B. It is important to note water levels in confined aquifer A would be higher than measured because the Walker wells, Bittner wells, and municipal well #4 are discharging (free flowing) out of buried pipes tapped into the well casings that convey water to the municipal storage tank to the southwest. During the pump test conducted on municipal well #6, drawdown was measured in municipal well #4, the Walker wells, observation well 162-075-07ADB5, and to a much lesser extent in the Bittner wells. During this pumping test drawdown was not measured in any other wells in the study area.

Municipal well #1 is completed in confined aquifer C (fig. 7). This is the only well in the study area completed in this aquifer. The water level in confined aquifer C is about 50 feet lower than the water level in confined aquifer B and about 90 to 110 feet lower than water levels measured in confined aquifer A. Confined aquifer C occurs from about 1815 to 1845 feet above mean sea level.

Municipal well #1 was not used by the city after October 2. Throughout much of October, water levels in municipal well #1 were recovering (fig. 10). During this same period, municipal wells #2, #3, and #5 were pumped periodically by the city to maintain its municipal supply (figs. 11, 12, and 14). No drawdown was measured in municipal well #1 when municipal wells #2, #3, and #5 were pumped by the city.

A pumping test was conducted on municipal well #1 from November 14 to November 16, 2001 (fig. 10). During the pumping test drawdown was not measured in any other wells in the study area. Based on the above, confined aquifer C is a discrete hydrogeologic unit with no direct hydraulic connection to confined aquifers A and B.

Confined aquifer D is shown in figure 8. It is inferred the Noble municipal well is completed in this aquifer. City records indicate the Noble well is 50 feet deep. As with the Walker and Bittner wells, the Noble well discharges by free flow into a buried pipe tapped into the well casing that conveys water to a storage tank to the southwest. On October 5, 2001, the depth of the Noble well was measured at 23.7 feet below the top of the 1-inch PVC measuring port that extends 0.97 feet above the well seal. It is possible the well has partially filled in with sand since its construction in 1939.

Simpson (1939) provides completion reports and pump-test data for wells completed in Section 7, T. 162 N., R. 75 W. The location of test hole/well 39-6 was reported about 10 feet east of Noble's house. This may be the site or, at least, may be close to the site of the existing Noble well. The driller's log of test hole/well 39-6 indicates topsoil from 0 to 2 feet below land surface, yellow clay from 2 to 16 feet, gravelly blue clay (probably till) from 16 to 35 feet, sand and gravel from 35 to 54 feet and blue clay at 54 feet. The water level was reported at two feet below land surface in October, 1939. It is estimated that this water level corresponds to an elevation of between about 1980 and 1985 feet above mean sea level. The existing Noble well likely is completed in the sand and gravel interval reported in test hole/well 39-6. If so, the static water level in the existing Noble well is about 55 to 60 feet higher than the water levels associated with confined aquifer B (fig. 8). Confined aquifer D occurs from about 1930 to about 1952 feet above mean sea level, which is about 50 feet above the top of confined aquifer B. No drawdown was observed in the Noble well when pump tests were conducted on municipal wells #1, #2, #3, #5, and #6. Based on the above, the Noble well is completed in a hydrogeologic unit with no direct hydraulic connection to confined aquifers B, and C. It is inconclusive as to whether confined aquifers A and D are hydraulically connected (see discussion of municipal well #6 pumping test).

It is possible that another discrete hydrogeologic unit (confined aquifer E) occurs at Simpson test holes/wells 80-4 and 80-7 (fig. 8). A sand and gravel interval occurs from about 1905 to 1925 feet in test hole/well 80-7. The water level in this well was reported at about 33 feet below land surface (estimated water-level elevation 1942 feet). This is about 15 feet above the water-level elevation in confined aquifer B and about 40 feet below the water-level elevation in confined aquifer D (fig. 8). Unfortunately, there were no observation wells completed in confined aquifer E to measure water-level response, if any, from pumping municipal wells #1 #2, #3, #5, and #6.

The last discrete hydrogeologic unit differentiated in this study is confined aquifer F (fig. 7). Confined aquifer F occurs at SWC test hole 162-075-07BBB1 and commercial observation well 162-075-07BBB2 (fig. 7). The water-level elevation in well 162-075-07BBB2 is about 8 feet higher than that measured in municipal well #1, which is completed in confined aquifer C. The elevations of the aquifer intervals at both of these wells are similar.

The pattern of water-level fluctuations at 162-075-07BBB2 and that at 162-075-07BDC (municipal well 1) are different (figs. 16 and 10). Water-level fluctuations at 162-075-07BBB2 are small and are almost entirely caused by fluctuations in barometric pressure (fig. 17). A domestic well located at 162-075-

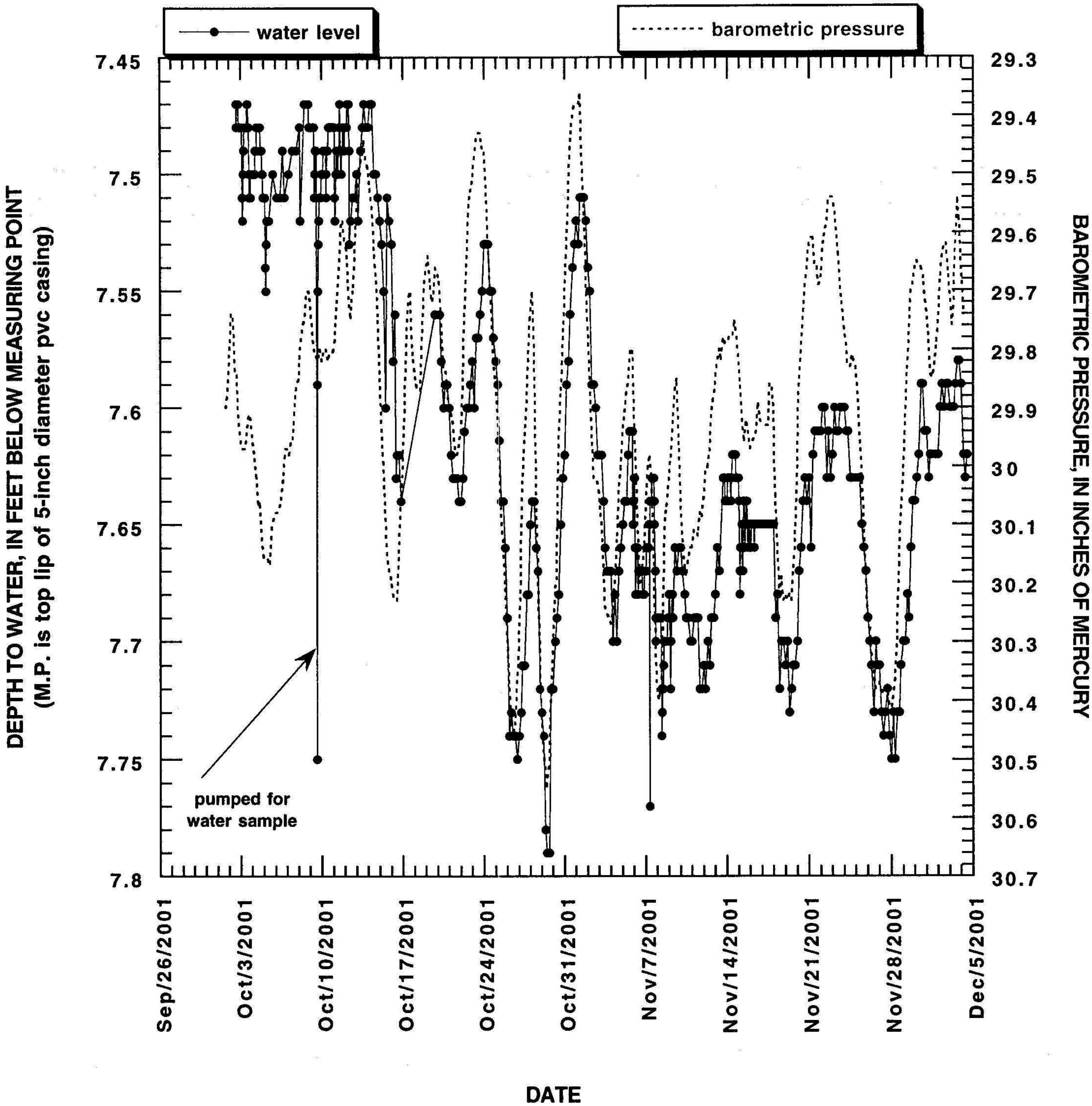


Figure 17. -- Comparison of water-level fluctuations at observation well 162-075-07BBB2 and fluctuations in barometric pressure

06CCC (Norman Geshoff) located about 200 feet north of 162-075-07BBB2 also caused minor drawdown interference. No drawdown response was observed at commercial observation well 162-075-07BBB2 when pumping tests were conducted on municipal wells #1, #2, #3, #5, and #6 and when the city pumped wells #2, #3, and #5 to maintain its municipal water supply during October and November 2001.

Analysis of pre-existing hydrogeologic data and the pumping-test data collected during October and November 2001 provided the basis for differentiating discrete hydrogeologic units (confined aquifers A-F) in the study area. Due to the fact that confined aquifers A through F are relatively small-scale features, the existing test-drilling data is not sufficient to map the areal extent and geometry of these units. In addition, it is not possible to map ground-water flow directions within each confined aquifer unit because of the impact on water levels by flowing wells and pumping of other municipal supply wells in the study area, and the limited number of observation wells in each unit. In general, it is assumed that the direction of ground-water flow in the confined aquifers in the study area is from northeast to southwest reflecting a subdued replica of the land-surface topography and the channel orientation.

Hydraulic Properties

C.A. Simpson and Son Drilling conducted pumping tests on most of the municipal wells in the study area and the data are available for analysis. In addition, the SWC conducted pumping tests on municipal wells #1, #2, #3, #5, and #6 during October and November 2001. As previously stated, analysis of pumping-test data provided a significant basis for differentiating the hydraulically discrete confined aquifers in the study area. Analysis of pumping-test data was also used to (1) determine aquifer hydraulic parameters (transmissivity and hydraulic conductivity), (2) to detect, and in some cases, evaluate the effects of various boundary conditions (barriers, leakage, etc.) on water-level drawdown, and (3) determine maximum sustained pumping rates.

Municipal Well #1 (162-075-07BDC) – Confined aquifer C

Municipal well #1 was constructed by C.A. Simpson and Son Drilling in April, 1968. The driller's log is shown in table 1.

Table 1. -- Driller's log of municipal well #1

LITHOLOGIC DESCRIPTION	DEPTH	
	From	To
Topsoil	0	0.5
Rock, gray clay	0.5	4.5
Gravelly yellow clay, rocks	4.5	5.5
Sandy gray clay, rocks	5.5	21
Rock	21	24
Gravelly gray clay	24	26
Very clayey sand and gravel	26	38
Clayey fine sand	38	40
Very gravelly blue clay	40	44
Clayey gravel with water	44	46
Somewhat clayey sand and gravel	46	57

The depth of the well was reported at 57.5 feet. When the well was constructed it flowed at land surface. The land surface was built up around the casing extension and a road was constructed up the earth mound to allow access to the well. The driller indicated 55.17 feet of 10-inch diameter steel casing and 9.58 feet of 10-inch diameter stainless steel was used to construct the well. The total reported length of casing and screen is 64.75 feet. On October 14, 2001, the depth of the well was measured at 63.34 feet below the top of the 10-inch well casing. An 8-inch liner was installed in the well because the 10-inch steel casing had failed. The well was bailed and redeveloped prior to measuring the total depth. It appears that 7.25 feet of casing (64.75 – 57.50 = 7.25 Ft.) extended above the original land surface. However, likely 1.41 feet of the extended casing was removed (64.75 – 63.34 = 1.41 Ft.) when the manhole was constructed around the well, thus making the total depth at 63.34 feet. Given the above, the top of the 10-inch steel casing inside the manhole is calculated at 5.84 feet above the original land surface.

On November 14, 2001, the SWC conducted a pumping test on rehabilitated municipal well #1. The well was pumped at a rate varying from 112 to 103 gallons per minute for the first 460 minutes of pumping. After 460 minutes of pumping, the discharge rate was reduced to 79 gallons per minute to prevent the pump from breaking suction. From about 1400 minutes of pumping until the end of the test, numerous adjustments (up to 10 GPM) in pumping rate were required to maintain a discharge rate of 79 gallons per minute. Pumping began at 1300 hours on November 14, 2001 and ended at 1300 hours on November 16, 2001. Water was discharged about 250 feet to the southwest into a dry stream bed. Water levels in the production well were monitored during the pumping period and the recovery period. Water levels were monitored in municipal wells #2, #3, #4, and #5; Walker wells; Bittner wells; and observation wells 162-075-07BBB2, 07ADB5, and 07CBB. No water-level drawdown was observed at any of these wells during the pumping test.

A plot of log of time versus arithmetic pumping level is shown in figure 18. The pumping levels plot on a straight line for about the first 10 minutes of pumping. Based on average pumping rate of 109 gallons per minute during this time period, an aquifer transmissivity of 406 ft^2/d was calculated using the method of Jacob (1946). Based on an aquifer thickness of 13 feet, a hydraulic conductivity of 31 ft/d was calculated. If the clay content is large enough, this value of hydraulic conductivity is reasonable.

As previously mentioned, the geometry of the confined aquifer units is complex. Test-drilling data is not sufficient to characterize the spatial distribution of channel boundaries in relation to production wells. Therefore, it is likely that early-time versus drawdown pumping-test data will be affected by at least one close barrier boundary. One way to determine if a close barrier boundary exists is to apply the method of Jacob (1946) by calculating storativity using early time versus drawdown data. The line connecting early-time versus drawdown points is

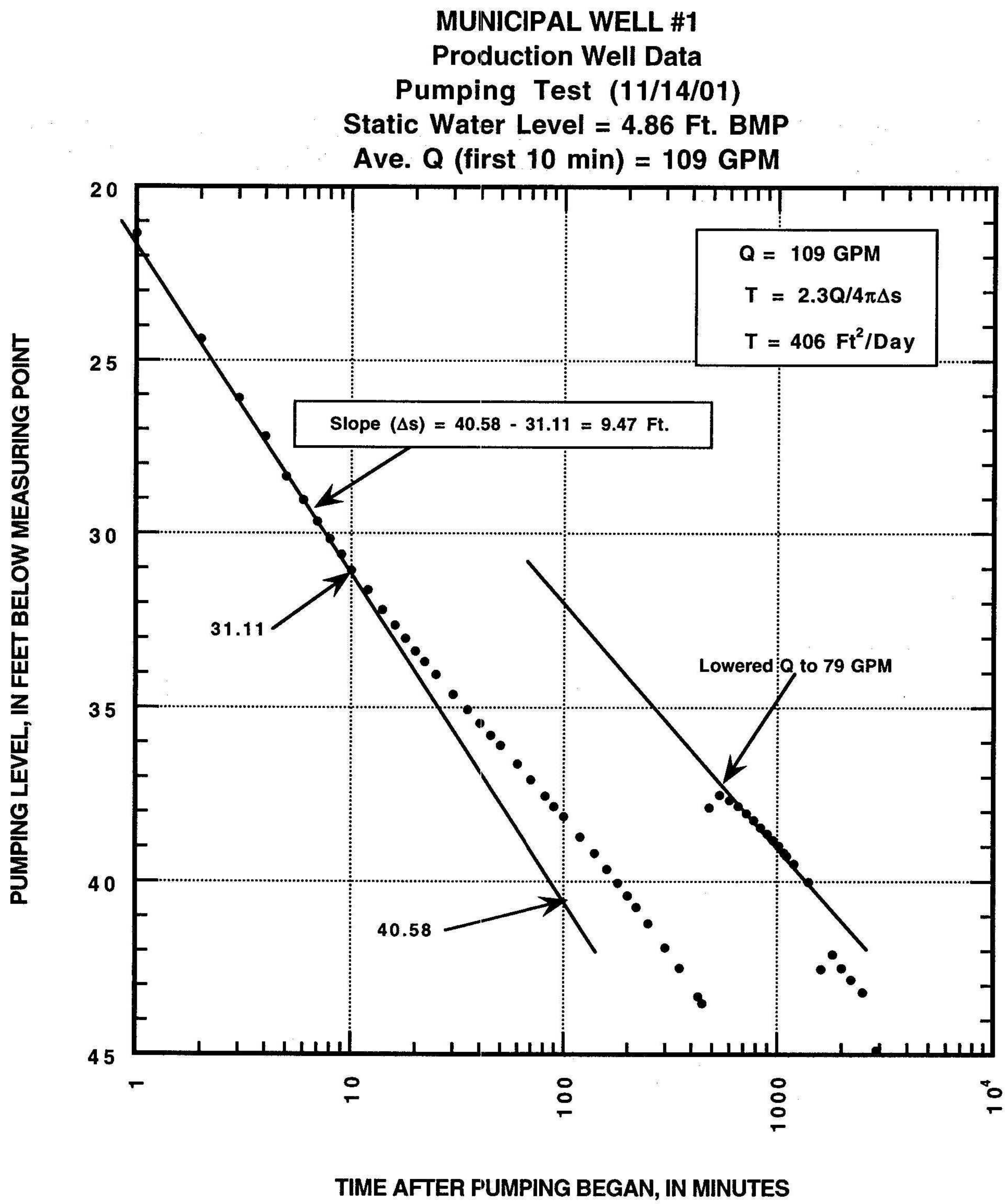


Figure 18 . -- Plot of log of time versus arithmetic pumping level in municipal well #1 (162-075-07BDC2)

extended to the zero drawdown (static water level) value. The time corresponding to this zero drawdown value is referred to as the t_o intercept. Storativity is calculated by equation 1.

$$S = 2.25\ T\ t_o/r_w^2 \qquad (1)$$

where,

T = transmissivity in feet squared per day

t_o = time in days, corresponding to point of zero drawdown

r_w = radius of pumping well, in feet

If the Theis assumptions are valid and the pumping well is 100 percent efficient, the storativity calculated using equation 1 will be the correct value. However, production wells rarely, if ever, are 100 percent efficient. Well inefficiency causes a downward shift in the time versus drawdown data and the t_o intercept is displaced to the left yielding a smaller t_o value. This results in the calculation of a smaller than actual storativity because t_o is directly proportional to storativity. However, if the early time versus drawdown data are affected by a barrier boundary, the slope of the line connecting these data points is doubled and the t_o intercept is displaced to the right yielding a larger t_o value. This results in the calculation of a larger than actual storativity.

Storativity of confined aquifers in North Dakota ranges from about 0.0001 to 0.0005. Extending the line connecting early time versus pumping level points in figure 18 yields a t_o intercept of 1.18×10^{-5} days. Based on a calculated transmissivity of 406 ft^2/d, and a pumping well radius of 0.417 feet (10-inch diameter well) a storativity of 0.062 is calculated using equation 1. This storativity value is about two orders of magnitude larger than typical values for confined aquifers in North Dakota. Based on the above analysis, the early time versus pumping level data in figure 18 is affected by a relatively close barrier boundary. Therefore, the transmissivity of 406 ft^2/d calculated using this early time versus drawdown data probably is about one-half actual transmissivity. Using a transmissivity of 812 ft^2/d, and a saturated thickness of 13 feet, a hydraulic conductivity of 63 ft/d is calculated. This value is reasonable for a clayey sand and gravel if the clay content is relatively small.

After about 10 minutes of pumping, pumping levels plot above the extended slope of the line formed by the pumping-levels measured during the first 10 minutes of pumping. This pumping level trend may be due to any one or more of the following:

1. Changes in aquifer geometry (channel widening/convergence).
2. Decrease in pumping rate.
3. Leakage from overlying/underlying lithologies.
4. Infiltration of well discharge downward to the aquifer.
5. Increase in transmissivity (textural or increased aquifer thickness) within the area of pumping influence.

As previously mentioned, the Bottineau aquifer consists of numerous relatively small-scale, braided channels characterized by a highly irregular geometry. Production wells located in aquifers characterized by channel geometries shown in figure 19 could give rise to the pumping-level pattern

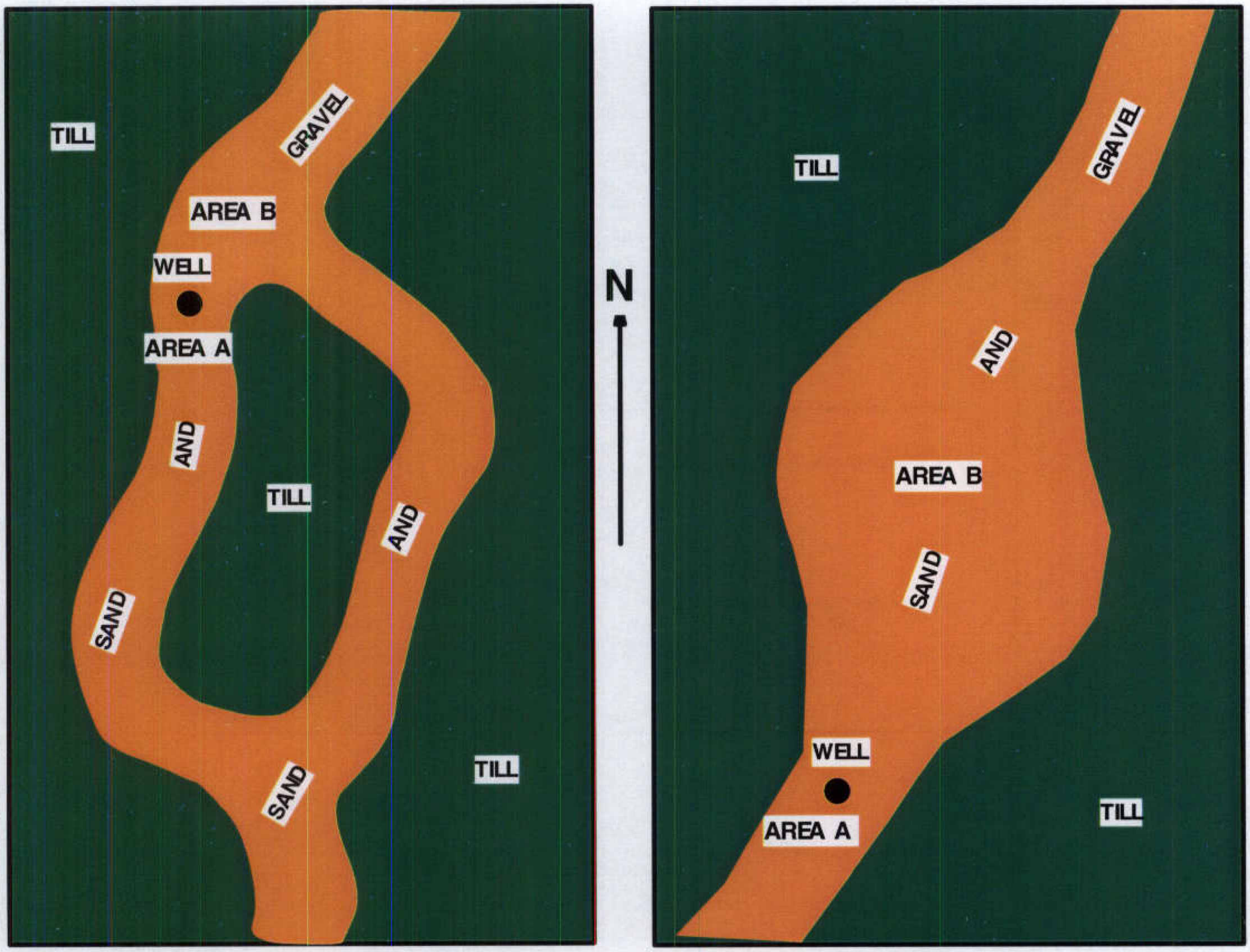


Figure 19. -- Schematic diagrams showing plausible channel geometries in the Bottineau aquifer

observed in figure 18 between about 10 and 460 minutes of pumping. For each channel geometry example in figure 19, the production well is located close to the intersection of areas A and B. Each channel in Area A is narrow enough such that the drawdown cone intersects the flanking barrier boundaries during the first 10 minutes of pumping. As the drawdown cone expands into Area B the capture area widens and cross-sectional transmissivity increases. This would cause the rate of change in drawdown to decrease, thereby causing pumping levels to plot above the trend line of the early-time data as in figure 18.

Between 10 and 200 minutes of pumping, the pumping rate declined from 108 to 103 gallons per minute. This could also cause the rate of change in drawdown to decrease, thereby causing pumping levels to plot above the extension of the slope of the line connecting pumping levels measured during the first 10 minutes of pumping (fig. 18).

Leakage from the overlying/underlying lithologies could also cause the rate of change in drawdown to decrease, thereby causing pumping levels to plot above the extension of the slope of the line connecting pumping levels measured during the first 10 minutes of pumping (fig. 18). The driller's log of municipal well #1 indicates an upper aquifer comprised of very clayey sand and gravel (26-38 ft.) and clayey fine sand (38-40 ft.) and a lower aquifer comprised of clayey gravel (44-46 ft.) and somewhat clayey sand and gravel (46-57 ft.). The upper and lower aquifer intervals are separated by a very gravelly blue clay from 40 to 44 feet. The production well is screened in the lower aquifer. Given that the very gravelly clay is continuous over the pump-test area of influence and the hydraulic diffusivity (ratio of vertical hydraulic conductivity to specific storage – K_v^1/S_s^1) of the gravelly clay layer is sufficiently large, leakage may be occurring from the upper aquifer interval downward through the very gravelly clay into the lower aquifer interval.

The driller's log indicates 26 feet of gravelly, sandy, rocky clay overlying the upper aquifer interval. This material probably is glacial till. If the till is characterized by a significant bulk hydraulic conductivity due to joints and fractures, the discharge water from the pump test could infiltrate downward to the aquifer. However, it was observed that the discharge water was flowing along the dry stream bed well beyond the road culvert about 1700 feet to the southwest. Based on the early time for pumping levels to be affected (10 minutes) and the volume of flow in the dry stream bed, downward infiltration of pump-test discharge to the aquifer after 10 minutes of pumping is not considered plausible.

After about 80 minutes of pumping, the slope of the line connecting pumping levels increases. This probably is the result of the influence of flanking barrier boundaries, which begin to override the influence of increased cross-sectional, transmissivity due to aquifer widening (fig. 19).

After 460 minutes of pumping, the pumping rate was reduced to 79 gallons per minute to prevent the pump from breaking suction. The slope (Δs_2) of the line connecting the five pumping-level points from 250 to 450 minutes is 8.91 feet. The slope (Δs_3) of the line connecting pumping level points from 720 to 1400 minutes is 6.95 feet. The ratio of Δs_3 to Δs_2 is 0.78. The ratio of pumping rate Q_2 (79 GPM) to pumping rate Q_1 (109 GPM) is 0.73. The small difference between the two ratios indicates virtually no change in boundary conditions during the two pumping periods.

For a confined aquifer of infinite areal extent, it is relatively easy to predict a pumping level for a given pumping rate and duration using data derived from a short-term pumping test. Slopes of log time versus pumping-level plots (Δs) are directly proportional to pumping rate (Q). Therefore, the Jacob (1946) equation can be used to extrapolate well drawdown over time for selected pumping rates.

The Bottineau study area is characterized by a number of relatively narrow, discrete, sand and gravel aquifers that generally are less than 100 feet below land surface. Long-term pumping levels in wells completed in these aquifers will be constrained in large part by the barrier boundary configurations (aquifer geometry). Predictions of well drawdown can be made from short-term pumping tests in bounded aquifers _if_ the configuration of the boundaries in relation to the pumped well are known. In the study area, the barrier boundary configurations of these discrete confined aquifers are very poorly defined.

Further, it is conceivable that long-term pumping in these aquifers may, over a relatively large area, cause water levels to fall below the overlying confining units thereby causing conversion from confined to unconfined conditions. The resulting increase in storativity will reduce long-term drawdown. Finally, leakage from overlying and underlying drift deposits may be significant over the long term, thereby reducing long-term drawdown.

The past pattern of ground-water withdrawals in the Bottineau municipal well field can provide some basis for selecting the maximum pumping period over which well drawdown can be predicted with a reasonable degree of certainty. Wells #4, #6, the Walker wells, the Bittner wells, and the Noble well flow continuously. Wells #2, #3, and #5 generally alternate operation for two-day continuous pumping periods. Well #1 is not used during the winter and is turned on and off by a relay-water-level sensor in the storage reservoir. The duration of pumping periods for well #1 is not known. When the city flushes hydrants in the fall, wells #1, #2, #3, and #5 are pumped continuously for about four days. As will be shown in a later section of this report, the current pattern of ground-water withdrawal in the Bottineau municipal well field is sustainable. Therefore, it is assumed that 10 days represents a maximum likely pumping time and is selected to estimate maximum well yield.

Typically, the SWC manages aquifer withdrawals based on production wells utilizing two-thirds of the available head above the well screen. The remaining one-third of the available head above the well screen is left to accommodate additional drawdown resulting from climate variability, interference from other ground-water withdrawals, and additional drawdown that may result due to other boundary conditions.

Given the above, estimated maximum pumping rates for this study are calculated based on a 10-day continuous pumping period that uses 50 percent of the available head above the top of the well screen. Actual specific capacities measured at the end of each of the pumping tests were extrapolated to 10 days.

Specific capacity extrapolation was accomplished using equation 2

$$\frac{Q}{s_w} = \frac{4\pi T}{2.30 \log_{10} 2.25 \frac{Tt}{r_w^2 S}} \qquad (2)$$

where:

Q = discharge in ft^3/d

s_w = drawdown in pumping well, in feet

T = transmissivity in ft^2/d

t = duration of pumping period, in days

S = storativity, dimensionless

r_w = radius of pumping well, in feet

A plot of specific capacity versus time was developed using typical aquifer parameters for the study area. Specific capacity measured during the pumping test was adjusted by multiplying that value by the relative decrease in specific capacity determined at 10 days on the above specific capacity versus time graph.

The maximum pumping rate was calculated based on using 50 percent of the available head above the well screen and the extrapolated, 10-day specific capacity. The extrapolated specific capacity and maximum pumping rate are based on Theis assumptions and do not incorporate the effects of irregular aquifer geometry, barrier boundaries, leakage, and conversion from confined to unconfined conditions. Due to uncertainty with regard to these boundary conditions, target pumping rates based on a 10-day continuous pumping period that uses 50 percent of the available head above the top of the well screen are selected.

Based on a "static" water level of two feet below the top of the 10-inch diameter well seal and the top of the screen at 53.8 feet below the well seal in municipal well #1, there is 51.8 feet of available drawdown above the top of the well screen. A drawdown of 38.66 feet was measured after 450 minutes of pumping at a rate of about 102 gallons per minute. This amounts to a specific capacity (discharge/drawdown) of 2.64 gallons per minute per foot of drawdown. Based on an extrapolated specific capacity of 2.2 gallons per minute per foot of drawdown calculated for 10 days of continuous pumping, an available drawdown of 25.9 feet (50 percent of total available head above top of well screen), a maximum pumping rate of 57 gallons per minute is calculated for municipal well #1.

Municipal well #2 (162-075-07ADB1) – Confined aquifer B

Municipal well #2 was constructed by C. A. Simpson and Son Drilling in January 1958. The driller's log is shown in table 2.

Table 2. -- Driller's log of municipal well #2

LITHOLOGIC DESCRIPTION	DEPTH	
	From	To
Topsoil	0	0.5
Gray clay	0.5	4
Yellow clay	4	11
Gray clay, rocks	11	68
Sand and coarse gravel	68	73
Very clayey sand, becoming finer	73	100

The depth of the well is reported at 80 feet. The well is constructed with 12-inch diameter steel casing to a depth of 68 feet and 12 feet of 12-inch diameter #60-slot Johnson "Everdur" screen from 68 to 80 feet. It is assumed the above depths are relative to the top of the 12-inch well seal inside the manhole.

On January 9, 1958, C.A. Simpson and Son Drilling conducted a pumping test on municipal well #2. The well was pumped at a relatively constant pumping rate, which averaged about 148 gallons per minute for 1444 minutes. Water levels were periodically measured in the pumping well during the pumping period and during a 2,972-minute recovery period. A plot of log of time versus arithmetic pumping level is shown in figure 20. The data indicate minor scatter from a straight line trend due to minor fluctuations in pumping rate. Linear regression analysis yields a slope (Δs) of 8.22 feet. Using the analytical method of Jacob (1946), a transmissivity of 635 ft^2/d was calculated. Based on lithologies reported in the driller's log, it is not possible to determine, with much certainty, the aquifer thickness. Therefore, it is not possible to calculate hydraulic conductivity. Given the previously described conceptual model of the aquifer, it is surprising that evidence for the effect of at least one barrier boundary does not exist on figure 20.

A plot of the ratio of log of time since pumping began divided by time since pumping ended versus arithmetic residual drawdown is shown in figure 21. Analysis of the recovery data provides a more accurate method of calculating transmissivity because data scatter caused by minor variations in pumping rate is eliminated during the recovery period. Most of the data plot along a line with a

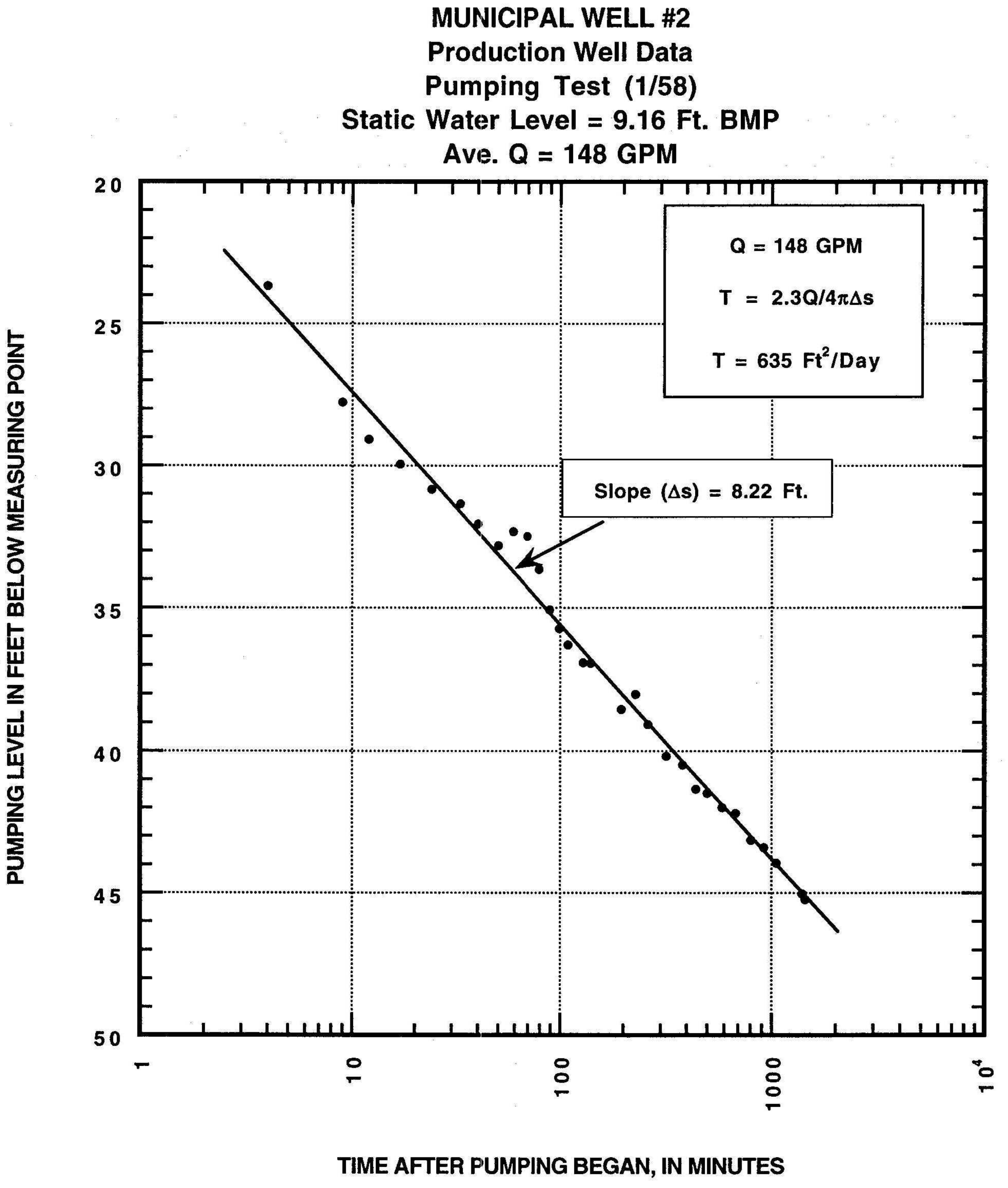


Figure 20. -- Plot of log of time versus arithmetic pumping level in municipal well #2 (162-075-07ADB1)

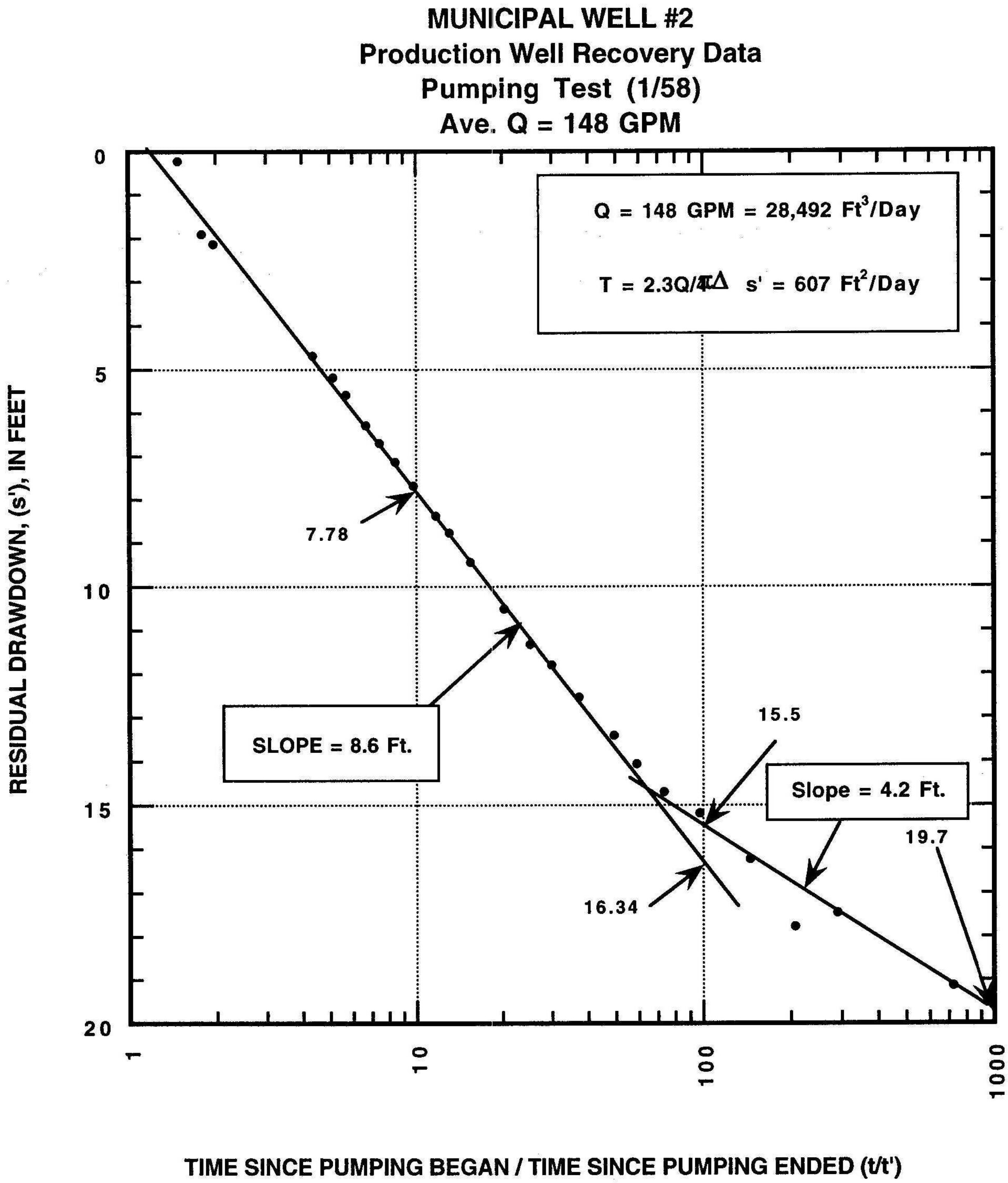


Figure 21. -- Plot of log of ratio of time since pumping began divided by time since pumping ended versus arithmetic residual drawdown

slope of 8.6 feet, which yields a transmissivity of 607 ft^2/d. Note, although there is some scatter, the first six recovery points are characterized by a line with a slope of 4.2 feet. This slope is about one-half the slope of the line formed by the later recovery data points suggesting a barrier boundary is relatively close to the pumping well. Based on the previously described conceptual model of the Bottineau aquifer, the existence of a nearby barrier boundary is likely.

On October 3, 2001, the SWC conducted a pumping test on municipal well #2. The well was pumped continuously at a rate of 65 gallons per minute for 350 minutes. Water was discharged at land surface in a tree shelterbelt about 250 feet south of the well. The discharge rate was measured using a Panametrics sonic flow meter. During the test, the Bittner wells, Walker wells, Noble well, and well #4 were flowing. Wells #1, #3, #5, and #6 were not pumping. In addition, water levels in confined aquifer B, in which wells #2, #3, and #5 are completed, were recovering due to recent pumping by the city to flush hydrants. Pumping and recovery water levels were corrected for recovery resulting from prior pumping. Water-level drawdown was measured in wells #3 and #5 during the pumping test indicating a hydraulic connection between wells #2, #3, and #5.

A plot of log of time versus arithmetic pumping level in municipal well #2 is shown in figure 22. The corrected pumping levels plot on a straight line for about the first 12 minutes of pumping. The slope (Δs) of this line is 1.57 feet. Using the method of Jacob (1946) and a (Δs) of 1.57 feet, an aquifer transmissivity of 1460 ft^2/d is calculated. The pump setting was not known. However, the effects of casing storage with no pump in the well would not affect the drawdown after four

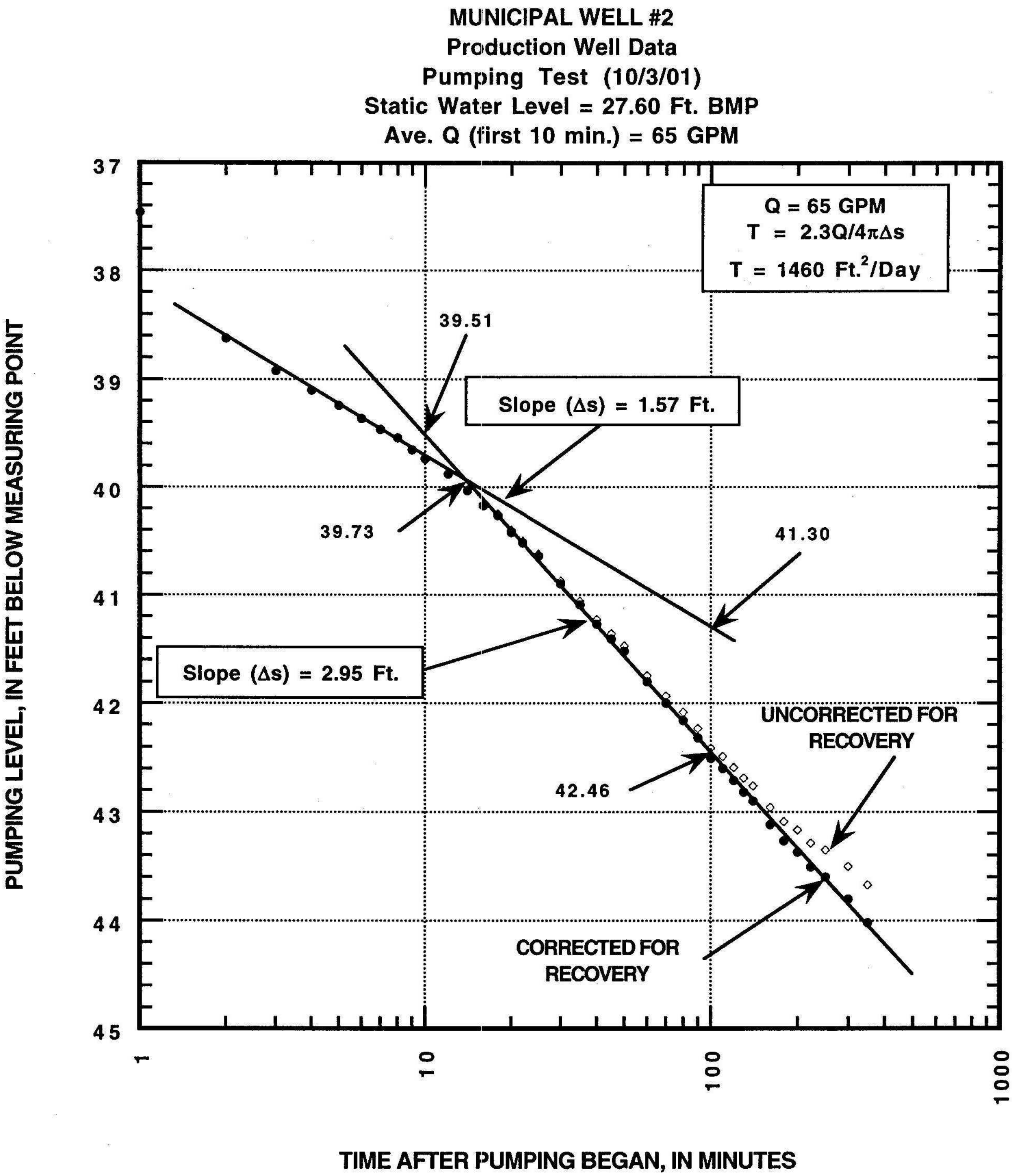


Figure 22. -- Plot of log of time versus arithmetic pumping level in municipal well #2 (162-075-07ADB1)

minutes of pumping at a rate of 65 gallons per minute. Extending the line connecting the first 12 minutes of pumping-level points to determine t_o and using equation 1 yields a storativity of 1.71 x 10^{-6}. This value of storativity is about two orders of magnitude smaller than typical values for confined aquifers in North Dakota. Therefore, it is concluded the pumping levels measured during the first 12 minutes are not affected by a barrier boundary.

After about 12 minutes of pumping, the corrected pumping levels plot along a straight line with a slope of 2.95 feet. This slope is about double that of the slope of the line connecting corrected pumping levels measured during the first 12 minutes of pumping. A doubling of the slope is indicative of the drawdown cone intersecting a barrier boundary. After 12 minutes of pumping until the end of the test, the corrected pumping levels plot along a single straight line suggesting the drawdown cone does not intersect another barrier boundary.

At the time of construction, C.A. Simpson and Son Drilling reported the screen interval from 68 to 80 feet below land surface. Assuming the top of the well seal inside the manhole represented the original land surface, and based on a "static" water level of 17 feet below the well seal, there is 51 feet of available head above the top of the well screen. After 350 minutes of pumping at a rate of 65 gallons per minute, the specific capacity was 3.96 gallons per minute per foot of drawdown. Based on an extrapolated specific capacity of 3.2 gallons per minute per foot of drawdown calculated for 10 days of continuous pumping, an available drawdown of 25.5 feet (50 percent of total available head above top of well screen), a maximum pumping rate of 82 gallons per minute is calculated.

It is important to note that because hydraulic continuity is indicated between municipal wells #2, #3, and #5, additional drawdown will occur at well #2 when wells #3 and #5 are pumped. Based on the following hydraulic analysis for well #3, well #2 should be used as a standby well, because drawdown interference from pumping well #3 and to a lesser extent from pumping well #5 will be too large, thereby significantly reducing the maximum target pumping rate.

Municipal Well #3 (162-075-07ACA) – Confined aquifer B

Municipal well #3 was constructed by C. A. Simpson and Son Drilling on October 14, 1987. This well was a replacement well for a nearby well drilled in 1968. The driller's log is shown in table 3.

Table 3. -- Driller's log of municipal well #3

LITHOLOGIC DESCRIPTION	DEPTH	
	From	To
Topsoil	0	1
Clay, gray	1	4
Clay, yellow	4	10
Sand	10	13
Clay, yellow	13	16
Clay, blue	16	46
Gravel	46	81

The depth of the well is reported at 81 feet. The well is constructed with 8-inch diameter steel casing to a depth of 61 feet and 20 feet of Johnson, stainless-steel, #60-slot, telescopic screen from 61 to 81 feet. The completion report indicates a static water level of 4.84 feet, pumping levels of 24.58 feet, 27.57 feet, and 29.46

feet below a measuring point of 1.8 feet above land surface after 20, 90, and 300 minutes of pumping at a rate of 210 gallons per minute. Specific capacity was 7.13 gallons per minute per foot after 300 minutes of pumping at a rate of 210 gallons per minute.

On October 11, 2001, the SWC initiated a one-day pumping test on municipal well #3. Prior to conducting the test, the pitless unit was removed to accommodate water-level measurement. The water level rose above the buried pitless discharge pipe, which is tapped into the well casing, causing the well to overflow into the water main leading to the storage tank. The shut-off valve in the discharge line leading to the water main would not close. Within one minute after the pump was turned off, the water level in the well rose above the level of the pitless discharge pipe, again causing discharge into the main. The submersible pump in the well was used during the pump test and with a small amount of back pressure yielded 84 gallons per minute. Based on the above, it was decided to run a second pumping test on well #3 using a larger-capacity test pump and properly sealing the buried pitless discharge pipe.

Prior to running the second pumping test on well #3, it was determined the original 8-inch diameter steel well casing had failed causing sediment to wash into the well. A 6-inch diameter steel liner was installed from 0.69 feet above the top of the 8-inch diameter casing to the top of the screen packer. The buried pitless discharge pipe was blocked by a valve installed in the metering manhole just south of the well.

The second pumping test on well #3 was begun at 0900 hours on November 27, 2001 and run until 0900 hours on November 30, 2001. For the first 3,010 minutes of the test, the pumping rate was held fairly constant varying from between 198 to 206 gallons per minute. After 3,010 minutes, the pumping rate was increased to 250 gallons per minute, which was maintained fairly constant until the end of the test (4,320 minutes). The pumping rate was measured using a Panametrics sonic flow meter. Discharge was routed into buried pipeline through the metering manhole just south of well #3.

During the test, the Bittner and Walker wells, the Noble well and well #4 were flowing. Wells #1, #5, and #6 were not pumping. In addition, water levels in confined aquifer B, in which wells #2, #3, and #5 are completed, were recovering due to recent pumping by the city of Bottineau. Pumping and recovery water levels were corrected for recovery resulting from prior pumping. Water-level drawdown was measured in wells #2 and #5 during the pumping test indicating a hydraulic connection between wells #2, #3, and #5. No other wells in the study area responded to pumping municipal well #3.

A plot of log of time versus arithmetic pumping level in municipal well #3 is shown in figure 23. For about the first 20 minutes of pumping, the corrected pumping levels plot along a straight line with a slope (Δs) of 5.08 feet. Using the analytical method of Jacob (1946), a transmissivity of 1409 ft^2/d is calculated. The driller's log indicates 35 feet of gravel (no texture range given) at the production well site. The hydraulic conductivity is calculated to be 40 ft/d. A hydraulic conductivity of 40 ft/d is typical of a fine to medium sand. The small hydraulic

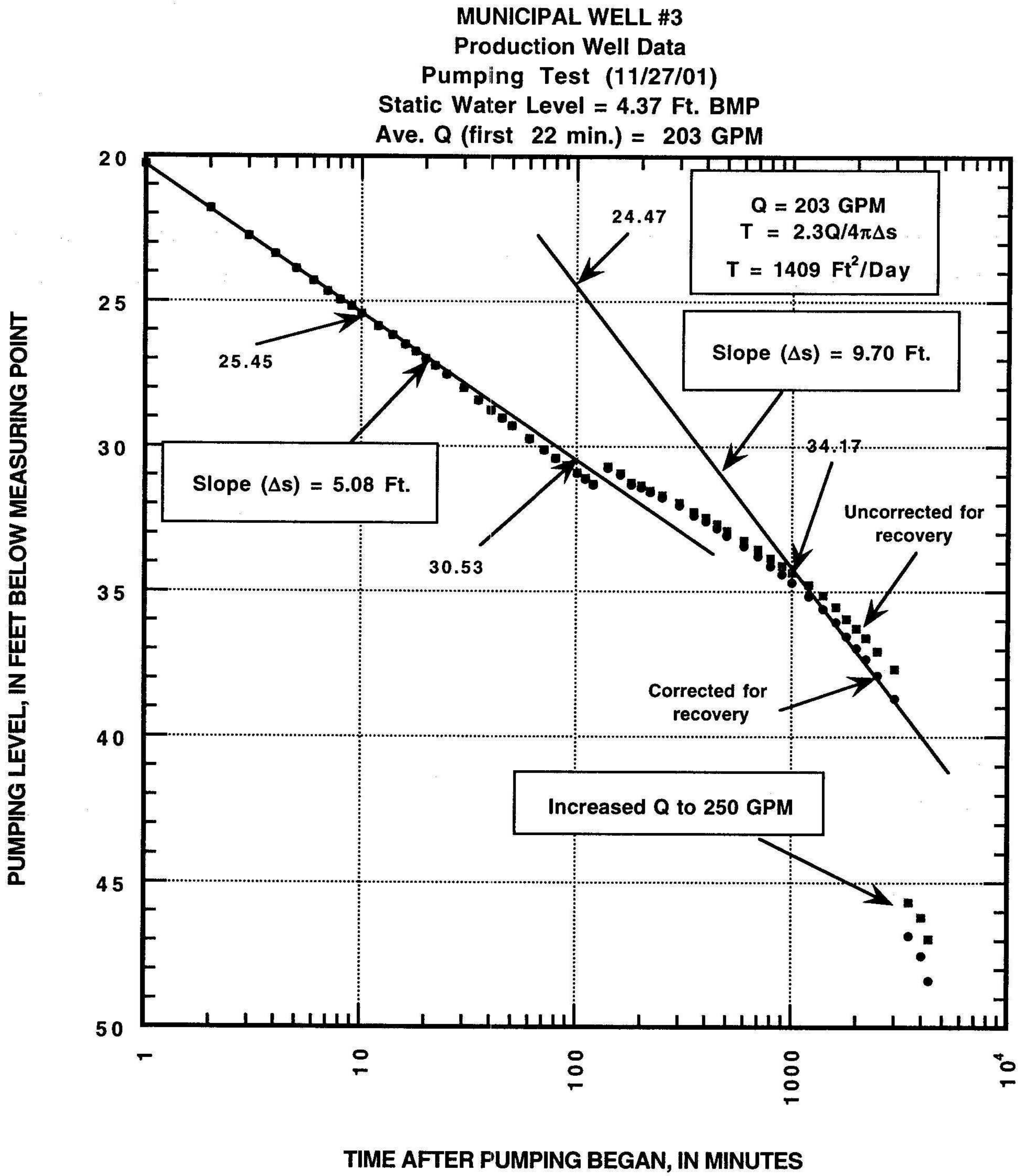


Figure 23. -- Plot of log of time versus arithmetic pumping level in municipal well #3 (162-075-07ACA)

conductivity suggests the first 20 minutes of water-level data likely are affected by a close barrier boundary.

Based on a calculated transmissivity of 1409 ft^2/d, a pumping well radius of 0.33 feet and a t_o intercept of 5.08×10^{-7} days, a storativity of 0.015 is calculated using equation 1. This storativity value is about two orders of magnitude larger than typical values for confined aquifers in North Dakota. The anomalously large calculated storativity indicates the early time versus pumping-level data in figure 23 is affected by a relatively close barrier boundary.

After about 20 minutes, the corrected pumping-levels fall below the extension of the slope of the line formed by the data points during the first 20 minutes of pumping. This suggests the drawdown cone is affected by a minor decrease in transmissivity (channel thinning or narrowing).

Somewhere between 120 and 140 minutes, the pumping level abruptly rises with the slope of the line connecting the first three pumping levels after 120 minutes following the same slope of the line connecting the last few pumping levels up to 120 minutes. This response probably is due to natural well development. It is important to note the well was re-developed (jetting, pumping, bailing) after the 6-inch diameter well liner was installed. Complete re-development may not have been achieved during the short development process.

After about 200 minutes, pumping levels plot along a line characterized by a smaller slope. After about 1000 minutes, pumping levels plot along a line characterized by a much larger slope.

The varied pattern of pumping-level response is indicative of complex aquifer geometry. Two examples of aquifer geometry that could affect a pumping level response similar to that in figure 23 are illustrated in figure 19. In both examples, the production well is located close to the west flank of the buried sand and gravel channel. As a result, the first 10 minutes of data are affected by the close barrier boundary, resulting in the calculation of an anomalously small transmissivity and associated hydraulic conductivity and an anomalously large storativity. After about 20 minutes, the pumping levels begin to plot along a line with a steeper slope suggesting the effect of a second barrier boundary located along the east flank of the aquifer or a decrease in transmissivity. As the drawdown cone intersects the east barrier or area of decreased transmissivity, it also expands into Area B (fig. 19), which is characterized by an increase in cross-sectional transmissivity. Expansion of the drawdown cone into the larger transmissivity area subdues the effect of the second barrier boundary along the east flank of the buried channel aquifer or the area of decreased transmissivity. With time, the effect of the second barrier boundary or the area of decreased transmissivity overrides the influence of increased cross-sectional transmissivity in Area B, and the slope of the line connecting pumping levels increases. Note the slope of the later-time data (1,000 to 3,000 minutes) is 9.70, which is about double that indicated by the slope of the early time data (1-200 minutes). The slope of the line connecting pumping levels should double when the drawdown cone intersects a barrier boundary.

Further evidence indicating the complex geometry of buried confined aquifer B is indicated by the composite log of the ratio of time divided by radius squared (t/r^2) versus log drawdown graph shown in figure 24. The drawdowns at municipal wells #2 and #5 shown in figure 22 were measured during the 4,320-minute pumping test on municipal well #3. If the Theis assumptions are valid (i.e. aquifer homogeneous, isotropic, and infinite areal extent) individual drawdown plots should form a single curve that corresponds to a segment of the Theis type curve. The two drawdown curves in figure 24 show considerable separation indicating the Theis assumptions are not valid. The position of the drawdown curve for well #5 in relation to that of well #2 suggests either 1) a poorer hydraulic connection between production well #3 and well #5 as compared to that between the production well #3 and well #2, and/or 2) a flow path between production well #3 and well #5 that is significantly larger than the radial distance between the two wells. In addition, after 20 minutes of pumping, the slope of the t/r^2 versus drawdown curve for well #2 increases, indicating either a decrease in transmissivity or the effect of a barrier boundary.

In the hydraulic discussion regarding municipal well #2, it was recommended that well #2 be used as a standby well because the drawdown interference from pumping both wells #3 and #5 would severely limit the pumping rate. A plot of log of time versus arithmetic drawdown plot showing water-level response in well #2 and well #5 resulting during the well #3 pump test is shown in figure 25. The slope of the line connecting the data points between 2,000 and 3,000 minutes is relatively steep indicating the effects of barrier boundaries.

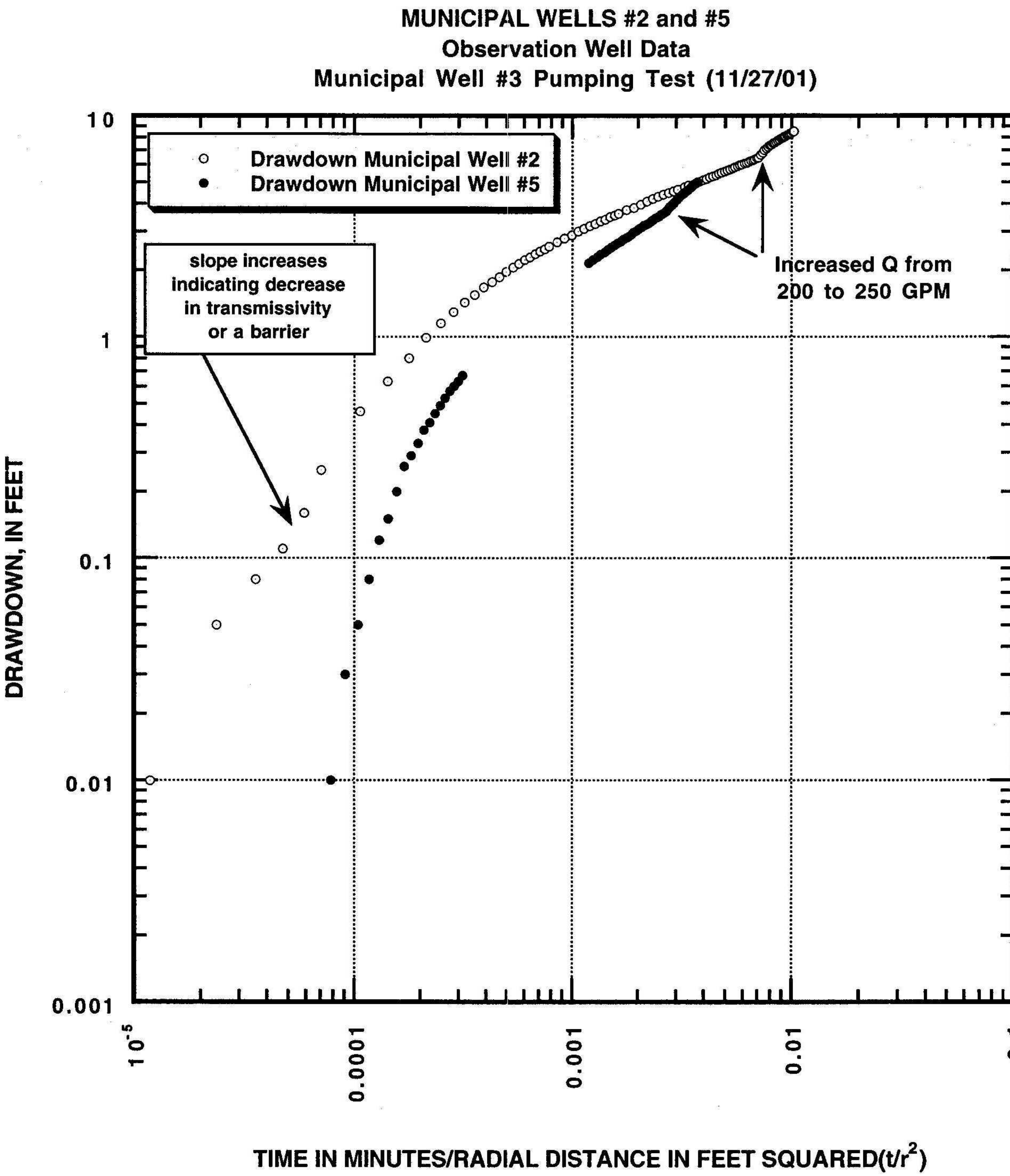


Figure 24. -- Composite plot of log of time divided by distance squared versus log drawdown in municipal wells #2 and #5

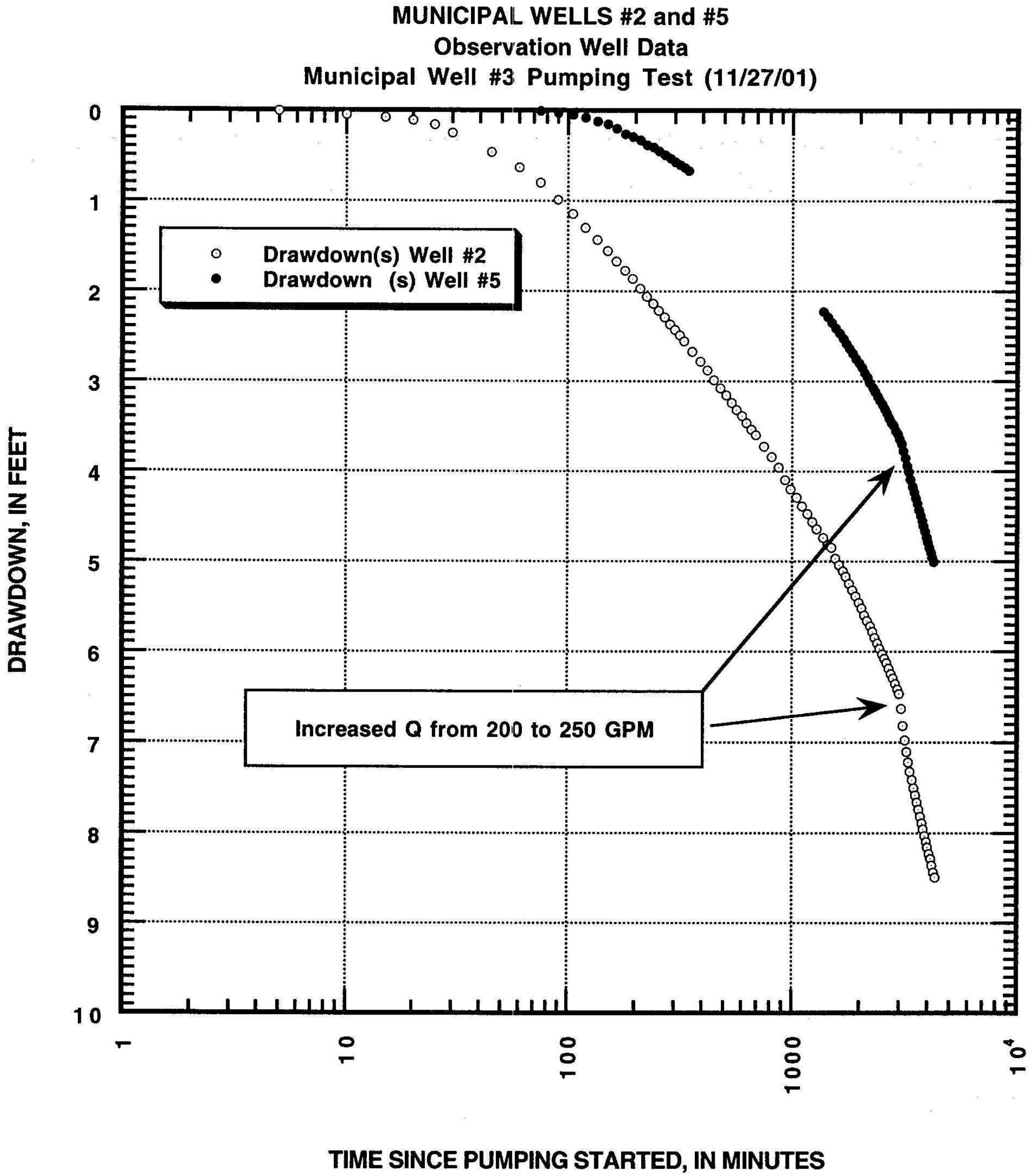


Figure 25. -- Plot of log of time versus arithmetic drawdown in municipal wells #2 and #5

During the pumping test, well #3 was pumped at a rate of about 200 gallons per minute up to 3,000 minutes. If a target pumping rate of 160 gallons per minute is used, the slope of the line connecting of the drawdown points between 2,000 and 3,000 minutes will be less but still relatively large (steep). Pumping well #3 continuously at a rate of 160 gallons per minute for 10 days will likely cause at least 10 feet of drawdown interference at well #2. This reduces the total available head above the top of the well screen by about 20 percent. Additional drawdown interference will occur at well #2 when well #5 is pumped, further reducing the available head above the top of the well screen.

Assuming a “static” water level at land surface for municipal well #3, there is 61 feet of available head above the top of the well screen. After 3,000 minutes of pumping at a rate of about 200 gallons per minute, the specific capacity was 5.8 gallons per minute per foot of drawdown. Based on an extrapolated specific capacity of 5.4 gallons per minute per foot of drawdown calculated for 10 days of continuous pumping, an available drawdown of 30 feet (50 percent of total available head above top of well screen), a maximum pumping rate of 160 gallons per minute is calculated.

Municipal Well #4 (162-075-07ABD1) – Confined aquifer A

Municipal well #4 was constructed by C.A. Simpson and Son Drilling in May 1956. The driller’s log is shown in table 4.

Table 4. – Driller's log of municipal well #4

LITHOLOGIC DESCRIPTION	DEPTH From	DEPTH To
Peat, soft	0	10
Sandy, light gray clay	10	16
Slightly sandy yellow clay	16	30
Muddy gravel, rocks	30	36
Sandy gray clay, rocks	36	58
Hardpan (till ?)	58	64
Coarse sand and gravel	64	67
Gravelly clay	67	68
Sand and gravel	68	76
Gravelly clay	76	80

The depth of the well is reported at 76 feet. The well was constructed with 10-inch diameter steel casing to a depth of 68 feet and eight feet of 10-inch diameter, #40 slot Johnson "Evurdur" screen from 68 to 76 feet. It is assumed the above depths are relative to the top of the 10-inch well seal inside the manhole. At the time of construction, the "static" water level was estimated at about 10 feet above land surface.

On May 16, 1956, C.A. Simpson and Son conducted a pumping test on well #4. Prior to start-up, the well was flowing at a rate of about 25 gallons per minute at two feet above land surface. The pump was shut off after 78 minutes of pumping for 35 minutes to refuel. The pump was also shut down three times throughout the test to check engine oil. As a result, the time versus drawdown data is very scattered and not usable for evaluating aquifer parameters.

On April 30, 1980, an 8-inch diameter steel liner was inserted into the well because the original 10-inch diameter steel casing had failed causing sediment to fall into the well screen and plug the submersible pump. The 8-inch liner could not be inserted to the top of the well screen because of a blockage, which was assumed to be the failed area of the 10-inch diameter casing. The top of the 8-inch diameter liner was set just below a buried discharge pipe that is about 10.75 feet below land surface. The city of Bottineau has removed the submersible pump from this well and the well is allowed to free-flow out of the buried discharge pipe tapped into the well casing located just above the top of the 8-inch diameter steel liner.

In October 1983, well #6 was constructed 52 feet northeast of well #4. Well #6 was installed due to the inability to completely rehabilitate municipal well #4. Well #6 is completed in the same aquifer interval (confined aquifer A) as well #4. Pumping well #6 at the maximum target pumping rate (to be discussed later) will cause too much drawdown interference at well #4 and, as a result, well #4 should not be used as a pumping well.

Municipal Well #5 (162-075-07ADC) – Confined aquifer B

Municipal well #5 was constructed in May 1980. The driller's log is shown in table 5.

Table 5. – Driller's log of municipal well #5.

LITHOLOGIC DESCRIPTION	DEPTH	
	From	To
Topsoil	0	2
Clay, gray	2	3
Clay, yellow	3	12
Clay, yellow with stones (till ?)	12	24
Clay, blue with stones (till ?)	24	53
Sand, yellow, medium, stones	53	66
Clay, blue, gravel layers	66	72
Gravel, medium to coarse	72	85
Clay, blue	85	

The depth of the well is reported at 85 feet below land surface. The well is constructed with 8-inch diameter steel casing to a depth of 74 feet, and 11 feet of Johnson 8-inch diameter, telescopic #25-slot, stainless steel screen from 74 to 81 feet and #50 slot screen from 81 to 85 feet. The screen was not gravel packed.

On June 13, 1980, C. A. Simpson and Son Drilling conducted a pumping test on municipal well #5. The well was pumped continuously at a rate of 49 gallons per minute for 1400 minutes. After one hour of pumping the specific capacity was 1.64 gallons per minute per foot of drawdown and after 1400 minutes of pumping the specific capacity was 1.53 gallons per minute per foot drawdown. Simpson reported that during the pumping test, water-level drawdown was measured at municipal well #2 and observation wells 80-6 (located 56 feet east of the production well) and 80-1 (located 460 feet south of the production well).

The SWC conducted a pumping test on municipal well #5 on October 4, 2001. The well was pumped continuously for 250 minutes at a fairly constant rate of 42 gallons per minute. Discharge was measured using a Panametrics sonic flow meter. The discharge was diverted about 250 feet south into a shelterbelt. During the test, the Bittner wells, Walker wells, Noble well and well #4 were flowing. Wells #2, #3, and #5, all of which are completed in confined aquifer B, were pumped continuously from September 28 to October 1, when the city of Bottineau flushed fire hydrants. As a result, water levels measured during pumping and recovery were corrected to account for water-level recovery from the previous pumping by the city. Only municipal wells #2 and #3 responded to pumping of municipal well #5. A water-level drawdown of 0.95 feet was measured at municipal well #2 and a water-level drawdown of 0.13 feet was measured at municipal well #3.

A plot of log of time versus arithmetic pumping level in municipal well #5 is shown in figure 26. For about the first four minutes of pumping the slope of a line connecting pumping levels (not shown) would be large (steep). This early-time response probably is due to the effects of casing storage. It is estimated that about two minutes would be required to remove the volume of water stored in the well casing. After about five minutes of pumping, pumping levels plot along a straight line with a slope (Δs) of 3.22 feet. Using the analytical method of Jacob (1946), a transmissivity of 460 ft^2/d is calculated. Based on an aquifer thickness of 13 feet, a hydraulic conductivity of 35 ft/d is calculated. The driller's log indicates the 13-foot aquifer interval is comprised of medium to coarse gravel. A hydraulic conductivity of 35 ft./d is much too small for a medium to coarse gravel. The small hydraulic conductivity may indicate pumping levels are almost

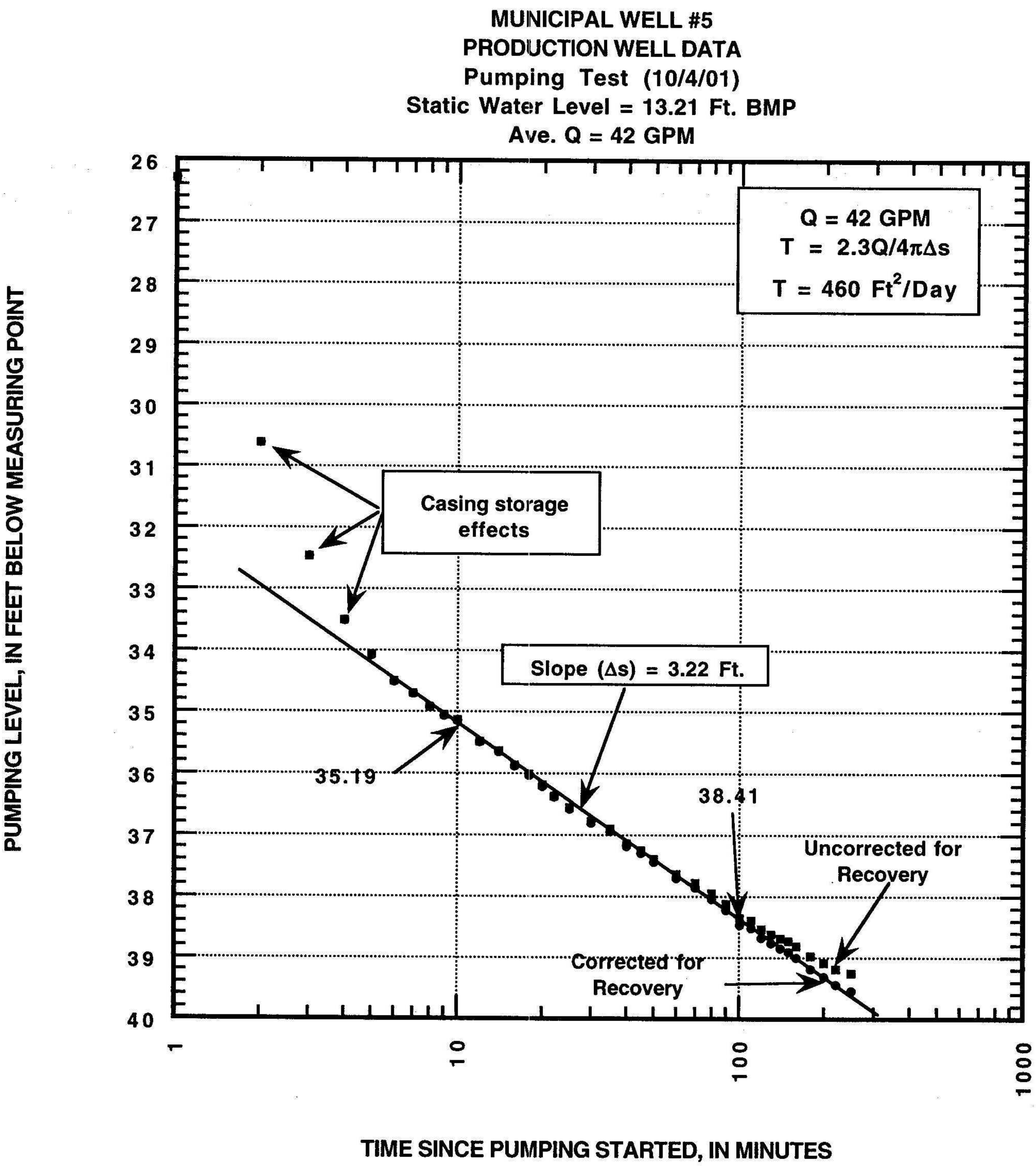


Figure 26. -- Plot of log of time versus arithmetic pumpiing level in municipal well #5 (162-075-07ADC3)

immediately affected by a barrier boundary that is located in close proximity to the production well.

Extending the line connecting early time versus pumping-level points in figure 26 yields a t_o intercept of 1.03×10^{-9} days. Based on a calculated transmissivity of 460 ft^2/d, and a pumping well radius of 0.33 feet (8-inch diameter well), a storativity of 9.8×10^{-6} is calculated. This value of storativity is about two orders of magnitude smaller than typical values of confined aquifers in North Dakota. This suggests early time pumping levels are not affected by a barrier boundary. The well may be highly inefficient or may be characterized by a low apparent efficiency caused by the well being completed in a coarse-textured pocket surrounded by a finer textured material. This could offset the value of apparent storativity thereby masking the effect of a close barrier boundary. Note that from five minutes until the end of the test (250 minutes), the data plot along a straight line suggesting no impact from a barrier boundary. Given the conceptual model of the aquifer system, it is highly unlikely at least one barrier boundary is not indicated during the 250-minute pumping test. Therefore, it is concluded that the well is located very close to a barrier boundary that affects pumping-level data almost immediately after pumping is initiated.

A plot of log of ratio of time since pumping began to time since pumping ended versus arithmetic residual drawdown is shown in figure 27. As in figure 26, about the first two minutes of recovery are affected by casing storage in the well. After about four minutes until about 40 minutes of recovery the values of residual drawdown plot along a straight line with a slope (Δs) of 2.17. Using the method

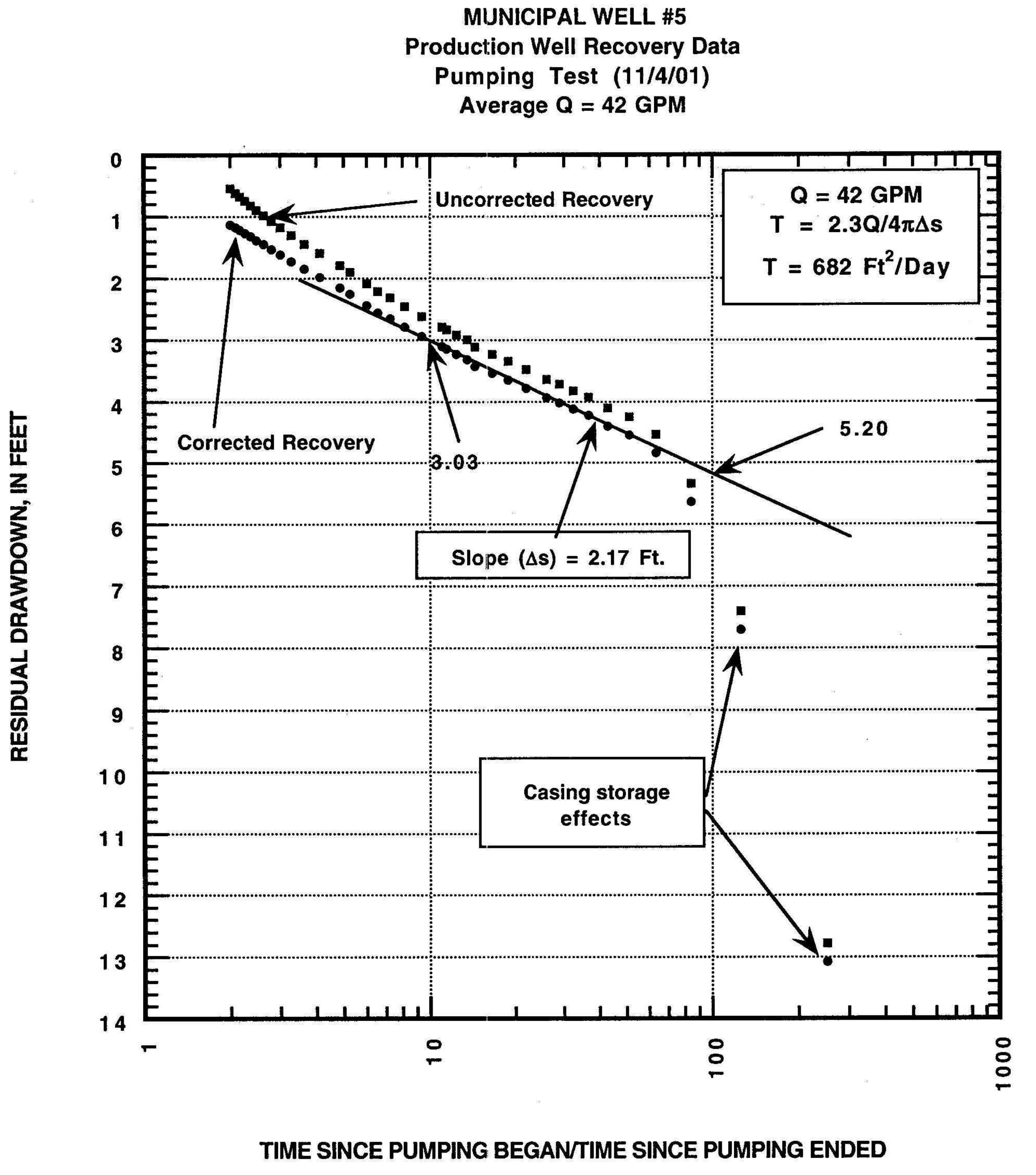


Figure 27. -- Plot of log of ratio of time since pumping began divided by time since pumping ended versus arithmetic residual drawdown in municipal well 5

of Jacob (1946), a transmissivity of 682 ft²/d is calculated. This slope (Δs value) of the recovery straight line is about 1.5 times larger than that calculated from the pumping water-level data. This same relationship was observed in the pumping/recovery test conducted by C.A. Simpson and Son Drilling in 1980. The difference between pumping and recovery response likely is due to the drawdown cone intersecting a barrier boundary or small transmissivity zone shortly after pumping was terminated.

Assuming a "static" water level of about eight feet below land surface at municipal well #5, there is 66 feet of available head to the top of the well screen. After 250 minutes of pumping at a rate of 42 gallons per minute, the specific capacity was 1.6 gallons per minute for foot of drawdown. Based on an extrapolated specific capacity of 1.25 gallons per minute per foot of drawdown calculated for 10 days continuous pumping, an available drawdown of 33 feet (50 percent of total available head above top of well screen), a maximum pumping rate of 41 gallons per minute is calculated.

Municipal Well #6 (162-075-07ABD2) – Confined aquifer A

Municipal well #6 was constructed in October 1983. The driller's log is shown in table 6.

Table 6. – Driller's log of municipal well #6

LITHOLOGIC DESCRIPTION	DEPTH	
	From	To
Bog, sandy	0	3
Topsoil	3	5
Clay, yellow	5	24
Clay, blue	24	51
Sand, medium to coarse	51	79
Clay, blue	79	83

The depth of the well is reported at 80 feet below land surface. The well is constructed with 8-inch diameter steel casing to a depth of 60 feet and 20 feet of Johnson, 8-inch diameter, telescopic, stainless-steel screen from 60 to 80 feet. From 60 to 65 feet the screen is #20-slot, from 65 to 72 feet the screen is #35 slot, and from 72 to 80 feet the screen is #50-slot. It appears the screen was not gravel packed.

On October 19, 1983, the well was test pumped by C.A. Simpson and Son Drilling at a rate of 248 gallons per minute for 5 1/2 hours. The specific capacity was calculated at 5.8 gallons per minute per foot of drawdown. During this test a water-level drawdown of 4.56 feet was measured in municipal well #4 located 52 feet to the southwest. In addition, a water-level drawdown of 0.85 feet was measured in observation well 83-3, which is reported as being located about 400 feet south and east of municipal well #6. Unfortunately, no driller's log is available for this observation well, but it appears the 1 1/4-diameter PVC observation well found at 162-075-07ADB5 is observation well 83-3. The well depth was measured at 99 feet below land surface on June 5, 2001. During additional well testing on April 20, 1984, C.A. Simpson and Son Drilling report a "static" water level of 34.65 feet below the measuring point (top of 1 1/4-inch diameter casing) which is close to the contemporary water level of about 34 feet below land surface.

Municipal well #6 was constructed with a 4-inch diameter discharge pipe that is tapped into the well casing about two feet below the pitless discharge pipe (fig. 28). The pitless discharge pipe is tapped into the well casing about eight feet below land surface. The pitless discharge pipe and the 4-inch diameter discharge pipe below the pitless discharge pipe intersect at a "tee" fitting just south of the well (fig. 28). A metering manhole is located just south of the "tee" junction. A spring-loaded shut-off valve is installed in the manhole discharge line. The 4-inch diameter discharge pipe below the pitless discharge pipe is equipped with a shut-off valve just south of the well (fig. 28). This valve is accessible at land surface using a long-stemmed steel handled key.

On October 9, 2001, the SWC conducted a pumping test on well #6. After the pitless unit in the well was removed to route discharge to the surface through the Panametrics sonic flow meter, attempts were made to close the spring-loaded valve in the metering manhole to prevent discharge from occurring through the pitless discharge pipe. The valve was rusted and would not fully close. Therefore, the "static" water level prior to initiating the pumping test was 5.78 feet below land surface with water flowing through 4-inch diameter pitless discharge pipe.

It was decided to run a short-term pumping test to primarily evaluate boundary conditions and interconnectedness, if any, with other aquifer units. During the pumping test, municipal well #6 was pumped at an average pumping

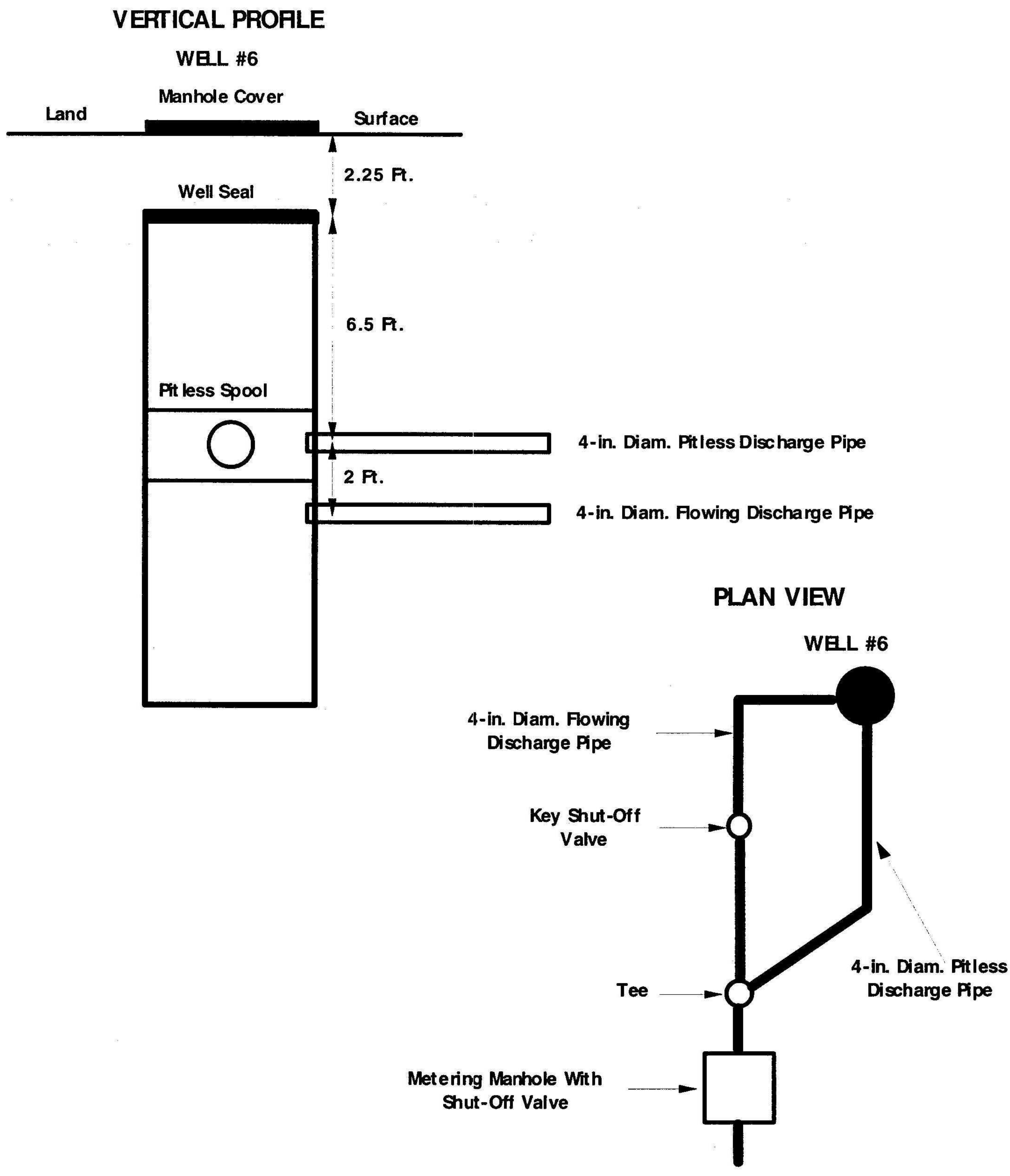


Figure 28.-- Schematic diagram showing plumbing at municipal well #6

rate of about 75 gallons per minute. The city estimated the pumping rate of this well at 90 gallons per minute. After the pumping test was completed, the submersible pump was removed from the well and it was noted the pump motor was only loosely attached to the pump with one bolt.

Within one minute of recovery, the water level in the well rose up to and flowed out of the pitless discharge pipe. As a result, analysis of water-level recovery was not possible.

Based on the above complications, it was decided to conduct a second pumping test on municipal well #6 using a larger capacity test pump. The city of Bottineau retained Bursinger Drilling, Bisbee, ND to install a large capacity test pump in well #6. After the 400-gallon per minute test pump was set, a preliminary pump test was run by the SWC on October 15, 2001, to set the pumping rate. As soon as the pump was turned on, a grinding noise was heard inside the well. The maximum discharge was only 175 gallons per minute, well below the maximum pump capacity of 400 gallons per minute. In addition, the discharge rate rapidly fluctuated about ± 10 to 15 gallons per minute. Inspection at the end of the discharge line found a large amount of manganese sulfide "chips" (less than 1/2-inch in diameter) and sand and gravel (up to about 3/4-inch in diameter). The pump was shut off and upon inspection, it was found that some of the impellers were plugged with gravel fragments, thereby reducing the pumping capacity.

Bursinger Drilling returned to redevelop the well and determined the casing had failed. A 6-inch diameter steel liner was installed in the well to the top of the screen packer. The test pump was repaired, reinstalled and a preliminary pump test to set the pumping rate was run on November 5, 2001.

On November 6, 2001, the SWC conducted a pumping test on municipal well #6. Pumping began at 0900 hours on November 6 and ended at 0900 hours on November 9. The well was pumped at a fairly constant rate of 198 gallons per minute. Discharge was measured using a Panametrics sonic flow meter. The discharge was diverted about 250 feet southwest of the well into an intermittent stream bed. The rusted valve in the metering manhole south of the well was removed and a temporary block valve was installed to prevent flow out of the pitless discharge pipe. The 1-inch diameter PVC measuring port was installed 0.4 feet above the top of the steel liner, which was 2.3 feet above land surface. Prior to starting the pumping test, the well was flowing over the 6-inch diameter steel liner. During the test, well #4, the Walker wells, Bittner wells and the Noble well were all flowing into the buried distribution pipelines leading to the storage tank. Well #4, the Walker wells (figs. 29 and 30), observation well 162-075-07ADB5 (fig. 15), and to a much lesser extent the Bittner wells (figs. 31-33) responded to pumping of municipal well #6. Drawdown interference at the Bittner wells ranged from about 0.4 to 0.6 foot. Given the aquifer is confined, these small-scale water level fluctuations could be, in large part, due to fluctuations in barometric pressure. Analysis of figures 31-33 indicates the timing and magnitude of drawdown and recovery cannot be entirely the result of changes in barometric pressure. Note the barometric pressure fluctuations from November 6 through November 9 have little or no impact on water levels during the same time period.

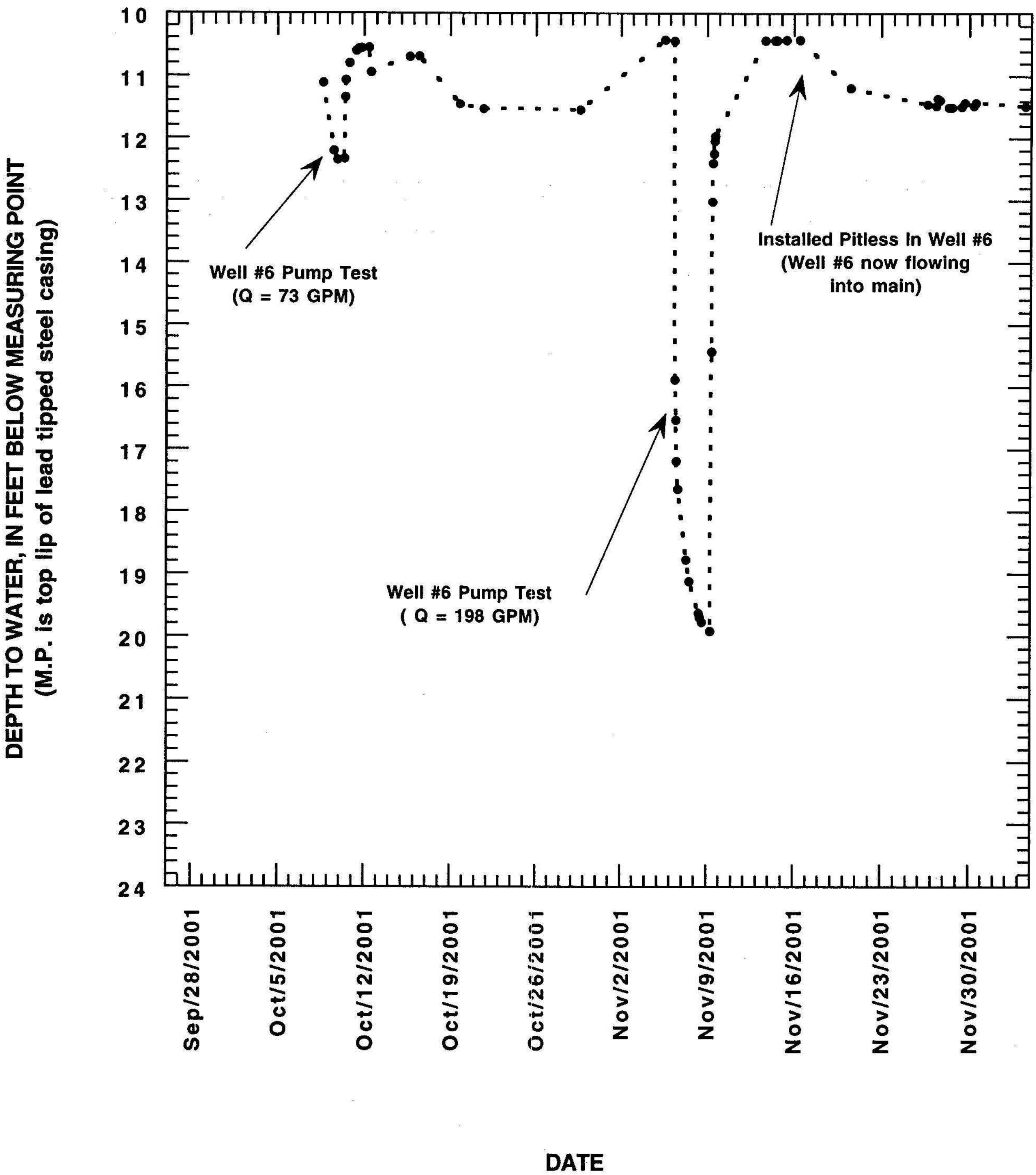


Figure 29. -- Water-level hydrograph Walker east well (162-075-07ABD4)

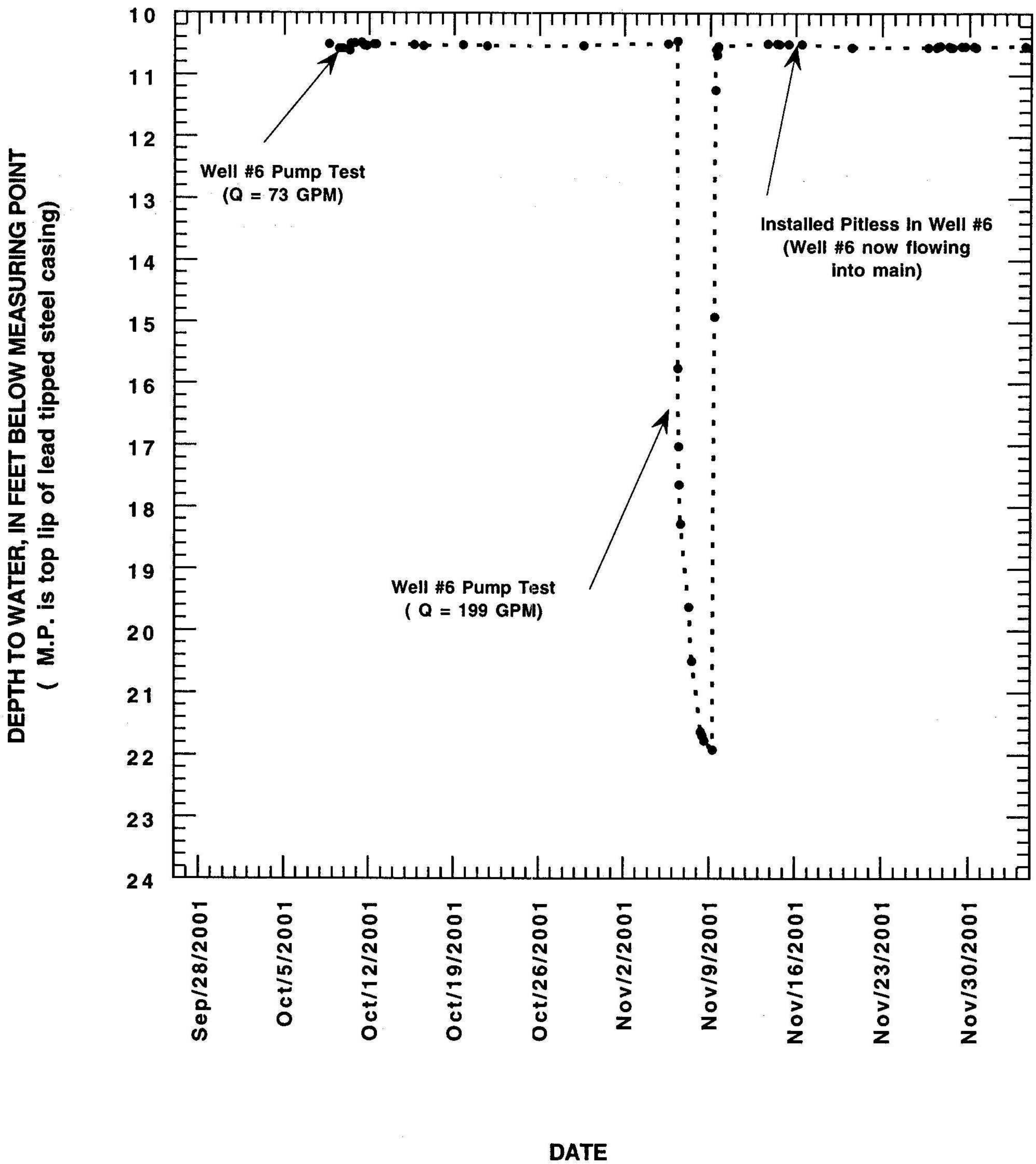


Figure 30. -- Water-level hydrograph Walker west well (162-075-07ABD3)

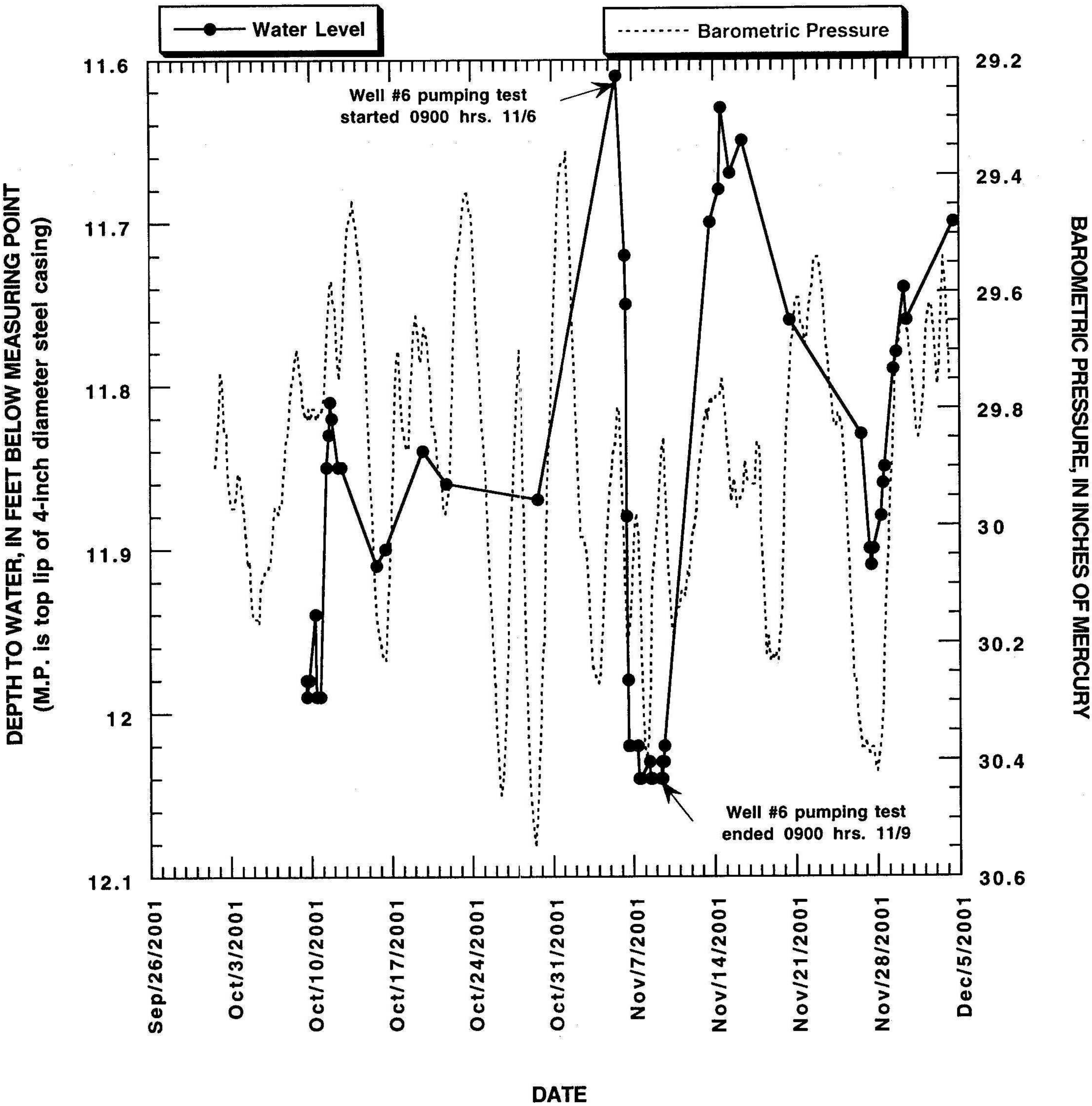


Figure 31. -- Comparison of water-level fluctuations at Bittner NW well (162-075-07ADB3) and fluctuations in barometric pressure

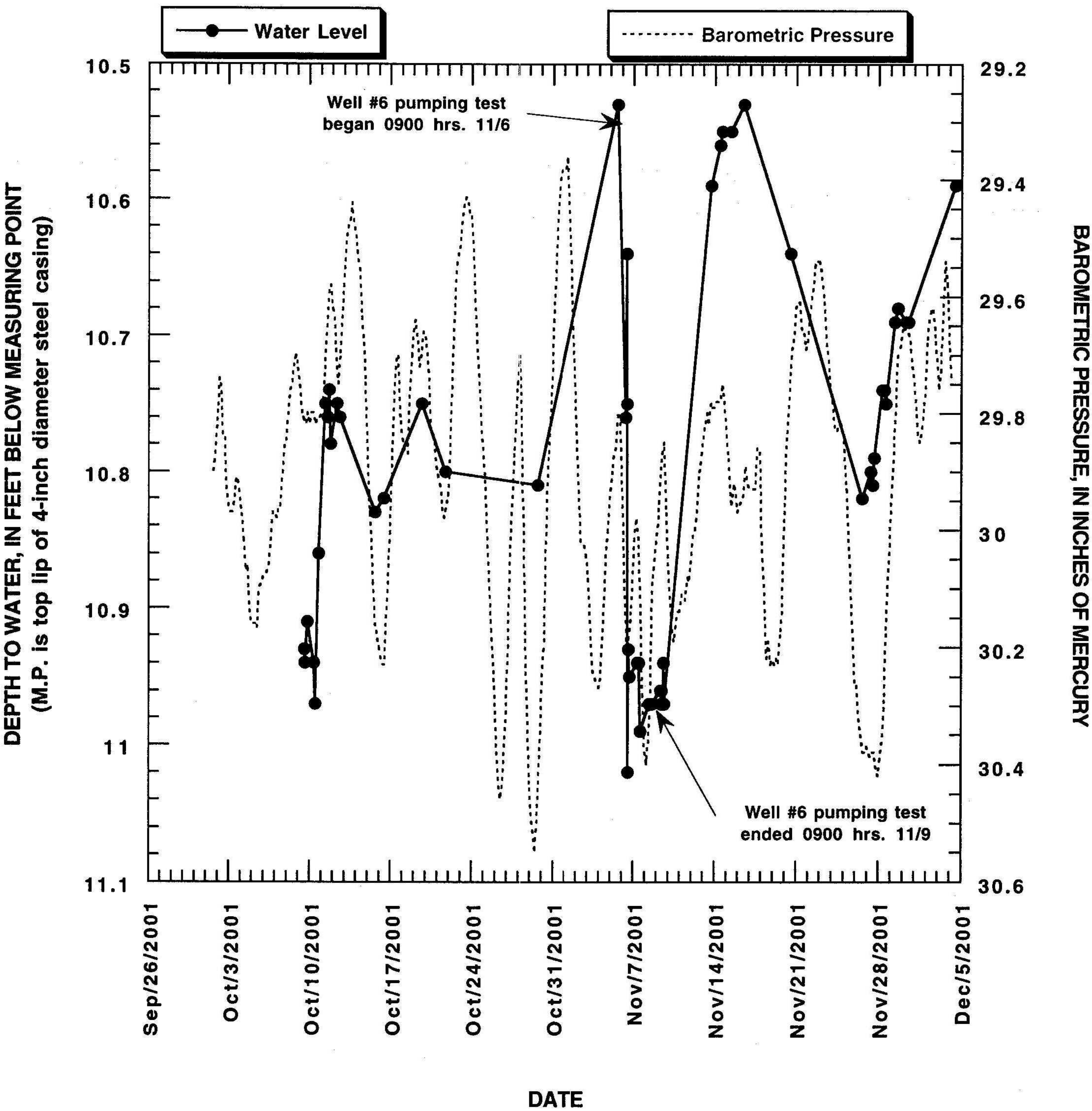


Figure 32. -- Comparison of water-level fluctuations at Bittner south well (162-075-07ADB4) and fluctuations in barometric pressure

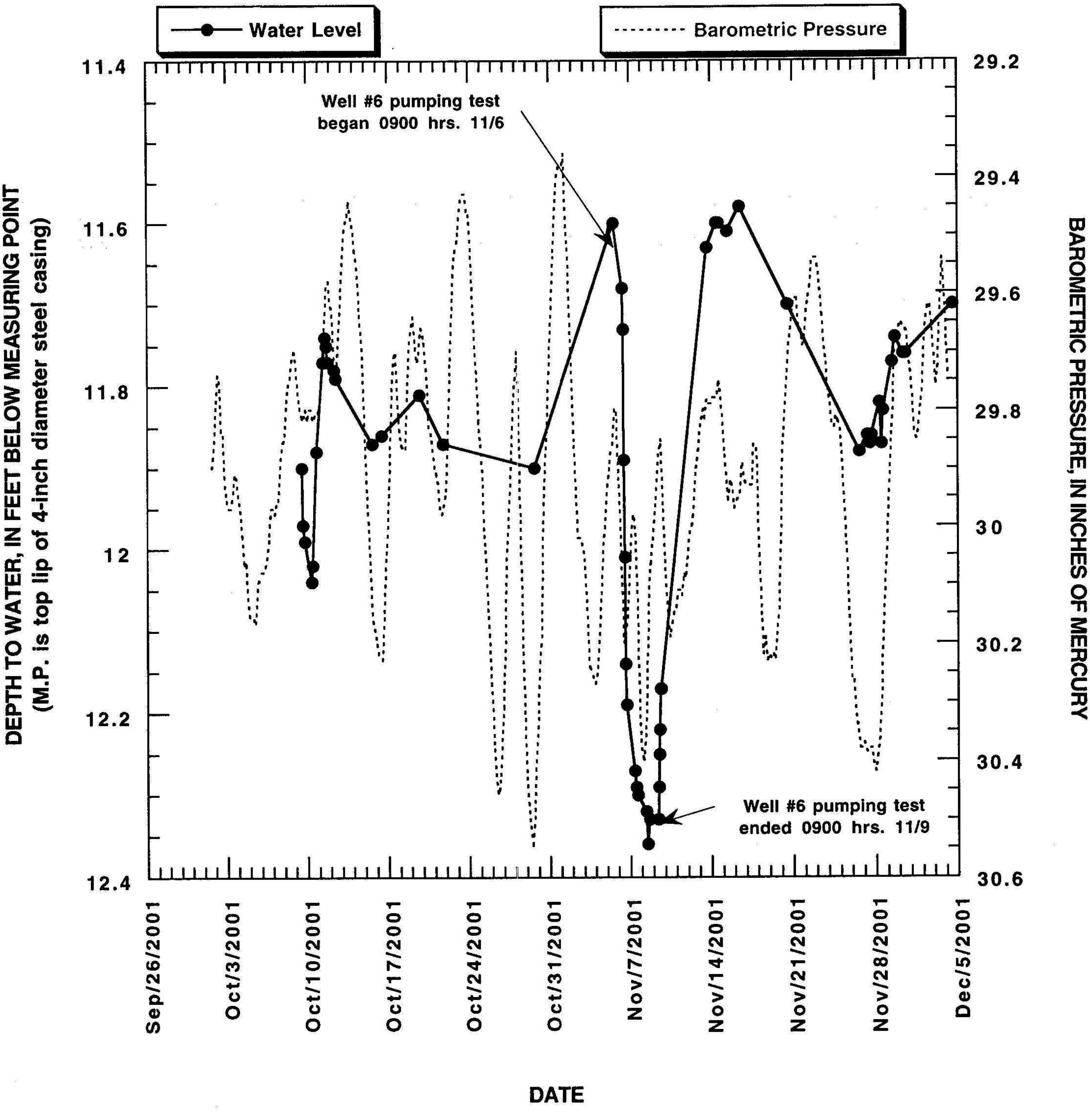


Figure 33. -- Comparison of water-level fluctuations at Bittner east well (162-075-07ADB2) and fluctuations in barometric pressure

Given the Bittner wells were flowing out of a buried discharge pipe tapped into the well casing, and the depth to the discharge pipe is not known, the Bittner wells may have continued to flow over the duration of the pumping test or may have ceased flowing at some time during the pumping test. If the latter occurred, this could account for the smaller than expected drawdown measured at the three Bittner wells.

A plot of log of time versus arithmetic pumping level is shown in figure 34. For about the first 25 minutes of pumping, the pumping levels plot along a straight line with a slope (Δs) of 4.68 feet. Using the analytical method of Jacob (1946), a transmissivity of 1499 ft^2/d is calculated. Based on an aquifer thickness of 28 feet, a hydraulic conductivity of 54 ft/d is calculated. This value of hydraulic conductivity is reasonable for a medium to coarse sand as reported by the driller for the aquifer interval. Due to the inability to measure a static water level prior to the pumping test (well flowing) it was not possible to determine a t_o value and calculate storativity. Therefore, it was not possible to verify if the early time versus pumping-level data were affected by a close barrier boundary.

After about 25 minutes of pumping, pumping levels plot above the extended slope of the line formed by the pumping-level points measured during the first 25 minutes. This response could be due to variations in transmissivity resulting from irregular aquifer geometry (Fig. 19), leakage, downward infiltration of discharge water, declining pumping rate, or elimination of nearby flowing wells (well #4 and Walker wells).

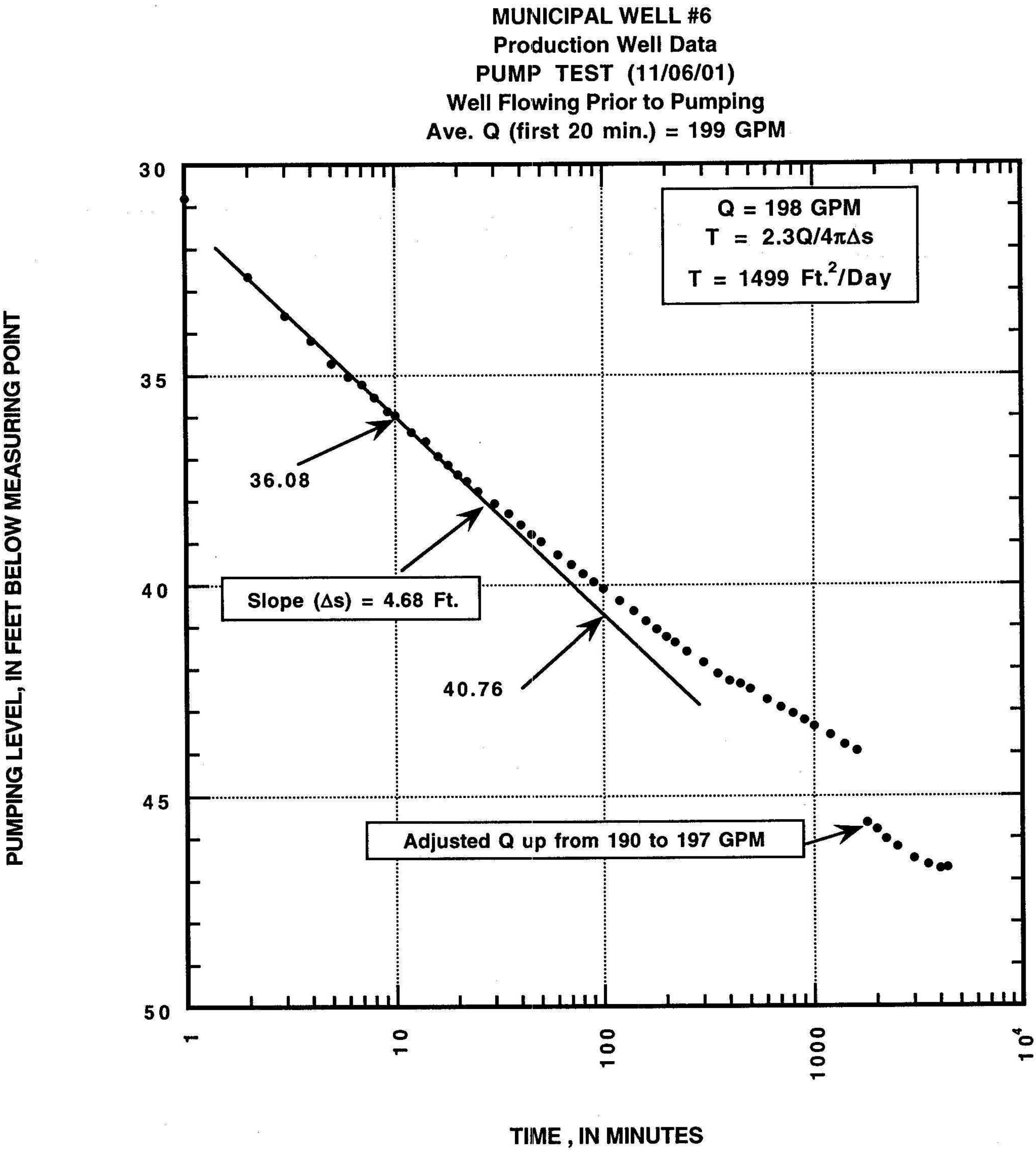


Figure 34. -- Plot of log of time versus arithmetic pumping level in municipal well #6 (162-075-07ABD2)

Based on previously described pumping test response, it is clear the Bottineau aquifer is a complex distribution of sand and gravel bodies characterized by irregular geometries, the plumbing of which is unclear. Further evidence supporting this conceptual model is indicated by the response at municipal well #4 from pumping municipal well #6. Municipal well #4 is located 52 feet south of municipal well #6. A plot of log time versus arithmetic drawdown in municipal well #4 is shown in figure 35. For about the first 260 minutes of pumping, the change in water level at municipal well #4 is anomalously small given the hydraulic properties of the aquifer at municipal wells #6 and #4, and the small distance between the two wells (52 ft.). After about 260 minutes of pumping, the slope of the line connecting the change in water level points increases abruptly. This response in municipal well #4 (up to about 2,000 minutes) is plausible if municipal well #4 is completed in an isolated pocket of coarse-textured deposits surrounded by much finer textured deposits (island effect). Note that after about 260 minutes of pumping, the slope of the line connecting pumping levels in municipal well #6 (fig. 34) decreases (flattens) suggesting increased capture from areas where the areal extent of the aquifer increases (as in figure 19), leakage, downward infiltration of discharge water, declining pumping rate or elimination of nearby flowing wells.

A recovery analysis of municipal well #6 (t/t^1 versus residual drawdown) was not initiated because the well was flowing prior to pumping and a static water level could not be determined. This prevented calculation of residual drawdown.

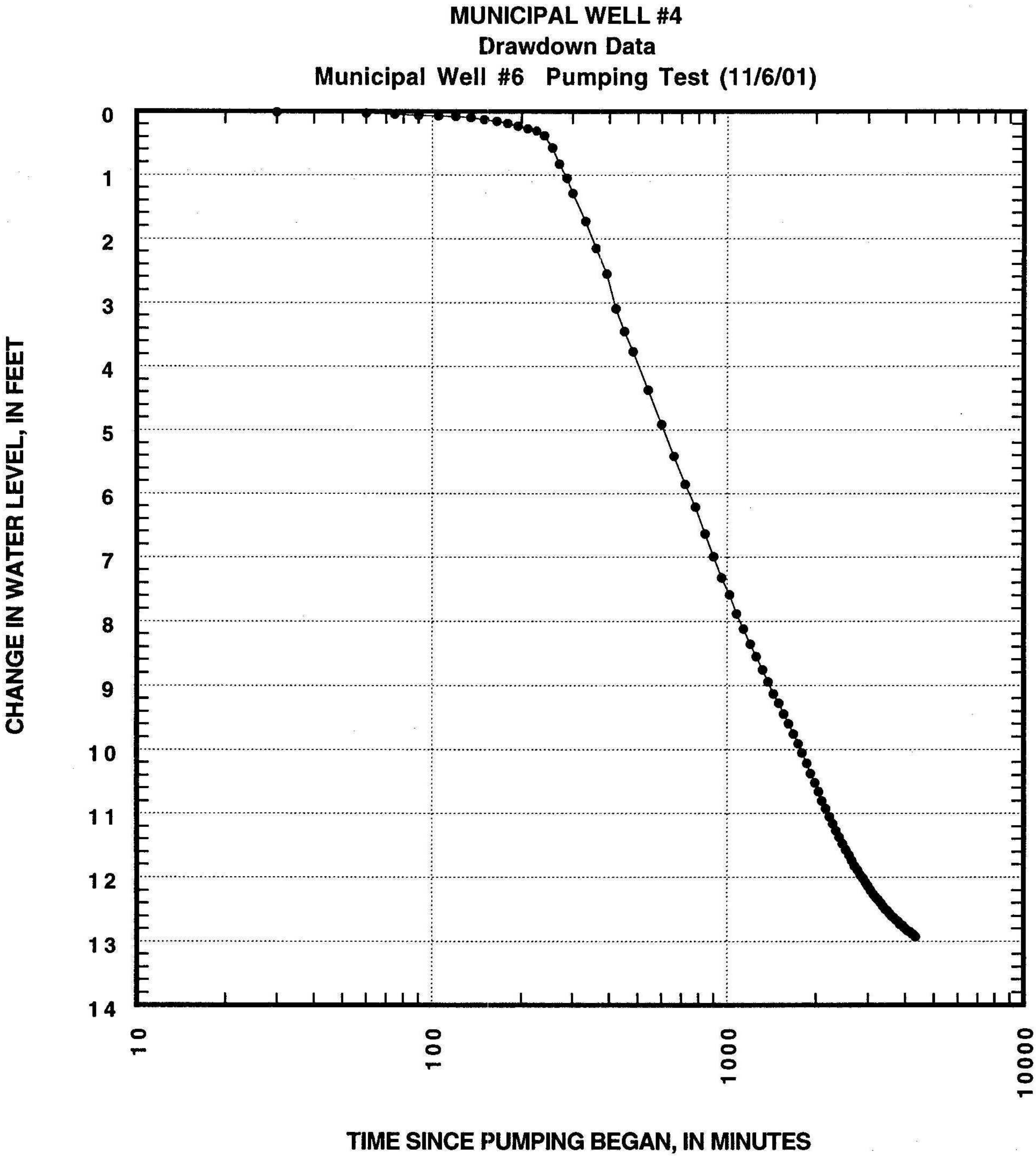


Figure 35. -- Plot of log of time versus arithmetic drawdown at municipal well #4 from pumping municipal well #6

Assuming a "static" water level of about three feet above land surface at municipal well #6, there is 63 feet of available head to the top of the well screen. After 4,320 minutes of pumping at a rate of 198 gallons per minute, the specific capacity was estimated at 4.2 gallons per minute per foot of drawdown. Based on an extrapolated specific capacity of 3.98 gallons per minute per foot of drawdown calculated for 10 days continuous pumping, an available drawdown of 31.5 feet (50 percent of total available head above top of well screen), a maximum pumping rate of 125 gallons per minute is calculated.

Walker Wells – Confined aquifer A

The Walker wells are located in the northeast part of the study area near municipal wells #4 and #6 (figure 4). The Walker east well (162-075-07ABD4) is 25 feet east of the Walker west well (162-075-07ABD3). The wells were apparently constructed in 1930. No drillers' logs are available. The east well is reported to be 51 feet deep and the west well is reported to be either 51 or 59 feet deep. Using a steel tape, the measured depth of the east well was 23.7 feet and the measured depth of the west well was 35.1 feet below the tops of the 4-inch diameter steel casing. The east well is reported to have a discharge pipe tapped into the well casing at 13 feet (below MP ? or land surface ?) and the west well is reported to have discharge pipe tapped into the well casing at 14 feet (below M.P. ? or land surface ?). The discharge rate of these flowing wells is not known.

The Walker east well is located 88 feet southeast of municipal well #6 and the Walker west well is located 85.5 feet southeast of municipal well #6. Based on the results of the pumping test for municipal well #6, it is clear the two Walker wells are completed in confined aquifer A. Given a target sustained maximum pumping rate of 125 gallons per minute for municipal well #6, the Walker wells will cease flowing shortly after pumping of municipal well #6 is initiated. Depending on the lengths of pumping and recovery periods, there will be time periods when the Walker wells will not flow. For planning purposes, it will be assumed that the Walker wells will not provide any yield during operation of the well field.

Bittner Wells – Confined aquifer A

The Bittner wells are located near the center of the northeast quarter of Section 7, T. 162 N., R. 75 W. (fig. 4) (Bittner east well –162-075-07ADB2; Bittner west well – 162-075-07ADB3; Bittner south well – 162-075-07ADB4). The wells were apparently constructed in 1936 and have reported depths of 41 feet. Measured from below the top of the 4-inch diameter galvanized steel casings, the depth of the Bittner west well is 16.2 feet, the depth of the Bittner east well is 15.6 feet, and the depth of the Bittner south well is 17.6 feet. The wells free flow out of discharge pipes tapped into the 4-inch diameter galvanized steel casings at unknown depths. The discharge rate of these three flowing wells is not known. The three wells are laid out in a triangular pattern with distances between wells ranging from 38 to 110 feet.

In 1980, C.A. Simpson and Son Drilling, Inc. drilled a test hole 80-13 at 162-075-07ADB6 (fig. 4). This test hole is located close to the Bittner wells. The deeper gravel interval reported on the driller's log occurs within the same elevation as confined aquifer A (fig. 6). In addition, a drawdown response was measured in all three of the Bittner wells when municipal #6 was pumped (figs. 31-33). The Bittner wells did not respond to pumping from municipal wells #2, #3, and #5, all of which are completed in confined aquifer B.

The Bittner wells are located about 950 feet southeast of municipal well #6. Given that the Theis assumptions are valid, and using well #6 pumping-test parameters (T = 1499 ft^2/d, estimated S = 2 $x10^{-4}$, Q = 198 GPM, t = 4,320 minutes, and r = 950 feet) about 8.2 feet of drawdown should have occurred at the Bittner wells at the end of the pumping test conducted on well #6. Actual measured drawdown (uncorrected for barometric effects) ranged from between about 0.4 to 0.7 feet. The Bittner wells were flowing prior to and probably during the pumping test. The depths of the buried discharge pipes are unknown. Therefore, it was not possible to measure maximum drawdown interference at the three Bittner wells. Depending on the lengths of the pumping and recovery periods for municipal well #6, there may be time periods when the Bittner wells will not flow. For planning purposes, it will be assumed that the Bittner wells will not provide any yield during operation of the well field.

Noble Well – Confined aquifer D

The Noble well is located at 162-075-07ADD1 (fig. 4). The well was apparently drilled in 1939 and the depth is reported at 50 feet. A driller's log of the well is not available. The well was constructed with 10-inch diameter steel casing and later lined with 8-inch diameter steel casing. A discharge pipe is tapped into the casing and liner at a depth of about 13 feet below the top of the well seal allowing the well to free flow into the buried distribution pipeline system leading to the above ground storage tank located to the west. Using a steel tape, the depth of the well was measured at 22.7 feet below the top of the well seal.

In October 1939, C.A. Simpson and Son Drilling completed six test holes in the study area. Test hole 39-6 was drilled 10 feet east of the Noble house. The house has since been removed, but test hole 39-6 likely was within 50 feet of the existing Noble well. The driller's log of test hole 39-6 is shown in table 7.

Table 7. – Driller's log of Simpson test hole 39-6

LITHOLOGIC DESCRIPTION	DEPTH	
	From	To
Topsoil	0	2
Yellow clay	2	16
Gravelly blue clay	16	35
Sand and gravel	35	54
Blue clay	54	

A test well was installed at test-hole site 39-6. Six feet of 10-inch diameter screen was set from 48 to 54 feet below land surface. The static water level was two feet below land surface. After pumping the test well continuously at a rate of 100 gallons per minute for eight hours, the specific capacity was five gallons per minute per foot of drawdown.

The top lip of the manhole for the Noble well has a surveyed elevation of 1986.11 feet above mean sea level. It is assumed the land surface elevation of test hole 39-6 is about 1985 feet above mean sea level. The reported static water level would be at 1983 feet above mean sea level. This water-level elevation is about 55 feet above the contemporary water-levels in confined aquifer B in which municipal wells #2, #3, and #5 are completed. The Noble well did not respond to pumping of wells #2, #3, and #5. This lack of response coupled with the 55-foot water-level differential indicates the sand and gravel unit is not hydraulically connected to confined aquifer B.

The water-level elevation at 39-6 is close to the contemporary water-level elevation of confined aquifer A. Both aquifer intervals (confined aquifer A and confined aquifer D) occur within the same elevation (figs. 6 and 8). However, no drawdown response was measured at the Noble well during the municipal well #6 pumping test. The Noble well was flowing prior to and during the pumping test. The depth of the buried discharge pipe is unknown. Because the Noble well was flowing, the lack of drawdown response does not necessarily indicate the lack of a hydraulic connection between confined aquifers A and D. Further testing is recommended in the Noble well area to verify if a hydraulically discrete confined aquifer D exists. If it does, another well could be installed in that area to provide additional yield, and the older Noble well should be plugged and abandoned.

Aquifer Recharge and Discharge in the Bottineau Aquifer

As previously described, the aquifer units that comprise the Bottineau aquifer are confined. The overlying confining layer consists primarily of till varying in thickness from about 30 to 60 feet in Section 7, T. 162 N., R. 75 W. At depths of less than about 50 feet, glacial till commonly is characterized as a dual porosity/permeability media. The matrix hydraulic conductivity ranges from about 1×10^{-6} to 1×10^{-4} ft/day and the bulk hydraulic conductivity (particularly for shallow, weathered till) ranges from about 1×10^{-4} to 1×10^{-1} ft/d (Shaver, 1994). Given this potentially large range in till hydraulic conductivity, recharge to the underlying Bottineau aquifer can vary greatly from about 0.001 inch to a few inches per year. In addition, given the complex glacial history of this area (numerous glacial advances and retreats), it is likely that local fluvial deposits extend through the overlying till linking the Bottineau aquifer to the water table. These hydraulic "short circuits" may provide a significant amount of recharge to the Bottineau aquifer. Based on the above, it is not possible to quantify areal recharge to the Bottineau aquifer.

A major recharge area for the Bottineau aquifer in Section 7, T. 162 N., Range 75 W., probably is located to the north and northeast in the hummocky uplands of the Turtle Mountains. This area is characterized by numerous ponds and sloughs where much of the recharge to the Bottineau aquifer probably is derived.

Prior to developing the municipal water supply for Bottineau, natural discharge from the Bottineau aquifer occurred through numerous springs that were located along the flanks of the Turtle Mountains. The areas where the two Walker wells and three Bittner wells are located, were once characterized by natural springs and seeps. These areas were once referred to as the Walker and

Bittner bogs. Simpson test hole 39-1 (see fig. 6) indicates an interval of peat from land surface to a depth of 16 feet.

Springs and seeps currently occur in a bog/marsh area located near the center of the E1/2SE1/4 of Section 7, T. 162 N., Range 75 W (fig. 4). This ground-water discharge flows into an intermittent drainage located in the SE1/4 of Section 7, T. 162 N., Range 75 W. This suggests there is additional ground water available for capture in the study area.

Water Use

The city of Bottineau holds perfected water permit #764 to divert 682.0 acre-feet of ground water annually from points of diversion located in the NE1/4, NW1/4, and SE1/4 of Section 7, T. 162 N., R. 75 W. at a maximum pumping rate of 900 gallons per minute. Based on data supplied by the city auditor on the year 2,000 annual water use report, the city water supply serves 2,598 people with approximately 1000 connections.

The ground-water capture system consists of 12 wells. Wells #1, #2, #3, #5, and #6 are equipped with submersible pumps. Well #4, the two Walker wells, the three Bittner wells, and the Noble well are free-flowing wells with discharge pipes tapped into the well casings at various depths below land surface. The city reports a pumping rate of 66 gallons per minute for well #1, 77 gallons per minute for well #2, 110 gallons per minute for well #3, 42 gallons per minute for well #5, and 90 gallons per minute for well #6. Discharge rates for the free-flowing wells are not known.

Annual water use reported by the city of Bottineau from 1975 through 2000 is shown in figure 36. Mean annual water use over this period was 355 acre-feet. Maximum annual water use was 465.7 acre-feet in 1984 and minimum annual water use was 160.6 acre-feet in 1975. There are no other water users diverting ground water from the Bottineau aquifer in Section 7, T. 162 N., Range 75 W.

Aquifer Response to Past Municipal Water Use

One of the objectives of this investigation is to determine, if possible, the maximum annual sustainable withdrawal from the city well field, which is completed in the Bottineau aquifer. Evaluation of aquifer response to past water use by the city provides a starting point to meet this objective. Throughout the 1980s and 1990s, Mr. Keith Fulsebakke, Bottineau City Works Superintendent, has periodically measured “static” water levels and pumping water levels in selected municipal wells. Analysis of these water levels and trends, if any, can provide a basis for determining if current average annual water use is sustainable.

Historic “static” and pumping water levels and associated pumping rates for municipal well #1 are shown in table 8. The “static” and pumping water levels are reported without any information regarding pumping history. A “static” water-level hydrograph for municipal well #1 is shown in figure 37. After the early developmental decline of about 10 feet, “static” water levels have fluctuated between about 8 and 28 feet below the top of the well seal. A rising or declining water-level trend over time is not indicated. This pattern of water-level

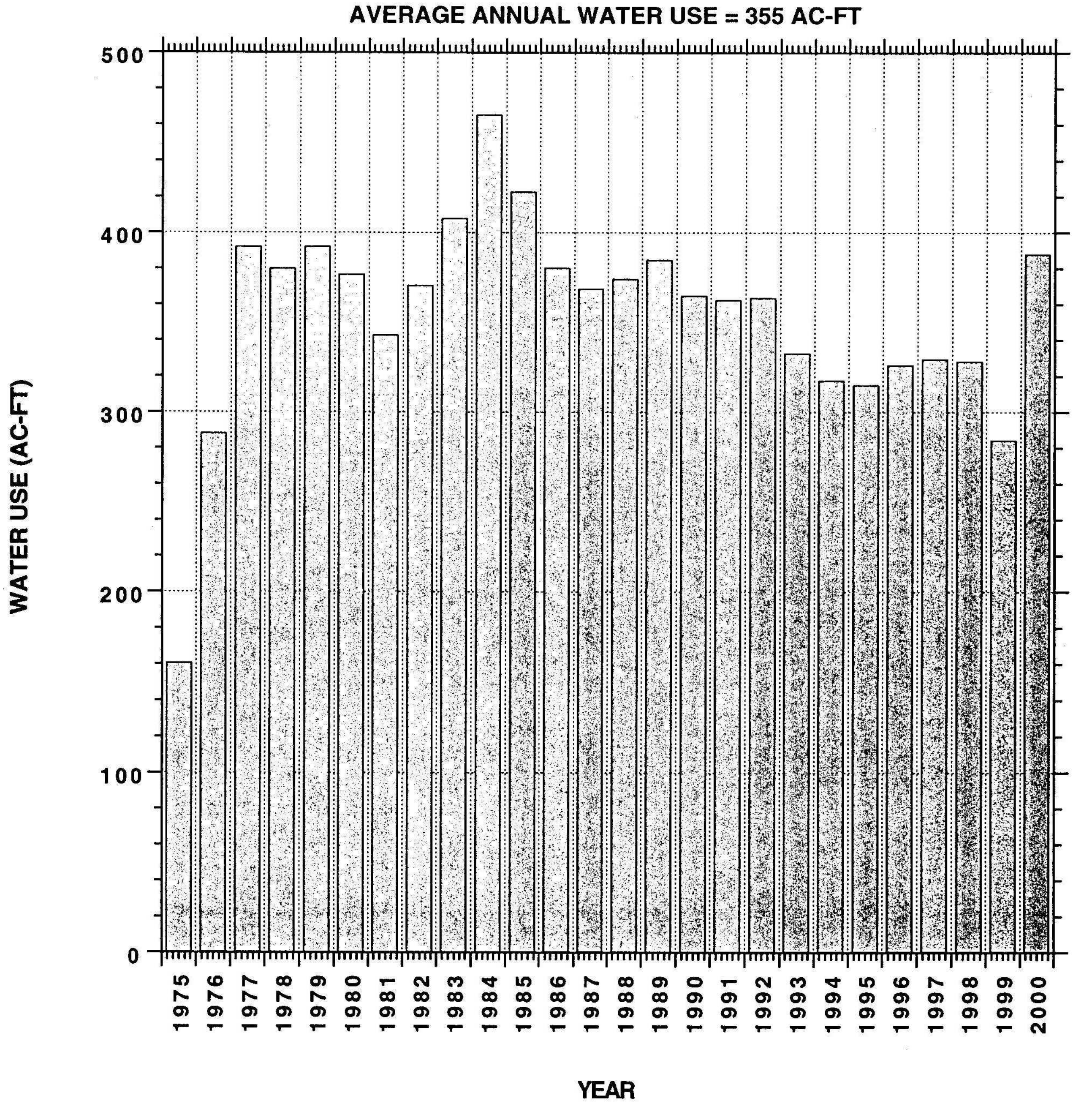
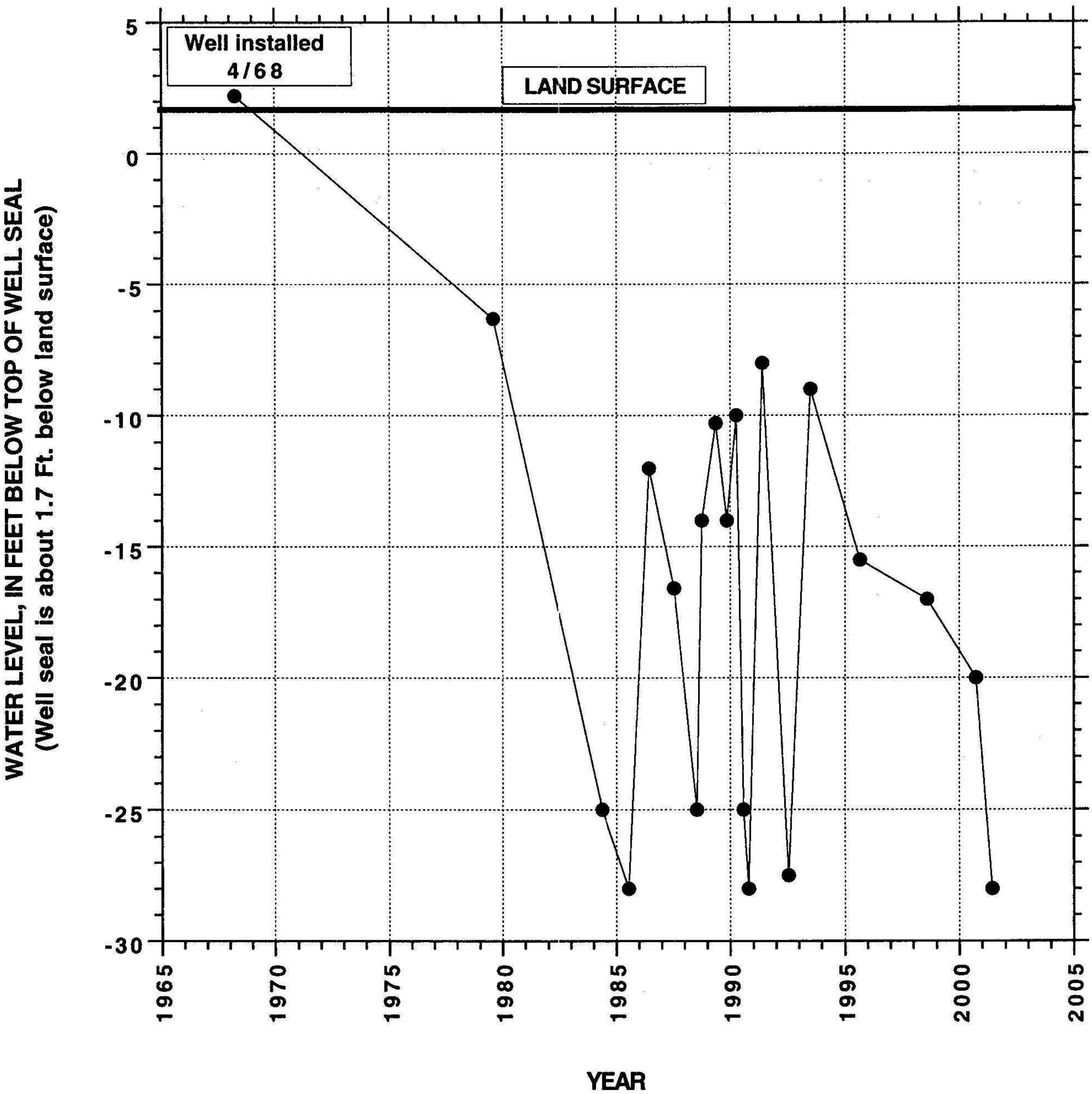


Figure 36. -- Annual reported water use by the city of Bottineau



Note: Reported "static" water levels give no indication of pumping history prior to measurement

Figure 37 . -- "Static" water-level hydrograph of municipal well #1 (162-075-07BDC2)

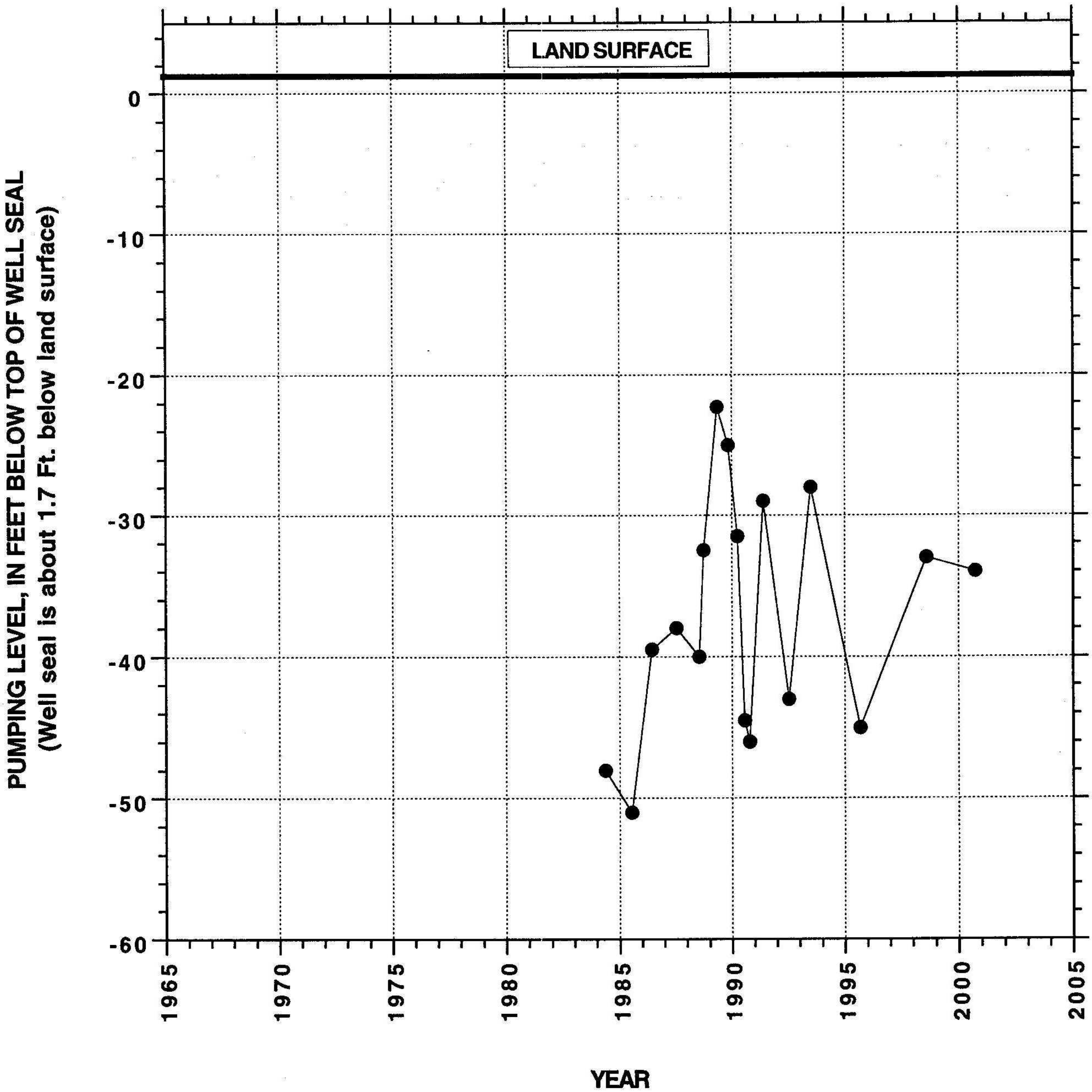
fluctuations indicates quasi-equilibrium conditions prevail in confined aquifer C and significant long-term ground-water mining is not occurring.

Table 8. – Historic "static" and pumping water levels and associated pumping rates for municipal well #1 (162-075-07BDC).

Date of Measurement	"Static" Water Level (Ft.)*	Pumping Water Level (Ft.)*	Pumping Rate GPM
4/68	+2.2	—	—
8/79	6.3	—	—
5/18/84	25	48	—
7/85	28	51	64
6/13/86	12	39.5	68
7/87	16.6	38	68
7/88	25	40	68
10/3/88	14	32.5	65
5/12/89	10.3	22.3	—
10/31/89	14	25	65
5/1/90	10	31.5	66
8/1/90	25	44.5	67
10/9/90	28	46	67
5/29/91	8	29	68
8/16/92	27.5	43	60
8/5/93	9	28	65
9/1/95	15.5	45	67
7/30/98	17	33	48
10/27/00	20	34	47
6/5/01	28	—	

* "Static" and pumping water levels reported without any information on pumping history.

A pumping-water level hydrograph for municipal well #1 is shown in figure 38. The pattern of pumping levels also indicates quasi-equilibrium conditions prevail in confined aquifer C and significant long-term ground-water mining is not occurring.



Note: Reported "pumping" water levels give no indication of pumping history prior to measurement

Figure 38. -- Pumping-level hydrograph of municipal well #1 (162-075-07BDC2)

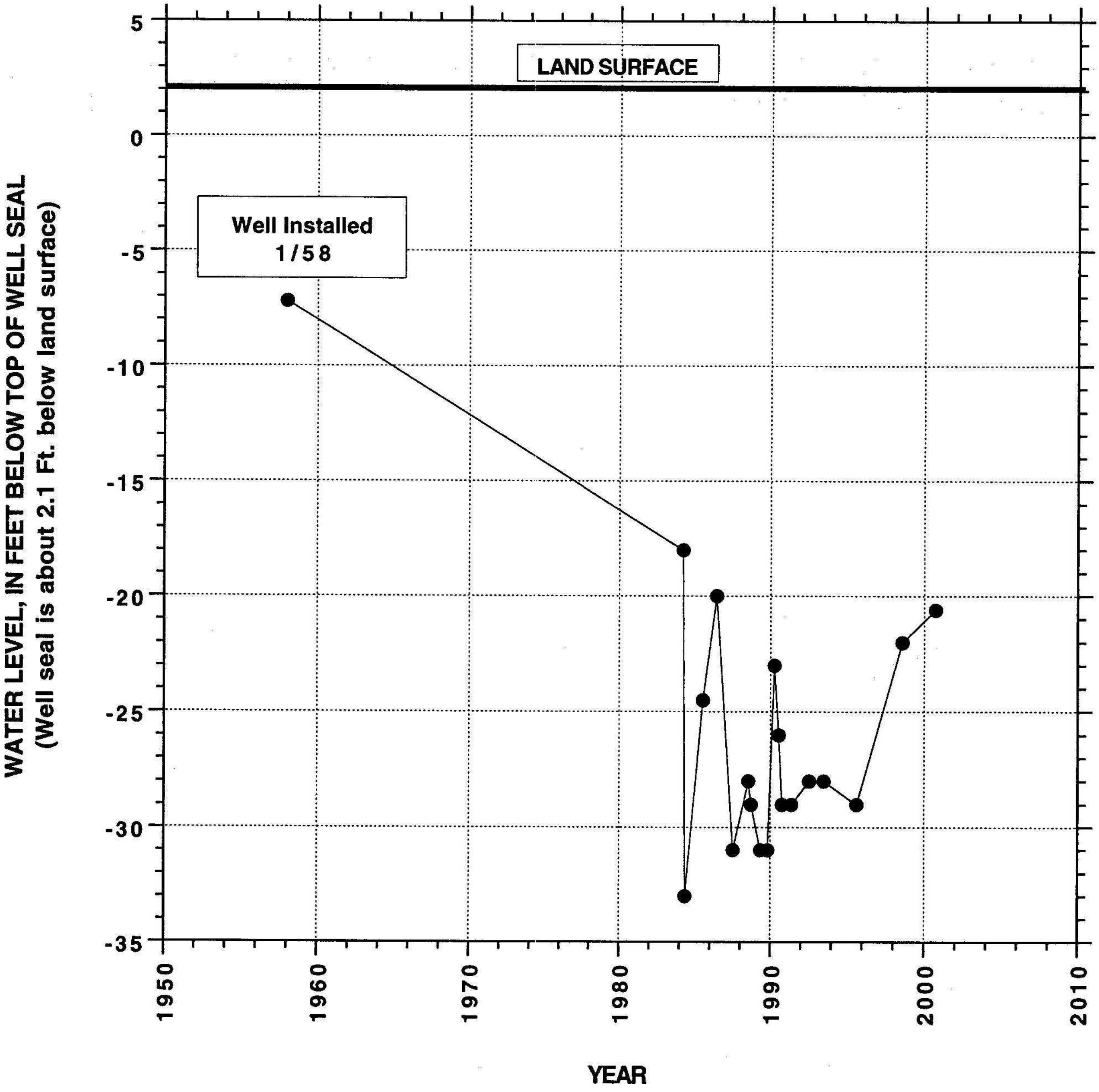
Historic "static" and pumping water levels and associated pumping rates for municipal well #2 are shown in table 9. The "static" and pumping water levels are reported without any information regarding pumping history.

Table 9. – Historic "static" and pumping water levels and associated pumping rates for municipal well #2 (162-075-07ADB1).

Date of Measurement	"Static" Water Level (Ft.)*	Pumping Water Level (Ft.)*	Pumping Rate GPM
1/9/58	5.2	—	—
4/26/84	18	—	—
7/85	33	50+	85
6/13/86	24.5	49	92
7/87	20	47	90
7/88	31	53	72
10/3/88	28	51	70
5/12/89	29	45.5	73
10/31/89	31	48	80
5/1/90	31	51.5	91
8/1/90	23	41	87
10/9/90	26	48	85
5/29/91	29	50	70
8/16/92	29	52	82
8/5/93	28	47	75
9/1/95	28	44	55?
7/30/98	29	41	31?
10/27/00	22	44	89
6/5/01	20.6	—	—

* "Static" and pumping water levels reported without any information on pumping history.

A "static" water-level hydrograph for municipal well #2 is shown in figure 39. After the early developmental decline of about 13 feet, "static" water levels have fluctuated between about 18 and 33 feet below the top of the well seal. A rising or declining water-level trend over time is not indicated. This pattern of water-level



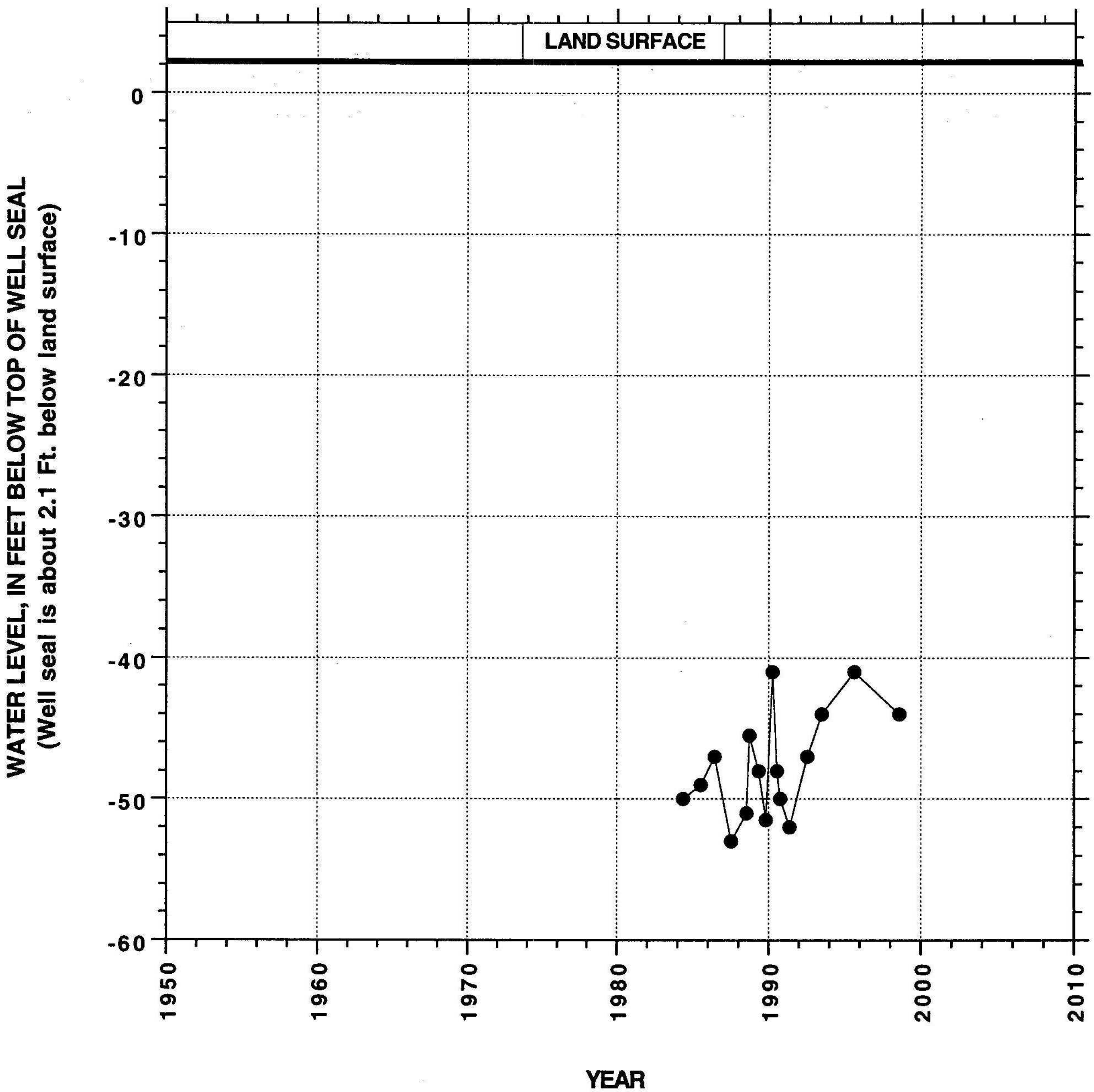
Note: Reported "static" water levels give no indication of pumping history prior to measurement

Figure 39. -- "Static" water-level hydrograph of municipal well #2 (162-075-07ADB1)

fluctuations indicates quasi-equilibrium conditions prevail in this area of confined aquifer B and significant long-term ground-water mining is not occurring.

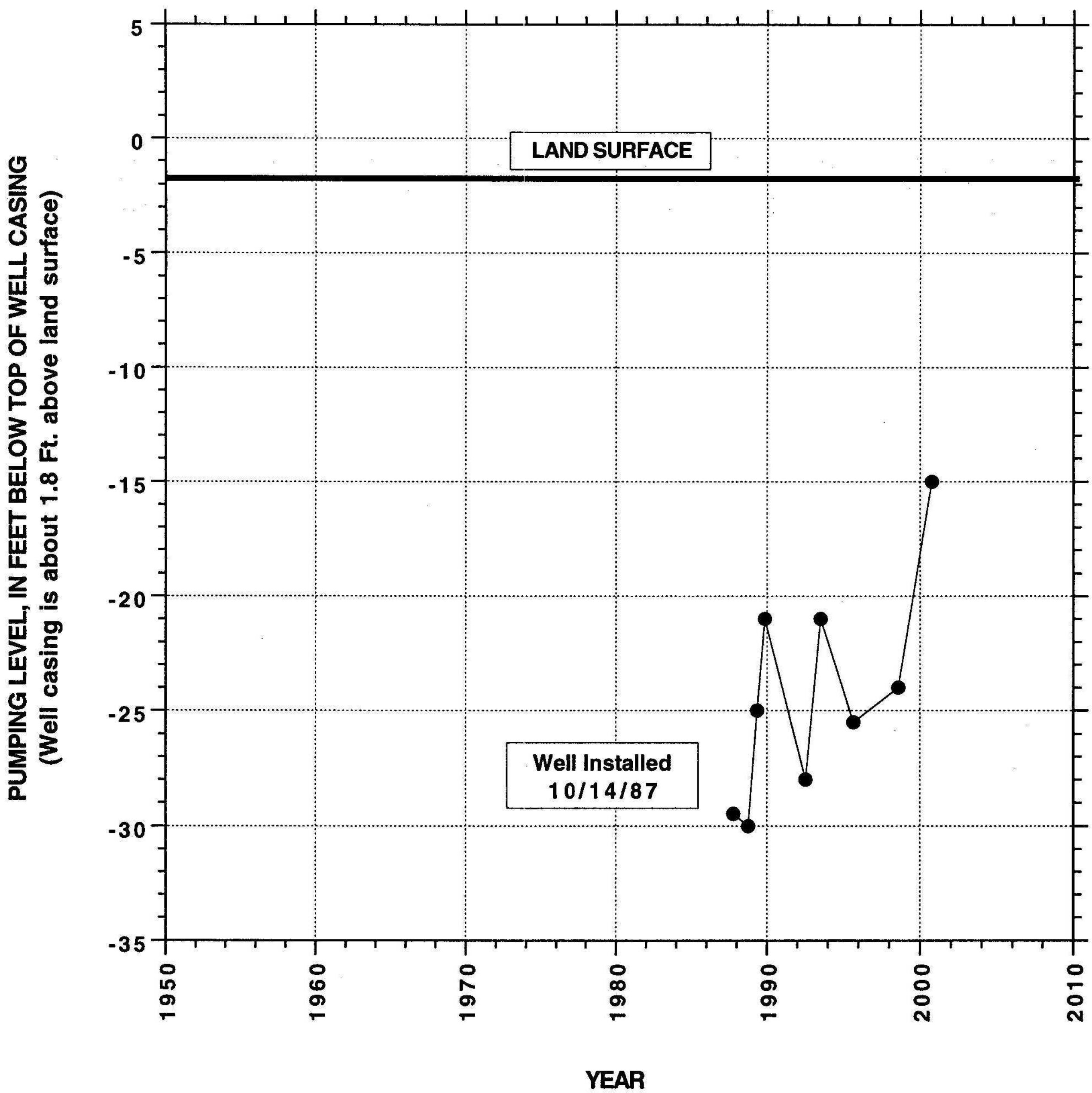
A pumping water-level hydrograph for municipal well #2 is shown in figure 40. The pattern of pumping levels also indicates quasi-equilibrium conditions prevail in this area of confined aquifer B and significant long-term ground-water mining is not occurring.

Historic pumping levels and associated pumping rates for municipal well #3 are shown in table 10. "Static" water levels are not shown because most measurements indicated the well was flowing out of pitless discharge pipe. The pumping water levels are reported without any information regarding pumping history. A pumping-level hydrograph for municipal well #3 is shown in figure 41. Pumping levels fluctuate between 15 and 30 feet below the top of the well casing. A rising pumping-level trend over time is indicated and probably is the result of reduced pumping of well #6 in recent years. The pattern of pumping-level fluctuations indicates significant long-term ground-water mining is not occurring in confined aquifer B.



Note: Reported "pumping" water levels give no indication of pumping history prior to measurement

Figure 40. -- Pumping-level hydrograph of municipal well #2 (162-075-07ADB1)



Note: Reported "pumping" water levels give no indication of pumping history prior to measurement

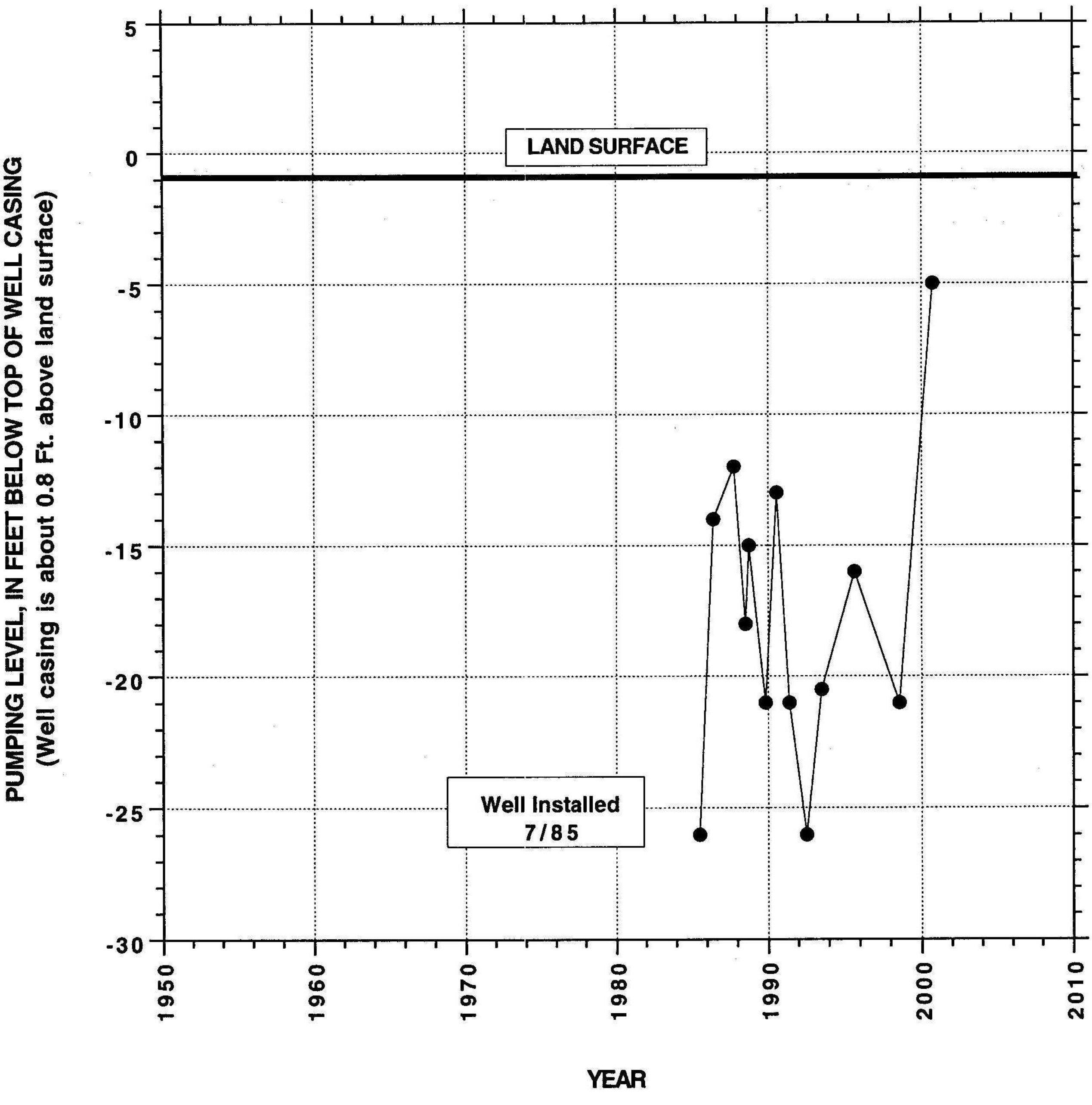
Figure 41. -- Pumping-level hydrograph of municipal well #3 (162-075-07ACA)

Table 10. – Historic "static" and pumping water levels and associated pumping rates for municipal well #3 (162-075-07ACA).

Date of Measurement	Pumping Water Level (Ft.)*	Pumping Rate GPM
10/14/87	29.5	210
10/3/88	30	110
5/12/89	25	115
10/3/89	21	110
8/16/92	28	90
8/15/93	21	110
9/1/95	25.5	100
7/30/98	24	95
10/27/00	15	110

* Pumping water levels reported without any information on pumping history.

Historic "static" and pumping water levels and associated pumping rates for municipal well #5 are shown in table 11. The "static" and pumping water levels are reported without any information regarding pumping history. A "static" water-level hydrograph for municipal well #5 is shown in figure 42. "Static" water levels fluctuate between about 5 and 26 feet below the top of the 8-inch diameter well casing. A rising or declining water-level trend over time is not indicated. This pattern of water-level fluctuation indicates quasi-equilibrium conditions prevail in this area of confined aquifer B and significant long-term ground-water mining is not occurring.



Note: Reported "pumping" water levels give no indication of pumping history prior to measurement

Figure 42. -- "Static" water-level hydrograph of municipal well #5 (162-075-07ADC3)

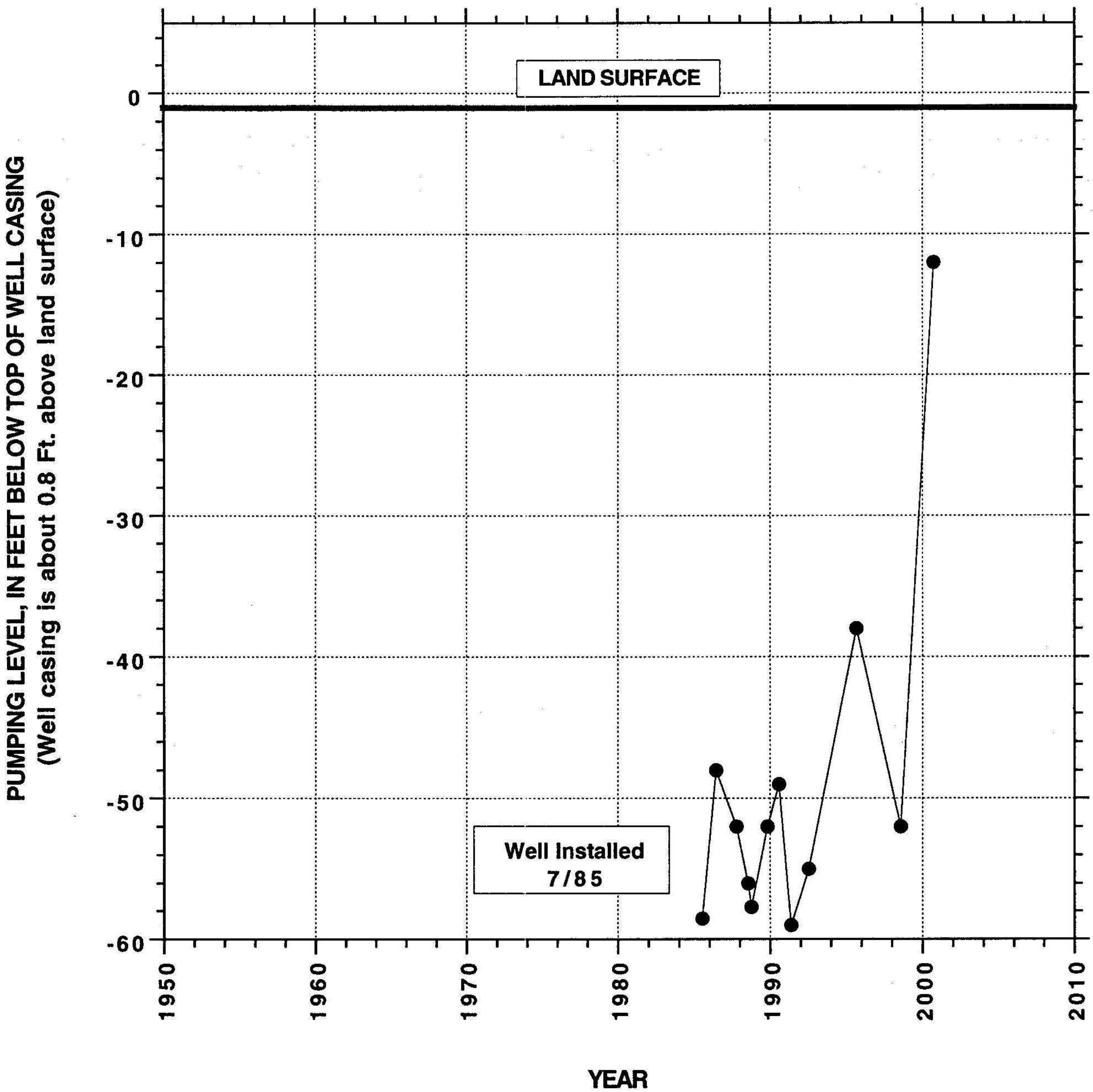
Table 11. – Historic "static" and pumping water levels and associated pumping rates for municipal well #5 (162-075-07ADC).

Date of Measurement	"Static" Water Level (Ft.)*	Pumping Water Level (Ft.)*	Pumping Rate GPM
7/85	26	58.5	49
6/86	14	48	40
7/87	12	52	50
7/88	18	56	40
10/88	15	57.7	40
10/89	21	52	41
8/90	13	49	45
6/91	21	59	42
8/16/92	26	55	40
8/5/93	20.5	—	—
9/1/95	16	38	45
7/30/98	21	52	50
10/27/00	5	17	52

* "Static" and pumping water levels reported without any information on pumping history.

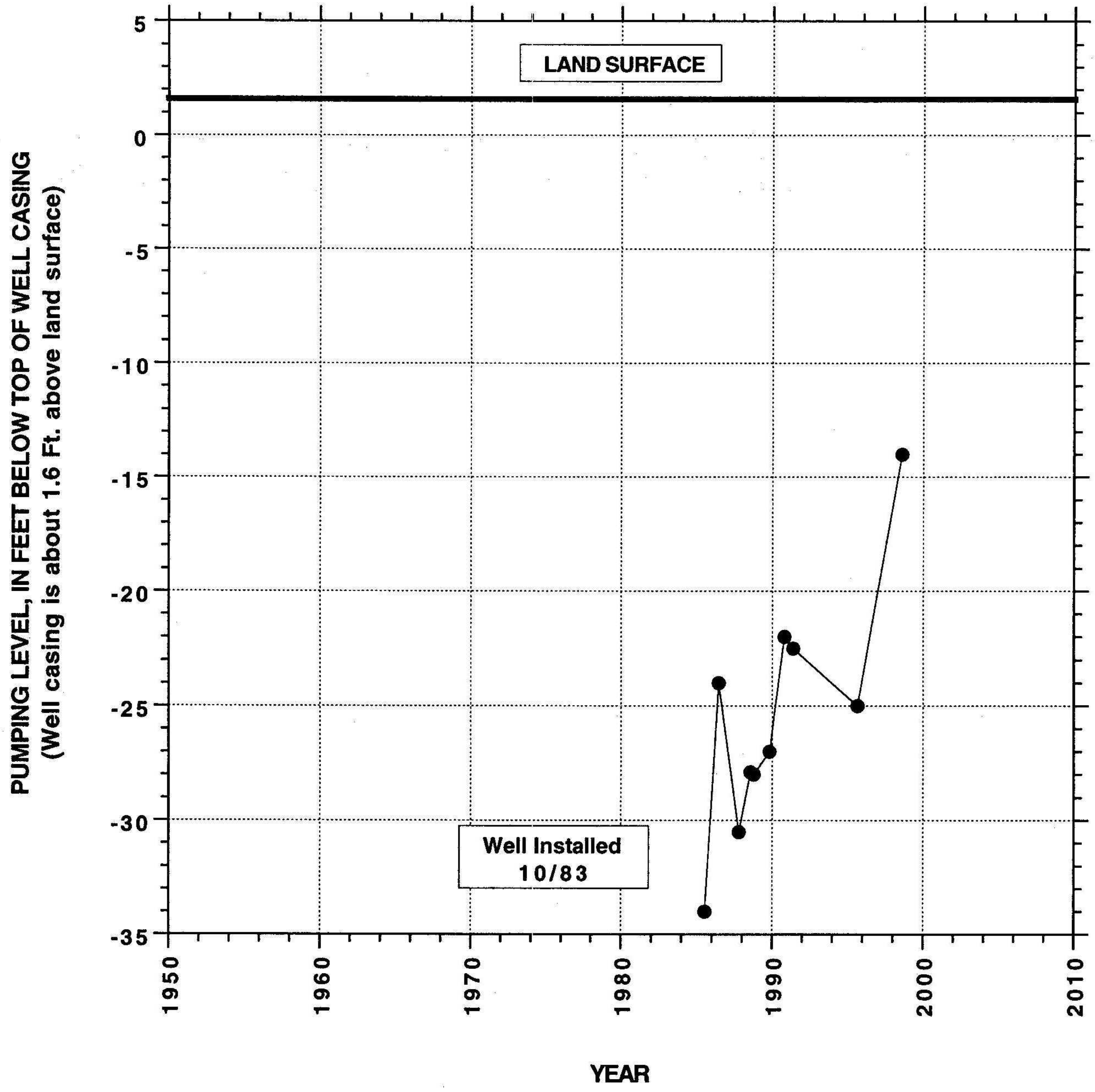
A pumping water-level hydrograph for municipal well #5 is shown in figure 43. The pattern of pumping levels also indicates quasi-equilibrium conditions prevail in this area of confined aquifer B and long-term ground-water mining is not occurring.

Historic pumping water levels and associated pumping rates for municipal well #6 are shown in table 12. "Static" water levels are not shown because all measurements indicated the well was flowing. The pumping water levels are reported without any information regarding pumping history. A pumping-level hydrograph for municipal well #6 is shown in figure 44. Pumping levels fluctuate from about 14 to 34 feet below the top of the 8-inch diameter well casing. A rising pumping-level trend over time is indicated. The rising pumping-level trend



Note: Reported "pumping" water levels give no indication of pumping history prior to measurement

Figure 43. -- Pumping-level hydrograph of municipal well #5 (162-075-07ADC3)



Note: Reported "pumping" water levels give no indication of pumping history prior to measurement

Figure 44. -- Pumping-level hydrograph of municipal well #6 (162-075-07ABD2)

probably is due to decreased use of well #6 in recent years and increased recharge associated with the recent period of above average precipitation.

Table 12. – Historic pumping water levels and associated pumping rates for municipal well #6 (162-075-07ABD2).

Date of Measurement	Pumping Water Level (Ft.)*	Pumping Rate GPM
7/85	34	110
6/86	24	110
7/87	30.5	115
7/88	27.9	90
10/88	28	90
10/89	27	90
8/90	22	90
6/91	22.5	90
9/1/95	25	90
7/30/98	14	85

* Pumping water levels reported without any information on pumping history.

Observation well 162-075-07ADB5 (Simpson test drilling site 83-3) is located about 730 feet southeast of municipal well #6 and is completed in the same aquifer (confined aquifer A - fig. 6). Prior to conducting a pumping test on municipal well #6 on October 19, 1983, Simpson reported a water level at observation well 162-075-07ADB5 of 34.65 feet below the top of the 1 1/4-inch diameter plastic casing. On December 4, 2001, the water level at this well was 33.84 feet below the same measuring point. The small water-level difference supports the conclusion that significant long-term ground-water mining is not occurring in confined aquifer A.

As previously reported, the average annual water use for the city of Bottineau is 355 acre-feet. Except for the Noble well, all other municipal wells are completed in confined aquifer A (wells #4 and #6, Walker wells, and Bittner wells), confined aquifer B (wells #2, #3, and #5), and confined aquifer C (well #1). Based on the conclusion that significant long-term ground-water mining is not occurring in confined aquifers A, B, and C, an annual ground-water withdrawal of at least 355 acre-feet is sustainable from the Bottineau aquifer (confined aquifers A, B, C, and D) in the N1/2 of Section 7, T. 162 N., R. 75 W.

Water Chemistry

Chemical analyses of 42 ground-water samples collected from 15 wells completed in the Bottineau aquifer provide the basis for evaluating water chemistry (table 13). The samples were collected/analyzed over a period from 1967 through 2002. The range and mean values of selected ions, dissolved solids, and hardness and USEPA secondary maximum contaminant levels (SMCL) are shown in table 14. SMCLs are non-enforceable recommended standards. Values exceeding SMCL are not considered a health hazard. Ground water in the Bottineau aquifer commonly exceeds SMCL for sulfate, iron, manganese, and dissolved solids.

Table 13. - Chemical analyses of 42 ground-water samples collected from 15 wells completed in the Bottineau aquifer

Location	Screened Interval (ft)	Date Sampled	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
			(milligrams per liter)																					
162-075-07ABD1	68-76	04/01/99		2.74	2.33	208	66.3	32.6	8.2	490	0	345	4.9	0.31			959	792				1310		
162-075-07ABD1	68-76	07/01/99		2.1	2.3	208	65.8	30.8	7.5	500	0	380	6.3	0.31			998	790				1230		
162-075-07ABD2	60-80	04/01/99		9.2	2.41	209	67.9	42.8	30.8	475	0	411	3.7	0.29			1050	801				1400		
162-075-07ABD2	60-80	07/01/99		10.5	1.85	198	67.7	43.5	8	445	0	440	4.7	0.29			1030	773				1280		
162-075-07ABD2	60-80	10/10/01		0.3	2.2	200	71	43	8.4	609	0	440	4.8	0.2	0.1		1070	790	290	10	0.7	1460	6	
162-075-07ABD2	60-80	11/09/01		0.12	2.2	200	70	43	8.3	594	0	420	5.7	0.2	0.1		1040	790	300	10	0.7	1446	7	
162-075-07ABD3	?	04/01/99		1.11	2.35	200	65.1	35.9	8.1	491	0	359	4.8	0.25			968	767				1400		
162-075-07ABD3	?	07/01/99		1.94	2.8	206	64.6	35.5	7.7	476	0	390	4.1	0.3			993	780				1260		
162-075-07ABD3	?	10/29/02		0.34	1.9	190	66	50	8.4	603	0	390	4.2	0.2	0.1		1010	750	250	13	0.8	1362		7.81
162-075-07ABD4	?	04/01/99		5.7	2.39	201	65.7	37	7.9	486	0	390	4.2	0.28				772						
162-075-07ABD4	?	07/01/99		7.1	2.4	195	66	49	8	472	0	430	3.8	0.24			1040	759				1310		
162-075-07ABD4	?	10/29/02		0.17	2.2	200	70	52	9.1	619	0	420	4	0.2	0.1		1060	790	280	12	0.8	1458		7.43
162-075-07ACA	61-81	08/16/79	30	0.36	2.8	200	61	52	7.3	590	0	390	0	0.2	0.5	0.23	1040	750	270	13	0.8	1475	7	
162-075-07ACA	61-81	08/05/87		0.04	2.3	161	56.1	42.9	6.6	601	0	342	3.6	0.2	0		908	633		12.8	0.74	1432		
162-075-07ACA	61-81	11/01/99		0.14	2.23	217	75.7	53.5	9.1	487	0	401	3.05	0.23			1060	854				1460		
162-075-07ACA	61-81	10/12/01		0.36	2.5	190	69	48	8.2	614	0	400	4.4	0.2	0.1		1020	760	260	12	0.8	1410	7	
162-075-07ACA	61-81	11/30/01		0.29	2.5	190	69	47	8.3	605	0	400	4.4	0.2	0.1		1020	760	260	12	0.7	1460	7	
162-075-07ADB1	68-80	04/01/99		1.99	2.78	178	62.5	52.3	7.8	468	0	324	4	0.28			909	702				1300		
162-075-07ADB1	68-80	07/01/99		3.8	1.68	140	59.6	56.5	7.7	424	0	290	3.1	0.26			811	595				1220		
162-075-07ADB1	68-80	10/03/01		0.08	2.8	170	65	52	8.3	614	0	370	4.6	0.2	0.1		975	690	190	14	0.9	1363	7	
162-075-07ADB2	?	04/01/99		2.02	2.01	190	62.8	47.7	8	464	0	362	4.5	0.28	3.4		957	733				1390		
162-075-07ADB2	?	07/01/99		2.25	1.99	202	65.6	66	7.6	476		420	3.8	0.28			1050	775				1280		
162-075-07ADB2	?	10/29/02		0.28	2.1	200	67	49	8.3	609	0	420	4.3	0.2	0.1		1050	780	280	12	0.8	1407		8.11
162-075-07ADB3	?	04/01/99		1.74	2.04	193	63.8	47.6	8.4	458	0	369	6.1	0.29			963	745				1400		
162-075-07ADB3	?	07/01/99		1.78	1.67	202	64.7	47.4	7.4	459	0	360	3.4	0.28			960	771				1250		
162-075-07ADB3	?	10/29/02		0.16	2.2	200	68	38	8	627	0	380	4.6	0.2	0.1		1010	780	260	9	0.6	1380		7.57
162-075-07ADB4	?	04/01/99		2.92	2.13	197	64.1	47.6	8.6	466	0	385	4.1	0.28			986	756				1430		
162-075-07ADB4	?	07/01/99		0.66	1.86	187	63.1	46.9	7.7	472	0	400	3.4	0.28			991	727				1260		
162-075-07ADB4	?	10/28/02		0.28	2	190	66	50	8.4	583	0	400	3.9	0.2	0.1		1010	750	270	13	0.8	1392		8.08
162-075-07ADC3	74-85	11/01/99		0.22	2.48	214	77.1	54.3	9.1	487	0	401	14.2	0.22			1060	852				1480		
162-075-07ADC3	74-85	10/04/01		0.3	2.8	180	67	47	8.2	618	0	370	4.2	0.2	0.1		984	730	220	12	0.8	1401	7	
162-075-07ADD1	?	?		0	1.6	68	63	46		537	72	360	2	0.3	0		1148	430				1091		
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
162-075-07BBB2	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	
162-075-07BDC1	50-57	08/25/67		1.13	1.5	220	61	57.5		525	0	350	8	0.2	4		1140	800				1425		
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	0.3	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	
162-075-07DBB2	52.5-55.5	05/16/80		2.56	0.7	180.5	60.5	58.5	7.3	583	0	358.6	0	0.2	2		954	700.2		15.31		1410		

Table 14. – Range and mean values of selected ions, dissolved solids, and hardness, in the Bottineau aquifer, and USEPA secondary maximum contaminant levels.

	Range (mg/L)	Mean (mg/L)	SMCL[1] (mg/L)
Calcium	68-220	192	N/A
Magnesium	56-79	66	N/A
Sodium	31-66	47	N/A
Potassium	6-31	9	N/A
Bicarbonate	627	529	N/A
Sulfate	290-480	390	250
Chloride	0.4-14.2	4.4	250
Iron	0.04-10.5	1.8	0.3
Manganese	0.7-2.8	2.10	0.05
Dissolved Solids	811-1160	1023	500
Hardness	430-854	753	N/A

1. USEPA secondary maximum contaminant level.

During Phase II of this study, pumping tests were conducted on municipal wells #1, #2, #3, #5, and #6. Water samples for chemical analysis were collected near the end of each pumping test. Water samples for chemical analysis also were collected from the Walker, Bittner, and Noble wells in October 2002. Trace element analysis included selenium, lead, mercury, arsenic, molybdenum, strontium, and uranium. Concentrations of these trace elements and USEPA primary maximum contaminant levels (MCL's) are shown in table 15. Except for uranium, trace elements do not exceed MCL.

The MCL for uranium (30μg/L) is exceeded in wells #2 and #3. The level of 140 μg/L in well #3 is 4.6 times the MCL. Potential health effects from ingestion of water exceeding uranium MCL are increased risk of cancer and kidney toxicity.

Table 15. – Concentrations of selected trace elements from ground water in the Bottineau aquifer and USEPA primary maximum contaminant levels.

Well Location	Selenium	Lead	Mercury	Arsenic	Lithium	Molybdenum	Strontium	Uranium
	micrograms per liter							
162-075-07BDC2 (Well #1)	1	0	0	2	140	0	1000	19
162-075-07ADB1 (Well #2)	3	2	0	2	120	2	900	37
162-075-07ACA (Well #3)	0	0	0	0	130	1	860	140
162-075-07ADC3 (Well #5)	3	2	0	2	120	2	920	25
162-075-07ABD2 (Well #6)	0	0	0	0	130	3	870	24
162-075-07ABD3 (Walker West Well)	1	<1	0	<1	120	4	810	20
162-075-07ABD4 (Walker East Well)	1	<1	0	<1	120	3	810	21
162-075-07ADB2 (Bittner East Well)	1	<1	0	1	120	4	850	21
162-075-07ADB3 (Bittner West Well)	<1	<1	0	<1	110	3	760	23
162-075-07ADB4 (Bittner South Well)	1	<1	0	2	120	5	840	20
162-075-07ADD1 (Noble Well)	<1	<1	0	<1	110	4	800	20
USEPA PMCL[1]	50	15[2]	2	50	NA	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 m/L water, systems must take additional steps.
3. Effective 12/8/03.

Analysis of water-chemistry data can provide additional insight into the nature of the ground-water flow system. As previously described, the Bottineau aquifer consists of at least five and possibly six discrete hydraulic units (confined aquifers A-F), which were identified using pumping test water-level response data, water-level elevation data, and stratigraphic data. The water-chemistry data may also provide a basis for identifying these discrete confined aquifers.

The relative distribution of major ions from 36 ground-water samples from 16 wells completed in the Bottineau aquifer is shown in figure 45. Ground water in the Bottineau aquifer is a calcium-bicarbonate to calcium-sulfate type. The relative distribution of major ions in analyses from all wells except those completed in confined aquifer A, is shown in figure 46. Municipal wells #4, #6, the Walker, and Bittner wells are completed in confined aquifer A. Except for an older sample from the Noble well (162-075-07ADD1 – confined aquifer D), two samples from well #1 (162-075-07BDC2 – confined aquifer C), which may reflect chemical bias because the sample was bailed from casing storage, and the 5-inch diameter commercial observation well (162-075-07BBB2 – confined aquifer F) the remainder of the analyses are a calcium-bicarbonate type. Confined aquifer A is characterized by a calcium-sulfate type ground water and confined aquifer B is characterized by a calcium-bicarbonate type ground water. The differences in relative concentrations of major ions throughout the Bottineau aquifer are small and are of no practical importance with regard to human consumption.

The absolute distribution of major ions from ground-water samples collected at each of the 12 municipal wells is shown in figure 47. Samples from wells #1, #2, #3, #5, and #6 were collected by the NDSWC at the end of pumping tests and samples from well #4, the Noble well, Walker, and Bittner wells were collected by Advanced Engineering and the NDSWC using a bailing method. The

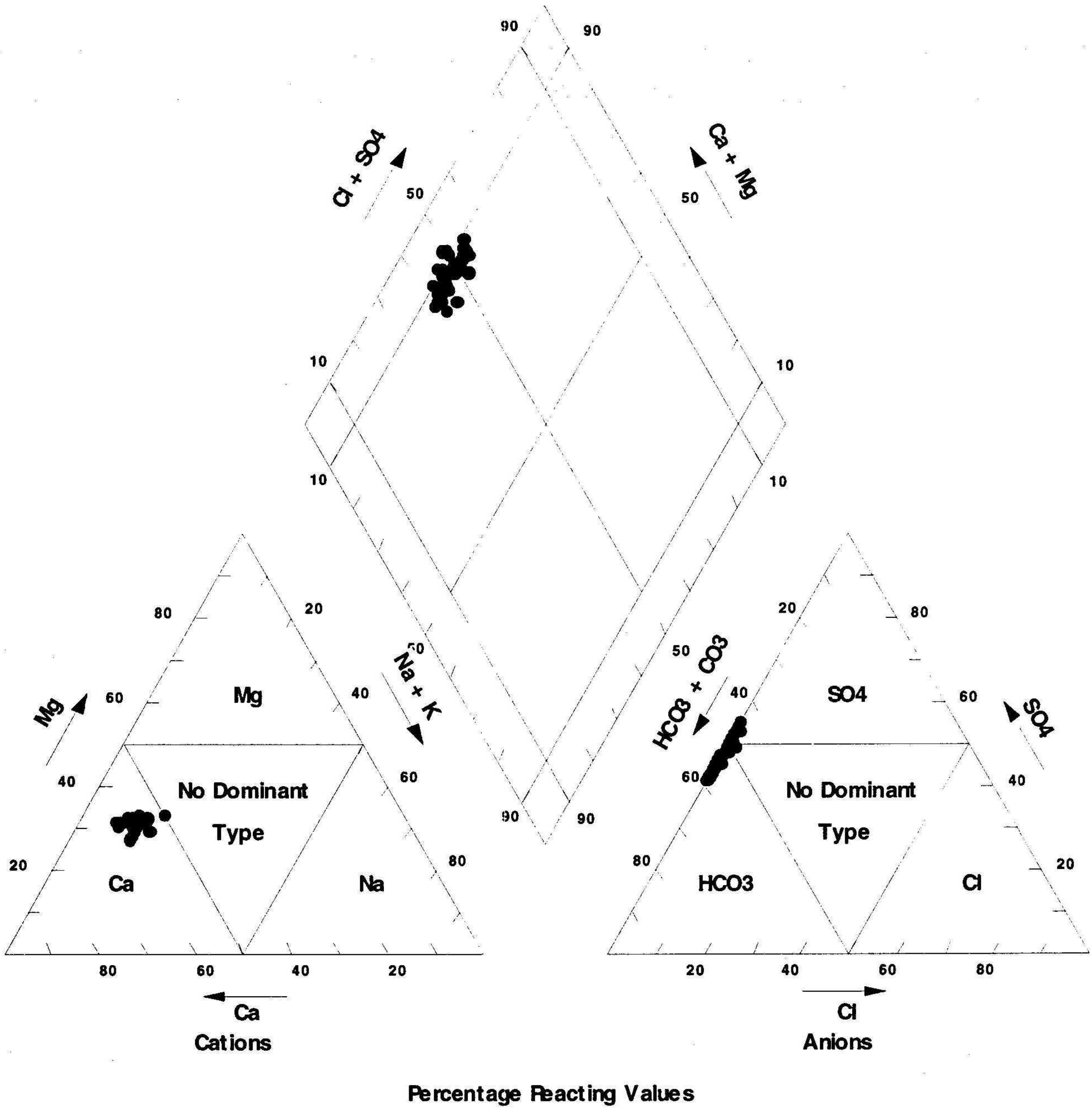


Figure 45. -- Relative distribution of major ions in the Bottineau aquifer

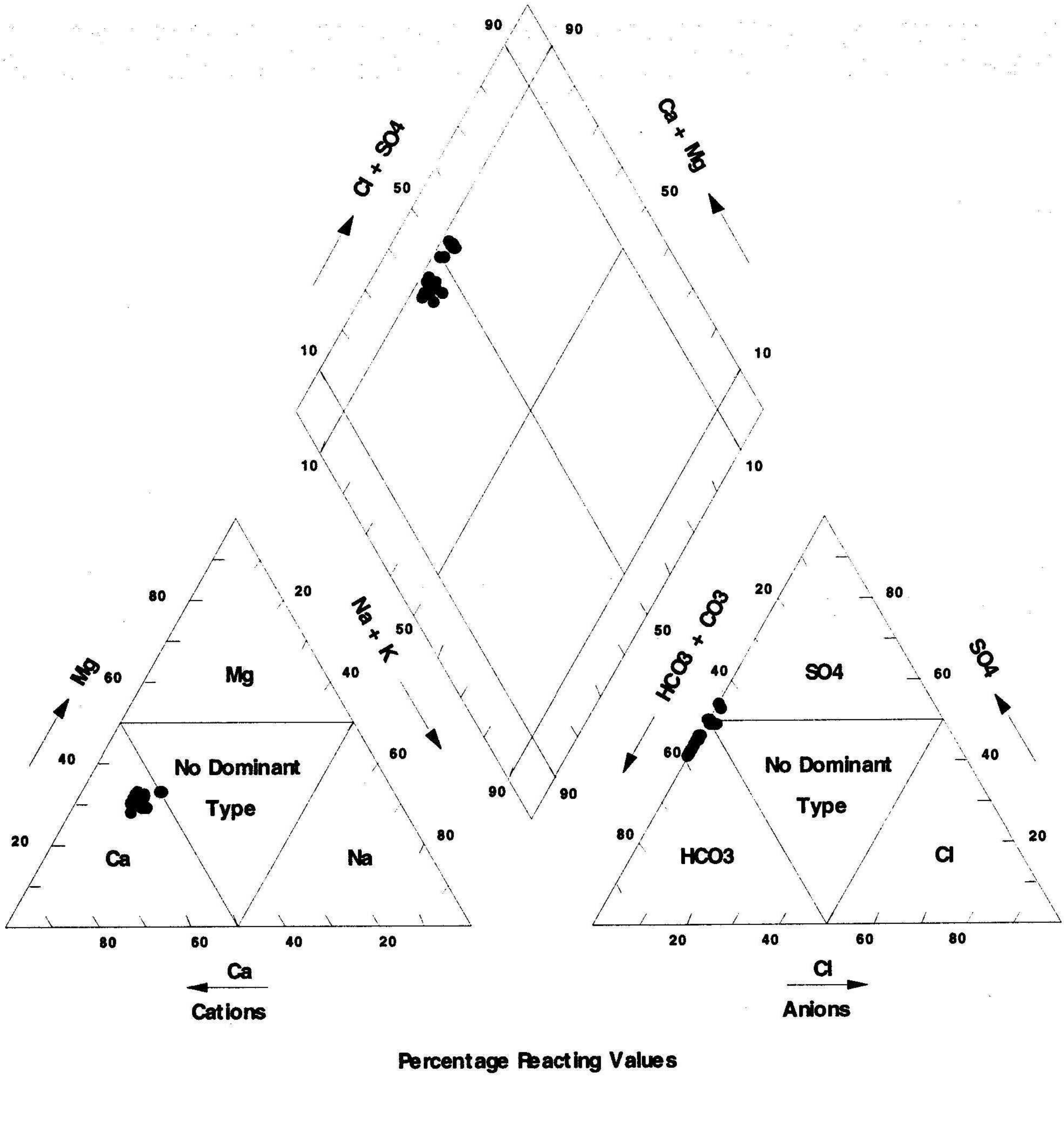


Figure 46. -- Relative distribution of major ions in wells not completed in confined aquifer A

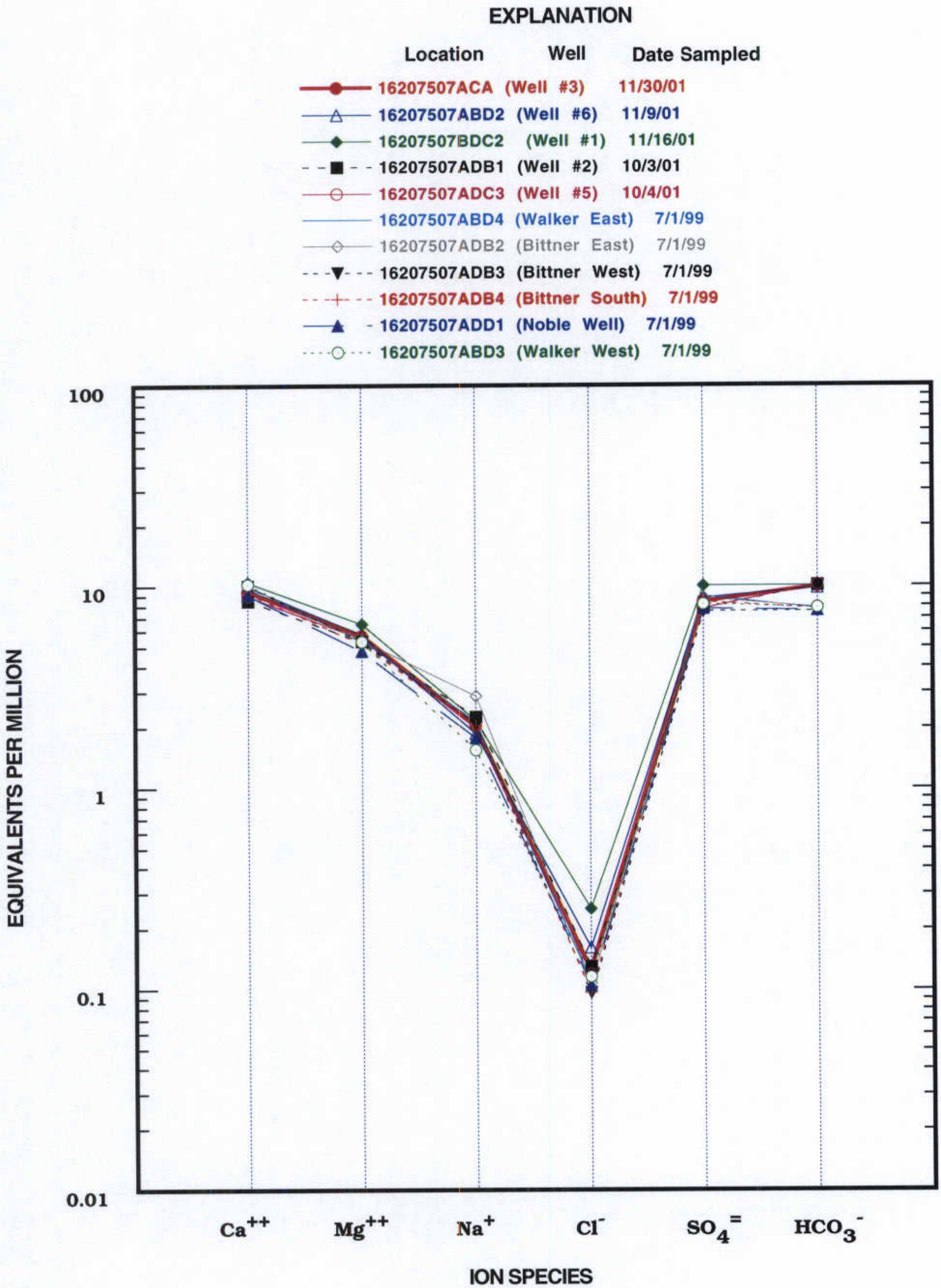


Figure 47. -- Absolute distribution of major ions in the Bottineau aquifer

range in major cations and anions is small indicating a rather uniform ground-water chemistry throughout the Bottineau aquifer.

Estimated Maximum Sustained Pumping Rate and Annual Ground-Water Withdrawal in the Bottineau Aquifer (162-075-07)

Based on pumping tests conducted on some of the Bottineau municipal wells and extrapolating pump-test data as previously described, the following maximum pumping rates are recommended:

Well #1	(162-075-07BDC2)	57 GPM
Well #3	(162-075-07ACA)	160 GPM
Well #5	(162-075-07ADC3)	42 GPM
Well #6	(162-075-07ABD2)	125 GPM

Additional drilling and testing should be completed near the Noble well. It is likely a new well can be completed near the Noble well in confined aquifer D and the maximum pumping rate should be at least 50 gallons per minute.

Additional drilling and testing should be completed near the 5-inch diameter commercial observation well located in the northwest corner of Section 7, Township 162 North, Range 75 West and throughout the NW1/4 of Section 7. A maximum well yield of at least 50 gallons per minute is likely for a properly completed well in this area.

Total maximum pumping rate for municipal wells #1, #3, #5, #6, a new well to replace the Noble well, and a new well located somewhere in the NW1/4 of Section 7 amounts to 484 gallons per minute.

The analysis of aquifer response to past municipal water use by the city of Bottineau indicates an annual withdrawal of at least 355 acre-feet of ground water from the Bottineau aquifer in Section 7, Township 162 North, Range 75 West is sustainable. Because of the complex aquifer geometry and uncertainty with regard to natural aquifer recharge and discharge, it is risky to predict an annual sustainable withdrawal greater than 355 acre-feet from this area of the Bottineau aquifer. An annual sustainable withdrawal over and above 355 acre-feet may be possible. The only practical approach to make this determination is to withdraw an additional volume of ground water while periodically monitoring water levels within each of the hydraulically discrete aquifers. Analysis of longer-term water-level trends will provide the basis for determining if the additional ground-water withdrawal is sustainable.

GEOLOGY AND GROUND-WATER HYDROLOGY OF THE SOURIS AQUIFER (ALL SEASONS WATER USERS SYSTEMS I AND II AREAS)

All Seasons Water Users District, a rural water association based in Bottineau, holds perfected water permits 4640 (System I) and 2492 and 4641 (System II). Perfected water permit 4640 allows for a maximum annual municipal/rural appropriation of 100 acre-feet at a maximum pumping rate of 200 gallons per minute. Perfected water permit 2492 allows for a maximum annual municipal/rural appropriation of 17 acre-feet at a maximum pumping rate of 35 gallons per minute and perfected water permit 4641 allows for a maximum annual municipal/rural appropriation of 25 acre-feet at a maximum pumping rate of 100 gallons per minute. All Seasons System I is located about seven miles west of Bottineau and All Seasons System II is located about 10 miles northwest of Bottineau (fig. 3).

Based on the previous analysis of the Bottineau municipal ground-water supply, the Bottineau well field will not provide a peak pumping rate of 1300 gallons per minute and likely will not provide a long-term sustained annual yield of 697.5 acre-feet. As a result, the All Seasons Systems I and II wells will need to be used in conjunction with the Bottineau well field and additional well fields (to be determined in Phase III of this study) to provide the target pumping rate of 1300 gallons per minute, and a sustained annual withdrawal of 697.5 acre-feet. This requires an analysis of All Seasons Systems I and II wells to determine maximum sustained pumping rates of individual wells and maximum sustained annual ground-water withdrawals.

A detailed hydrogeologic investigation was conducted in the All Seasons Systems I and II areas by the NDSWC (Wanek, 1993). Therefore, only a brief description of the hydrogeologic setting of these areas is presented in this report.

All Seasons System I

The All Seasons System I well field is located along a northwest-southeast trending belt of land, which includes ice-contact fluvial deposits (kames and eskers) (fig. 48). The ice-contact fluvial deposits along this belt of land will be referred to as the Souris aquifer. The ice-contact outwash deposit associated with All Seasons System I is about one-mile long and about 3/4-mile wide. The aquifer consists of variable amounts of sand and gravel that generally are overlain

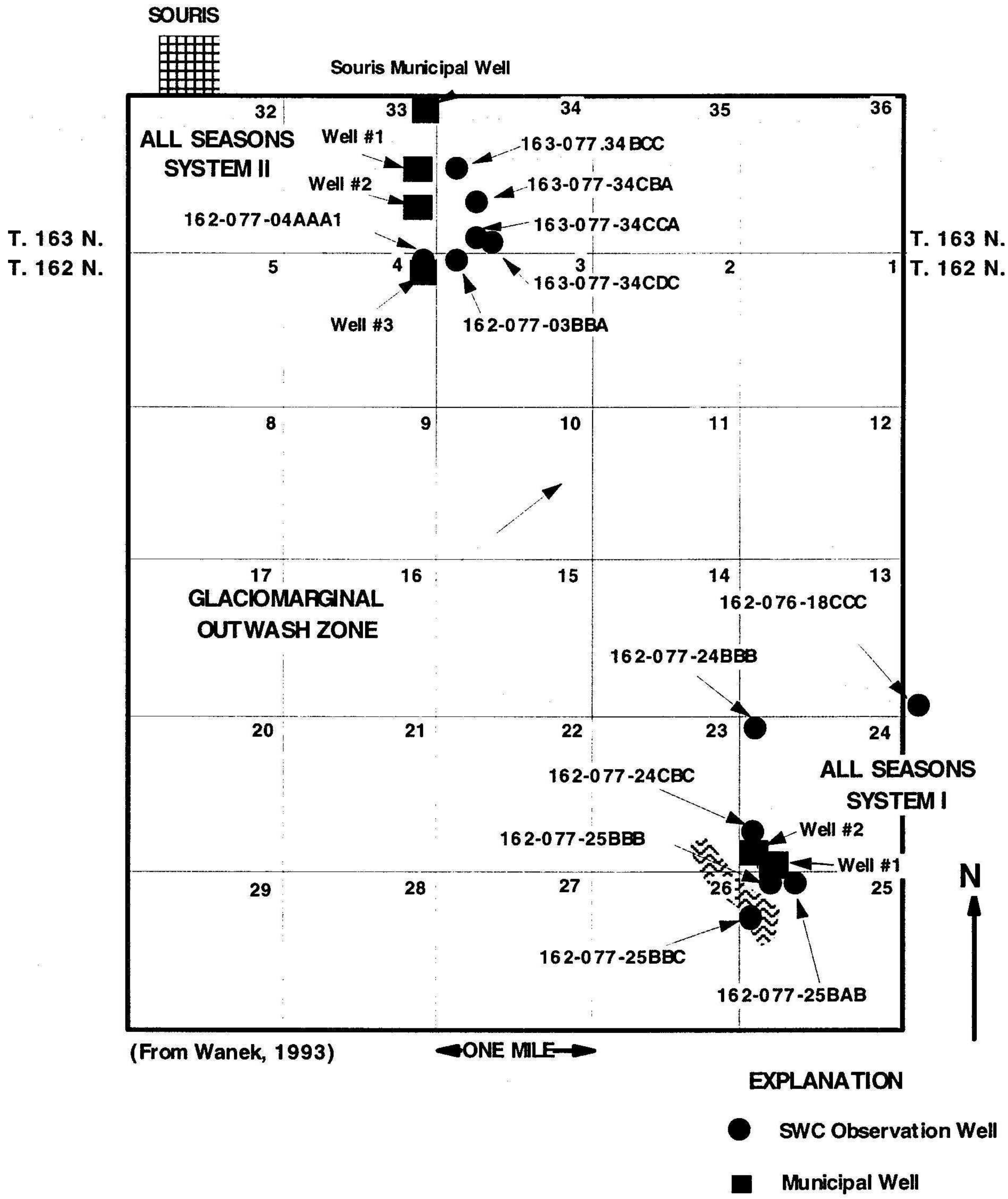


Figure 48. -- Location of observation and municipal wells in the All Seasons System I and II areas of the Souris aquifer

by silt and/or till and, in places, are unconformably underlain by sands of the Fox Hills Formation. For the most part, the aquifer is unconfined. The saturated thickness varies from less than one foot up to about 45 feet.

The capture system for All Seasons System I consists of two wells located in the SW1/4SW1/4SW1/4 of Section 24, Township 162 North, Range 77 West. Well #1 (162-077-24CCC1) is located 140 feet southeast of well #2 (162-077-24CCC2). Both wells were constructed by LTP Enterprises, Inc., Fargo, ND. The driller's log for well #1 is shown in table 16.

Table 16. – Driller's log of well #1, All Seasons System I

LITHOLOGIC DESCRIPTION	DEPTH	
	From	To
Topsoil	0	2
Lenses of sand and clay	2	18
Fine sand	18	33
Fine to medium sand	33	47.5
Coarser sand	47.5	56.5
Medium sand	56.5	63
Sandy clay	63	78

The well is constructed with 50 feet of 8-inch diameter steel casing and 13 feet of 8-inch diameter, 45-slot, stainless-steel screen from 50 to 63 feet below land surface. The screen is gravel packed.

LTP Enterprises, Inc. conducted a pumping test on the well in August 1993. The well was pumped continuously at a rate of 260 gallons per minute for 1410 minutes. The static water level was 16.5 feet below land surface and the final pumping level was 30.67 feet below land surface. The specific capacity was 25.5 gallons per minute per foot of drawdown. The distance from the pumping well to the point of discharge was not indicated on the pumping test report. Infiltration of well discharge may have affected well drawdown if the point of discharge was too close to the production well.

A plot of log of time versus arithmetic pumping level from the pumping test conducted by LTP Enterprises, Inc. in August 1993 is shown in figure 49. For about the first 200 minutes of pumping, the pumping levels plot along lines characterized by a smaller (flatter) slopes than the slope of the line connecting pumping levels after 200 minutes of pumping. The early-time pumping levels are affected by delayed yield resulting from gravity drainage that occurs in the top part of the aquifer being dewatered (capillary fringe). Applying the analytical method of Jacob (1946) to the pumping-level data measured after 200 minutes of pumping, transmissivity of 13,400 ft^2/d was calculated. Assuming an aquifer saturated thickness of 46.5 feet, a hydraulic conductivity of 288 ft/d is calculated. This is much too large for fine to medium sand as reported on the driller's log. Hydraulic conductivity of a fine to medium sand should range from about 10 to 50 feet per day. The anomalously large transmissivity and associated hydraulic conductivity may be due to the influence of delayed gravity drainage and/or infiltration of pumping well discharge downward to the water table. It is also possible the aquifer matrix may be more coarse textured than reported on the driller's log.

Based on a static water level of 16.5 feet below land surface at well #1, there is 33.5 feet of available head above the top of the screen. After 10 minutes of pumping at a rate of 260 gallons per minute, the specific capacity was calculated

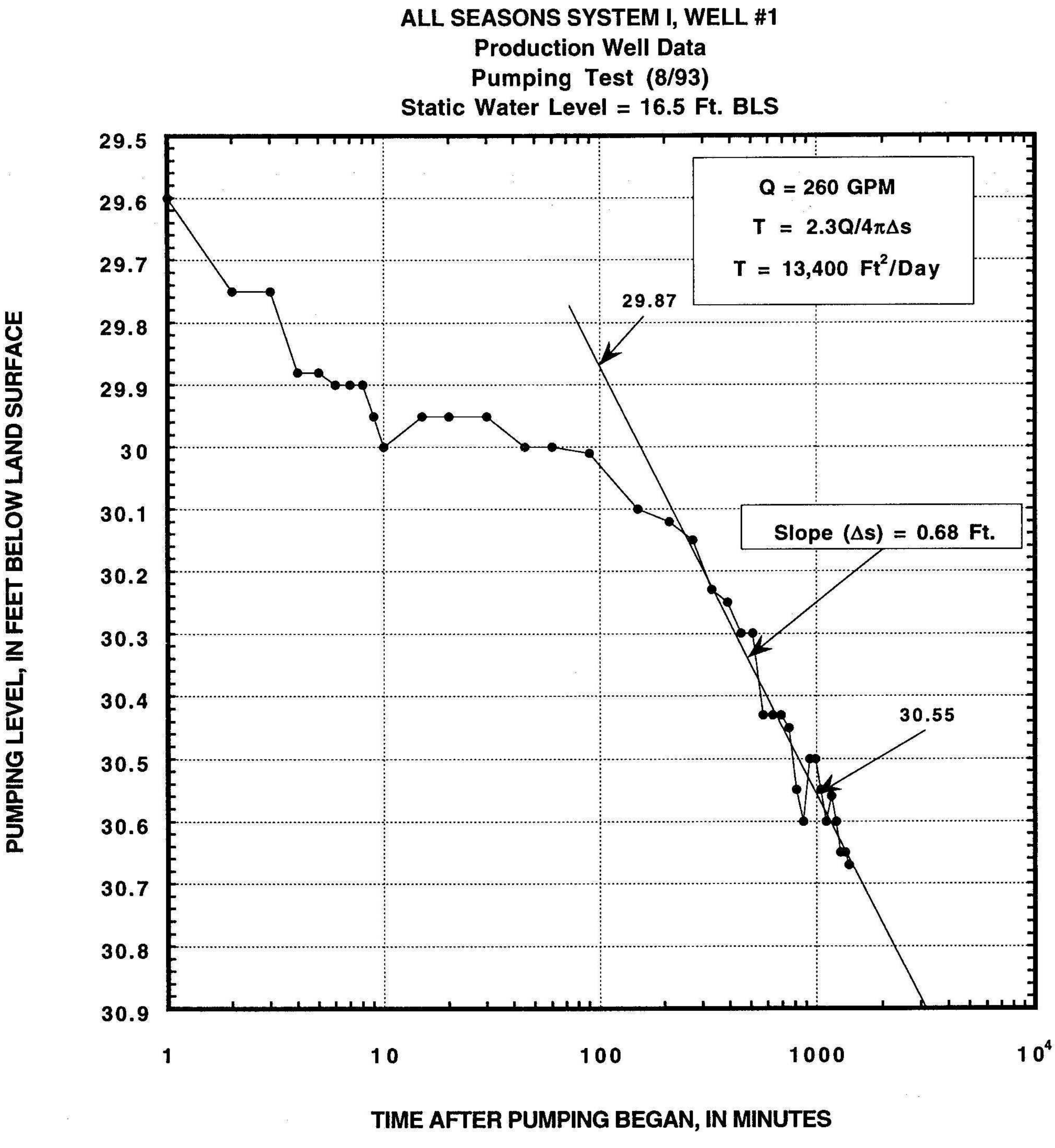


Figure 49. -- Plot of log of time versus arithmetic pumping level in All Seasons System I, Well #1 (162-077-24CCC2)

at 19.3 gallons per minute per foot of drawdown. Based on an extrapolated specific capacity of 13.5 gallons per minute per foot of drawdown calculated after 10 days of continuous pumping, an available drawdown of 16.8 feet (50 percent of total available head above top of well screen), a maximum pumping rate of 227 gallons per minute is calculated. The extrapolated specific capacity and associated drawdown are based on Theis assumptions and do not incorporate the effects of delayed yield from gravity drainage and barrier boundaries.

Well #2 (162-077-24CCC2) is located about 140 feet northwest of well #1 (162-077-24CCC1). The driller's log for well #2 is shown in table 17.

Table 17. – Driller's log of well #2, All Seasons System I.

LITHOLOGIC DESCRIPTION	DEPTH	
	From	To
Topsoil	0	1
Silty sand	1	17
Sand	17	46
Sand, coarse	46	48
Sand	48	57
Sandy clay	57	70

The well is constructed with 49 feet of 8-inch diameter steel casing and eight feet of 8-inch diameter, 45-slot, stainless-steel screen from 49 to 57 feet below land surface. The screen was gravel packed.

LTP Enterprises, Inc. conducted a pumping test on the well in August 1993. The well was pumped continuously at a rate of 161 gallons per minute for 1430 minutes. The static water level was 14.4 feet below land surface and the final pumping level was 35.88 feet below land surface. The specific capacity after 1430 minutes of pumping at a rate of 161 gallons per minute was 7.5 gallons per minute per foot of drawdown. The distance from the pumping well to the point of discharge was not indicated on the pumping test report. Infiltration may have affected well drawdown if the point of discharge was too close to the production well.

A plot of log of time versus arithmetic pumping level from the pumping test on well #2 is shown in figure 50. For about the first 700 minutes of pumping, the pumping levels plot along lines characterized by smaller (flatter) slopes than the slope of the line connecting pumping levels after about 700 minutes of pumping. The early-time pumping levels (up to about 700 minutes) likely are affected by delayed yield resulting from gravity drainage that occurs in the top part of the aquifer being dewatered (capillary fringe). Using the analytical method of Jacob (1946) and pumping-level data measured after 700 minutes of pumping, a transmissivity of 2,243 ft^2/d is calculated. Assuming an aquifer thickness of 42.5 feet, a hydraulic conductivity of 53 ft/d is calculated. This value is reasonable for fine to medium sand as reported on the driller's log.

Based on a static water level of 14.5 feet below land surface at well #2, there is 34.5 feet of available head above the well screen. After 1430 minutes (0.99 days) of pumping at a rate of 161 gallons per minute, the specific capacity was calculated at 7.5 gallons per minute per foot of drawdown. Based on an extrapolated specific capacity of 6.6 gallons per minute per foot of drawdown calculated for 10 days of continuous pumping, an available drawdown of 17.3 feet (50 percent of total available head above top of well screen), a maximum pumping

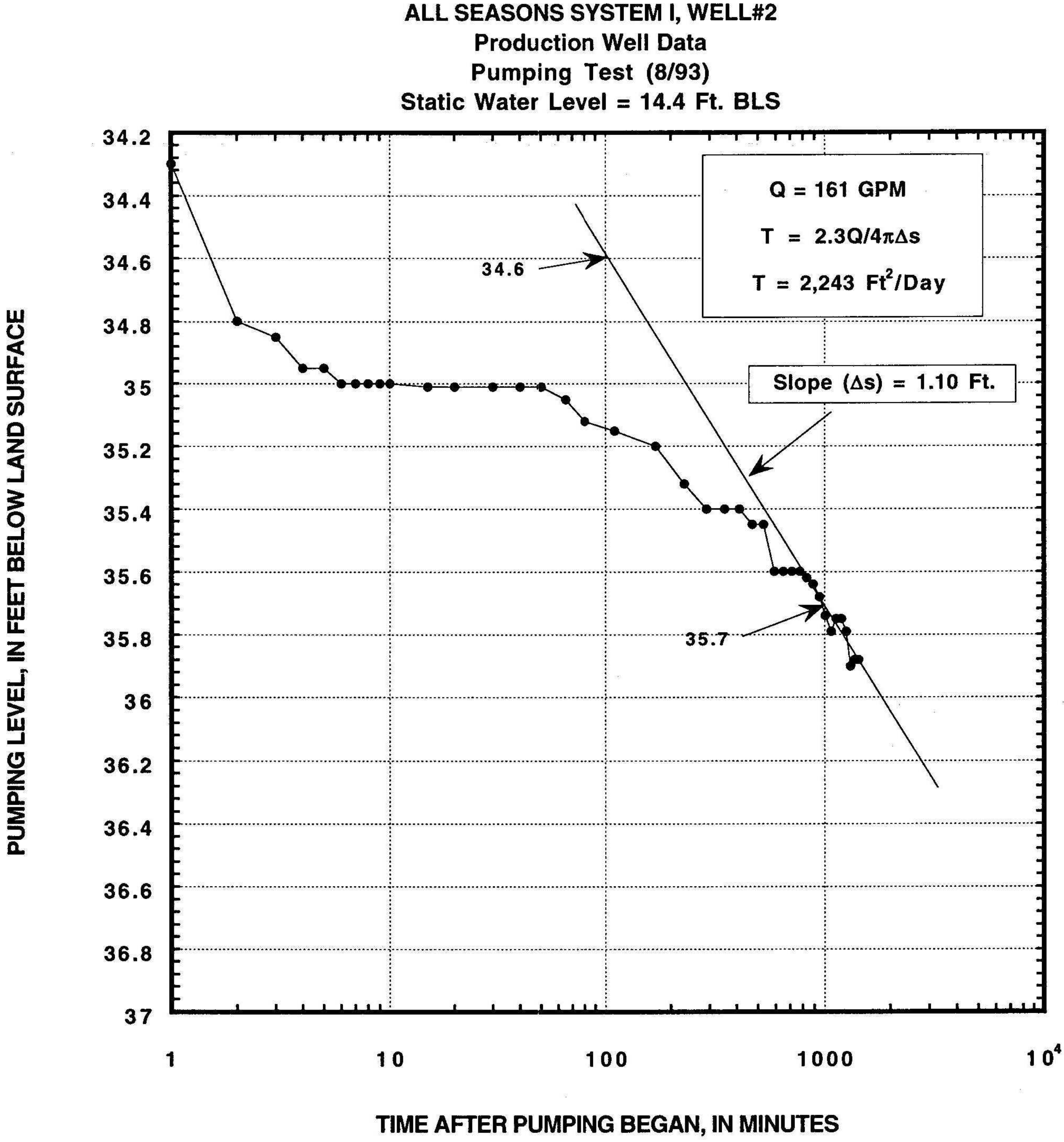


Figure 50. -- Plot of log of time versus arithmetic pumping level in All Seasons System I, Well #2 (162-077-24CCC2)

rate of 115 gallons per minute is calculated. The extrapolated specific capacity and associated drawdown are based on Theis assumptions and do not incorporate the effects of barrier boundaries.

The relatively small areal extent of the Souris aquifer is an important consideration with regard to the maximum, sustained, long-term ground-water withdrawal. Wanek (1993) shows the sand and gravel deposits of this ice-contact feature occupy an area of about one square mile in the SW1/4 of Section 24, SE1/4 of Section 23, NE1/4 of Section 26 and the NW1/4 of Section 25, all in Township 162 North, Range 77 West. Based on 1, 2, 3, and 4-inch annual recharge rates over a one square mile area, the volume of annual recharge amounts to 53, 106, 159, and 212 acre-feet, respectively. Although the Souris aquifer area and the practical range in annual recharge is relatively small, it appears there are relatively thick silt deposits of significant areal extent that are hydraulically connected to the Souris aquifer. These silt deposits have the potential to provide a significant source of recharge (as underflow) to the sand and gravel aquifer. In addition, as will be discussed in a later section of this report, the pumping test completed for well #3, All Seasons System II, indicates the Fox Hills aquifer is hydraulically connected to the Souris aquifer and can provide an additional source of recharge (as underflow) to the Souris aquifer. Lithologic logs of test holes/wells completed in the All Seasons System I area indicate the Fox Hills aquifer also is hydraulically connected to the Souris aquifer in the All Seasons System I area.

All Seasons Rural Water Users District holds perfected water permit #4640, which allows for an annual withdrawal of 100 acre-feet of ground water at a maximum rate of 200 gallons per minute from this area of the Souris aquifer. Water was first put to beneficial use in 1994. From 1994 through 2000, water use reported to the State Engineer ranged from 33.4 to 70.0 acre-feet with the average annual use of 59.4 acre-feet. Dan Schaefer, Manager, All Seasons Rural Water Users District, reports each of the two production wells are alternately pumped at a rate of 90 gallons per minute, generally daily for 12-hour pumping periods.

To gain insight into the impact of All Seasons System I withdrawals on water levels in this area of the Souris aquifer, water-level hydrographs are superimposed on annual water use bar graphs (figs. 51 and 52). Observation well 162-077-25BBB (fig. 51) is located closer to the two System I production wells than observation well 162-077-25BAB (fig. 52). From 1995 to 1998 the magnitude of water-table rise is smaller at 162-077-25BBB than at 162-077-25BAB. This probably is due to differences in the magnitude of water-level developmental decline, which is larger closer to the production wells. The abrupt water-level rise in 1999 and maintenance of the high water table after 1999 is due to anomalously high precipitation and associated ground-water recharge. This relationship is evident by comparing annual precipitation with water-level fluctuations (fig. 53). Note recharge to the aquifer from 1999 through 2001 overwhelms the water-level developmental decline caused by pumping. As a result, a desk-top analysis of aquifer response to past water use provides little insight into the maximum long-term sustained yield of the aquifer. However, based on the areal extent of the

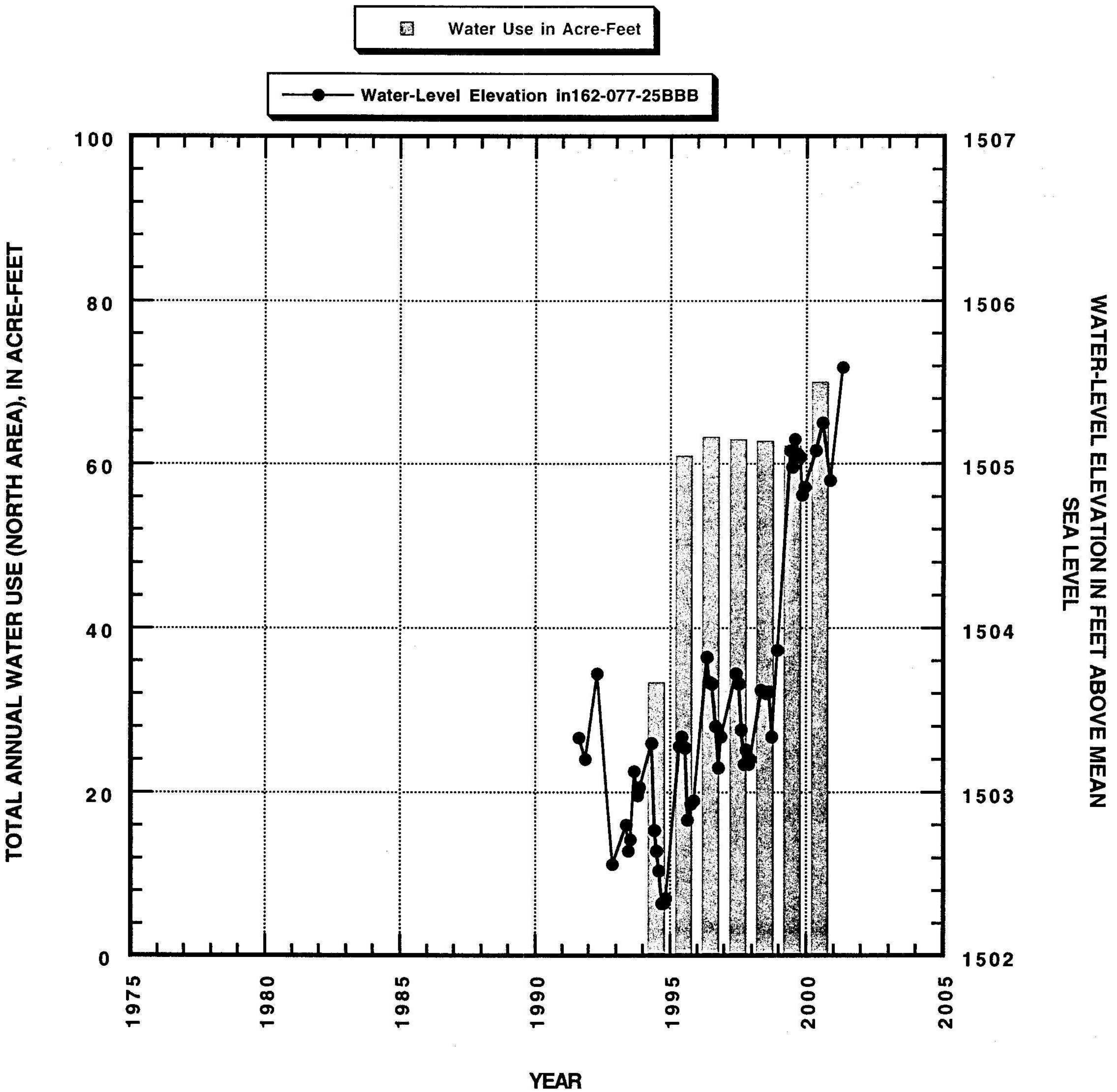


Figure 51. -- Comparison of water-levels in observation well 162-077-25BBB and annual water use for All Seasons System I

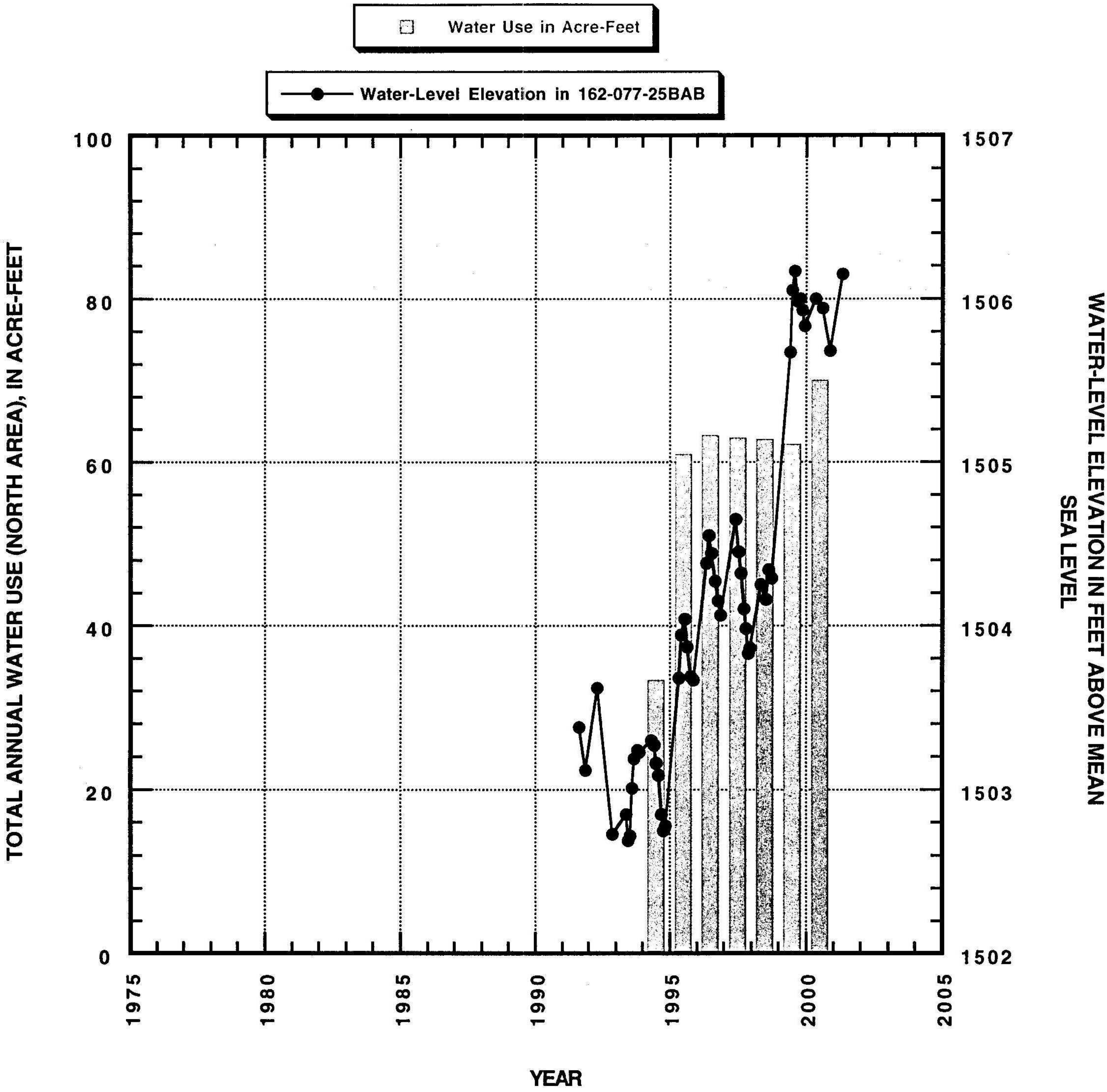


Figure 52. -- Comparison of water levels in observation well 162-077-25BAB and annual water use for All Seasons System I

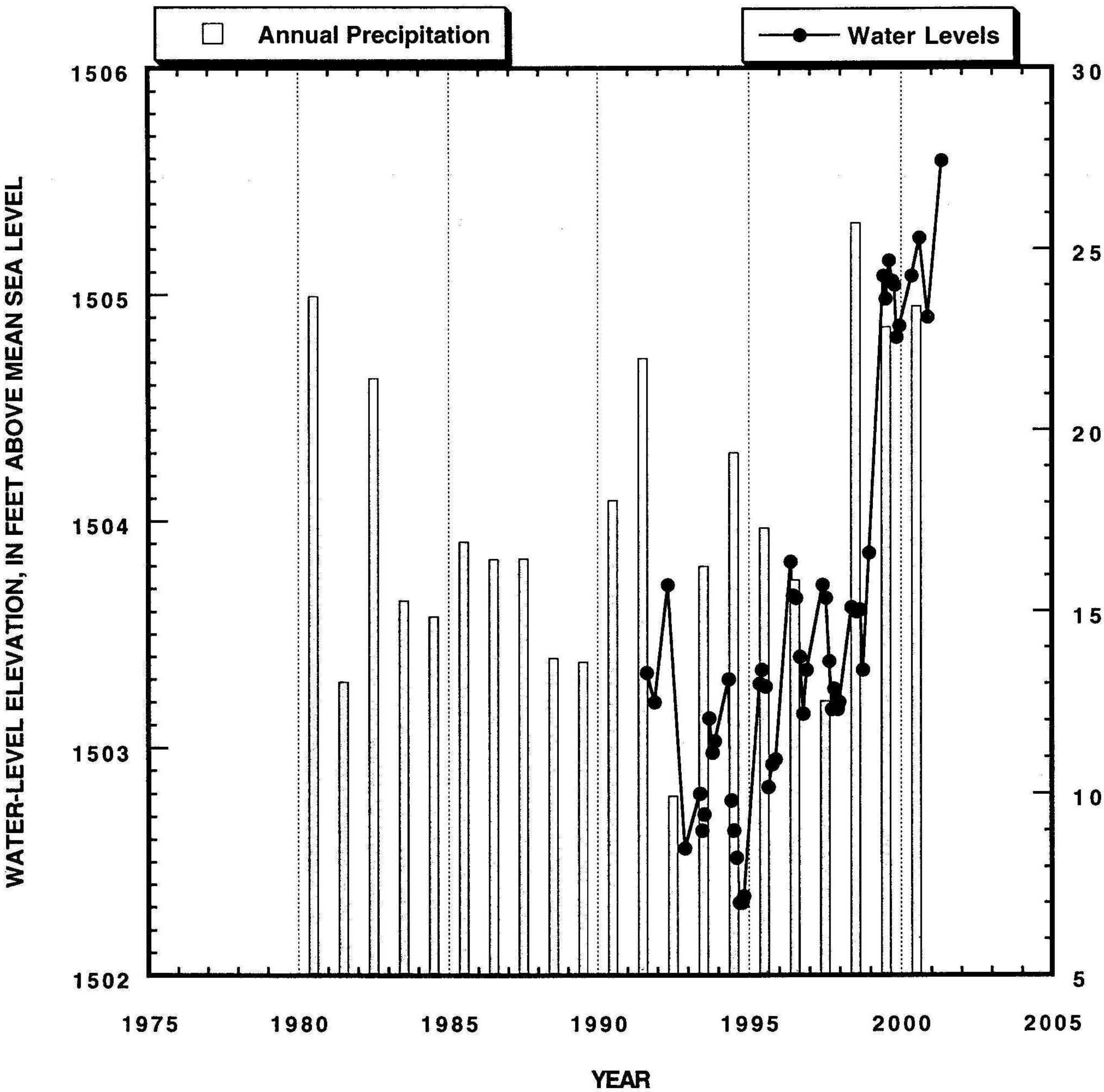


Figure 53. -- Relationship between annual precipitation and water-level fluctuations at observation well 162-077-25BBB

sand and gravel deposits, and the potential for additional recharge as underflow from adjacent silt layers and the Fox Hills aquifer, an annual withdrawal of 100 acre-feet from this area of the Souris aquifer appears sustainable. This aquifer may sustain a larger annual withdrawal. A more detailed hydrogeologic analysis, which may include a ground-water modeling study will be required to determine if a larger ground-water withdrawal is sustainable.

At this point in time, it appears the current All Seasons System I two-well capture system can provide an annual withdrawal of 100 acre-feet. Based on a 10-day continuous pumping period, the maximum pumping rate of well #1 (162-077-24CC1 – SE well of two) is 227 gallons per minute and the maximum pumping rate of well #2 (162-077-24CCC2 – NW well of two) is 115 gallons per minute. These pumping rates are based on alternate operation of the wells. Short-term pumping tests should be conducted on these two wells to verify maximum pumping rates. These tests could be incorporated into the Phase III part of this investigation.

All Seasons System II

The All Seasons System II well field is located along the same northwest-southwest trending belt of land in which the All Seasons System I well field is completed (fig. 48). The ice-contact outwash deposit associated with All Seasons System II is about 1 1/2 miles long and about 1/2 mile wide. The aquifer consists of variable amounts of sand and gravel that, in some areas, is overlain by silt or till and, in places, is unconformably underlain by sands of the Fox Hills

Formation. The aquifer is mostly unconfined and the saturated thickness varies from less than one foot up to about 59 feet.

The capture system for All Seasons System II consists of two wells located in the E1/2NE1/4SE1/4 of Section 33, Township 163 North, Range 77 West (well #1 north well – 163-077-33DAA1 and well #2 south well – 163-077-33DAA2) and one well located in the NE1/4NE1/4NE1/4 Section 4, Township 162 North, Range 77 West (162-077-04AAA2) (fig. 48). Well 163-077-33DAA1 is located about 285 feet north of well 163-077-33DAA2.

Well #1 (163-077-33DAA1) was completed by Russell Drilling Co. on October 7, 1976. The driller's log of well #1 is shown in table 18.

Table 18. – Driller's log of well #1, All Seasons System II.

LITHOLOGIC DESCRIPTION	DEPTH	
	From	To
Topsoil	0	1
Brown till	1	6
Gravelly till	6	19
Fine sand	19	24
Gravel	24	38

The well is constructed with 30 feet of 8-inch diameter casing and eight feet of 8-inch diameter Johnson 50-slot, stainless-steel screen from 30-38 feet below land surface. The screen does not appear to have been gravel packed.

Pumping test data is not available for well #1. All Seasons Rural Water Users periodically measures "static" and pumping water levels in well #1 and other Systems I and II production wells. "Static" water levels are reported without information regarding pumping history. "Static" water levels have ranged from a low of 19 feet below land surface measured on December 27, 1988 to a high of 12.8 feet below land surface on June 26, 1997. The pumping rate of well #1 is 40 gallons per minute and pumping levels range from about 24 to 26 feet below land surface. A pumping test needs to be conducted on well #1 to determine a maximum sustainable pumping rate. However, a pumping rate of at least 40 gallons per minute appears to be sustainable.

Well #2 (163-077-33DAA2) also was completed by Russell Drilling Co. on October 18, 1976. The driller's log of well #2 is shown in table 19.

Table 19. – Driller's log of well #2, All Seasons System II.

LITHOLOGIC DESCRIPTION	DEPTH	
	From	To
Topsoil	0	1
Brown till	1	7
Oxidized gravel with till	7	19
Fine sand	19	25
Medium to coarse sand and coarse gravel	25	39

The well is constructed with 31 feet of 8-inch diameter steel casing and eight feet of 8-inch diameter Johnson 80-slot, stainless-steel screen from 31 to 39 feet below land surface. The screen was not gravel packed.

Russell Drilling Co. conducted a pumping test on well #2 on October 20, 1975. The well was pumped continuously at a rate of 65 gallons per minute for 12.5 hours. The static water level was 14 feet below the measuring point and the final pumping level was 20.58 feet below the measuring point. The specific capacity was 9.9 gallons per minute per foot of drawdown. The distance from the pumping well to the point of discharge was not indicated on the pumping test report. Even though the aquifer is overlain by 19 feet of "gravel with till" at this well site, infiltration of well discharge may have affected well drawdown if the point of discharge was too close to the production well.

A plot of log of time versus arithmetic pumping level from the pumping test on well #2, conducted by Russell Drilling Co. on October 20, 1975 is shown in figure 54. The data is not useful for calculating aquifer transmissivity and hydraulic conductivity. For the most part, pumping levels trend along two lines characterized by nearly flat slopes. This indicates the data could be affected by delayed drainage from gravity yield (early time) as the aquifer begins to dewater, and/or downward infiltration of discharge water to the water table.

Based on a static water level of 14 feet below land surface at well #2, there is 17 feet of available head above the top of the well screen. After 20 minutes of pumping at a rate of 65 gallons per minute, the specific capacity was calculated at 11.0 gallons per minute per foot of drawdown. Based on an extrapolated specific capacity of 5.8 gallons per minute per foot of drawdown calculated after 10 days of continuous pumping, an available drawdown of 8.5 feet (50 percent of total available head above top of well screen) a maximum pumping rate of 50 gallons per minute is calculated. The extrapolated specific capacity and associated drawdown are based on Theis assumptions and do not incorporate the effects of conversion from confined to unconfined conditions and barrier boundaries.

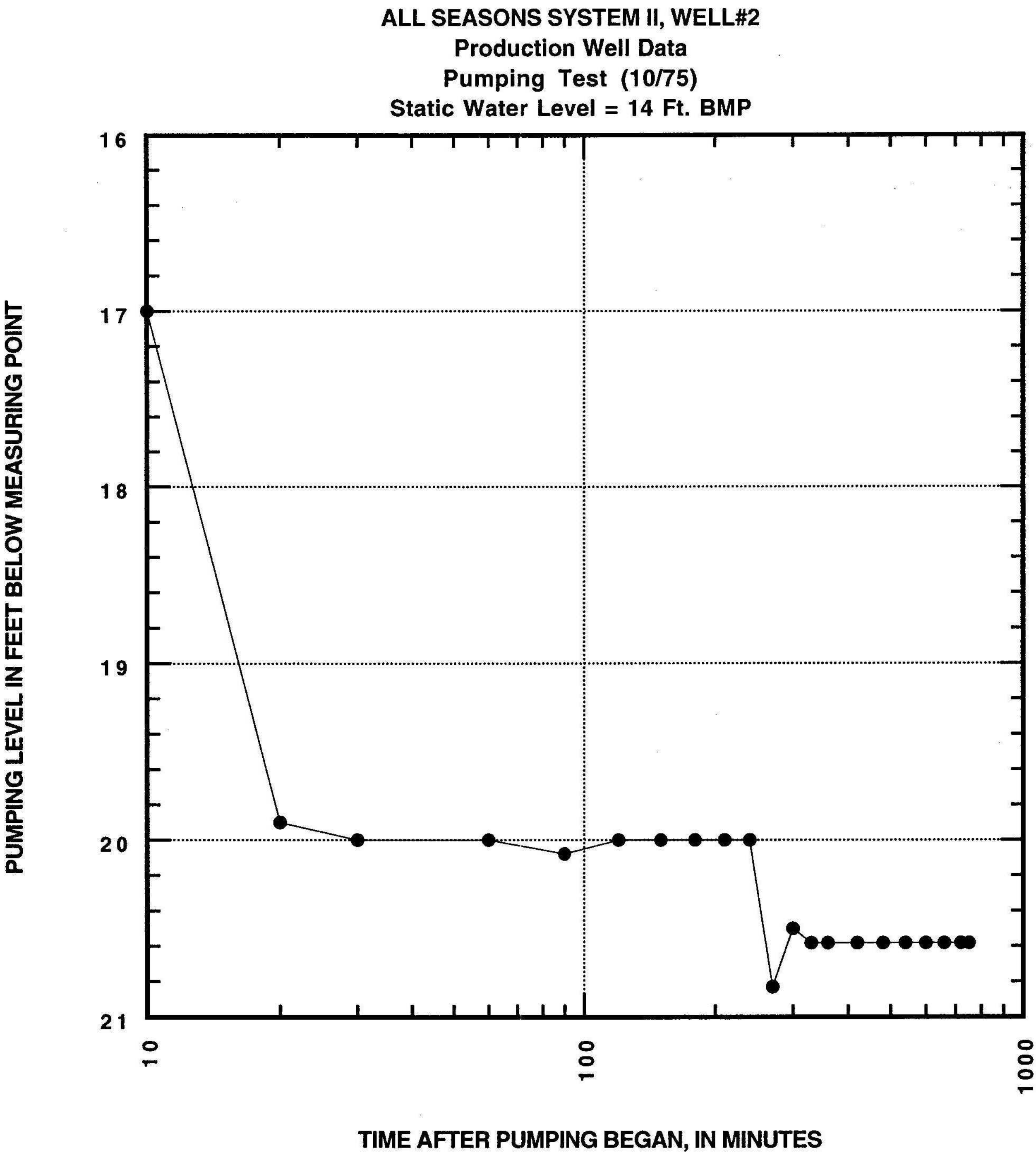


Figure 54. -- Plot of log of time versus arithmetic pumping level in All Seasons System II, Well #2 (163-077-33DAA2)

Well #3 (162-077-04AAA2) is located about 2,400 feet southeast of well #2 (fig. 48). The driller's log for well #3 is shown in table 20.

Table 20. – Driller's log of well #3, All Seasons System II.

LITHOLOGIC DESCRIPTION	DEPTH	
	From	To
Topsoil	0	1
Silty sand	1	10
Sand, with lenses of clay	10	18
Fine sand	18	30
Coarse sand	30	38
Fine sand	38	58
Sand	58	63
Dirty sand	63	67
Sand	67	75
Sandy clay	75	78
Clay	78	87

The well was completed by LTP Enterprises, Inc. on August 18, 1993. The well was constructed with 68 feet of 8-inch diameter steel casing and eight feet of #60 slot, stainless-steel screen from 68 to 76 feet below land surface. The well screen was gravel packed.

LTP Enterprises, Inc. conducted a pumping test on well #3 in August 1993. The well was pumped continuously at a rate of 60 gallons per minute for 1410 minutes. The static water level was 15.0 feet below land surface and the final pumping level was 49.13 feet below land surface. The specific capacity after 1410 minutes of pumping was 1.76 gallons per minute per foot of drawdown. The distance from the pumping well to the point of discharge was not indicated on the pumping test report. Infiltration may have affected well drawdown if the point of discharge was too close to the production well.

A plot of log of time versus arithmetic pumping level from the pumping test on well #3 is shown in figure 55. For about the first four minutes of pumping the slope of the line connecting pumping level points is large (steep) as compared to the slope of the line connecting pumping level points after four minutes of pumping. Based on the static water level, a 60 gallon per minute pumping rate, and depending on the diameter of the pump column, the effects of casing storage can affect water-level drawdown in the well for about the first two to three minutes of pumping. After about eight minutes of pumping, the slope of the line connecting pumping level points abruptly decreases and remains small until the end of the pumping test. The small slope could be caused by delayed yield from gravity, drainage, leakage, or infiltration of discharge water. As a result, it is not possible to calculate aquifer transmissivity and hydraulic conductivity of the aquifer.

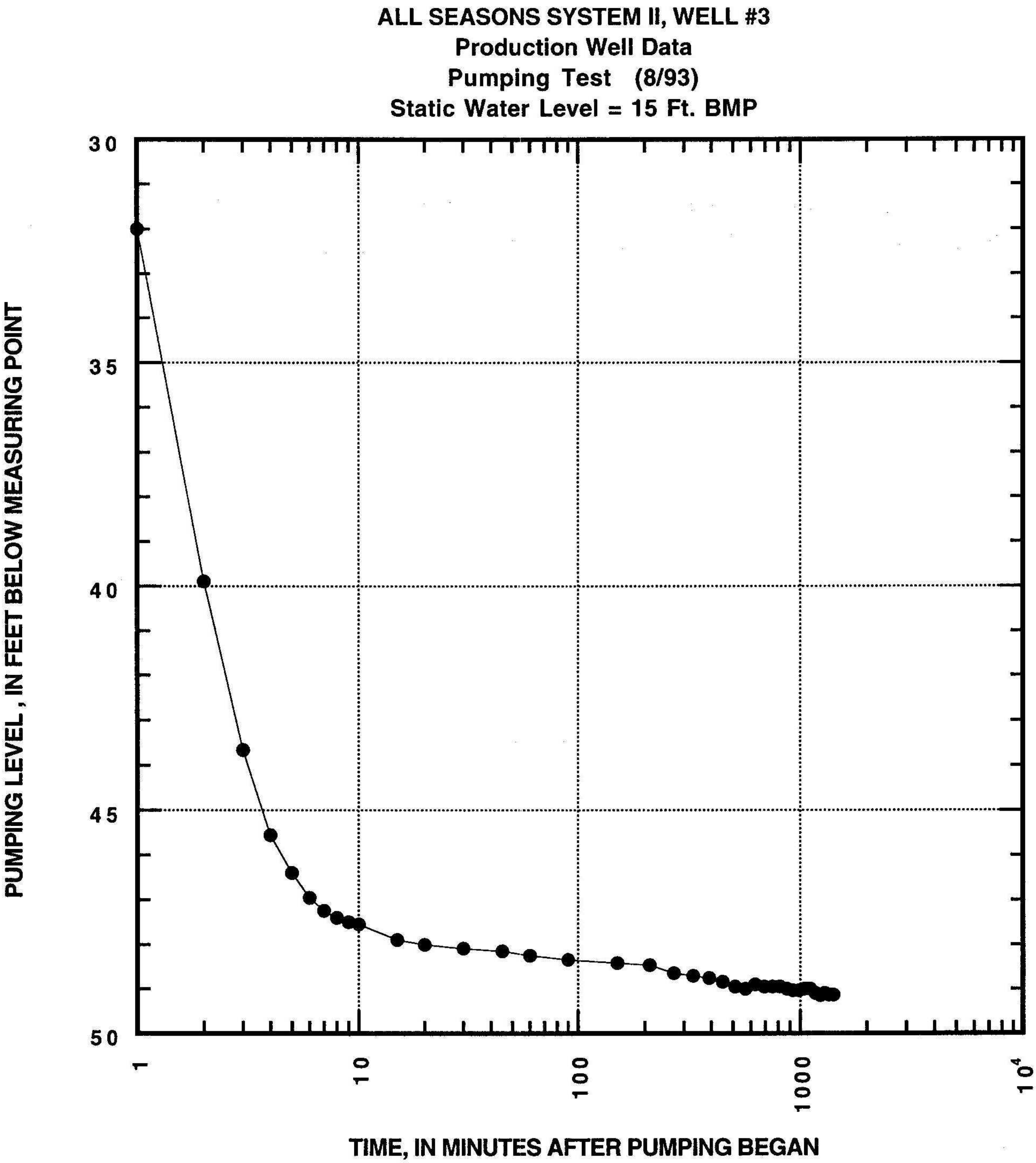


Figure 55.--Plot of log of time versus arithmetic pumping level in All Seasons System II, Well #3, (162-077-04AAA2)

Wanek (1993) completed an observation well at 162-077-04AAA1 and this observation well is located about 150 feet north of well #3. The lithologic log of this observation well is shown in table 21.

Table 21. – Lithologic log of observation well 162-077-04AAA1.

LITHOLOGIC DESCRIPTION	DEPTH	
	From	To
Topsoil	0	2
Sand and gravel, well graded, 45 % gravel, subrounded to subangular, silicates and carbonates.	2	44
Sand and gravel, as above interbedded with silt and very fine gray olive gray to greenish gray sand.	44	55
Sand and gravel, as from 2-44 feet.	55	67
Sand, fine grained, well sorted, subrounded, semi-indurated, quartz, glauconite, interstitial clay, indurated at 74 feet (Fox Hills Formation)	67	74

Based on the lithologies, associated depths, the screened interval and small specific capacity of well #3, as reported by LTP Enterprises, Inc., it appears well #3 is completed in the bedrock Fox Hills Formation and not in the overlying glaciofluvial deposits. Test drilling by Wanek (1993) indicates 50- to 60-foot thick sand and gravel bodies occur near well #3. Properly completed wells in the sand gravel deposits should have specific capacities of at least 20 to 25 gallons per minute per foot of drawdown and may provide individual sustained well yields of up to about 200 gallons per minute.

Due to the fact that well #3 appears to be completed in the Fox Hills Formation, and the yield capacity is relatively small, this well should be plugged and abandoned. To increase the maximum sustained pumping rate for All Seasons System II, another well should be constructed and completed within the glaciofluvial sand and gravel deposits of the Souris aquifer. A pumping test should be conducted to determine maximum pumping rate. For planning purposes, a maximum pumping rate of 200 gallons per minute is estimated.

The relatively small areal extent of Souris aquifer is an important consideration with regard to the maximum, sustained long-term ground-water withdrawal. Wanek (1993) shows the sand and gravel deposits of this ice-contact feature occupy an area of about 1/2-square mile. Based on 1-, 2-, 3-, and 4-inch annual recharge rates over a 1/2-square mile area, the volume of annual recharge amounts to 26, 52, 78, and 104 acre-feet, respectively. Although the Souris aquifer area and range in associated annual recharge are relatively small, it appears there are relatively thick silt deposits of significant areal extent that are hydraulically connected to the Souris aquifer. These silt deposits have the potential to provide a significant source of recharge (as underflow) to Souris aquifer. In addition, as shown from the pumping test in well #3, the Fox Hills aquifer is hydraulically connected to the Souris aquifer and can also provide an additional source of recharge (as underflow) to the Souris aquifer in the All Seasons System II area.

All Seasons Rural Water Users District holds perfected water permit #2492, which allows for an annual ground-water appropriation of 17.0 acre-feet at a maximum pumping rate of 35 gallons per minute from this area of the Souris aquifer (fig. 48). As previously described, the capture system consists of two wells located at 163-077-33DAA1 (well #1 – north well) and 163-077-33DAA2 (well #2 – south well). The two wells are alternately pumped at a rate of 40 gallons per minute, generally over a daily, six-hour pumping period.

All Seasons Rural Water Users District holds perfected water permit #4641, which allows for annual ground-water appropriation of 25 acre-feet at a maximum pumping rate of 100 gallons per minute from this area of the Souris aquifer (fig. 48). As previously described, the capture system consists of one well located at 162-077-04AAA2 (well #3). Well #3 generally is pumped alternately with wells 1 and 2. The pumping rate is reported at 70 gallons per minute over a daily operational period of three hours.

The city of Souris holds perfected water permit #965, which allows for an annual ground-water appropriation of 25.7 acre-feet at a maximum pumping rate of 105 gallons per minute from this area of the Souris aquifer (fig. 48). The 8-inch diameter well is screened from 21 to 36 feet below land surface. Specific capacity of the well is 4.3 gallons per minute per foot of drawdown after six hours pumping continuously at a rate of 65 gallons per minute.

The total permitted annual ground-water appropriation from this area of the Souris aquifer is 67.7 acre-feet. Based on data from annual water use reports, from 1976 through 2000, average annual use is 20.9 acre-feet, with a maximum annual use of 26.0 acre-feet and a minimum annual use of 8.1 acre-feet.

To gain insight into the impact for city of Souris and All Seasons System II withdrawals on water levels in this area of the Souris aquifer, water-level hydrographs are superimposed on annual water use bar graphs (figs. 56 and 57).

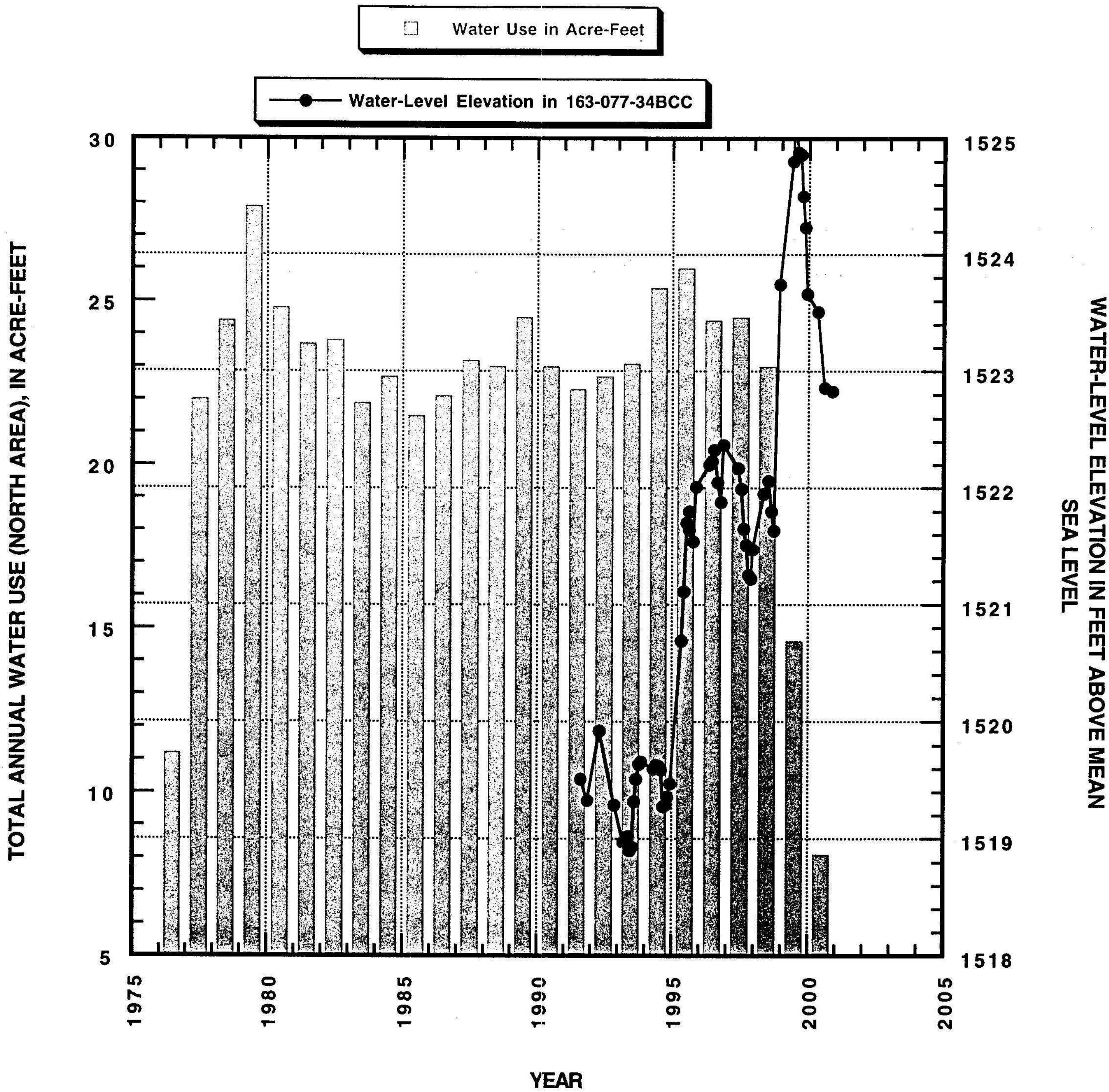


Figure 56. -- Comparison of water levels in observation well 163-077-34BCC and annual water use for All Seasons System II and city of Souris

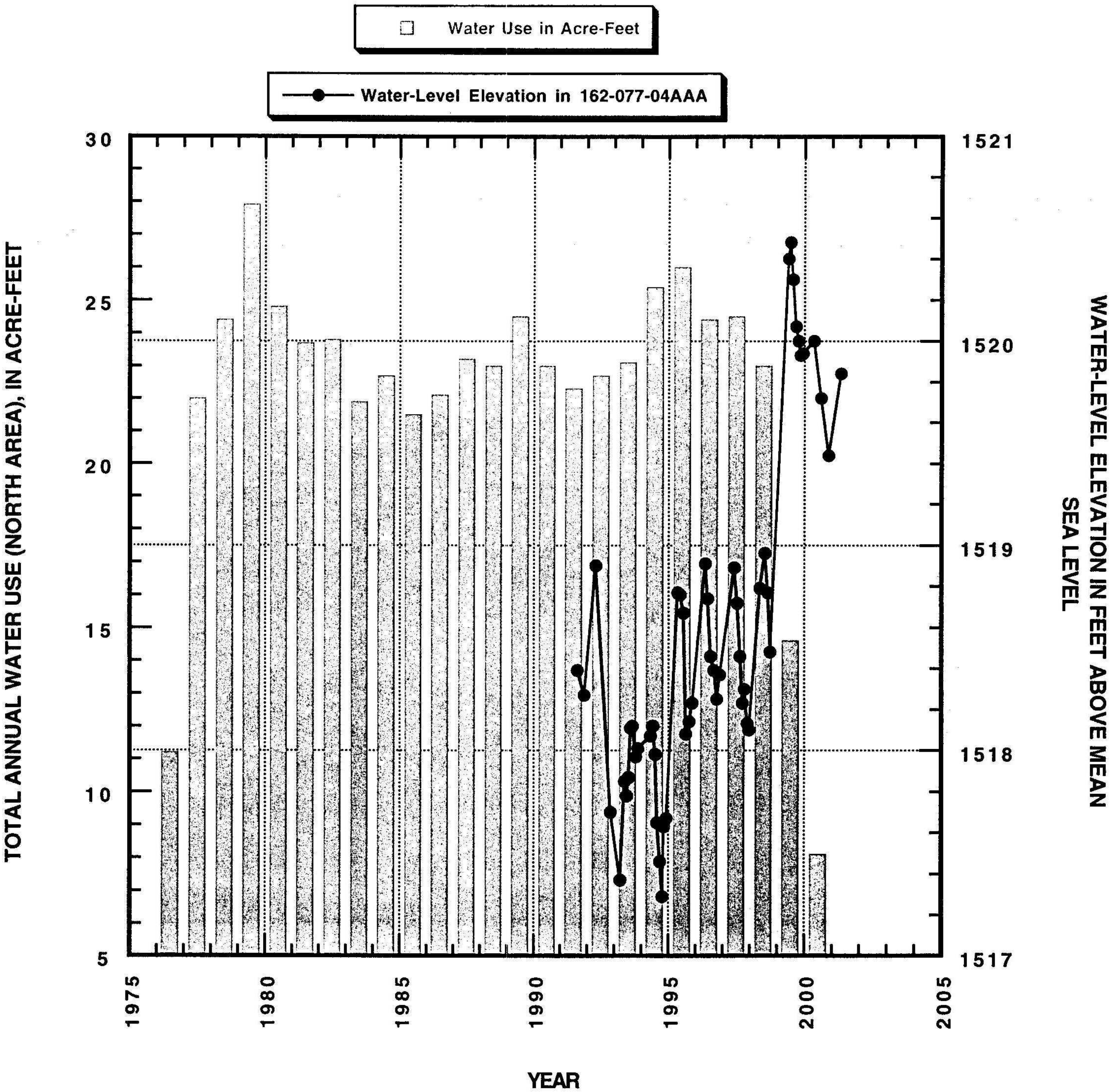


Figure 57. -- Comparison of water levels in observation well 162-077-04AAA and annual water use for All Seasons System II and city of Souris

The pattern of water-level fluctuation is very similar to that observed in the Souris aquifer to the south where All Seasons System I is located (figs. 51-52). The abrupt rise in water levels in 1999 is due to anomalously high precipitation and associated ground-water recharge. Average annual water use in this area of the Souris aquifer is about one-third the water use in the Souris aquifer area to the south (All Seasons System I). Recharge to this part of the Souris aquifer from 1999 through 2001 overwhelms the water-level developmental decline caused by pumping. As a result, a desk-top analysis of aquifer response to past water use provides little insight into the maximum long-term sustained yield of the aquifer. However, based on the areal extent of the aquifer and the potential for additional recharge as underflow from adjoining silts and Fox Hills aquifer, an annual withdrawal of 100 acre-feet from this part of the Souris aquifer appears sustainable. This aquifer may sustain a larger annual withdrawal. A more detailed hydrogeologic analysis, which may include a ground-water modeling study, will be required to determine if a larger ground-water withdrawal is sustainable.

At this point in time, for planning purposes, the current All Seasons System II capture system, modified to replace well #3 with a new well completed in this area of the Souris aquifer, can provide an annual withdrawal of 75 acre-feet. The maximum pumping rate for a properly completed replacement well in the Souris aquifer should be comparable to that of well #1 in All Seasons System I, which is about 200 gallons per minute. The final determination of a maximum pumping rate will be based on the results of pumping tests for wells #1 and #2, and a new well to be completed in the Souris aquifer near existing well #3. The pumping tests could be incorporated into the Phase III part of the investigation. For planning purposes, a maximum pumping rate of 290 gallons per minute is estimated (40 gallons per minute well #1, 50 gallons per minute well #2, and 200 gallons per minute new well #3).

All Seasons Systems I and II Water Chemistry

Chemical analyses of 31 ground-water samples collected from 15 wells completed in the Souris aquifer provide the basis for evaluating water chemistry (table 22). The samples were collected/analyzed over a period from August 1991 through August 1995. The range and mean values of selected ions, dissolved solids and hardness and USEPA secondary maximum contaminant levels (SMCL) are shown in table 23. SMCLs are non-enforceable recommended standards. Values exceeding SMCL are not considered a health hazard. Ground water in the Souris aquifer commonly exceeds SMCL for sulfate, iron, manganese, and dissolved solids.

Table 22. - Chemical analyses of 31 ground-water samples collected from 15 wells completed in the Souris aquifer

Location	Screened Interval (ft)	Date Sampled	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)
			(milligrams per liter)																				
162-076-18CCC	30-35	08/21/91	27	0.07	0.13	30	9	480	6.1	763	0	540	19	0.3	3.2	0.61	1490	110	0	90	20	2300	15
162-077-03BBA	46-51	08/20/91	25	0.09	0.28	55	23	110	3.1	397	0	170	13	0.2	1	0.14	597	230	0	50	3.2	881	11
162-077-03BBA	46-51	10/08/91		0.31	0.31																	852	9
162-077-03BBA	46-51	08/22/95		0.61	0.28	54	23	110	3.4	412	0	140	11	0.2	1		546	230	0	51	3.2	750	7.5
162-077-04AAA	58-63	08/20/91	29	0.07	0.15	60	23	85	3.6	348	0	160	12	0.2	0.3	0.12	544	240	0	43	2.4	822	10
162-077-04AAA	58-63	08/22/95		1.2	0.15	58	22	90	4.3	347	0	150	13	0.2	1		511	240	0	45	2.5	705	7.2
162-077-04AAA2	68-76	08/18/93		0.27	0.1	43.4	16.2	99	3.5	302	0	82	11.8	0.24			437	175			3.26	744	
162-077-24BBB	29-34	08/21/91	25	0.02	0.01	78	25	30	4.4	344	0	58	2.9	0.1	59	0.05	451	300	16	18	0.8	669	9
162-077-24BBB	29-34	08/23/95		0.01	0.01	85	25	31	5.4	343	0	55	3.6	0.1			399	320	34	17	0.9	615	7.3
162-077-24CBC	44-49	08/21/91	26	0.08	0.23	84	31	37	3.1	418	0	84	6.8	0.1	1	0.05	479	340	0	19	0.9	742	9
162-077-24CBC	44-49	08/23/95		0.46	0.24	84	33	35	3.6	424	0	86	7.8	0.1	1		460	350	0	18	0.8	630	7.6
162-077-24CCC1	50-63	08/11/93		0.12	0.2	67	27.9	33.2	4.1	318	0	39	3.6	0.1			366	282			0.86	667	
162-077-24CCC1	50-63	07/29/94		0.053	0.299	77.4	30.3	32.9	3.9	374	0	67	4.2	0.13			402	318		18.3	0.8	652	
162-077-24CCC2	49-57	08/24/93		0.1	0.27	71	26	31.2	3.9	310	0	51	5	0.15			374	284			0.81	653	
162-077-24CCC2	49-57	07/29/94		0.031	0.065	77	31.6	37.6	3.9	365	0	62	3	0.13			397	323			0.91	629	
162-077-25BAB	37-42	08/21/91	25	0.01	0.04	78	36	79	7.7	322	0	240	8.5	0.1	16	0.1	649	340	79	33	1.9	995	10
162-077-25BAB	37-42	08/23/95		0.03	0.28	85	32	36	4.3	333	0	140	7.6	0.1	1		470	340	71	18	0.8	650	8
162-077-25BBB	47-52	08/21/91	23	0.07	0.28	68	29	21	3	326	0	72	2.4	0.1	1	0.08	381	290	22	13	0.5	591	10
162-077-25BBB	47-52	10/08/91		0.02	0.34																	566	9
162-077-25BBB	47-52	08/23/95		0.33	0.27	71	33	20	3.3	364	0	74	4.9	0.1	1		387	310	14	12	0.5	540	8
162-077-25BBC	48-53	08/21/91	30	0.14	0.03	38	70	390	28	1290	0	200	28	0.2	1	0.49	1420	380	0	67	8.7	2230	9
162-077-25BBC	48-53	10/08/91		0.67	0.07																	1972	10
162-077-25BBC	48-53	08/23/95		0.94	0.02	35	63	380	25	1280	0	130	30	0.2	1		1300	350	0	69	8.8	1715	7.5
163-077-34BCC	44-49	08/20/91	21	0.05	0.39	130	47	350	6.6	444	0	890	36	0.2	1.9	0.28	1700	520	150	59	6.7	2320	11
163-077-34BCC	44-49	08/22/95		1.2	0.44	140	48	360	6.1	432	0	940	49	0.2	1		1760	550	190	59	6.7	1950	7.6
163-077-34CBA	42-47	08/20/91	27	0.01	0.19	51	20	200	4.4	474	0	280	11	0.2	0.8	0.23	828	210	0	67	6	1146	10
163-077-34CBA	42-47	08/22/95		0.08	0.32	93	33	240	4.3	480	0	490	25	0.1	1		1120	370	0	58	5.4	1390	7.3
163-077-34CCA	26-31	08/20/91	27	0.49	0.21	78	30	80	4.9	408	0	170	8	0.1	1	0.1	601	320	0	35	1.9	877	10
163-077-34CCA	26-31	08/22/95		0.68	0.14	58	23	70	4.5	342	0	130	1.4	0.1	1		457	240	0	38	2	640	7
163-077-34CDC	44-49	08/20/91	26	0.02	0.07	56	24	250	5.1	570	0	340	14	0.2	1	0.27	998	240	0	69	7	1433	10
163-077-34CDC	44-49	08/22/95		0.12	0.1	47	18	200	4.1	411	0	270	14	0.2	1		757	190	0	69	6.3	980	6.9

Table 23. -- Range and mean values of selected ions, dissolved solids, and hardness in the Souris aquifer (All Seasons System I and II areas) and USEPA secondary maximum contaminant levels.

	Range (mg/L)	Mean mg/L	SMCL[1] (mg/L)
Calcium	30-140	70	N/A
Magnesium	9-70	31	N/A
Sodium	20-480	160	N/A
Potassium	3-28	7	N/A
Bicarbonate	322-1290	490	N/A
Sulfate	55-940	253	250
Chloride	1.4-49	14.3	250
Iron	0.01-1.2	0.30	0.3
Manganese	0.01-0.44	0.19	0.05
Dissolved Solids	374-1780	803	500
Hardness	110-550	305	N/A

1. USEPA secondary maximum contaminant level

Wanek (1993) provides selected trace-element analyses from five observation wells completed in the Souris aquifer. Concentrations of these trace elements and USEPA primary maximum contaminant levels (MCLs) are shown in table 24. None of the trace element analyses exceed MCL.

The relative distribution of major ions from 23 ground-water samples from 15 wells completed in the Souris aquifer is shown in figure 58. Ground water in the Souris aquifer ranges from a calcium-sodium bicarbonate type to a sodium sulfate type. Observation well 162-076-18CCC appears to be completed in an isolated sand and gravel deposit characterized by a relatively large dissolved-solids concentration (1490 mg/L) and a large relative sodium concentration (89 percent). Observation wells 163-077-34BCC, 34CBA, and 34CDC are completed with screened intervals at the base of the sand and gravel deposits of the Souris aquifer

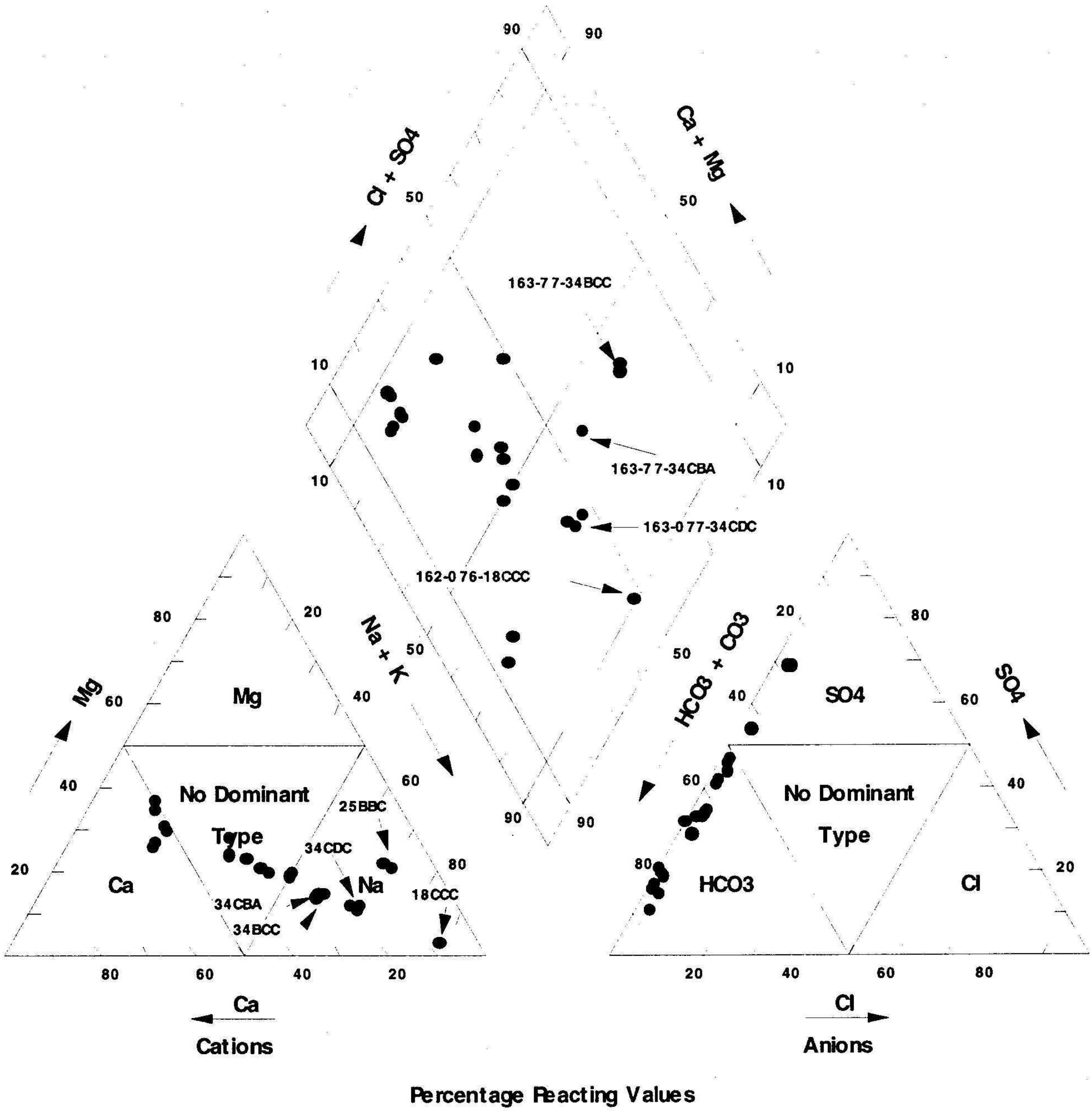


Figure 58.-- Relative distribution of major ions in observation wells completed in the Souris aquifer, All Seasons Systems I and II areas

that unconformably overlie the Fox Hills aquifer. All three wells are characterized by relative sodium concentrations in excess of 55 percent. The Fox Hills aquifer is characterized by large concentrations of sodium (Randich and Kunzniar, 1984). It appears the larger concentrations of sodium at observation wells 163-077-34BCC, CBA, and CDC are affected by upward advection and diffusion of ground water from the underlying Fox Hills aquifer. This hydrochemical pattern provides additional evidence to support the conceptual model which, in part, describes the Fox Hills aquifer as a recharge source (through underflow) to areas of the Souris aquifer.

Table 24. – Concentrations of selected trace elements from ground water in the Souris aquifer and USEPA primary maximum contaminant levels.

	Selenium	Lead	Mercury	Arsenic	Lithium	Molybdenum	Strontium
	Micrograms per liter						
162-077-03BBA	1	0	0	1	40	1	320
162-077-25BBB	1	0	0	1	30	0	230
162-077-25BBC	1	0	0	2	150	0	470
162-077-26AAA	1	0	0	1	30	0	230
163-077-34CBA	1	0	0	3	60	0	340
U.S.E.P.A. PMCL[1]	50	15[2]	2	10	N/A	N/A	N/A

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 on action level of 15 mg/L water, systems must take additional steps.

Dan Schaefer, Manager, All Seasons Rural Water Users District, provided five water-quality analyses from wells #1 and #2, System I and well #3, System II. The relative distribution of major ions from these wells is shown in figure 59. The analyses from well #1 and #2, System I are characterized by a calcium – to mixed

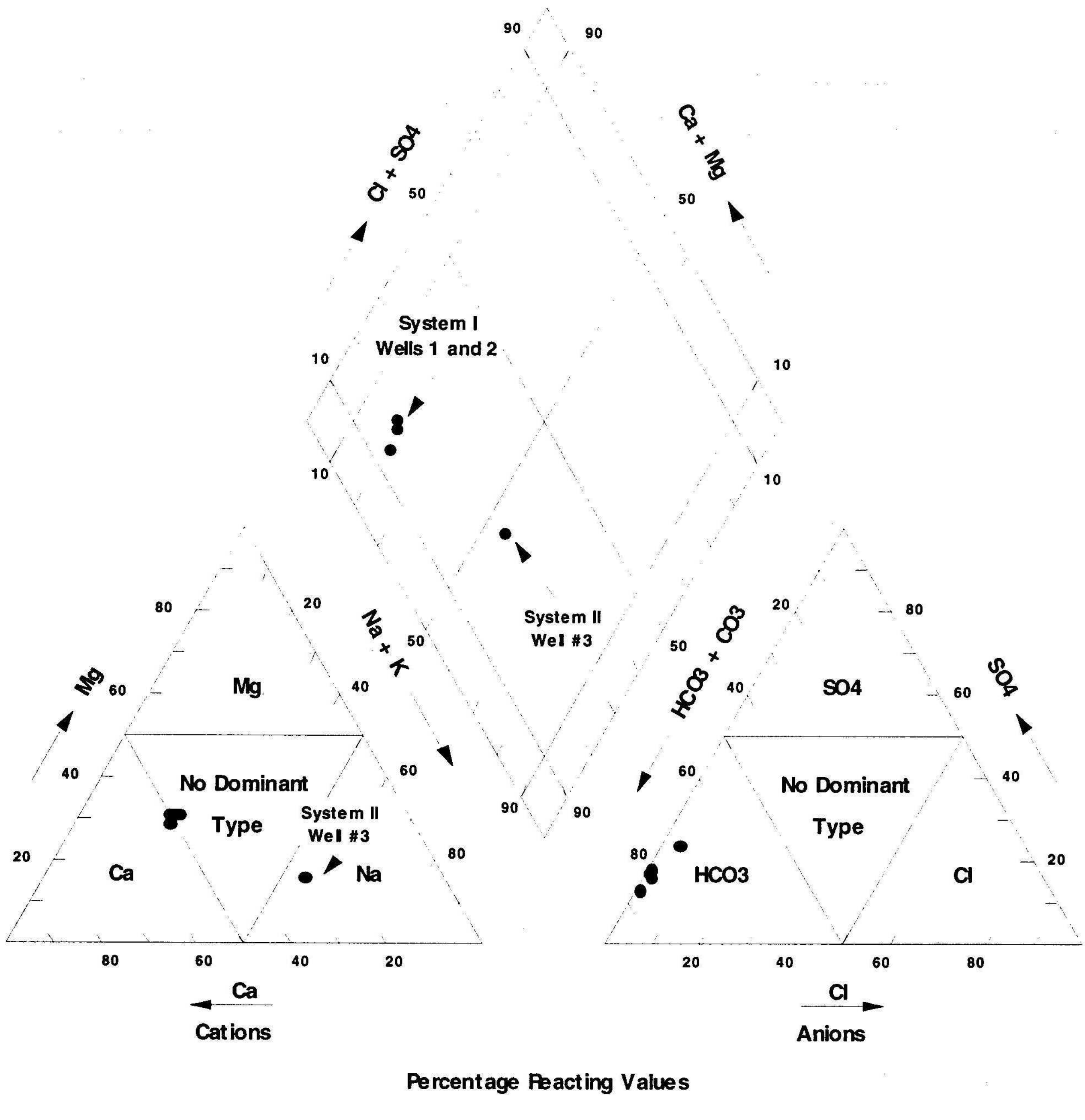


Figure 59. -- Relative distribution of major ions in All Seasons System I, wells 1 and 2, and System II, well 3

cation – bicarbonate type ground water. Well #3, System II is characterized by a sodium – bicarbonate type water. The hydrochemical signature of well #3 (large relative sodium concentration, and large absolute chloride concentration, 13 mg/L, relative to other observation/production wells) further supports the assertion that well #3 is completed in the Fox Hills aquifer.

SUMMARY AND CONCLUSIONS

The Bottineau municipal well field consists of 12 wells completed in the Bottineau aquifer, which is located along a flank area of the Turtle Mountains about three miles north of Bottineau. The Bottineau aquifer is comprised of sand and gravel deposits of glaciofluvial origin. The sand and gravel deposits occupy numerous, relatively small braided channels characterized by a highly irregular geometry. Based on water-level elevations, response to pumping, and to a lesser extent stratigraphic position and water chemistry, at least five and possibly six discrete hydrogeologic units were identified in the Bottineau well field study area. Water occurs under confined conditions within each of the five or possibly six discrete aquifer units (confined aquifers A through F). Municipal wells #4, #6, the two Walker wells, and the three Bittner wells are completed in confined aquifer A. Municipal wells #2, #3, and #5 are completed in confined aquifer B. Water levels in confined aquifer A are between about 40 and 60 feet higher than those in confined aquifer B. Municipal well #1 is completed in confined aquifer C. Water levels in confined aquifer C are about 50 feet lower than those measured in confined aquifer B. The Noble well is completed in confined aquifer D. Water levels in confined aquifer D are about 55 to 60 feet higher than those measured in confined aquifer B. Further aquifer testing in the Noble well area is recommended to determine if confined aquifer D is connected hydraulically to confined aquifer A. Confined aquifer E is located in the east-central area of Section 7. This aquifer unit is defined based on test drilling and water-level data reported by C.A. Simpson and Sons Drilling completed in 1980. There are no municipal or observation wells completed in confined aquifer E. Confined aquifer F was identified by the commercial observation well located at 162-075-07BBB2. Water levels in this well did not respond to pumping of any of the Bottineau municipal wells.

Given the complex aquifer geometry and the lack of test-drilling data, it was not possible to map the areal extent of the Bottineau aquifer and the individual hydraulically discrete aquifer units. As a result, it was not possible to quantify areal recharge and discharge rates. Probably, a major source area of recharge to the Bottineau aquifer in Section 7, T. 162 N., R. 75 W. is to the northeast in the Turtle Mountains. Recharge occurs as downward leakage through the overlying glacial drift, which consists primarily of till. Fluvial inhomogeneities probably occur within the overlying drift and these "hydraulic short-circuits" may facilitate localized recharge.

Prior to development of the Bottineau municipal well field, discharge from the Bottineau aquifer probably occurred primarily to springs. The "Walker" and "Bittner" bog areas were once characterized by seeps and springs. Springs and seeps currently occur in a bog/marsh area located near the center of the

E1/2SE1/4 of Section 7, T. 162 N., R. 75 W. This suggests there is additional ground water available for capture in the study area.

The city of Bottineau is the only water user diverting ground water from the Bottineau aquifer in Section 7, T. 162 N., Range 75 W. Mean annual water use from 1975 through 2000 is 355 acre-feet. Maximum annual water use was 465.7 acre-feet in 1984 and minimum annual water use was 160.6 acre-feet in 1975. Analysis of historic "static" and "pumping" level trends in selected municipal wells indicates significant long-term ground-water mining is not occurring in confined aquifers A, B, C, and D, and collectively, confined aquifers A, B, C, and D can sustain an annual ground-water withdrawal of at least 355 acre-feet.

Ground water in the Bottineau aquifer is a calcium-bicarbonate to calcium-sulfate type. U.S. Environmental Protection Agency SMCLs are exceeded for sulfate, iron, manganese, and dissolved solids concentrations. SMCLs are non-enforceable recommended standards. Values exceeding SMCL are not considered a health hazard. Except for uranium, the trace elements selenium, lead, mercury, arsenic, lithium, molybdenum, and strontium do not exceed USEPA MCL. The MCL for uranium is 30 µg/L and is exceeded in municipal wells #2 (37 µg/L) and #3 (140 µg/L). Potential health effects from injection of water exceeding uranium MCL are increased risk of cancer and kidney toxicity.

Maximum pumping rates of individual wells were calculated using specific capacities measured from pumping tests and extrapolated to the end of a 10-day continuous pumping period, for a drawdown amounting to 50 percent of the initial available head above the top of the well screen. The extrapolated specific capacity and associated drawdown were based on Theis assumptions and do not incorporate the effects of irregular channel geometry, additional barrier boundaries, leakage, and conversion from confined to unconfined conditions. Due to uncertainty with regard to these boundary conditions, extrapolating well drawdown beyond a 10-day pumping period is tenuous. Based on the above, the following maximum pumping rates are recommended:

Well #1	(162-075-07BDC2)	57GPM
Well #3	(162-075-07ACA)	160 GPM
Well #5	(162-075-07ADC3)	42 GPM
Well #6	(162-075-07ABD2)	125 GPM

Municipal well #2 should be used as a stand-by well. A new well should be completed in confined aquifer D at the Noble well site. A maximum well yield of at least 50 gallons per minute is feasible at this site. Another new well should be completed in confined aquifer F, somewhere in the NW1/4NW1/4 of Section 7, T. 162 N., Range 75 W. near commercial observation well 162-075-07BBB2. A maximum well yield of at least 50 gallons per minute is feasible at this site. Thus, the maximum sustained well yield (wells #1, #3, #5, #6, Noble well site, commercial well site) of the Bottineau aquifer in Section 7, T. 162 N., R. 75 W. is estimated at 484 gallons per minute.

All Seasons Systems I and II are located along a northwest-southeast belt of land, which includes ice-contact fluvial sand and gravel deposits (kames and eskers). These sand and gravel deposits comprise the Souris aquifer. All Seasons System I is located about seven miles west of Bottineau and All Seasons System II is located about 10 miles northwest of Bottineau. The Souris aquifer is of limited areal extent at both the System I and II sites. However, available data indicates the Souris aquifer is hydraulically connected to silt deposits of glacial origin and the Fox Hills aquifer. These hydraulic units have the potential of providing significant recharge to the Souris aquifer as underflow.

It appears likely the Souris aquifer in the area of All Seasons System I can provide a sustained annual ground-water withdrawal of 100 acre-feet. Using the same analytical procedure and assumptions for calculating maximum pumping rates for the Bottineau municipal wells, the maximum pumping rate of well #1 (162-077-24CCC1 – SE well of two) is 227 gallons per minute and the maximum pumping rate of well 2 (162-077-24CCC2 – NW well of two) is 115 gallons per minute. These pumping rates are based on alternate operation of the wells.

All Seasons System II has a three-well capture system (well #1: 163-077-33DAA1, well #2: 163-077-33DAA2, well #3: 162-077-04AAA1). Wells #1 and #2 are completed in sand and gravel deposits of glaciofluvial origin and well #3 appears to be completed in the Fox Hills aquifer. As with the System I area, the Souris aquifer in the System II area is hydraulically connected to silt deposits of glacioaqueous origin and the Fox Hills aquifer. These hydraulic units have the potential for providing significant recharge to the Souris aquifer as underflow.

It appears likely the Souris aquifer in the area of All Seasons System II can provide a sustained annual ground-water withdrawal of 100 acre-feet (All Seasons System II yielding 75 ac-ft., city of Souris yielding 25 ac-ft.). Using the same analytical procedure and assumptions for calculating maximum pumping rates from the Bottineau municipal wells, the maximum pumping rate of well #1 (163-

077-33DAA1) is 40 gallons per minute and the maximum pumping rate of well 2 (163-077-33DAA2) is 50 gallons per minute. These two wells can be pumped simultaneously.

Well #3 (162-077-04AAA2) has an unacceptably small specific capacity (1.76 gallons per minute per foot of drawdown) and appears to be completed in the Fox Hills aquifer. This well should be plugged and abandoned and a new nearby well should be completed in the sand and gravel deposits of the Souris aquifer. Available data indicates a maximum well yield of about 200 gallons per minute is possible from a properly constructed well in this area of the Souris aquifer.

The Souris aquifer in the All Seasons Systems I and II areas can provide a maximum sustained annual ground-water withdrawal of 175 acre-feet at a maximum pumping rate of 517 gallons per minute. Two- or three-day pumping tests should be conducted on wells #1 and #2 (System I), and wells #1 and #2 and a new well #3 completed in the Souris aquifer (System II) to verify maximum pumping rates. These tests could be incorporated into the Phase III part of the investigation.

Ground water in the Souris aquifer ranges from a calcium-sodium bicarbonate type to a sodium-sulfate type. USEPA SMCLs commonly are exceeded for sulfate, iron, manganese, and dissolved solids. The trace elements selenium, lead, mercury, arsenic, lithium, molybdenum, and strontium do not exceed USEPA MCL.

Projected water demands for the city of Bottineau and the All Seasons Water Users District Systems I and II, through a 20-year planning period ending in 2022 are an annual withdrawal of 697.9 acre-feet at a maximum peak pumping rate of 1300 gallons per minute. Results of this investigation indicate an annual sustained withdrawal of 530 acre-feet is possible with 355 acre-feet from the Bottineau aquifer and 175 acre-feet from the Souris aquifer, Systems I and II areas. The maximum pumping rate is 991 gallons per minute with 484 gallons per minute from the Bottineau aquifer, 227 gallons per minute from the Souris aquifer, All Seasons System I area, and 290 gallons per minute from the Souris aquifer, All Seasons System II area.

The projected requirements exceed the calculated sustainable amounts by 167.9 acre-feet of water at a pumping rate of 299 gallons per minute. Therefore, a Phase III study will be required to identify and develop additional sources of ground-water supply.

REFERENCES CITED

Abbott, G.A. and Voedisch, F.W., 1938, The municipal ground-water supplies of North Dakota: North Dakota Geological Survey Bulletin 11, 99 p.

Advanced Engineering and Environmental Services, Inc., 2001, Water supply and treatment facility plan report: Advanced Engineering and Environmental Services, Inc., in association with Wold Engineering, P.C.

Bluemle, J.P., 1985, Geology of Bottineau County, North Dakota: North Dakota Geological Survey Bulletin 78, part I, and North Dakota State Water Commission County Ground-Water Studies 35, part I, 57 p.

Des Lauriers, L.L., 1982, Soil survey of Bottineau County, North Dakota: U.S. Department of Agriculture, Soil Conservation Service, in cooperation with the North Dakota Agricultural Experiment Station, 160 p.

Froelich, L.L., 1963, Investigation of ground water conditions in the Bottineau area, Bottineau County, North Dakota: North Dakota State Water Commission Ground-Water Study 52, 60 p.

Hydrosphere Data Products, Inc., (2000), 1002 Walnut, Suite 200, Boulder, CO 80302

Kuzniar, R.L., and Randich, P.G., 1982, Ground-water data for Bottineau and Rolette Counties, North Dakota: North Dakota Geological Survey Bulletin 78, part II, and North Dakota State Water Commission County Ground-Water Studies 35, part II, 742 p.

North Dakota State Department of Health, 1961, Survey of the water quality of the city of Bottineau water supply: North Dakota State Department of Health, Sanitary Engineering Services, Bismarck, 6 p.

North Dakota State Department of Health, 1964, Chemical analyses of municipal waters in North Dakota: North Dakota State Department of Health, Environmental Health and Engineering Services, 25 p.

Randich, P.G., and Kuzniar, R.L., 1984, Ground-water resources of Bottineau and Rolette Counties, North Dakota: North Dakota Geological Survey Bulletin 78, part III, and North Dakota State Water Commission County Ground-Water Studies 35, part III, 41 p.

Shaver, R.B., 2001, Proposal and workplan for a water supply study for the city of Bottineau, phases I and II: North Dakota State Water Commission written communication, 10 p.

Simpson, C.A., 1939, Report on test wells constructed under docket ND 1221-F, Waterworks improvements, Bottineau, ND: C.A. Simpson and Sons Drilling, Inc., 3 p.

Simpson, C.A., 1980, Report of test drilling : C.A. Simpson and Sons Drilling Inc., 6 p.

Simpson, H.E., 1929, Geology and ground-water resources of North Dakota: U.S. Geological Survey Water Supply Paper 598, 312 p.

Wanek, A., 1993, Investigation to identify a water supply for a rural water association in Bottineau County, North Dakota: North Dakota State Water Commission Ground-Water Study 101, 68 p.

APPENDIX I

Lithologic Logs of Wells and Test Holes

162-075-07AAA
NDSWC 8-738

Date Completed:	05/21/1962	Purpose:	Test Hole
L.S. Elevation (ft):	2061		
Depth Drilled (ft):	94.5		
		Data Source:	NDSWC Geologists Log
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

162-075-07ACA
City of Bottineau

Date Completed:	10/14/1987	Purpose:	Municipal Well
L.S. Elevation (ft):	1927.80	Well Type:	8in. - Steel
Depth Drilled (ft):	81	Aquifer:	Bottineau
Screen Int. (ft.):	61-81	Data Source:	Drillers Log
Completion Info:			

Remarks: Bottineau municipal well #3 M.P. Elevation = 1930.50 Ft. AMSL

Lithologic Log

Depth (ft)	Unit	Description
0-1	TOPSOIL	
1-4	CLAY	gray
4-10	CLAY	yellow
10-13	SAND	
13-16	CLAY	yellow
16-46	CLAY	blue
46-81	GRAVEL	

162-075-07ABD2
City of Bottineau

Date Completed:	10/18/1983	Purpose:	Municipal Well
L.S. Elevation (ft):	1990.22	Well Type:	8in. - Steel
Depth Drilled (ft):	83	Aquifer:	Bottineau
Screen Int. (ft.):	60-80	Data Source:	Drillers Log

Completion Info:

Remarks: Bottineau Municipal well #6 M.P. Elevation = 1991.82 Ft. AMSL

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

162-075-07BDC2
City of Bottineau

Date Completed:	04/25/1968	Purpose:	Municipal Well
L.S. Elevation (ft):	1881	Well Type:	10in. - Steel
Depth Drilled (ft):	57	Aquifer:	Bottineau
Screen Int. (ft.):	54.3-63.3	Data Source:	Drillers Log

Completion Info:

Remarks: Bottineau Municipal well #1 M.P. Elevation = 1879.72 Ft. AMSL
MP is top of 1-inch diameter pvc pipe extending 1.28 feet above top of well seal inside manhole. Casing extended above original land surface. Land surface built up after construction. This accounts for the screened interval being greater than the total drilled depth.

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

162-075-07ADB1
City of Bottineau

Date Completed:	01/09/1958	Purpose:	Municipal Well
L.S. Elevation (ft):	1946	Well Type:	12in. - Steel
Depth Drilled (ft):	100	Aquifer:	Bottineau
Screen Int. (ft.):	68-80	Data Source:	Drillers Log

Completion Info:

Remarks: Bottineau Municipal well #2 M.P. Elevation = 1945.34 Ft. BMSL
MP is top of 1-inch diameter pvc pipe extending 2.26 feet above top of well seal inside manhole.

Lithologic Log

Depth (ft)	Unit	Description
0-0.5	TOPSOIL	
0.5-4	CLAY	gray
4-11	CLAY	yellow
11-68	CLAY	gray, rocks
68-73	SAND	and coarse gravel
73-100	SAND	very clayey, becoming finer

162-075-07ADC3
City of Bottineau

Date Completed:	1980	Purpose:	Municipal Well
L.S. Elevation (ft):	1927.25	Well Type:	8in. - Steel
Depth Drilled (ft):	85	Aquifer:	Bottineau
Screen Int. (ft.):	74-85	Data Source:	Drillers Log

Completion Info:

Remarks: Bottineau Municipal well #5 M.P. Elevation = 1928.05 Ft. AMSL

Lithologic Log

Depth (ft)	Unit	Description
0-2	TOPSOIL	
2-3	CLAY	gray
3-12	CLAY	yellow
12-24	CLAY	yellow, with stones
24-53	CLAY	blue, with stones
53-66	SAND	yellow, medium, with stones
66-72	CLAY	clay, blue, gravel layers
72-85	GRAVEL	medium to coarse

162-075-07BBB2
Other

Date Completed:	4/1996	Purpose:	Domestic Well
L.S. Elevation (ft):	1891.80	Well Type:	5in. - PVC
Depth Drilled (ft):	74	Aquifer:	Bottineau
Screen Int. (ft.):	54-74	Data Source:	Drillers Log

Completion Info:

Remarks: Open casing, drilled for retirement home that is not yet built. M.P. Elevation = 1893.40 Ft. AMSL

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

162-075-07DAB
Bottineau

Date Completed:	11/01/1980	Purpose:	Observation Well
L.S. Elevation (ft):	1912	Well Type:	1.25in. - PVC
Depth Drilled (ft):	100	Aquifer:	Bottineau
Screen Int. (ft.):	51-55	Data Source:	Drillers Log

Completion Info:

Remarks: Simpson 1980-1

Lithologic Log

Depth (ft)	Unit	Description
0-3	TOPSOIL	black
3-14	CLAY	yellow
14-50	CLAY	blue, with a few pebbles
50-62	SAND & GRAVEL	small and large pebbles and rocks, from 60-62 feet somewhat finer with clay chunks
62-64	SHALE	boulder
64-100	CLAY	blue with a few small gravel, some rocks

162-075-07DAC
Bottineau

Date Completed:	1980	Purpose:	Test Hole
L.S. Elevation (ft):	1883		
Depth Drilled (ft):	120		
		Data Source:	Drillers Log

Completion Info:

Remarks: Simpson 1980-2

Lithologic Log

Depth (ft)	Unit	Description
0-1	TOPSOIL	
1-10	CLAY	somewhat sandy
10-20	SAND & GRAVEL	pebbles, quite a few shale particles, with some clay
20-25	SAND	fine, gray
25-82	CLAY	gray, some gravel
82-86	SAND	very fine, gray
96-120	CLAY	or shale?, gray, no sand

162-075-07DBA
Bottineau

Date Completed:	01/01/1980	Purpose:	Test Hole
L.S. Elevation (ft):	1883		
Depth Drilled (ft):	100		
		Data Source:	Drillers Log

Completion Info:

Remarks: Simpson 1980-3

Lithologic Log

Depth (ft)	Unit	Description
0-1	TOPSOIL	
1-10	CLAY	yellow
10-39	CLAY	blue with a few stones
39-45	SAND & GRAVEL	some shale particles
45-48	CLAY	gray
48-49	SHALE	rock
49-60.5	CLAY	with a few small gravel, gray
60.5-61	CLAY	very gravelly
61-100	CLAY	or shale?, gray, petrified wood at 95 ft.

162-075-07DAA1
Bottineau

Date Completed:	11/1980	Purpose:	Test Hole
L.S. Elevation (ft):	1950		
Depth Drilled (ft):	140		
		Data Source:	Drillers Log

Completion Info:

Remarks: Simpson 1980-4

Lithologic Log

Depth (ft)	Unit	Description
0-1	TOPSOIL	sandy
1-12	CLAY	yellow, with fine to coarse sand
12-18	CLAY	blue with gravel and pebbbles
18-20	CLAY	blue, very gravelly
20-24	GRAVEL	somewhat clayey
24-26	CLAY	
26-30	GRAVEL	pebbles
30-33	CLAY	blue
33-38	CLAY	yellow, gravelly, rock
38-49	SAND & GRAVEL	fine to coarse, nice
49-61	CLAY	gray
61-78	SAND	fine to coarse, gravelly, some clayey, upper part fine
78-88	CLAY	gray, some pebbles, some shale particles
88-110	SAND & GRAVEL	some clay, not much fines
110-140	CLAY	

162-075-07DAA2
Bottineau

Date Completed:	11/01/1980	Purpose:	Test Hole
L.S. Elevation (ft):	1935		
Depth Drilled (ft):	100		
		Data Source:	Drillers Log

Completion Info:

Remarks: Simpson 1980-5A

Lithologic Log

Depth (ft)	Unit	Description
0-2	TOPSOIL	black
2-16	CLAY	gray
16-24	CLAY	yellow with a few pebbles
24-33	SAND & GRAVEL	rocks
33-56	CLAY	gray, pebbles
56-69	SAND & GRAVEL	50% shale, with clay chunks and layers, took water used drilling mud
69-72	CLAY	yellow
72-77	SAND & GRAVEL	
77-82	CLAY	
82-86	SAND & GRAVEL	
86-94	CLAY	losing fluid, no sample recovery
94-96	ROCK	soft
96-100	CLAY	

162-075-07ADC1
City of Bottineau

Date Completed:	1980	Purpose:	Observation Well - Destroyed
L.S. Elevation (ft):	1923	Well Type:	1.25in. - PVC
Depth Drilled (ft):	85	Aquifer:	Bottineau
Screen Int. (ft.):	74-79	Data Source:	Drillers Log

Completion Info:

Remarks: Simpson 1980-6

Lithologic Log

Depth (ft)	Unit	Description
0-1	TOPSOIL	black
1-2	CLAY	gray
2-14	CLAY	yellow
14-52	CLAY	with a few gravel and rocks
52-63	SAND	fine to medium, yellow, some rocks
63-67	SAND & GRAVEL	some coarse
67-68	CLAY	
68-80	SAND & GRAVEL	coarse with pebbles
80-85	CLAY	gray

162-075-07ADC2
City of Bottineau

Date Completed:	1980	Purpose:	Test Hole
L.S. Elevation (ft):	1927		
Depth Drilled (ft):	85.5		
		Data Source:	Drillers Log

Completion Info:

Remarks: Simpson 1980-12 Site of Municipal Well #5 162-075-07ADC3

Lithologic Log

Depth (ft)	Unit	Description
0-2	TOPSOIL	
2-3	CLAY	gray
3-12	CLAY	yellow
12-24	CLAY	yellow, stones
24-53	CLAY	blue, stones
53-66	SAND	yellow, medium, some stones
66-72	CLAY	blue, gravel layers
72-85	GRAVEL	medium to coarse
85-85.5	CLAY	blue

162-075-07ADD3
City of Bottineau

Date Completed:	01/01/1980	Purpose:	Observation Well - Destroyed
L.S. Elevation (ft):	1975	Well Type:	1.25in. - PVC
Depth Drilled (ft):	80	Aquifer:	Bottineau
Screen Int. (ft.):	60-65	Data Source:	Drillers Log

Completion Info:

Remarks: Simpson 1980-7

Lithologic Log

Depth (ft)	Unit	Description
0-1	TOPSOIL	
1-8	CLAY	yellow, sandy
8-21	CLAY	blue, a few gravel particles
21-22	ROCK	
22-23	CLAY	blue
23-30	SAND & GRAVEL	pebbles, mostly shale
30-50	CLAY	blue
50-66	SAND	fine to coarse to small gravel, mostly shale
66-68	CLAY	
68-71	SAND & GRAVEL	
71-80	CLAY	yellow

162-075-07DBB1
Bottineau

Date Completed:	1980	Purpose:	Test Hole
L.S. Elevation (ft):	1877		
Depth Drilled (ft):	100		
		Data Source:	Drillers Log

Completion Info:

Remarks: Simpson 1980-8

Lithologic Log

Depth (ft)	Unit	Description
0-1	TOPSOIL	black
1-3	CLAY	gray, a little sandy
3-7	CLAY	yellow
7-10	GRAVEL	
10-22	CLAY	blue, gray
22-30	SAND	fine, clayey
30-41	CLAY	blue
41-70	SAND	fine, clayey, with shale particles
70-91	CLAY	blue, soft
91-100	CLAY	blue

162-075-07DBB2

Date Completed:	1980	Purpose:	Observation Well - Destroyed
L.S. Elevation (ft):	1888	Well Type:	1.25in. - PVC
Depth Drilled (ft):	61	Aquifer:	Bottineau
Screen Int. (ft.):	52.5-55.5	Data Source:	Drillers Log

Completion Info:

Remarks: Simpson 1980-9A

Lithologic Log

Depth (ft)	Unit	Description
0-1	TOPSOIL	
1-3	CLAY	gray
3-5	CLAY	yellow
5-16	GRAVEL	
16-39	CLAY	blue
39-40	ROCK	
40-49	CLAY	blue
49-58	GRAVEL	shale rock layers
58-61	CLAY	blue

162-075-07ACC
Bottineau

Date Completed:	11/01/1980	Purpose:	Test Hole
L.S. Elevation (ft):	1897		
Depth Drilled (ft):	101		
		Data Source:	Drillers Log

Completion Info:

Remarks: Simpson 1980-10

Lithologic Log

Depth (ft)	Unit	Description
0-1	TOPSOIL	
1-3	CLAY	gray
3-24	GRAVEL	
24-44	CLAY	blue
44-45	GRAVEL	
45-67	CLAY	blue, some rocks
67-68	GRAVEL	rocks
68-101	CLAY	blue

162-075-07DDC
City of Bottineau

Date Completed:	1980	Purpose:	Test Hole
L.S. Elevation (ft):	1852		
Depth Drilled (ft):	101	Data Source:	Drillers Log

Completion Info:

Remarks: Simpson 1980-11

Lithologic Log

Depth (ft)	Unit	Description
0-1	TOPSOIL	
1-18	CLAY	yellow
18-26	CLAY	blue
26-27	ROCK	white
27-30	SAND	green, fine, some small clay layers
30-51	CLAY	blue
51-69	SAND	fine, blue, with small clay layers
69-71	SANDSTONE	
71-101	SHALE	blue

162-075-07ADB6
City of Bottineau

Date Completed:	1980	Purpose:	Observation Well - Destroyed
L.S. Elevation (ft):	1950	Well Type:	1.25in. - PVC
Depth Drilled (ft):	41	Aquifer:	Bottineau
Screen Int. (ft.):	24.5-26.5	Data Source:	Drillers Log

Completion Info:

Remarks: Simpson 1980-13

Lithologic Log

Depth (ft)	Unit	Description
0-1	TOPSOIL	black
1-8	GRAVEL	mostly shale
8-14	CLAY	yellow
14-17	CLAY	blue
17-30	GRAVEL	
30-41	CLAY	blue

162-075-07DDA
Bottineau

Date Completed:	1980	Purpose:	Test Hole
L.S. Elevation (ft):	1878		
Depth Drilled (ft):	81		
		Data Source:	Drillers Log

Completion Info:

Remarks: Simpson 1980-14

Lithologic Log

Depth (ft)	Unit	Description
0-0.5	TOPSOIL	black
0.5-21	CLAY	yellow
21-23	CLAY	blue
23-27	SAND	blue, fine
27-68	CLAY	blue
68-75	SHALE	blue, hard
75-81	SHALE	blue, sandy

162-075-07ABD1
City of Bottineau

Date Completed:	5/1956	Purpose:	Municipal Well
L.S. Elevation (ft):	N/A	Well Type:	10in. - Steel
Depth Drilled (ft):	80	Aquifer:	Bottineau
Screen Int. (ft.):	68-76	Data Source:	Drillers Log

Completion Info:

Remarks: City of Bottineau Municipal Well #4 M.P. Elevation = 1989.50 Ft. AMSL MP is top of 1-inch diameter pvc pipe extending 1.90 feet above well seal inside manhole.

Lithologic Log

Depth (ft)	Unit	Description
0-10	PEAT	soft
10-16	CLAY	sandy, light gray
16-30	CLAY	yellow, slightly sandy
30-36	GRAVEL	muddy, rocks
36-58	CLAY	sandy, gray, rocks
58-64	HARDPAN	
64-67	SAND & GRAVEL	coarse, little water
67-68	CLAY	gravelly
68-76	SAND & GRAVEL	flowing water
76-80	CLAY	gravelly

162-075-07ADB5
City of Bottineau

Date Completed:	1983	Purpose:	Observation Well
L.S. Elevation (ft):	2013.66	Well Type:	1.25in. - PVC
Depth Drilled (ft):	?	Aquifer:	Bottineau
Screen Int. (ft.):	?	Data Source:	

Completion Info:

Remarks: Probably Simpson Test Hole Site 1983-3 for which no log is available. Measured well depth is 99 feet. M.P. Elevation = 2014.94 Ft. AMSL

Lithologic Log

Depth (ft)	Unit	Description

NO LOG AVAILABLE

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:	NDSWC Geologists Log

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

162-075-07CBB1
NDSWC 33-738

Date Completed:	06/27/1962	Purpose:	Test Hole
L.S. Elevation (ft):	1825		
Depth Drilled (ft):	42		
		Data Source:	NDSWC Geologists Log

Completion Info:

Remarks:

Lithologic Log

Depth (ft)	Unit	Description
0-5	SAND	medium to coarse, with fine to coarse gravel, pebbles, cobbles, and boulders
5-10	SAND	fine, silty, moderate olive brown, subangular to subrounded, oxidized, noncalcareous
10-24	SAND	fine, silty, dark greenish-gray, noncalcareous
24-31	SILT	dark greenish-gray, compact
31-42	SAND	fine, silty, dark greenish-gray, more indurated with depth

162-075-07ABD4
City of Bottineau

Date Completed:	1930	Purpose:	Municipal Well
L.S. Elevation (ft):	1990.84	Well Type:	4in. - Steel
Depth Drilled (ft):	51	Aquifer:	Bottineau
Screen Int. (ft.):	?	Data Source:	No log available

Completion Info:

Remarks: Walker East Well - flows

Lithologic Log

Depth (ft)	Unit	Description

NO LOG AVAILABLE

162-075-07ADB2
City of Bottineau

Date Completed:	1936	Purpose:	Municipal Well
L.S. Elevation (ft):	1972.60	Well Type:	4in. - Steel
Depth Drilled (ft):	41	Aquifer:	Bottineau
Screen Int. (ft.):	?	Data Source:	No log available

Completion Info:

Remarks: Bittner East Well — flows M.P. Elevation = 1975.30 Ft. AMSL

Lithologic Log

Depth (ft)	Unit	Description

NO LOG AVAILABLE

162-075-07ADB3
City of Bottineau

Date Completed:	1936	Purpose:	Municipal Well
L.S. Elevation (ft):	1972.34	Well Type:	4in. - Steel
Depth Drilled (ft):	41	Aquifer:	Bottineau
Screen Int. (ft.):	?	Data Source:	No log available

Completion Info:

Remarks: Bittner West Well — flows M.P. Elevation = 1975.72 Ft. AMSL

Lithologic Log

Depth (ft)	Unit	Description

NO LOG AVAILABLE

162-075-07ADB4
City of Bottineau

Date Completed:	1936	Purpose:	Municipal Well
L.S. Elevation (ft):	1972.22	Well Type:	4in. - Steel
Depth Drilled (ft):	41	Aquifer:	Bottineau
Screen Int. (ft.):	?	Data Source:	No log available

Completion Info:

Remarks: Bittner South Well — flows M.P. Elevation = 1974.10 Ft. AMSL

Lithologic Log

Depth (ft)	Unit	Description

NO LOG AVAILABLE

162-075-07ADD1
City of Bottineau

Date Completed:	1939	Purpose:	Municipal Well
L.S. Elevation (ft):	1986	Well Type:	10in. - Steel
Depth Drilled (ft):	50	Aquifer:	Bottineau
Screen Int. (ft.):	?	Data Source:	No log available

Completion Info:

Remarks: Noble Well M.P. Elevation = 1985.35 Ft. AMSL
MP is 1-inch diameter pvc pipe extending 0.97 feet above the well seal inside manhole. Well has 8-inch diameter steel liner.

Lithologic Log

Depth (ft)	Unit	Description

NO LOG AVAILABLE

162-075-07ADD2
City of Bottineau

Date Completed:	1939	Purpose:	Observation Well
L.S. Elevation (ft):	1985(estimated)	Well Type:	10in. - Steel
Depth Drilled (ft):	54.5	Aquifer:	Bottineau
Screen Int. (ft.):	48-54.5	Data Source:	Drillers Log

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 considered 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

162-075-07ABD3
City of Bottineau

Date Completed:	1930	Purpose:	Municipal Well
L.S. Elevation (ft):	1991.31	Well Type:	4in. - Steel
Depth Drilled (ft):	51	Aquifer:	Bottineau
Screen Int. (ft.):	?	Data Source:	No log avaiable

Completion Info:

Remarks: Walker West Well

Lithologic Log

Depth (ft)	Unit	Description

NO LOG AVAILABLE

162-075-18BB
NDSWC 16-738

Date Completed:	06/11/1962	Purpose:	Test Hole
L.S. Elevation (ft):	1780		
Depth Drilled (ft):	52.5		
		Data Source:	NDSWC Geologists Log

Completion Info:

Remarks:

Lithologic Log

Depth (ft)	Unit	Description
0-1	TOPSOIL	sandy, black
1-6	SAND	medium, dark yellowish brown, subangular to rounded, well sorted
6-9	GRAVEL	very coarse, no samples
9-17	SAND	fine to medium, with some silt and fine gravel, light olive gray, well rounded
17-22	SAND	fine to coarse, silty to gravelly
22-43	SAND	fine, dark greenish gray, well rounded, well sorted, noncalcareous
43-52.5	SHALE	olive black, thinly laminated, platy, noncalcareous

162-075-07CBB2
Gary Hasenwinkel

Date Completed:	1994	Purpose:	Domestic Well
L.S. Elevation (ft):	N/A	Well Type:	5in. -
Depth Drilled (ft):	85	Aquifer:	Bottineau
Screen Int. (ft.):	65-85	Data Source:	Drillers Log

Completion Info:

Remarks: No pump installed. Well not currently used.

Lithologic Log

Depth (ft)	Unit	Description
0-40	GRAVEL	
40-60	CLAY	gray, yellow
60-81	SAND	very fine
81-85	CLAY	gray

162-075-07DDD
NDSWC 7-738

Date Completed:	05/21/1962	Purpose:	Test Hole
L.S. Elevation (ft):	1854		
Depth Drilled (ft):	63		
		Data Source:	

Completion Info:

Remarks:

Lithologic Log

Depth (ft)	Unit	Description
0-2	TOPSOIL	black
2-7	GRAVEL	fine to coarse, sandy, subrounded
7-13	CLAY	silty to gravelly, dark yellowish orange, cohesive, oxidized, calcareous, till
13-38	CLAY	silty to gravelly, dark greenish gray, cohesive, till
38-40	GRAVEL	fine to medium, sandy, subrounded to rounded
40-41	CLAY	silty to gravelly, dark greenish gray, cohesive, till
41-50	SAND	very fine to medium, very silty, angular to subrounded
50-63	SILT	clayey to sandy, olive gray, noncalcareous