AN ANALYSIS AND CONCEPTUAL HYDROGEOLOGIC MODEL OF A TILL AQUITARD OVERLYING THE SPIRITWOOD AQUIFER IN SOUTHEASTERN NORTH DAKOTA

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Water Resource Investigation No. 17
North Dakota State Water Commission

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INTRODUCTION AND PURPOSE

The objectives of first generation hydrogeologic exploration studies commonly focus on defining the occurrence, movement, and quality of water in geologic materials that are more permeable (aquifers). In addition, hydraulic properties of these aquifers are measured and evaluated. The above objectives, to a great extent, were achieved by the county ground-water studies program conducted in North Dakota from 1955 to 1985.

Some of the most productive aquifers delineated in the county ground-water studies were buried-valley type aquifers of glaciofluvial origin. Since the mid-1970s, ground-water irrigation development in these aquifers has increased significantly (Paulson, 1983). Buried-valley aquifers are becoming an important source of ground water for large-scale industrial applications (Pusc, 1986).

Buried-valley aquifers consist mainly of sand and gravel deposits overlain by glacial drift comprised predominantly of till. Till thickness ranges from about 3 m (10 ft.) to about 122 m (400 ft.). Fluvial sand and gravel deposits and lacustrine sand, silt, and clay deposits are scattered throughout the till. In the eastern part of North Dakota, Cretaceous shales commonly underlie buried-valley aquifers. Cretaceous sandstones and siltstones underlie these aquifers in the central part of the state, and Tertiary mudstones, siltstones, and sandstones underlie these aquifers in the western part of the state.

The ground-water transmitting capacity of buried-valley aquifers is much greater than the transmitting capacity associated with the overlying till and underlying bedrock formations. As a result, the till and bedrock formations are classified as aquitards. These aquitards control recharge, discharge, response to pumping, water chemistry, and rates of contaminant movement to buried-valley aquifers (Keller, and others 1989).

In many hydrogeological settings, the volume of ground-water storage in the overlying till aquitard is large in relation to the volume of ground-water storage in the underlying buried-valley aquifer. For example, the Spiritwood aquifer in LaMoure and Dickey Counties, between Grand Rapids and Oakes occupies an area of about 259 km^2 (100 mi^2). Assuming an average till thickness of 46 m (150 ft.) overlying the aquifer and a porosity of 0.30, there is 3.6×10^5 ha-m (2.9×10^6 ac-ft.) of ground water stored in the till. Based on an average aquifer thickness of 10 m (33 ft.) (Shaver, 1984) and an effective porosity of 0.25, there is about 6.5×10^4 ha-m (5.3×10^5 ac-ft.) of water in storage in the Spiritwood aquifer in this area. Thus, aquitard storage represents a potentially large source of water available to the aquifer through leakage.

The volume of water derived from storage in the aquitard over a given time period depends to a large extent on the hydraulic conductivity (K') and specific storage (S_s') of the aquitard. Currently data describing aquitard hydraulic properties in North Dakota are very limited. Efforts have been made by some investigators to measure till hydraulic conductivity using data derived from single-well response (slug) tests. (Sloan, 1972; Groenwald and others, 1979; Beal, 1986; Patch and Knell, 1988; and Murphy, 1992). Investigations in North Dakota that determined specific storage of till do not exist.

Based on the above, future investigations of buried-valley aquifers must include more detailed aquitard analysis. Till commonly is fractured

(Grisak and others, 1976) and, therefore, represents a dual porosity/permeability media. Efforts must be made to evaluate, at greater depths, the effects of fractures on bulk till hydraulic properties. In addition, test drilling indicates the ocurrence of numerous fluvial and lacustrine silt, sand, and gravel deposits scattered through the till. These deposits may act as rapid transmission conduits for recharge to underlying buried-valley aquifers. Therefore, the spatial distribution and interconnectedness of these deposits are important hydraulic considerations.

The purpose of this paper is to develop a conceptual model of a buried-valley aquifer/aquitard system based on conclusions drawn from previous investigations described in the literature and investigations conducted by the State Water Commission in southeastern North Dakota. Based on the evaluation of previous work, recommendations are made describing an approach to investigate till hydrogeology as related to buried-valley aquifer management in North Dakota.

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 quarter-quarter-quarter section (10-acre tract). For example, well

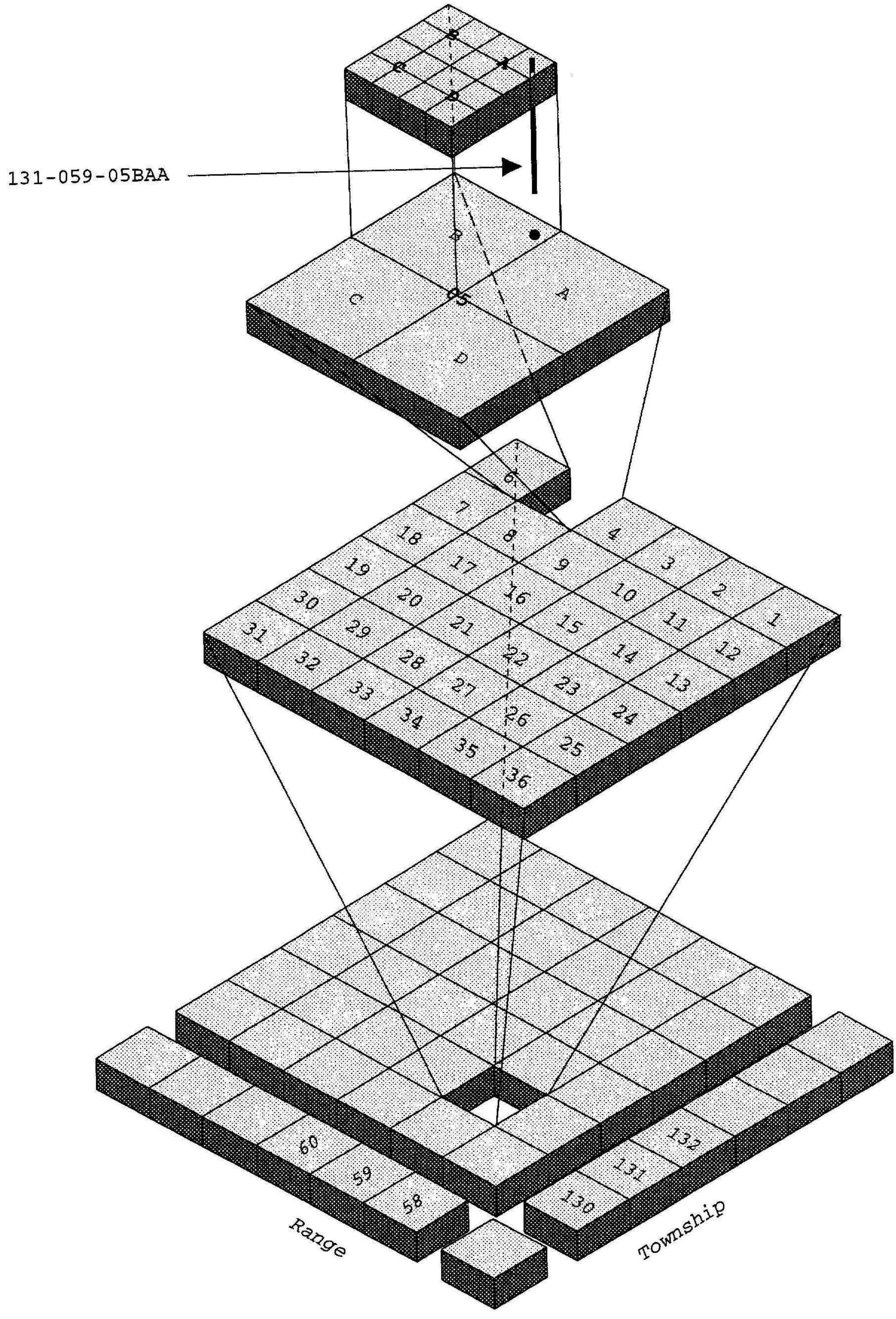


Figure 1. --Location-numbering system

131-059-05BAA is located in the NE1/4 NE1/4 NW1/4 Section 5, Township 131 North, Range 59 West. Consecutive terminal numerals are added if more than one well or test hole is located within a 10-acre tract.

HYDROGEOLOGY OF TILL

Geology of Till

Till can be defined as a compact, unstratified, poorly sorted, mineralogically heterogenious sediment of glacial origin (Dreimanis, 1976). Bluemle (1979) provides the following description of till found at or near the surface in Dickey and LaMoure County, southeastern North Dakota.

> "Till is most commonly a mixture of varying proportions of sand, silt, clay, pebbles, cobbles, and boulder-sized particles. The matrix, composed mostly of silt and clay-sized particles, is usually yellowish-brown to brownish-gray in oxidized exposures and light-olive gray where it is unoxidized. The coarser-grained materials are generally angular to subrounded and consist of carbonate, igneous, metamorphic, and shale rock fragments with small amounts of lignite. The till is mostly poorly indurated and it may be weakly jointed, but it has no other structure, such as bedding or sorting."

Based on 30 till samples in LaMoure County, Bluemle (1979) reports a mean sand, silt, and clay ratio of 35:36:29. Based on 27 surface and near surface till samples in Sargent County, Bluemle (1979) reports a mean sand, silt, and clay ratio of 32:40:28. These characteristics probably are typical for much of the till throughout North Dakota. Bulk textural and mineralogical characteristics of tills do not differ greatly from North Dakota to southern Alberta (Grisak and others, 1976).

Fractures

Fractures have been observed in till at numerous locations across the Interior Plains Region of North Dakota (Grisak and others, 1976). From 1963 to 1964, 158 excavations up to 21 m (69 ft.) deep were dug for ICBM missile installations in North Dakota. The following observations were made with regard to till fractures at these excavations: (Grisak and others, 1976)

1) Fractures in till were observed in 70 percent of the excavations.

2) Both vertical and horizontal fractures exist with vertical fractures more obvious.

3) Vertical fracture systems generally ended at till-Cretaceous shale contact. At two sites, the till and shale shared a single fracture system.

4) Some fracture planes occurred in exceptionally hard till and cut through cobbles.

5) At some sites, fractures passed through till, then silt layers, then till again.

6) Iron and manganese oxides were the most common secondary minerals on fracture surfaces.

7) Gypsum was present as selenite crystals on fracture surfaces in the upper few meters of till.

Hendry (1982) observed fractures in the surficial weathered till and found no evidence of fractures in the non-weathered till at Lethbridge, Alberta. Both small-scale and large-scale fracture patterns were identified in the weathered till. The spacing of small-scale fractures was 10 mm (0.4 in.) and the spacing of large-scale fractures ranged from 20 to 630 mm (0.8 to 24.8 in.). Fractures were oriented vertical to subvertical. Fracture surfaces were stained yellow-brown throughout and contained gypsum.

Prudic (1982) observed fractures in tills in New York. Some fractures were reported to extend into underlying unoxidized till to depths of 4.5 m (14.8 ft.) below land surface.

Grisak and Cherry (1975), in an investigation in southeastern Manitoba observed fractures in Shelby tube core samples extending to depths of up to 6.1 m (20.0 ft.). Fractures occurred in both weathered and non-weathered till zones. In a 4.6 m (15.1 ft.) deep pit, fracture spacing was measured at 4 cm (1.6 in.). Fractures were coated with calcium carbonate and iron oxide.

Bradbury and others (1985) reported joints that extend to at least 5.4 m (17.7 ft.) below land surface at the Ashland site in northwestern Wisconsin.

D' Astous and others (1989) observed fractures to depths of 7.7 m (25.3 ft.) in a clay till near Sarnia, Ontario. The top 4 to 6 m (13.1 to 19.7 ft.) of till was weathered and contained root channels. Test pits were excavated to map fractures. Water drained into the pits at significant rates indicative of fracture flow.

In a fine-grained till in southeastern Wisconsin, Simpkins and Bradbury (1992) reported maximum "effective" fracture depth to about 10 m (32.8 ft.). Effective fracture depth refers to the ability of the fracture to increase bulk hydraulic conductivity.

Based on field derived hydraulic conductivities, Van der Kamp and Maathius (1986) concluded that fractures did not contribute to the bulk hydraulic conductivity of the till aquitard below depths of about 10 to

20 m (32.8 to 65.6 ft.). It was hypothesized that fractures tend to be effectively closed at greater depths due to higher effective stress.

Day (1977) investigated the hydrogeology of clay and till deposits in the Winnipeg area of Manitoba. He reported predominantly vertical fractures in the surficial lacustrine clays and underlying till. The fractures commonly were lined with gypsum. A maximum fracture depth was not reported. The average calculated fracture spacing in the clay and till deposits was probably between 5 and 15 cm (2 and 5.9 in.). Calculated representative fracture widths ranged from 1.3×10^{-4} to 5.5×10^{-4} cm (5.1×10^{-5} to 2.2×10^{-4} in.) in the clay and from 5.0×10^{-4} to 1.4×10^{-3} cm (2.0×10^{-4} to 5.5×10^{-4} in.) in the till.

Cravens and Ruedisili (1987) excavated seven test pits to a depth of 3.1 m (10 ft.) in till in east-central South Dakota. The oxidized (weathered) till contained numerous vertical root channels and macropores. There was no evidence of widespread systematic fracturing.

Ruland and others (1991) evaluated fracture depths in a clayey till plain in southeastern Ontario. Test pits were dug to a depth of 6 m (19.7 ft.). Fractures were observed beyond 5.6 m (18.4 ft.) at two sites. Fracture spacing increased from one fracture every centimeter near land surface to one fracture every 50 cm (19.7 in.) to 2 m (6.6 ft.) at a 4.5 m (14.8 ft.) depth. Near the land surface, fractures were interconnected. Fracture orientation was vertical to near vertical. Long fractures up to 5 m (16.4 ft.) in length were infrequent.

In a prairie pot-hole investigation in Stutsman County, North Dakota, Sloan (1972) reported the till was jointed. In addition, he quotes a comment from Meyboom and others (1966, p. 38) that "drilling fluid was lost at 16.8 m (55 ft.) and 13.4 m (44 ft.) and shortly after, drilling fluid emanated from surface fractures 6.1 m (20 ft.) from the drill hole."

Keller (1985) evaluated the hydrogeology of the glacial till confining the Dalmeny aquifer near Martensville, Saskatchewan. At the test site, the Floral Formation (till) occured from 1 to 2 m (3.3 to 6.6 ft.) below land surface and is 18.5 m (60.7 ft.) thick. The top 10 to 12 m (32.8 to 39.4 ft.) was oxidized. The Floral Formation contained vertical and horizontal fractures spaced about one cm (0.4 in.) apart. Gypsum crystals were commonly observed in fracture surfaces. Visual inspection of Shelby tube samples showed no fractures in the bottom 6 to 8 m (19.7 to 26.2 ft.) of the unoxidized till. Hydraulic conductivity values determined from lab tests generally were one to three orders of magnitude smaller than those determined from field (slug) tests. Based on this and other hydraulic data obtained from oedometer and pump tests, Keller (1985) concluded that the unoxidized till must be fractured.

In contrast to the Dalmeny site, Keller and others (1988) found that hydraulic conductivity values determined from lab tests were the same as those determined from field tests at the Warmen site in Saskatchewan. This coupled with stable isotope data suggested that recharge at the Warmen site occured only in the shallow, oxidized zone and that discharge primarily was upward from evapotranspiration, freezing, or other causes. The Warmen site appears to be similar to that previously described by Cravens and Ruedisili (1987).

Origin of Fractures

Vertical fractures may be accounted for by several mechanisms including (Grisak and others, 1976; Day, 1977; Harding, 1986):

1) regional extension of the earth's crust due to crustal rebound following glacial loading,

2) conjugate shearing in response to over-riding ice movement,

3) tension fracturing as a result of a primarily vertical stress release following removal of the load imposed by the glacial ice,

4) propagation of fractures within till from joint patterns in the underlying bedrock under the influence of earth tides, and

5) volume changes due to geochemical processes such as ion exchange and volume changes due to desiccation.

Grisak and Cherry (1975) state that the lack of horizontal fractures in relation to vertical fractures suggests crustal rebound rather than glacial unloading.

Till Fracture Conclusions

Based on existing investigations, the following generalizations are considered valid regarding till in North Dakota:

1) fractures are ubiquitous in the yellow brown, weathered zones of till,

2) fractures also occur in the non-weathered till but are less frequent, more widely spaced and probably effect bulk hydraulic conductivity to depths of no more than about 18.3 m (60 ft.),

3) fracture orientation predominantly is vertical to near vertical, and

4) iron oxides and gypsum commonly occur on fracture surfaces.

Hydraulic Properties

Hydraulic Conductivity

As previously stated, aquitard storage represents a potentially large source of water available to buried-valley aquifers through leakage. The volume of water derived from storage in the aquitard over a given time period depends, in part, on aquitard hydraulic conductivity. Since the till aquitard is a duel porosity/permeability media, particularly in the shallow zone, efforts have been made to measure both primary (intergranular) and bulk (fracture) hydraulic conductivity.

Methods used by previous investigators to measure intergranular and bulk hydraulic conductivity include the following: (Grisak and others, 1976)

1) permeameter tests in the lab,
2) tracer tests using artificially injected tracers with subsequent travel time monitoring,
3) tracer studies using naturally occurring (oxygen-18, deuterium) or bomb produced isotopes (tritium, carbon-14),
4) single-well, water-level response tests (slug tests),
5) aquifer pumping tests with drawdown measurements only in the aquifer,
6) aquifer pumping tests with drawdown measurements in the aquifer and in the till confining beds,
7) analysis of downward propagation of seasonal water-table fluctuations,
8) calculations using fracture geometry observation with equations developed by Snow (1969), and,
9) calibration of 1-, 2-, and 3-dimensional ground-water flow simulation models.

Laboratory permeameter tests may not provide reliable bulk hydraulic conductivity values because it is difficult to obtain undisturbed representative samples. In a fractured setting the sample length (core) may be small in relation to fracture spacing. Therefore, calculated hydraulic conductivity may only reflect intergranular values and not bulk values. In addition, the ionic composition of water used in lab permeameter tests may differ significantly from in-situ sample ionic composition. A change in water chemistry from field to lab can effect volume changes (shrink swell) in clays thereby altering hydraulic conductivity. Finally, longer-term lab permeameter tests can be affected by bacterial clogging which reduces hydraulic conductivity (Ripley and Saleem, 1973).

The use of natural isotopes and artificial tracers also pose problems on the reliability of calculated hydraulic conductivity values. To compute hydraulic conductivity using tracer data requires a knowledge of effective porosity. In most fractured settings, effective porosity (intergranular and bulk) is poorly defined. In addition, diffusion is an important flow component in materials characterized by small hydraulic conductivities. In fractured tills, tracer penetration depths are retarded by diffusion from fractures into intergranular pores (Day, 1977). The result can be to underestimate hydraulic conductivity.

In many aquitard investigations, hydraulic conductivity is calculated using water-level data measured during single-well response (slug) tests. Analytical methods include Hvorslav (1951), Ferris and others (1962), Cooper and others (1967), Bouwer and Rice (1976) and Nguyen and Pinder (1984). Single-well response tests generally are small time and length scale tests that are economical to perform. The reliability of hydraulic conductivity values calculated from single-well response tests in fractured clayey media is questionable. D' Astous and others (1989) report smearing along borehole wells that significantly reduces hydraulic conductivity. Also, piezometer intake intervals may not intercept any fractures, thus precluding evaluation of bulk hydraulic conductivity. Herzog and Morse (1986) found that the average values of hydraulic conductivity calculated from single-well response tests in angled drill holes/piezometers were greater than for vertical holes. Fractures were mostly vertical to near vertical and angled piezometers provided a better evaluation of bulk hydraulic conductivity.

Keller and others (1989) question the validity of extrapolating the results of short-term, high-gradient, single-well response tests to long-term, low-gradient conditions. At their Warmen test site in Saskatchewan, which is characterized by a thick, unfractured, clayey till, it was concluded that single-well response tests provided reasonable estimates of bulk hydraulic conductivity. However, the authors further state that hydraulic conductivities calculated from single-well response tests should be checked using bulk-scale methods, and slug tests should be carried out on piezometers with intake intervals of various lengths and in boreholes completed by various techniques.

Pump tests provide methods for calculating aquitard hydraulic conductivity on larger length and time scales. There are two basic test types, 1) those with drawdown measurements in the aquifer (Hantush, 1956; 1960), and 2) those with drawdown measurements in both the aquifer and aquitard (Neuman and Witherspoon, 1969). Unlike single-well response tests, pump tests are much more expensive because they require the construction of a production well and generally two or more observation wells. In addition, buried-valley aquifers in North Dakota are strip-like aquifers (parallel barrier boundaries), commonly less than a few miles wide. As a result, assumptions in the above analytical methods commonly are violated. The Noordbergun effect (Rodrigues, 1983) distorts early time-drawdown data and barrier boundary effects distort intermediate and late-time data rendering analytical approaches invalid.

The step-head test (Bredehoeft and Hanshaw, 1968) as described using a field example (Wolf, 1970) is a type of pump test that can be applied in aquifer/aquitard settings with more complex boundary conditions. The pumping rate can be reduced as pumping proceeds to maintain a constant head over the duration of the test. An example of this analytical approach using water-level response data from the Spiritwood aquifer is presented later in this paper.

Some investigators have developed 1-, 2-, or 3-dimensional ground-water simulation models to evaluate hydraulic conductivity in till aquitards (Prudic, 1982; Grisak and Cherry, 1975). More complex boundary conditions can be considered using these models as compared to analytical techniques. In addition, models can be more effective tools for evaluating larger length and time scales in complex hydrogeologic systems. Solution non-uniqueness, however, is an important consideration with regard to computer models. Drawdown response in an aquitard resulting from pumping an adjacent aquifer is, in part, a function of hydraulic diffusivity of the aquitard. Hydraulic diffusivity is the ratio of vertical hydraulic conductivity (K_V') and specific storage (S_S') of the aquitard. Drawdown in the aquitard is directly proportional to hydraulic conductivity and inversely proportional to specific storage. Various combinations of K_V' and S_S' yield identical hydraulic diffusivities.

If at least one of these parameters is not known a priori, the most one can hope for is an evaluation of hydraulic diffusivity.

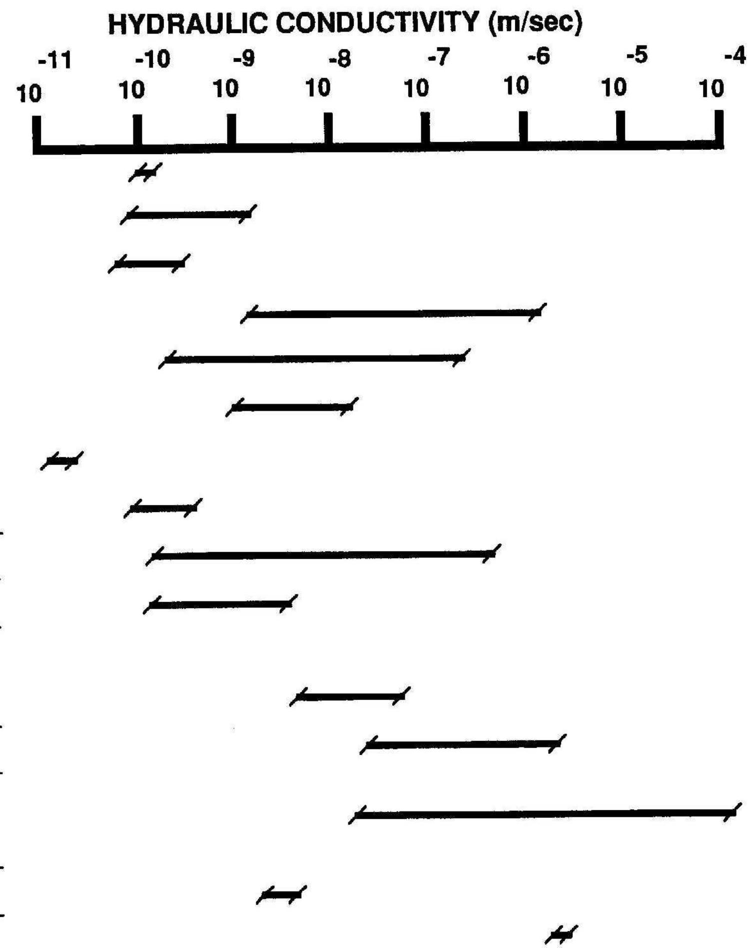
The approach by Snow (1969) was used by Grisak and others (1976) to evaluate fracture flow in till. This analytical method requires data on average fracture spacing, half-aperture width, and total number of fractures in a measured area. Collecting this data at large depths in thick tills is not practical.

Table 1 summarizes hydraulic conductivity values calculated by previous investigators in non-weathered till and table 2 summarizes hydraulic conductivity values calculated by previous investigators in weathered till. The single-well response test was the most common field method used to evaluate till hydraulic conductivity. For the most part, field derived values (single-well response tests) of hydraulic conductivity were between 1 to 3 orders of magnitude larger than those derived by lab methods when investigators applied both lab and field techniques. Larger field hydraulic conductivity values were attributed to fracture flow.

The problem of determining hydraulic conductivity of clayey tills can be viewed in terms of length and time scales (Neuzil, 1986). At typical laboratory sample length-scales of 0.01 to 0.10 m (0.003 to 0.03 ft.), hydraulic conductivity tests can be carried out with time scales of 0.1 to 10.0 days, (Van der Kamp and Maathius, 1986). Field tests (slug tests, aquifer tests) commonly are carried out on a time scale of 1 to 100 days. In tight (effectively unfractured) tills induced transient head changes penetrate about 0.1 to 10 m (0.03 to 32.8 ft.) into the till. These tests generally do not provide bulk hydraulic conductivity values for thicker, tighter tills. To answer long-term, water-resource management

TABLE 1. -- Hydraulic conductivity of nonweathered till

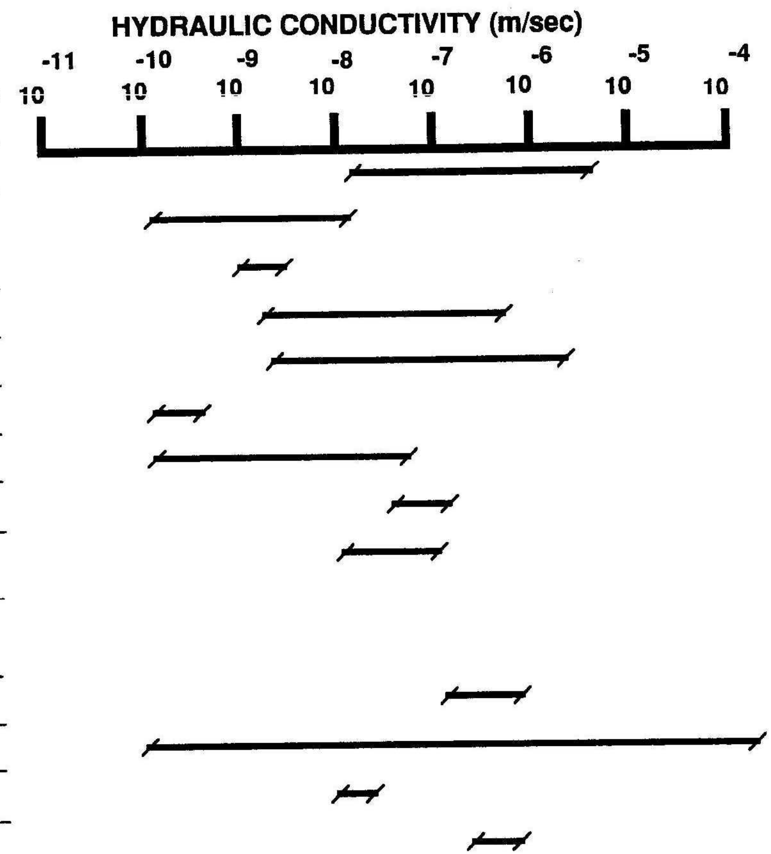
REFERENCE	COMMENTS
SITES OUTSIDE OF NORTH DAKOTA	
PRUDIC (1982) (NEW YORK)	N = 12; DEPTH RANGES FROM 4.0 TO 16.2 m; MEAN TEXTURE: 50% CLAY 27% SILT 10% SAND 13% GRAVEL; MEAN k = 2 E-10 m/sec
BRADBURY and OTHERS (1985) (WISCONSIN)	N = 12; SUPERIOR SITE; 77% CLAY 16% SILT 7% SAND; GEOMETRIC MEAN k = 2.1 E-10m/sec
	N = 5; ASHLAND SITE: 44% CLAY 41% SILT 15% SAND; GEOMETRIC MEAN k = 1.4 E-10m/sec
MULDOON (1987) (WISCONSIN)	N = 20; MARATHON FORMATION: 32-39% CLAY 43-47% SILT 18-20% SAND; GEOMETRIC MEAN k = 5.8 E-08 m/sec
CRAVENS and RUEDISILI (1987) (SOUTH DAKOTA)	N = 35; 28% CLAY 51 % SILT 22% SAND; DEPTH RANGES FROM 4.6 m-16.8 m; MEDIAN k = 4.3 E-09 m/sec
KELLER (1985) (SASKATCHEWAN)	N = 9; DALMENY SITE; 26% CLAY 29% SILT 45% SAND; MEAN k = 1 E-08 m/sec
KELLER and OTHERS (1988) (SASKATCHEWAN)	N = 14; WARMAN SITE; MEAN k = 3.2 E-11 m/sec
RULAND and OTHERS (1991) (ONTARIO)	N = 60; DEPTH RANGES FROM 5 TO 16.2 m; MEAN k = 2.1 E-10 m/sec
DAY (1977) (MANITOBA)	N = 13; DEPTH RANGES FROM 5.5 TO 18.1 m; MEAN k = 1.5 E-07 m/sec
SIMPKINS and BRADBURY (1992) (WISCONSIN)	N = 7; 35% CLAY 53% SILT 12% SAND; DEPTH RANGES FROM 10 TO 22.4 m; MEAN k = 3.1 E-10 m/sec
NORTH DAKOTA SITES	
SLOAN (1972) (STUTSMAN COUNTY)	N = 8; 33% CLAY 36% SILT 27% SAND; DEPTH RANGES FROM 8.2 TO 13.3 m
GROENWALD and OTHERS (1979) (FALKIRK AREA)	N = 4; DEPTH RANGES FROM 7.3 TO 15.8 m; MEAN k = 7 E-07 m/sec
BEAL (1986) (NORTH-CENTRAL NORTH DAKOTA)	N = 24; ABOUT 30% CLAY 35% SILT 35% SAND; DEPTH RANGES FROM 7 TO 18.4 m; MEAN k = 2.9 E-06 m/sec
PATCH and KNELL (1988) WELLS COUNTY)	N = 3; 20-27% CLAY 34-44% SILT 36-41% SAND
MURPHY (1992) (DEVILS LAKE)	N = 2; DEPTH RANGES FROM 11.6-13.6 m; MEAN k = 3.6 E-06 m/sec



[METHOD OF HVORSLEV (1951) USED BY ALL INVESTIGATORS TO CALCULATE HYDRAULIC CONDUCTIVITY]

TABLE 2. -- Hydraulic conductivity of weathered till

REFERENCE	COMMENTS
SITES OUTSIDE OF NORTH DAKOTA	
PRUDIC (1982) (NEW YORK)	N = 3; 50% CLAY 27% SILT 10% SAND 13% GRAVEL
KELLER and OTHERS (1988) (SASKATCHEWAN)	N = 11; DALMENY SITE; DEPTH RANGES FROM 1.9 TO 11.9 m; MEAN k = 1.8 E-09 m/sec N = 5; WARMEN SITE; DEPTH RANGES FROM 4.5 TO 6.0 m; MEAN k = 3.5 E-09 m/sec
HENDRY (1982) (SOUTHERN ALBERTA)	N = 41; TEXTURE RANGES FROM SANDY CLAY TO CLAYEY SAND
CRAVENS and RUEDISILI (1987) (SOUTH DAKOTA)	N = 26; 28% CLAY 51% SILT 22% SAND; MEDIAN k = 7.41 E-08 m/sec; AVERAGE OXIDATION ZONE DEPTH = 7.9 m
RULAND and OTHERS (1991) (ONTARIO)	N = 40; DEPTH RANGES FROM 1 TO 4 m; 23 k's REPORTED AS > 1 E-09 m/sec
SIMPKINS and BRADBURY (1992) (WISCONSIN)	N = 10; 35% CLAY 53% SILT 12% SAND; DEPTH RANGES FROM 0.8 TO 3.2 m; MEAN k = 2.1E-08 m/sec
BENDER and CARLSON (1984) (SOUTH DAKOTA)	USED SPRINKLER IRRIGATION APPLICATIONS COUPLED WITH TENSIOMETRIC DATA TO CALCULATE SATURATED HYDRAULIC CONDUCTIVITY IN TILL
D'ASTOUS and OTHERS (1989) (SOUTHWESTERN ONTARIO)	BULK k OF WEATHERED TILL FROM BAIL-DOWN TEST IN LARGE DIAMETER WELL AND TRACER TESTS DEPTH RANGES FROM 1 TO 3.5 m
NORTH DAKOTA SITES	
PATCH and KNELL (1988)	N = 2; 20-27% CLAY 34-44% SILT 36-41% SAND
RCRA FACILITY INVEST.(1991)	N = 8; DEPTH RANGES FROM 1 TO 8.5 m; MEAN k = 4.2 E-05 m/sec
SCHUH and OTHERS (1992)	N = 3; DEPTH RANGES FROM ABOUT 3.1 TO 6.1 m; MEAN k = 2.3 E-08 m/sec k MEASURED USING TRANSIENT FLOW WATER-BALANCE METHOD
TROOIEN (1993)	N = 18; DEPTH = 2m; MEAN k = 4.7E-07 m/sec; CALCULATED HYDRAULIC CONDUCTIVITY USING TENSIOMETERS AND NEUTRON ACCESS TUBES



[METHOD OF HVORSLEV (1951) USED BY ALL INVESTIGATORS TO CALCULATE HYDRAULIC CONDUCTIVITY UNLESS OTHERWISE NOTED] questions, reliable information is needed on the bulk hydraulic conductivity of clayey aquitards (tills) at a length scale of the practical problem which typically is on the order of thousands of meters (Keller and others, 1989) and a time-scale ranging from 0.3 to 3,000 years (Van der Kamp and Maathius, 1986).

Specific Storage

Specific storage (S_S') of a confined saturated layer is defined as the volume of water that the material will release per unit bulk volume of material per unit decline in average hydraulic head over the volume (Grisak and others, 1976). It is dependent on the compressibilities of the porous medium and of the pore water.

Specific storage can be determined from lab consolidation tests, single-well response tests, and pumping tests. The coefficient of consolidation as used in soil mechanics has been shown by Domenico (1972) to be the ratio of hydraulic conductivity to specific storage (hydraulic diffusivity).

When fractured, till has both a specific storage (S_S') associated with fractures and an intergranular specific storage. Fracture specific storage is smaller than intergranular specific storage. Grisak and others, 1976) states the following:

> "Till with intergranular specific storage values transmits pore water pressure changes very slowly because the process of intergranular consolidation must take place in order for the pressure change to proceed. In other words, water must escape from the pore spaces. Compared to fractured till, the intergranular matrix is much more compressible, but the rate of consolidation (or compression) is very slow because of the very low hydraulic conductivity of the medium."

Specific storage values associated with till are not commonly found in the literature. Table 3 shows both lab and field determined values from previous investigations. Aquifer test values probably are more representative of bulk specific storage values. The larger specific storage reported by Van der Kamp and Maathius (1986) is calculated from a 12-year "pumping test" and probably reflects a greater contribution from intergranular flow. The smaller specific storage values reported by Grisak and Cherry (1975) were calculated from pumping tests of a much shorter duration (8.75-120 hours) and, as a result, the contribution from intergranular flow may be smaller.

Porosity

In a fractured setting, tills have both an intergranular and fracture porosity. Grisak and Cherry (1975) using tritium tracer tests calculated a till fracture porosity of 2×10^{-4} to a maximum depth of 13 m (42.6 ft.). Till intergranular porosities calculated from lab analyses ranged from 0.25 to 0.40. Lind (1989) for a silty, sandy till in Sweden measured porosities from 18 to 48 percent with 80 percent of the samples ranging between 20 and 35 percent. Effective (drainable) porosity ranged from 2.5 to 32 percent with 25 percent of the samples ranging between 3 and 10 percent. Bender and Carlson (1984) measured drainable porosities between 0.03 and 0.06 in a shallow weathered till in South Dakota. Within the 1 to 3 m (3.3 to 9.8 ft.) layer, the most probable drainable porosity ranged from 0.04 to 0.05. Cartwright (verbal communication, 1992) estimates that drainable porosity near land surface and excluding fractures is about 10 percent of the total porosity in Illinois tills. Day

Table 3. -- Values of specific storage and hydraulic diffusivity

REFERENCE	TEXTURE	SAMPLE DEPTH	LAB SPECIFIC STORAGE	FIELD SPECIFIC STORAGE	HYDRAULIC DIFFUSIVITY (Kv'/Ss')
KELLER (1985) DALMENEY SITE (SASKATCHEWAN)	45% SAND 29% SILT 26% CLAY	0.3 TO 18.9 m	1.2 TO 3.1 E-04 m-1 MEAN = 1.3 E-04 m-1	--------	4.5 E-05m2/sec
GRISAK and CHERRY (1975) (SOUTHEASTERN MANITOBA)	-------	----	7.6 E-04 TO 1.5 E-03 m-1 MEAN = 1.1 E-03 m-1 MANITOBA HWY DEPT. MEAN = 9.2 E-04 m-1	AQUIFER TEST 1.5 TO 3.0 E-04 m-1 (SMALL VALUE INDICATIVE OF FRACTURES)	-------------
VAN DER KAMP and MAATHIUS (1986) (WEYBURN SASKATCHEWAN)	-------	----	--------	LONG-TERM AQUIFER TEST 1.0 E-03 TO 1.0 E-04 m-1	5.0 E-07 to 2.0 E-06 m2/sec

(1977) calculated fracture porosities ranging from 3.9×10^{-5} in clay and till in the Winnipeg area of Manitoba.

Hydraulic Gradient

Hydraulic gradient is a useful parameter to infer hydraulic conductivity changes in a ground-water flow field. Hydraulic gradient varies inversely with hydraulic conductivity. Therefore, effective fracture depths in till may be distinguished by changes in hydraulic gradient. Table 4 summarizes reported hydraulic gradients in relation to depth below land surface. Smaller hydraulic gradients are associated with shallow, weathered tills where fractures are ubiquitous. Larger hydraulic gradients are associated with deeper, non-weathered tills where fractures are less widespread.

Hydrochemistry of Till

Calcite and dolomite are ubiquitous in tills throughout Alberta and North Dakota (Grisak and others, 1976). As a result, ground water in till commonly is high in Ca^{2+}, Mg^{2+}, and HCO_3^-. Most till ground waters are saturated or oversaturated with respect to calcite and dolomite. Excess Ca^{2+}, Mg^{2+}, and all Na^+, Cl^-, and SO_4^- can be accounted for by dissolution of other minerals, ion exchange, and upward diffusion of solutes from underlying bedrock formations. Gypsum associated with fractures probably formed by evapotranspiration.

At the Superior and Ashland sites in northwestern Wisconsin, Bradbury and others (1985) found that ground water in the till was oversaturated with respect to calcite and dolomite near the surface, but saturation indices decreased with depth. Concentrations of Ca^{2+}, Mg^{2+}

Table 4. -- Hydraulic gradients in till

REFERENCE	HYDRAULIC GRADIENT	HYDRAULIC GRADIENT
SIMPKINS and BRADBURY (1992) (SOUTHEASTERN WISCONSIN)	0.01 TO 0.08 (< 10 m DEEP)	0.11 TO 1.06 > 10 m DEEP
CRAVENS (1987) (EAST-CENTRAL SOUTH DAKOTA)	-0.12 TO 0.77 MEAN = 0.09 WEATHERED TILL < 7.44 ± 2.5m DEEP	-0.36 TO 2.06 MEAN = 0.68 NONWEATHERED TILL >7.44 ± 2.5 m DEEP
HENDRY and OTHERS (1986) (SOUTHERN ALBERTA)	0.1 TO 0.2 WEATHERED TILL <12 TO 15 m DEEP	0.02 TO 0.7 NONWEATHERED TILL >12 TO 15 m DEEP

[NEGATIVE VALUES INDICATE UPWARD GRADIENTS] and HCO_3^- also decreased with depth, while Cl^- consistently increased. Concentrations of all ions were most variable in the upper 15 m (49.2 ft.) of the profile, possibly a result of weathering processes or fracture flow in the shallow zone.

Desaulniers and others (1981) also observed increased Cl^- concentrations with depth in Quaternary clays in southwestern Ontario. This trend was accounted for by molecular diffusion against the hydraulic gradient.

Fortin, and others (1991) identified "leached" and "unleached" hydrochemical settings at the Dalmery site near Saskatoon, Saskatchewan. "Leached" settings were defined as areas associated with depressions and other minor water-collecting features in which the oxidized till contains no solid gypsum throughout its thickness. In these areas, recharge was relatively large and the oxidized till/sulfate reservoir was well flushed. Dissolved-solids concentrations averaged about 1,200 mg/L and the water was a calcium-bicarbonate type. "Unleached" settings occur beneath topographic highs where rain and snowmelt run off on the surface into surrounding depressions. In these areas, recharge was relatively small and the oxidized till/sulfate reservoir was not well flushed. As a result, gypsum was still present in the till. Dissolved-solids concentrations averaged about 5,000 mg/L and the water was a calcium sulfate type. Sulfate content generally exceeded 50 meq/L and these waters were saturated with gypsum. The major geochemical processes occurring at this site were carbonate dissolution, pyrite oxidation, precipitation and dissolution of gypsum, oxidation of organic carbon, and cation exchange. The solid gypsum found in the oxidized till appears to have been formed in situ owing to oxidation of pyrite, with little subsequent transport. Hendry and others (1986) on the other hand determined that the source of sulfate in the till in southern Alberta was from oxidation of organic sulfur. Regardless of sulfate genesis, surficial, oxidized till functions as a sulfate reservoir.

Fortin and others (1991) also concluded that areas of surficial stratified drift played an important role on spatial hydrochemical patterns in both the till and underlying buried aquifer. In areas where relatively thick stratified drift occurred, the water table was above the till and the till was mostly unoxidized, thus diminishing the importance of the sulfate reservoir (i.e. pyrite or organic sulfur is not oxidized to produce sulfate). Furthermore, the authors concluded that flow through the aquitard probably was relatively large because the occurrence of sand at the ground surface allowed rapid infiltration and significant recharge to occur even in non-depressional areas. This setting is very similar to that described by Shaver (1985, p. 68-69) in the Spiritwood aquifer in southeastern LaMoure County, North Dakota. Based on the above, it is apparent that mapping land-surface topography, surficial geology (including soil surveys) in buried-valley aquifer studies may facilitate location of some significant recharge areas.

Cravens and Ruedisili (1987) compared water quality in the non-weathered till to that in the weathered till in east-central South Dakota. Total dissolved solids of water samples from the weathered zone averaged about 2,000 mg/L higher than those from the non-weathered zone. The large decrease in total dissolved solids with depth was attributed to decreased concentrations of sulfate and magnesium. Decreased salinity with depth suggests little or no deep percolation or recharge to deeper buried-valley aquifers.

Rozkowski (1967) described the hydrochemistry of a small local basin in hummocky moraine in southern Saskatchewan. The upland recharge area was characterized by a calcium-magnesium-sulfate type water which was formed primarily in the zone of aeration. Dissolved-solids concentrations ranged from 3,200 to 3,800 mg/L. The discharge area near the slough was characterized by a magnesium-(sodium)-sulfate type water with increased salinity. Dissolved-solids concentrations were 50,000 mg/L. The discharge area also was characterized by vertical chemical zonation with increased water salinity towards land surface. Evapotranspiration was the primary solute concentrating mechanism. In addition, the discharge area was characterized by larger temporal (seasonal) fluctuations in salinity.

WATER-LEVEL RESPONSE AND HYDROCHEMISTRY IN PIEZOMETER NESTS IN THE SPIRITWOOD AQUIFER STUDY AREA

Throughout the 1980s eight piezometer nests were installed in the Spiritwood aquifer study area in southeastern LaMoure, northeastern Dickey, and northwestern Sargent counties. The piezometer nests were installed to monitor temporal vertical distribution of hydraulic head in the Spiritwood aquifer and overlying till and lacustrine silty clay/clayey silt aquitards. In addition, water samples were periodically collected from the piezometer nests to determine vertical water chemistry distribution. The locations of the piezometer nests are shown in figure 2. Geologists logs of the piezometer nests are presented in Appendix 1. Water levels measured at the piezometer nest sites are presented in Appendix 2, and water chemistry analyses for samples collected from each piezometer are presented in Appendix 3.

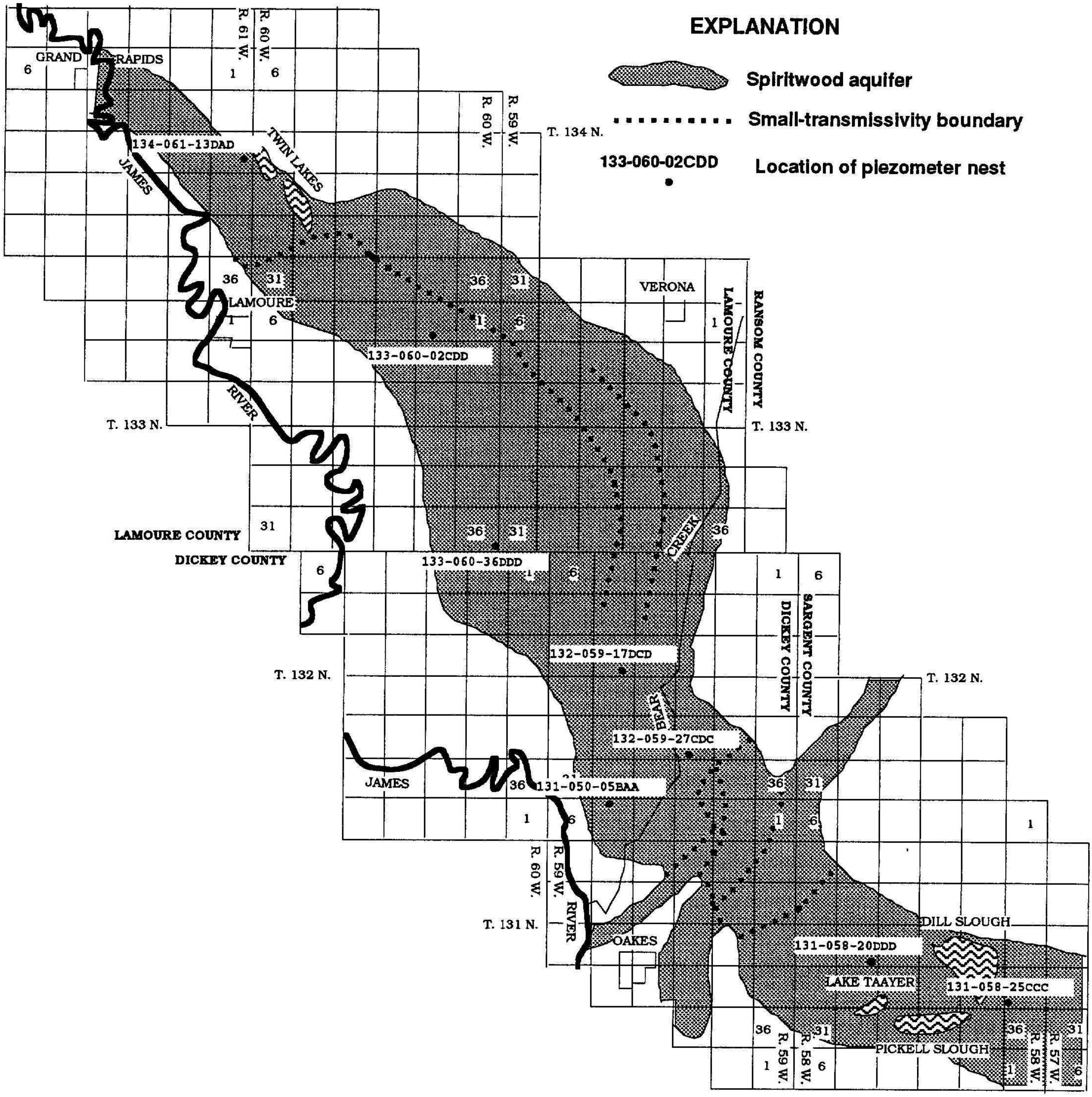


Figure 2. -- Location of piezometer nests in the Spiritwood aquifer study area

Piezometer Nest 134-061-13DAD

Water-Level Response

Piezometer 134-061-13DAA1 is screened from 78.4 to 79.9 m (257 to 262 ft.) below land surface near the base of the Spiritwood aquifer; piezometer 13DAD2 is screened from 40.2 to 41.8 m (132 to 137 ft.) below land surface near the top of the Spiritwood aquifer; and piezometer 13DAD3 is screened from 20.7 to 22.3 m (68 to 73 ft.) below land surface in a shallow, undefined, fluvial sand and gravel.

Hydrographs of the three piezometers are shown in figure 3. Water-level elevations decrease with increasing depth indicating downward ground-water flow. The vertical hydraulic gradient between 13DAD2 and 13DAD3 (across the till) was 0.34 (measured 5/1/87) and the vertical hydraulic gradient between 13DAD2 and 13DAD1 (across the Spiritwood aquifer) was 0.015.

Piezometer nest 134-061-13DAD is located on a local, land-surface topographic upland area that is near two local, land-surface topographic low areas (James River Valley - Twin Lakes). The screened interval of piezometer 13DAD3 is within about 6.1 m (20 ft.) of the Twin Lakes water-surface elevation shown on the U.S. Geological Survey 7 1/2-minute topographic quadrangle (Grand Rapids, ND). A water-level decline of about 2.4 m (8 ft.) was measured at piezometer 13DAD3 during the drought of 1988. Water levels in other piezometers at similar depths southeast of this area declined about 1.5 m (5 ft.) during the drought of 1988. It is possible that the sand and gravel in which piezometer 13DAD3 is screened is hydraulically connected to Twin Lakes. The larger water-level decline during 1988 may be the result of a lack of recharge

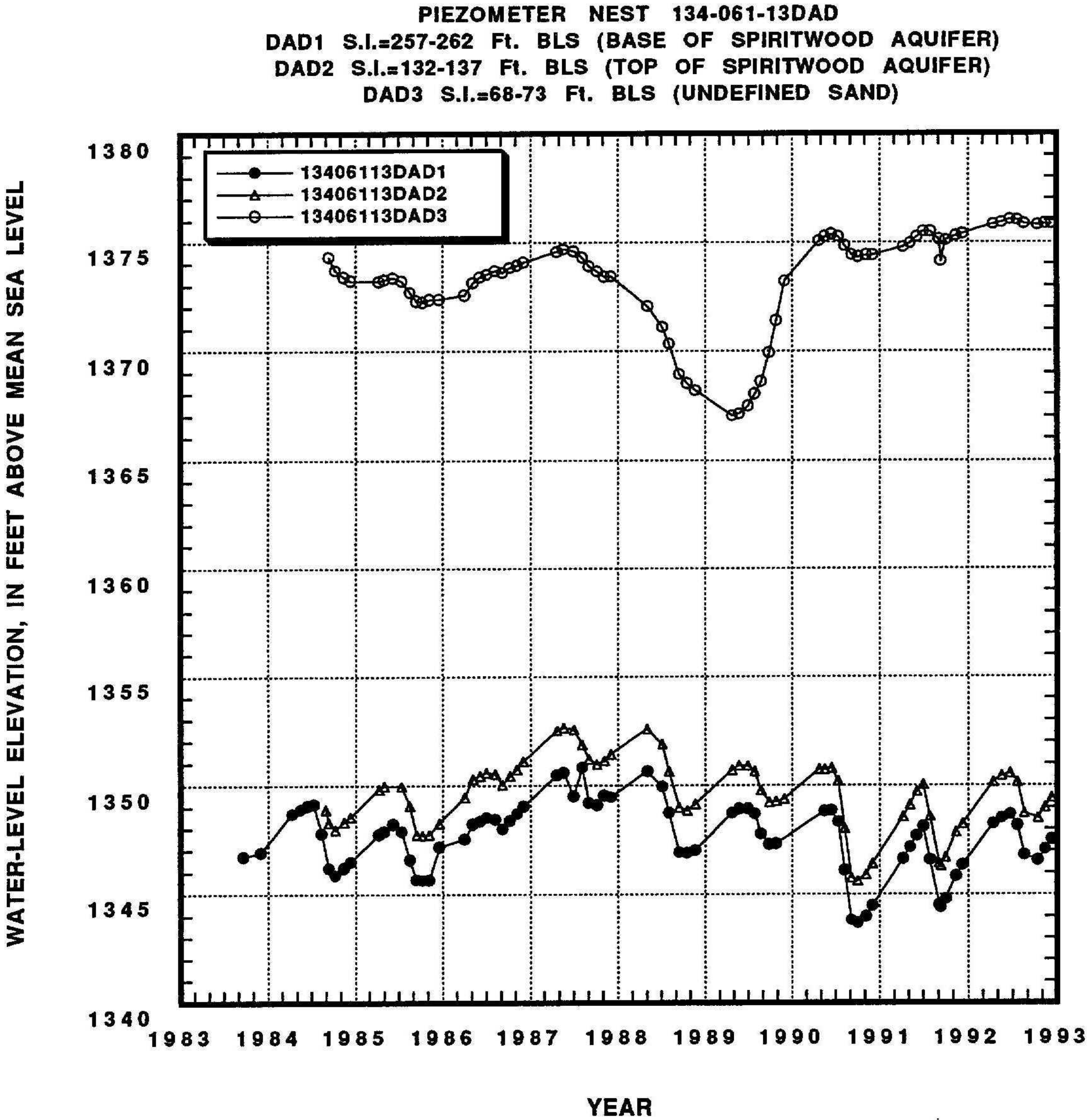


Figure 3.-- Hydrographs showing water levels at piezometer nest 134-061-13DAD

coupled with increased discharge by evapotranspiration from nearby Twin Lakes.

It is also important to note that the pattern of water-level fluctuations in 13DAD3 did not resemble those of 13DAD1 and 13DAD2. The upper part of the flow system does not appear to be well connected hydraulically to the deeper part of the flow system (Spiritwood aquifer). This suggests that the till from 22 to 34 m (72 to 112 ft.), separating the two flow systems, has a relatively small hydraulic diffusivity (K_V'/S_S').

Water Chemistry

As compared to other parts of the Spiritwood aquifer study area, the Twin Lakes area has smaller dissolved solids concentrations (generally less than 600 mg/L) (Shaver, 1985). The small sulfate concentrations suggest that surficial oxidized till (sulfate reservoir) is not ubiquitous and/or is well flushed in this area. The water chemistry of 13DAD1 and 13DAD2 was very similar (figs. 4 and 5) indicating minor upward flow from underlying bedrock shale (Pierre Formation).

Piezometer Nest 133-060-02CDD

Water-Level Response

Observation well 133-060-02CDD1 was completed in 1983, one year prior to piezometers 2CDD2, 3, and 4. The well is screened from 77.7 to 79 m (255 to 260 ft.) at the base of the Spiritwood aquifer. After the casing and screen were inserted into the drill hole, the well was blown with air to collapse the formation around the screen and drill cuttings were shoveled into the annular area. Cement or bentonite grout was not injected into the annular area of this well. The inside of the well

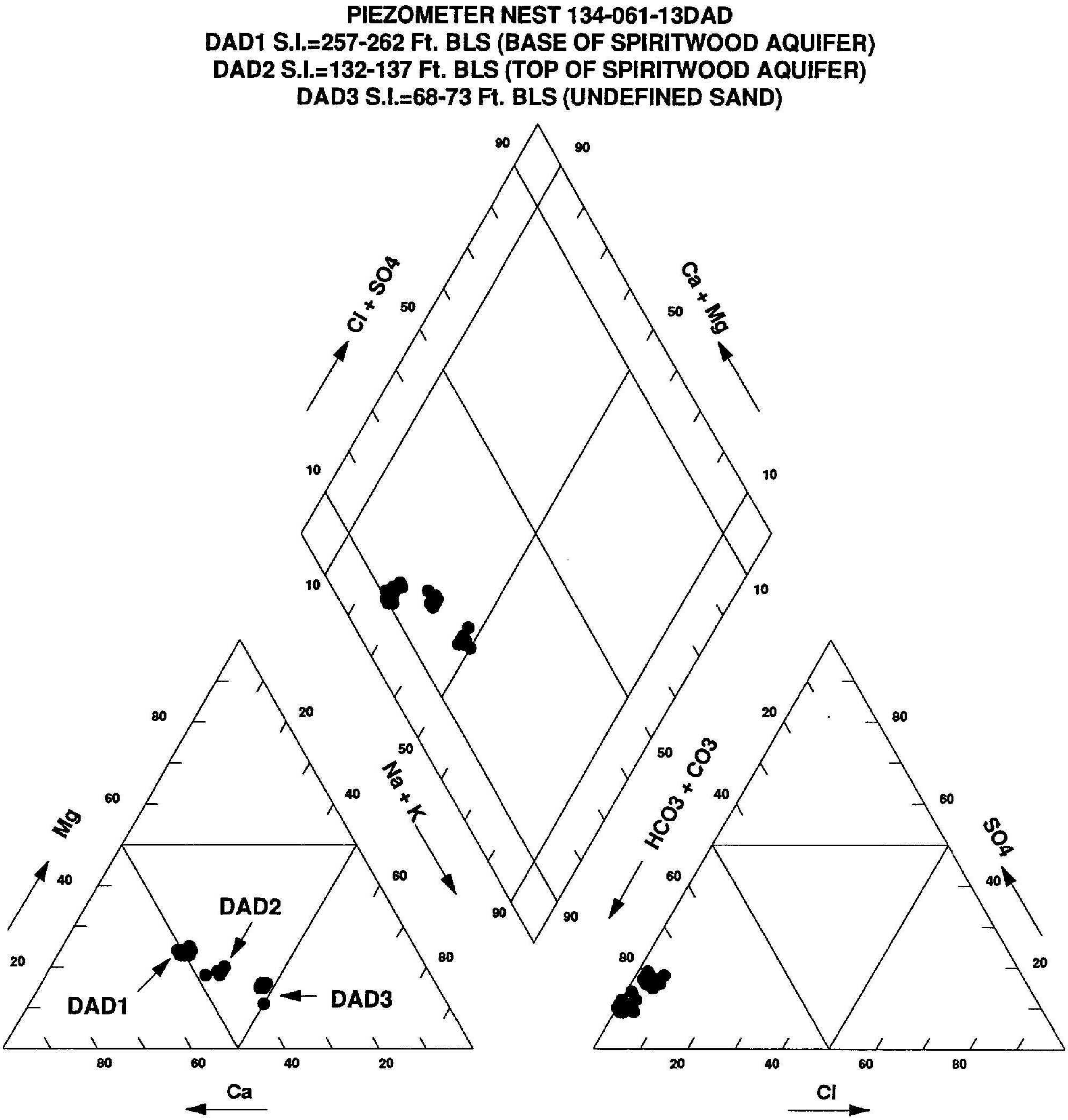


Figure 4.-- Piper trilinear diagram showing range in water chemistry at piezometer nest 134-061-13DAD

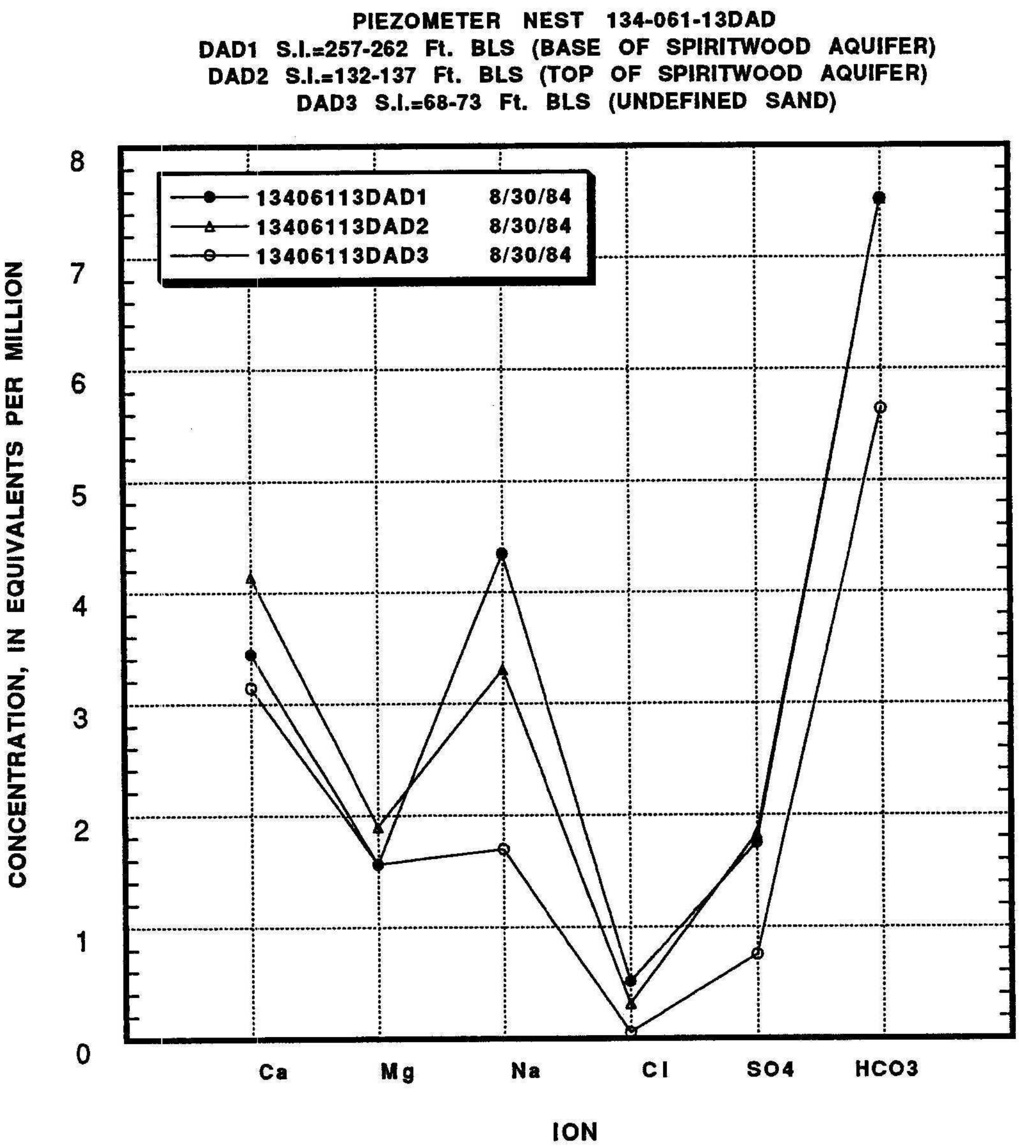


Figure 5.-- Schoeller diagram showing concentrations of selected ions at piezometer nest 134-061-13DAD

was inadvertently plugged with cement grout during the installation of piezometer 2CDD2 and, as a result, the well was abandoned. Piezometer 2CDD2 is screened from 59.5 to 61 m (195 to 200 ft.) in the top of the Spiritwood aquifer, piezometer 2CDD3 is screened from 35.7 to 37.2 m (117 to 122 ft.) in till, and piezometer 2CDD4 is screened from 7.9 to 9.5 m (26 to 31 ft.) in an undefined sand.

Hydrographs of the three piezometers are shown in figure 6. Water-level elevations decrease with increasing depth indicating downward ground-water flow. The hydraulic gradient between 2CDD4 and 2CDD3 was 0.28 and the hydraulic gradient between 2CDD3 and 2CDD2 was 0.27. The similar hydraulic gradients suggest rather uniform hydraulic conductivity throughout the non-weathered till at this site.

The hydrograph of piezometer 2CDD2 (top of Spiritwood aquifer) is characterized by declining water levels during the summer and rising water levels during the fall, winter, and spring. Declining water levels during the summer were the result of irrigation withdrawals from the Spiritwood aquifer. The pattern of water-level fluctuations in 2CDD3 (till) was similar to that of 2CDD2 indicating significant upward propagation of drawdown and recovery into the till.

Bredehoeft and Hanshaw (1968) describe an analytical method to evaluate excess head throughout a sedimentary sequence. The method defines the excess-head distribution in the semi-infinite medium (aquitard) after imposing a step change in head at the boundary

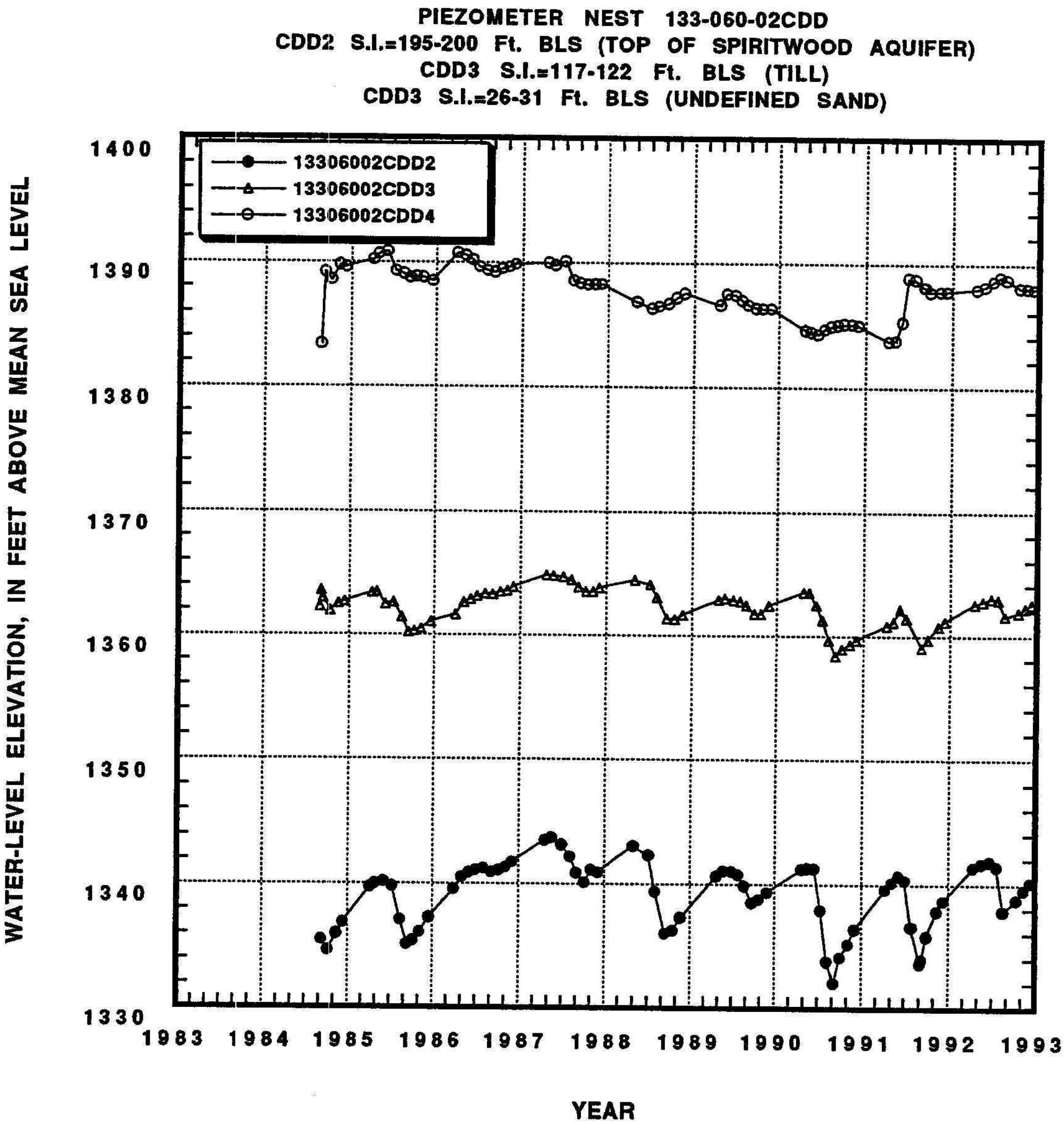


Figure 6.-- Hydrographs showing water levels at piezometer nest 133-060-02CDD

(adjacent aquifer). The solution (Carslaw and Jaeger, 1959, p. 60) is:

$$h^1 = H_o \operatorname{erf}\left\{\frac{z}{(4Kt/S_s)^{1/2}}\right\}$$

where,

H_o - step change in head in aquifer, in meters
h^1 - excess residual head in aquitard, in meters
K - hydraulic conductivity of aquitard, in meters per day
t - time, in days
S_s - specific storage of aquitard, in meters (-1)
z - vertical distance above or below aquifer/aquitard boundary, in meters
erf - error function (from mathematical table)

The drawdown at any point in the aquitard is the difference between H_o and h' (H_o - h').

This analytic method was used to evaluate hydraulic diffusivity of the till aquitard using the water-level response in piezometer 2CDD3 (till) and piezometer 2CDD2 (top of Spiritwood aquifer). The 1990 summer irrigation season was selected to apply this method because drawdown was the largest on record in both the Spiritwood aquifer and till piezometers. It was assumed that the maximum irrigation season drawdown 2.81 m (9.23 ft.) occurred as an "instantaneous" step drawdown at time (t) = 0 (beginning of irrigation season). In reality, the maximum drawdown 2.81 m (9.23 ft.) was not instantaneous as shown by the water-level hydrograph of piezometer 2CDD3 (fig. 6). A more realistic H_o would be smaller than 2.81 m (9.23 ft.). Using a larger H_o yields a more conservative (smaller) value of hydraulic diffusivity.

The calculated drawdown profile in the till aquitard above the Spiritwood aquifer at 133-060-02CDD is shown in figure 7. Note that at 100 days, the drawdown profile intersects land surface at just over 0.3 m (1 ft.) of drawdown. Thus, the semi-infinite aquitard boundary condition

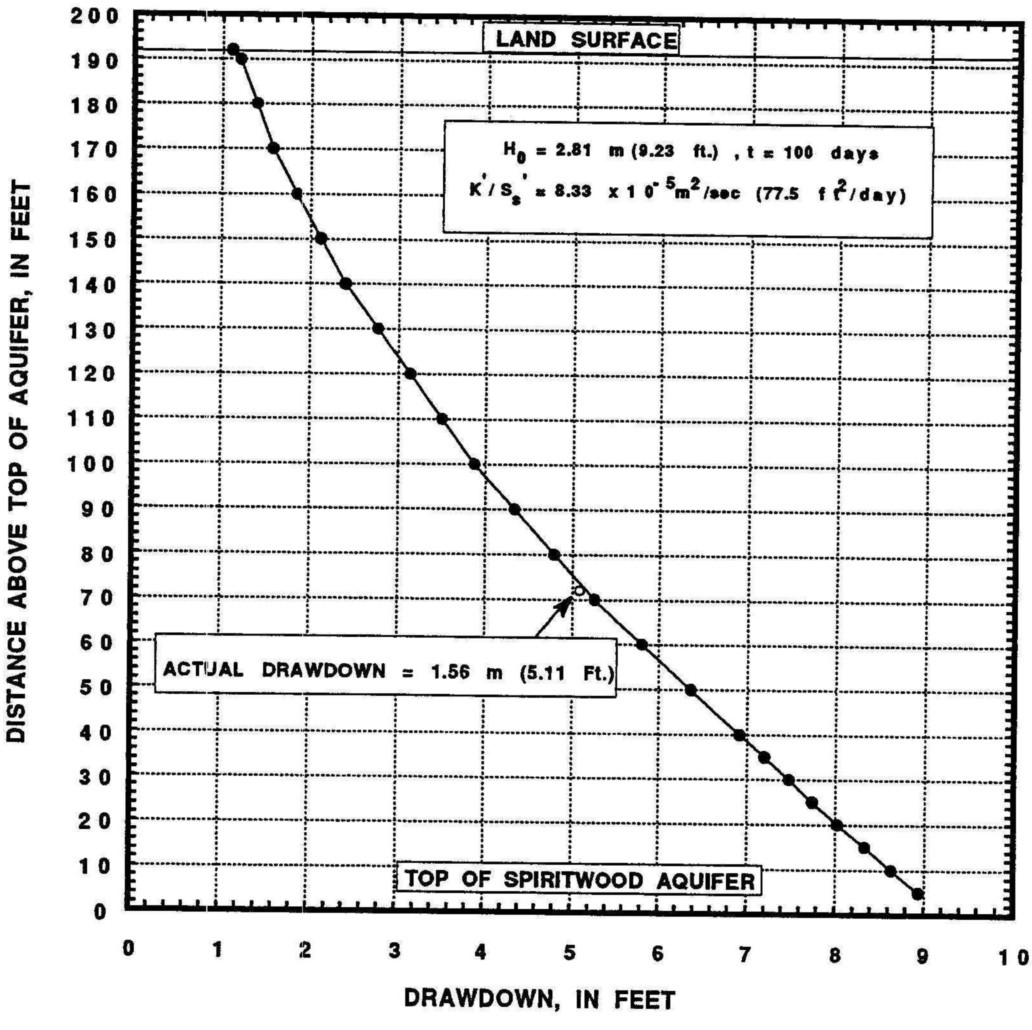


Figure 7.-- Vertical drawdown distribution in till at piezometer nest 133-060-02CDD computed using the stepped-drawdown analytical approach

in the analytical method is violated. However, the amount of drawdown 0.3 m (1 ft.) is considered small and probably would not greatly alter the drawdown profile as shown, particularly at the depth of piezometer 2CDD3 (SI = 35.7-37.2 m; 117-122 ft.).

The actual maximum drawdown measured at piezometer 2CDD3 was 1.56 m (5.11 ft.) and was approximated analytically using a hydraulic diffusivity of 8.33 x 10^{-5} m^2/sec (37.5 ft^2/day) (fig. 7). This hydraulic diffusivity is about twice the value reported by Keller (1985) in the Dalmeny, Saskatchewan site and about one order of magnitude larger than the value reported by Van der Kamp and Maathius, 1986 (Table 3). Using the largest specific storage of 1.0 x 10^{-4} m^{-1} (3.05 x 10^{-5} ft^{1}) reported by Van der Kamp and Maathius, 1986 (Table 2) requires a vertical hydraulic conductivity of 8.33 x 10^{-9} m/sec (2.36 x 10^{-3} ft/day) to yield a hydraulic diffusivity of 8.33 x 10^{-5} m^2/sec (77.5 ft^2/day). This vertical hydraulic conductivity falls into the low end of typical values for weathered, fractured till (Table 2).

A vertical hydraulic conductivity of 5 x 10^{-10} m/sec (1.42 x 10^{-4} ft/day) which is typical of a non-weathered, unfractured till requires a specific storage of 6.0 x 10^{-6} m^{-1} (1.83 x 10^{-6} ft^{1}) to yield a hydraulic diffusivity of 8.33 x 10^{-5} m^2/sec (77.5 ft^2/day). This specific storage is about two orders of magnitude smaller than the smallest value reported by Van der Kamp and Maathius (1986) (Table 3). Thus, it appears that the aquitard response at 2CDD3 is anomalous.

A regression analysis of maximum annual (irrigation season) aquifer drawdown and aquitard drawdown is shown in figure 8. The analysis indicates that an instantaneous head change of 0.45 m (1.45 ft.) over a 100-day period in the Spiritwood aquifer is required to produce a

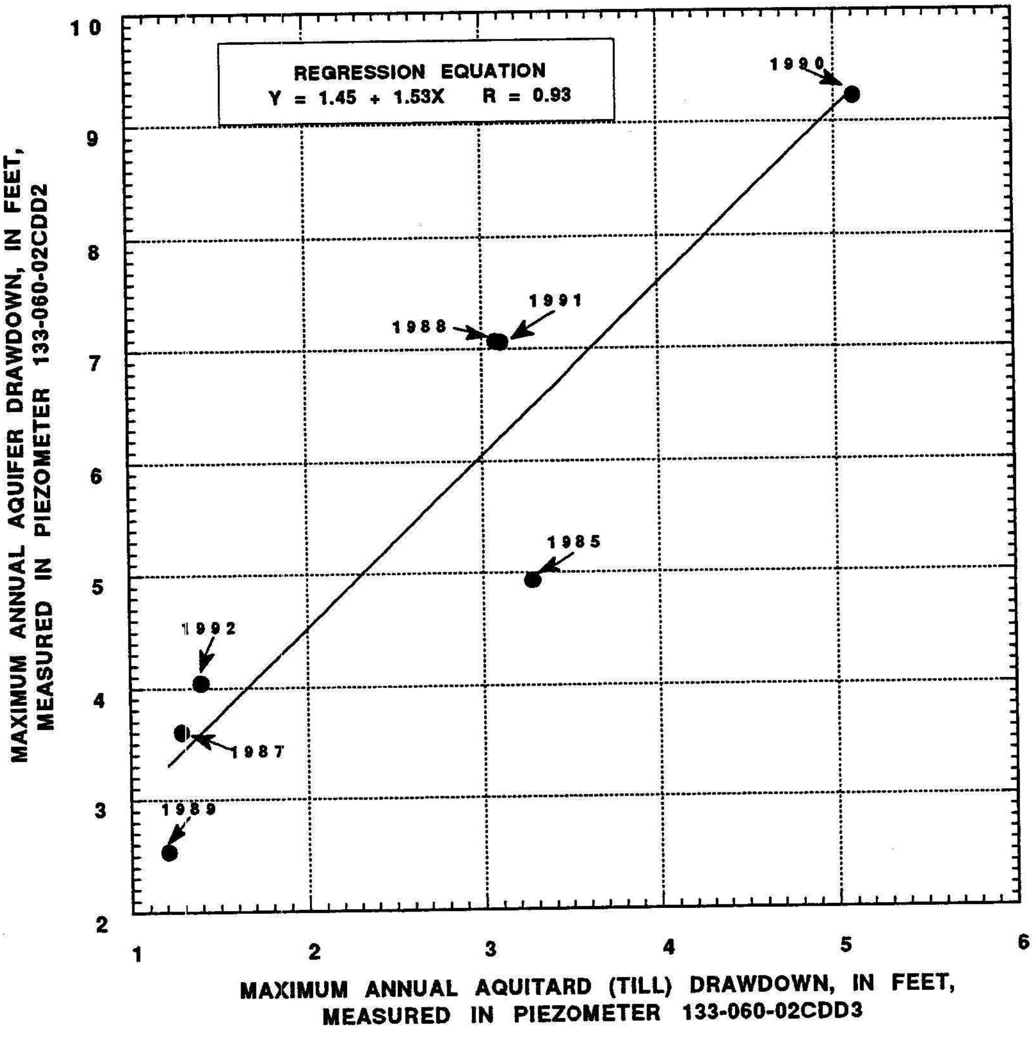


Figure 8.-- Regression analysis of measured drawdown response in the Spiritwood aquifer and overlying till

head change at 2CDD3, 21.3 m (70 ft.) above the top of the Spiritwood aquifer. The slope of the regression line is relatively small which coupled with the relatively small y-intercept indicate an anomalously large hydraulic diffusivity. Later in this paper, this regression analysis is compared to that of piezometer nest 132-059-17DCD to support the anomalous aquitard response at piezometer 133-060-02CDD3.

Water Chemistry

The relative distribution of cations and anions in piezometer nest 133-060-02CDD is shown in figure 9 and the absolute distribution of cations and anions is shown in figure 10. The shallow undefined sand (2CDD4) is characterized by a mixed cation, bicarbonate type water with relatively small dissolved-solids concentrations. The till at piezometer 2CDD3 is characterized by a sodium-sulfate type water; the top of the Spiritwood aquifer (02CDD2) is characterized by a sodium-bicarbonate type water; the bottom of the Spiritwood aquifer (02CDD1) is characterized by a sodium-mixed anion type with relatively large chloride concentrations. If the overlying till provides significant recharge to the Spiritwood aquifer, then the water chemistry in the top of the Spiritwood aquifer should be similar to that of the overlying till. The till water (piezometer 2CDD3) is a sulfate type and the top of the Spiritwood aquifer (piezometer 2CDD2) is a bicarbonate type. In addition, the mean dissolved-solids concentration of the till water is 959 mg/L and the mean dissolved-solids concentration of the top of the Spiritwood aquifer is 885 mg/L.

Sulfate decreases about 2 equivalents per million (epm) from piezometer 2CDD3 to the top of the Spiritwood aquifer (2CDD2) (fig. 10).

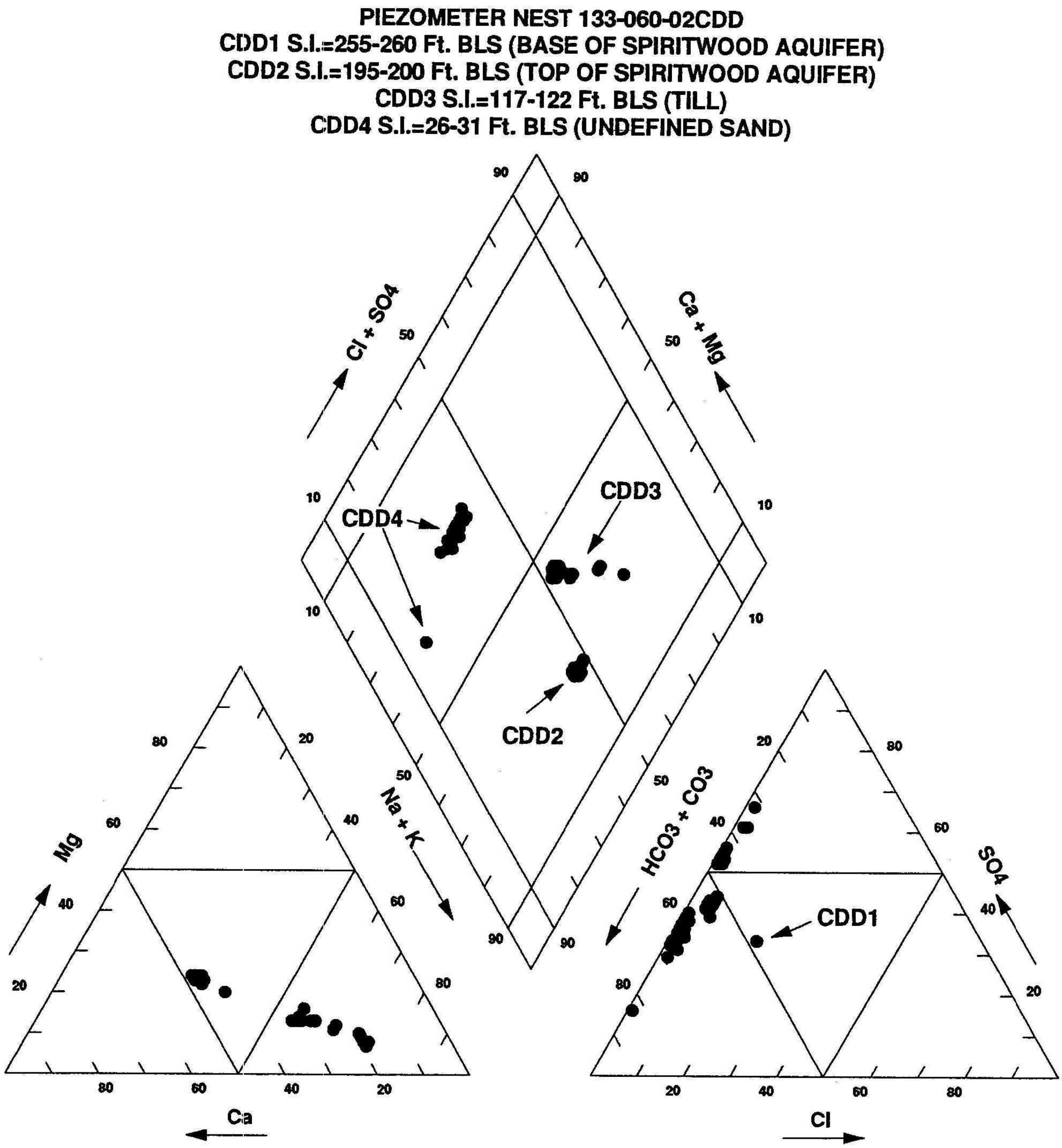


Figure 9.-- Piper trilinear diagram showing range in water chemistry at piezometer nest 133-060-02CDD

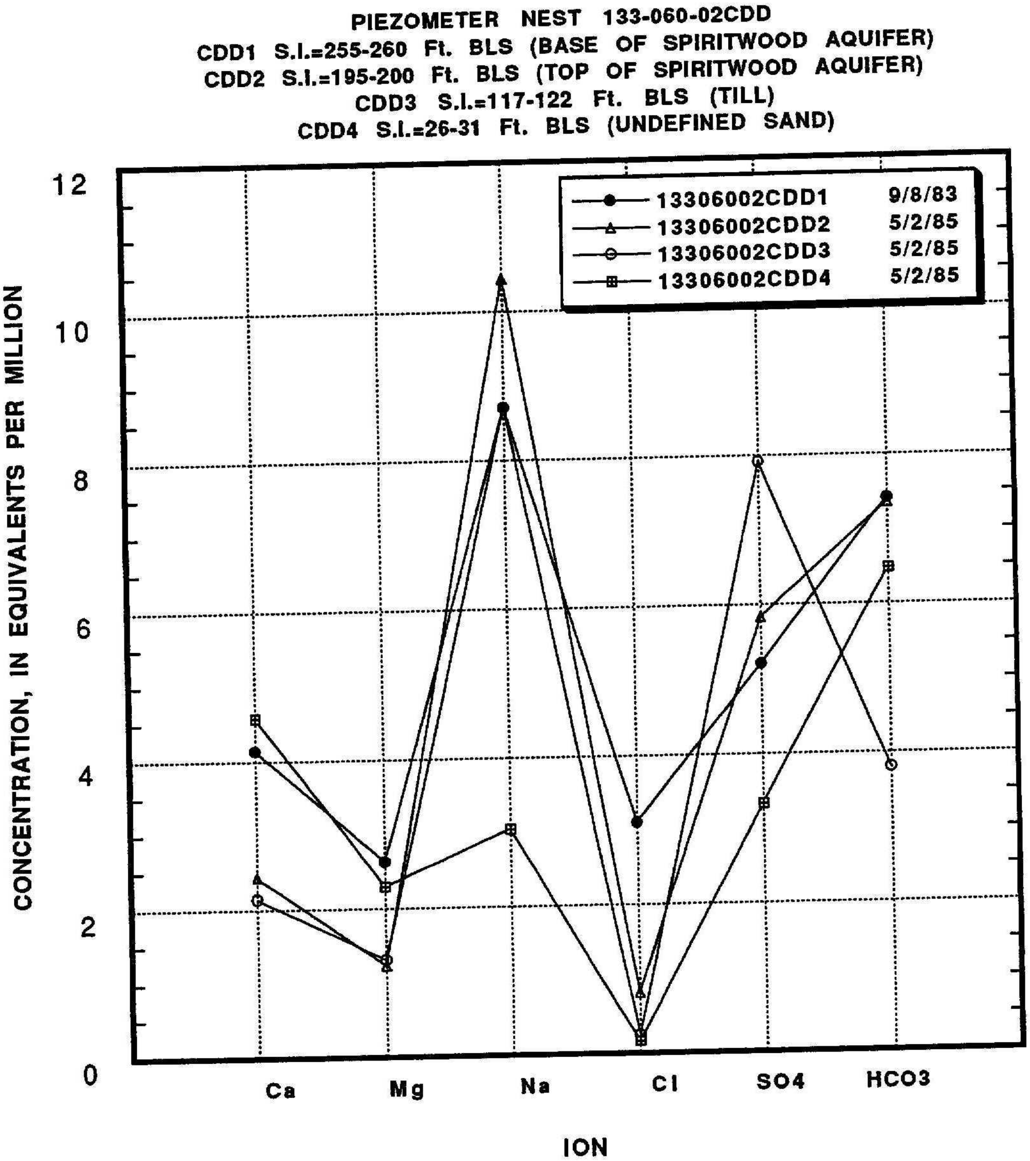


Figure 10.-- Schoeller diagram showing concentrations of selected ions at piezometer nest 133-060-02CDD

If recharge to the Spiritwood aquifer from the overlying till is significant, then a mechanism must exist to account for decreased sulfate in the top of the Spiritwood aquifer. Possible mechanisms are gypsum precipitation or sulfate reduction. Gypsum precipitation is not thermodynamically plausible because both the deep till (2CDD3) and top of Spiritwood aquifer (2CDD2) waters are undersaturated with respect to gypsum. (Table 5).

Sulfate reduction also does not appear to be a sulfate sink mechanism in the base of the till or in the top of the Spiritwood aquifer. Sulfate reduction by anaerobic microbes is accompanied by oxidation of organic compounds which produces CO_2. Increased CO_2 lowers the pH causing dissolution of carbonate minerals (calcite and dolomite) which are ubiquitous in the glacial drift throughout North Dakota. Thus, ground water should be characterized by very small sulfate concentrations and large bicarbonate concentrations if sulfate reduction is occurring near the base of the till or top of the Spiritwood aquifer. This is not the case for ground water in piezometers 2CDD3 and 2CDD2 (fig. 10).

The decrease in sulfate and dissolved-solids concentrations from piezometer 2CDD3 to 2CDD2 suggests that the Spiritwood aquifer receives significant recharge along flow paths that short-circuit the overlying till/sulfate reservoir. These flow paths probably consist of localized inhomogeneties in the overlying drift that are characterized by relatively large transmissivity.

Upward ground-water flow into the bottom of the Spiritwood aquifer from the underlying bedrock shale (Niobrara Formation) is

Table 5. -- Calcite and gypsum saturation indices for piezometer nest 133-060-02CDD

PIEZOMETER	SCREENED INTERVAL (Ft. BLS)	SAMPLED 4/2/87		SAMPLED 5/4/87		SAMPLED 6/11/87	
		S.I. CALCITE	S.I. GYPSUM	S.I. CALCITE	S.I. GYPSUM	S.I. CALCITE	S.I. GYPSUM
133-060-02CDD2 TOP OF SPIRITWOOD AQUIFER	195-200	0.194	-1.352	-0.035	-1.348	0.124	-1.382
133-060-02CDD3 TILL	117-122	0.276	-1.019	0.309	-1.010	0.270	-1.026
133-060-02CDD4 UNDEFINED SAND	26-31	0.128	-1.424	0.093	-1.388	0.166	-1.395

[S.I. = Saturation Index]

inferred at this piezometer nest site by the larger chloride concentration in piezometer 2CDD1 (figs. 9 and 10).

Piezometer Nest 133-060-36DDD

Water-Level Response

Observation well 133-060-36DDD1 was completed in 1975 during the Dickey-LaMoure Counties Ground Water Study (Armstrong and Luttrell, 1978). The well is screened from 64.6 to 65.6 m (212 to 215 ft.) below land surface in the Spiritwood aquifer. After the casing and screen were inserted into the drill hole, the well was blown with air to collapse the formation around the screen and drill cuttings were shoveled into the annular area. Cement or bentonite grout was not injected into the annular area of this well.

Piezometers 36DDD2, 36DDD3, and 36DDD5 were completed in 1984. Cement was injected into the annular areas of the piezometers using 3.18 cm (1 1/4 in.) diameter PVC tremie pipe. Piezometer 36DDD2 is screened from 72 to 73.5 m (236 to 241 ft.) at the base of the Spiritwood aquifer, piezometer 36DDD3 is screened from 36.6 to 38.1 m (120 to 125 ft.) in till, and piezometer 36DDD5 is screened from 12.2 to 13.7 m (40 to 45 ft.) in till.

Hydrographs of the three piezometers are shown in figure 11. Water-level elevations decrease with increasing depth indicating downward ground-water flow. Based on water levels measured in April 22, 1987, the vertical hydraulic gradient between 36DDD5 and 36DDD3 was 0.15 and the vertical hydraulic gradient between 36DDD3 and 36DDD2 was 0.27. The larger gradient between 36DDD3 and 36DDD2

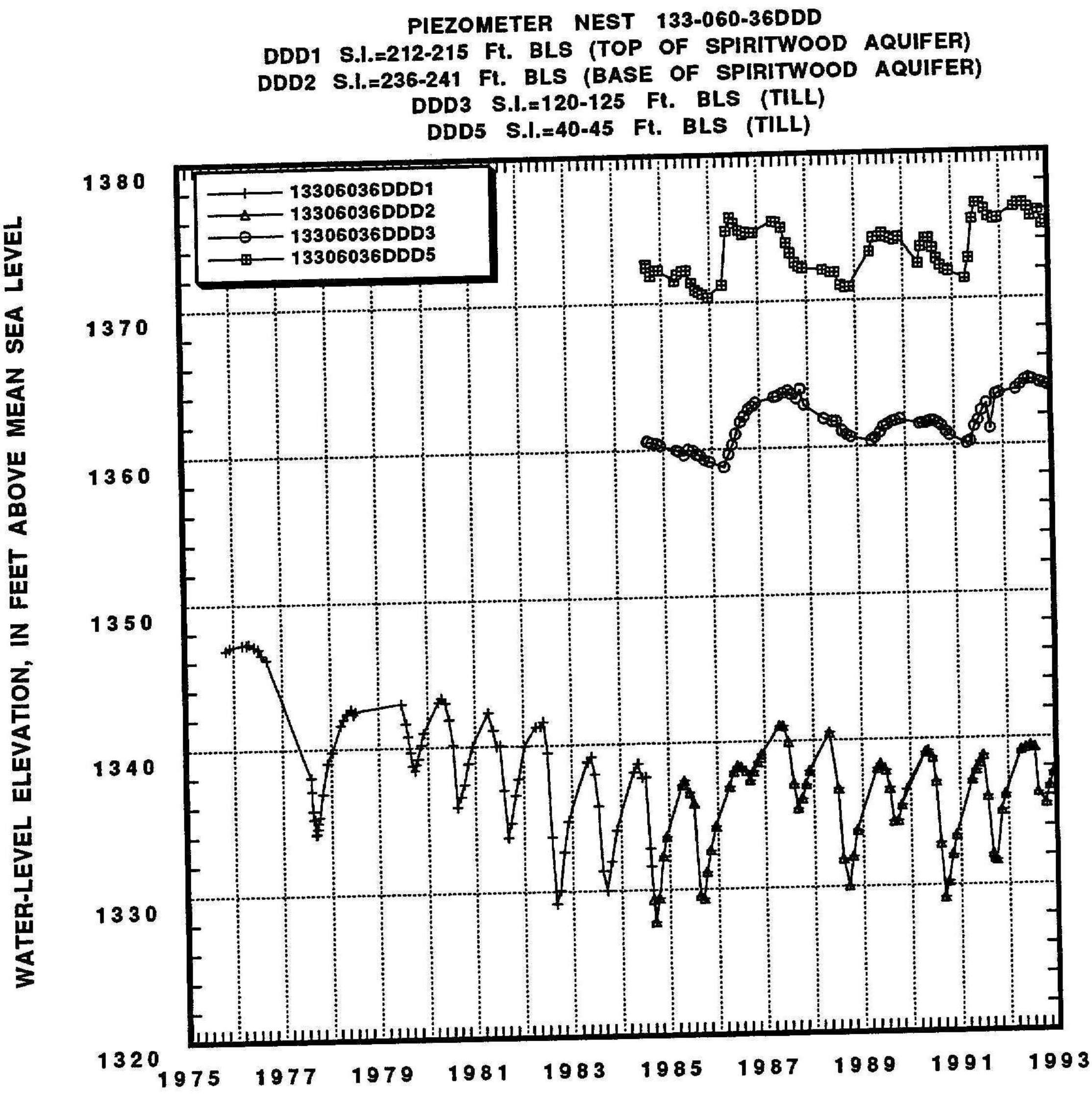


Figure 11.-- Hydrographs showing water levels at piezometer nest 133-060-36DDD

was, in part, due to an approximate 1.8 m (6 ft.) residual drawdown in the Spiritwood aquifer since irrigation development began in 1975.

The hydrographs of piezometers 36DDD1 and 36DDD2 (top and bottom of the Spiritwood aquifer) are characterized by declining water levels during the summer and rising water levels during the fall, winter, and spring. Declining water levels during the summer were the result of irrigation withdrawals from the Spiritwood aquifer. The pattern of water-level fluctuations in 36DDD3 was similar to that of 36DDD5. The upward propagation of the drawdown/recovery cycles in the Spiritwood aquifer appears minor in piezometer 36DDD3. This suggests a relatively small till hydraulic diffusivity between 36.6 and 62.2 m (120 and 204 ft.) below land surface.

The previously described method of Bredehoeft and Hanshaw (1968) was used to estimate the maximum till hydraulic diffusivity that would produce zero drawdown at 36DDD3 based on an H_0 of 2.4 m (8 ft.) and a 100-day pumping period. The calculated maximum hydraulic diffusivity is 5.1×10^{-6} m^2 sec^{-1} (4.72 ft^2/day). This value is about 2.5 times that of the largest value reported by Van der Kamp and Maathius (1986) (Table 2).

Water Chemistry

The relative distribution of cations and anions in piezometer nest 133-060-36DDD is shown in figure 12 and the absolute distribution of cations and anions is shown in figure 13. The shallow till (36DDD5) is characterized by a mixed cation, sulfate type water and the deeper till is characterized by a sodium-sulfate type water (fig. 12). Dissolved-solids concentration in 36DDD5 is 1,390 mg/L and the dissolved-solids

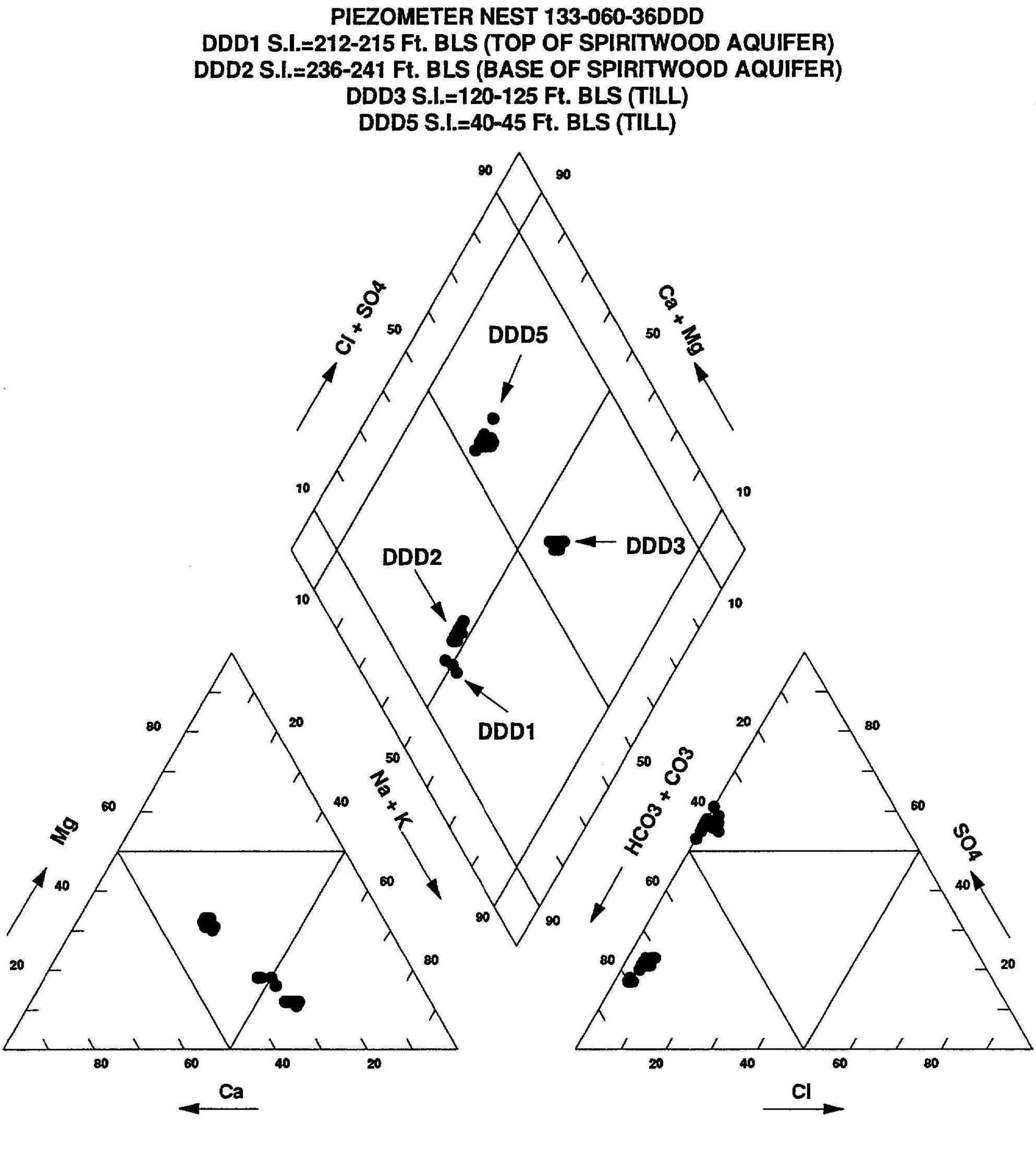


Figure 12.-- Piper trilinear diagram showing range in water chemistry at piezometer nest 133-060-36DDD

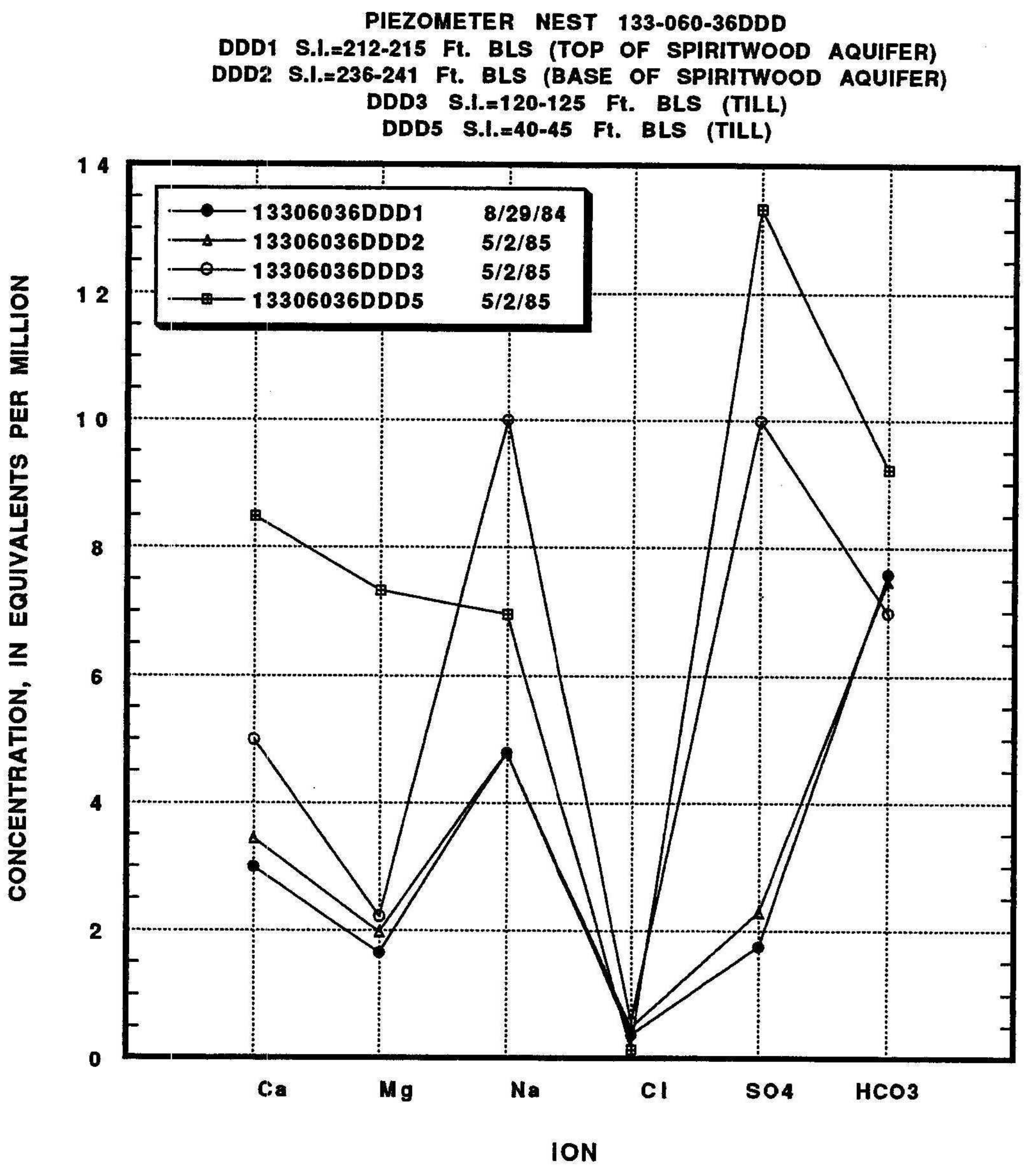


Figure 13.-- Schoeller diagram showing concentrations of selected ions at piezometer nest 133-060-36DDD

concentration in 36DDD3 is 1,110 mg/L (sample date: 5/2/85). Water from 36DDD3 has 3.49 epm less calcium, 5.10 epm less magnesium, 3.05 epm more sodium, 3.33 epm less sulfate, and 2.25 epm less bicarbonate. The change in water chemistry from 36DDD5 to 36DDD3 negates significant vertical ground-water flow between these two points. Cation exchange on clay can account for a 3.05 epm decline in calcium plus magnesium. This still leaves 5.54 epm calcium plus magnesium. Water from both 36DDD5 and 36DDD3 is oversaturated with respect to calcite indicating that calcite precipitation is thermodynamically plausible (Table 6). If one assumes 2.25 epm carbonate precipitation (decrease in bicarbonate from 36DDD5 to 36DDD3) this still leaves 3.29 excess calcium plus magnesium which is almost equal to the decrease in sulfate (3.33 epm) from 36DDD5 to 36DDD3. Precipitation of a calcium/magnesium sulfate mineral is required to account for the remaining decrease in calcium, magnesium, and sulfate. Water from both 36DDD5 and 36DDD3 is undersaturated with respect to gypsum (Table 6). Thus, calcium sulfate (gypsum) precipitation is not thermodynamically plausible. Other sulfate species (mirabilite, epsomite, etc.) are much more soluble than gypsum and as a result, precipitation of these sulfate species also is not thermo-dynamically plausible.

The decrease in sulfate from 36DDD5 to 36DDD3 could be caused by sulfate reduction. However, as previously mentioned, in the presence of carbonate species sulfate reduction is accompanied by increased bicarbonate. Bicarbonate concentration, however, decreases from 36DDD5 to 36DDD3.

The difference in water chemistry from 36DDD5 to 36DDD3 may indicate the occurrence to two distinct flow systems (fig. 14). Piezometer

Table 6. -- Calcite and gypsum saturation indices for piezometer nest 133-060-36DDD

PIEZOMETER	SCREENED INTERVAL (Ft. BLS)	SAMPLED 4/2/87		SAMPLED 5/4/87		SAMPLED 6/11/87	
		S.I. CALCITE	S.I. GYPSUM	S.I. CALCITE	S.I. GYPSUM	S.I. CALCITE	S.I. GYPSUM
133-060-36DDD2 BOTTOM OF SPIRITWOOD AQUIFER	236-241	0.249	-1.544	0.276	-1.547	0.260	-1.591
133-060-36DDD3 TILL	120-125	0.426	-0.933	0.290	-0.956	0.367	-0.923
133-060-36DDD5 TILL	40-45	0.292	-0.700	0.289	-0.714	0.075	-0.656

[S.I. = Saturation Index]

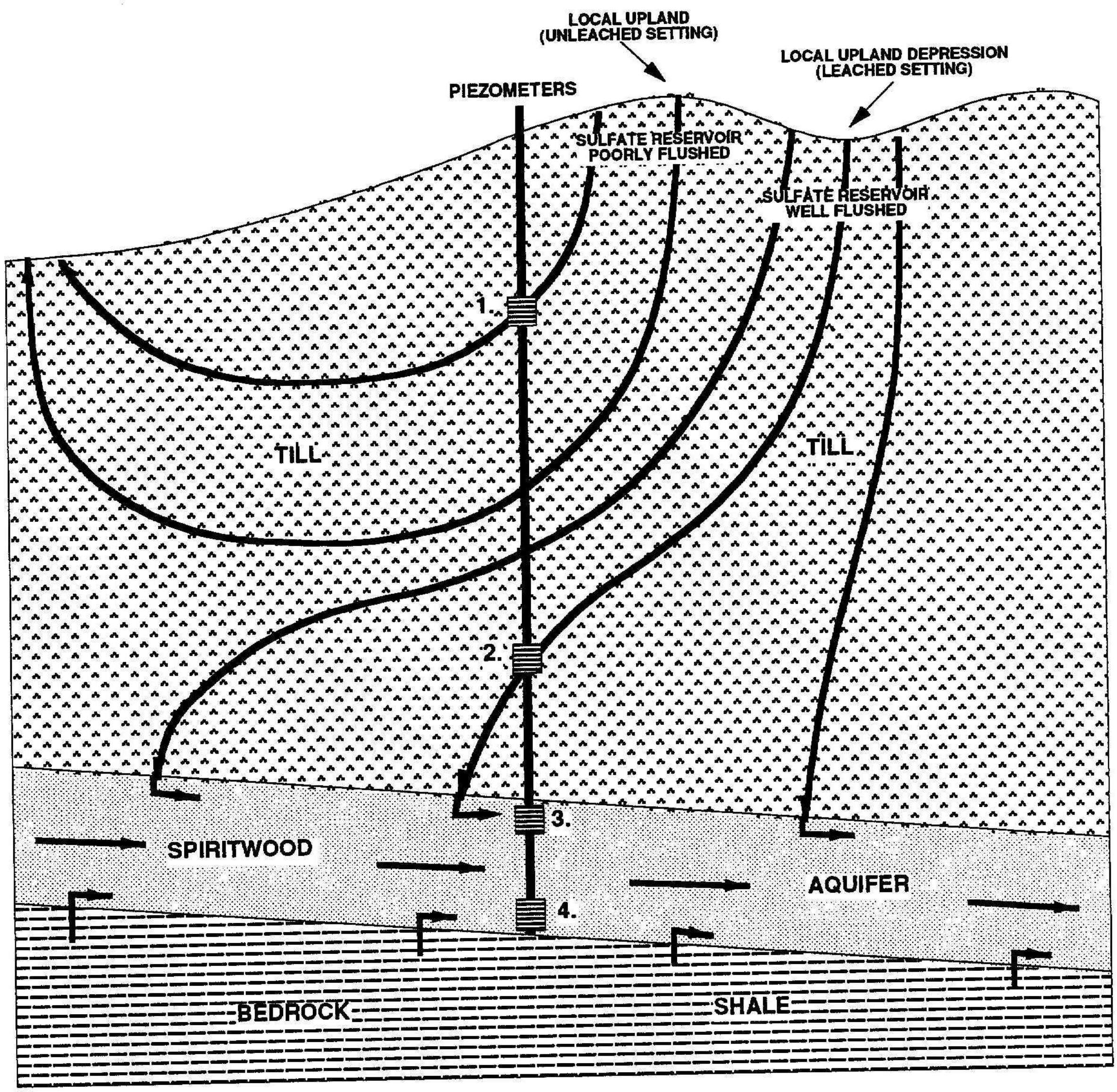


Figure 14. -- Schematic diagram of ground-water flow at piezometer nest 133-060-36DDD

36DDD5 may be completed in a shallow, poorly flushed flow cell in an "unleached" setting in the till (Fortin, and others, 1991). Piezometer 36DDD3 may be completed along a flow path originating at the water table in a "leached" setting where recharge is relatively large and the oxidized till/sulfate reservoir is well flushed (Fortin and others (1991). The smaller vertical hydraulic gradient between 36DDD5 and 36DDD3 as compared to that between 36DDD3 and 36DDD1 also suggests that DDD5 is located in an upper flow cell which maybe influenced to a greater degree by lateral flow-components (fig. 14).

The water chemistry in 36DDD1 and 2 (top and bottom of the Spiritwood aquifer, respectively) is a mixed cation to a sodium-bicarbonate type (fig. 12). Hydrochemical stratification is minor from top to bottom in the Spiritwood aquifer in this area.

The difference in hydrochemical facies between the deep till (36DDD3) and the top (36DDD1) and bottom (36DDD2) of the Spiritwood aquifer indicates downward movement of water through the till matrix into the Spiritwood aquifer is relatively minor in this area. From 36DDD3 to 36DDD1, sulfate decreases 7.7 epm. Neither gypsum precipitation (Table 6) or sulfate reduction is a plausible mechanism to account for the decreased sulfate.

Piezometer nest 133-060-36DDD is located about 1.6 km (1 mi.) south, southeast of an area where recharge to the Spiritwood aquifer through the overlying drift is relatively large (Shaver, 1984). The recharge area is a topographic upland comprised of surficial sand underlain by unoxidized till. In this area, the importance of the till/sulfate reservoir is diminished because the water table occurs within the overlying sand and the underlying till remains unoxidized. Test drilling also indicates that highly transmissive fluvial units occur throughout the overlying drift in this area and may enhance recharge downward to the underlying Spiritwood aquifer (Shaver, 1984, test hole 133-060-27DDD).

It is apparent from the spatial distribution of hydrochemical patterns at 133-060-36DDD that the recharge area located about 1.6 km (1 mi.) up gradient locally dominates the ground-water flow system in the Spiritwood aquifer. Recharge to the Spiritwood aquifer upward through the underlying bedrock shale and downward through the overlying till is relatively minor in this area.

Piezometer nest 132-059-17DCD

Water-Level Response

Piezometer 132-059-17DCD1 is screened from 57.3 to 58.8 m (188 to 193 ft.) below land surface in the bottom one-third of the Spiritwood aquifer, piezometer 17DCD2 is screened from 34.8 to 36.3 m (114 to 119 ft.) in till with thin sand and gravel layers, and piezometer 17DCD3 is screened from 17.7 to 19.2 m (58 to 63 ft.) in an undefined sand.

Hydrographs of the three piezometers are shown in figure 15. Water-level elevations decrease with increasing depth indicating downward ground-water flow. Based on water levels measured on April 22, 1987, the vertical hydraulic gradient between 17DCD3 and 17DCD2 was 0.14 and the vertical hydraulic gradient between 17DCD2 and 17DCD1 was 0.18. These vertical gradients are on the lower end of reported values in non-weathered tills (Table 4).

The hydrographs of all three piezometers were characterized by declining water levels during the summer and rising water levels during

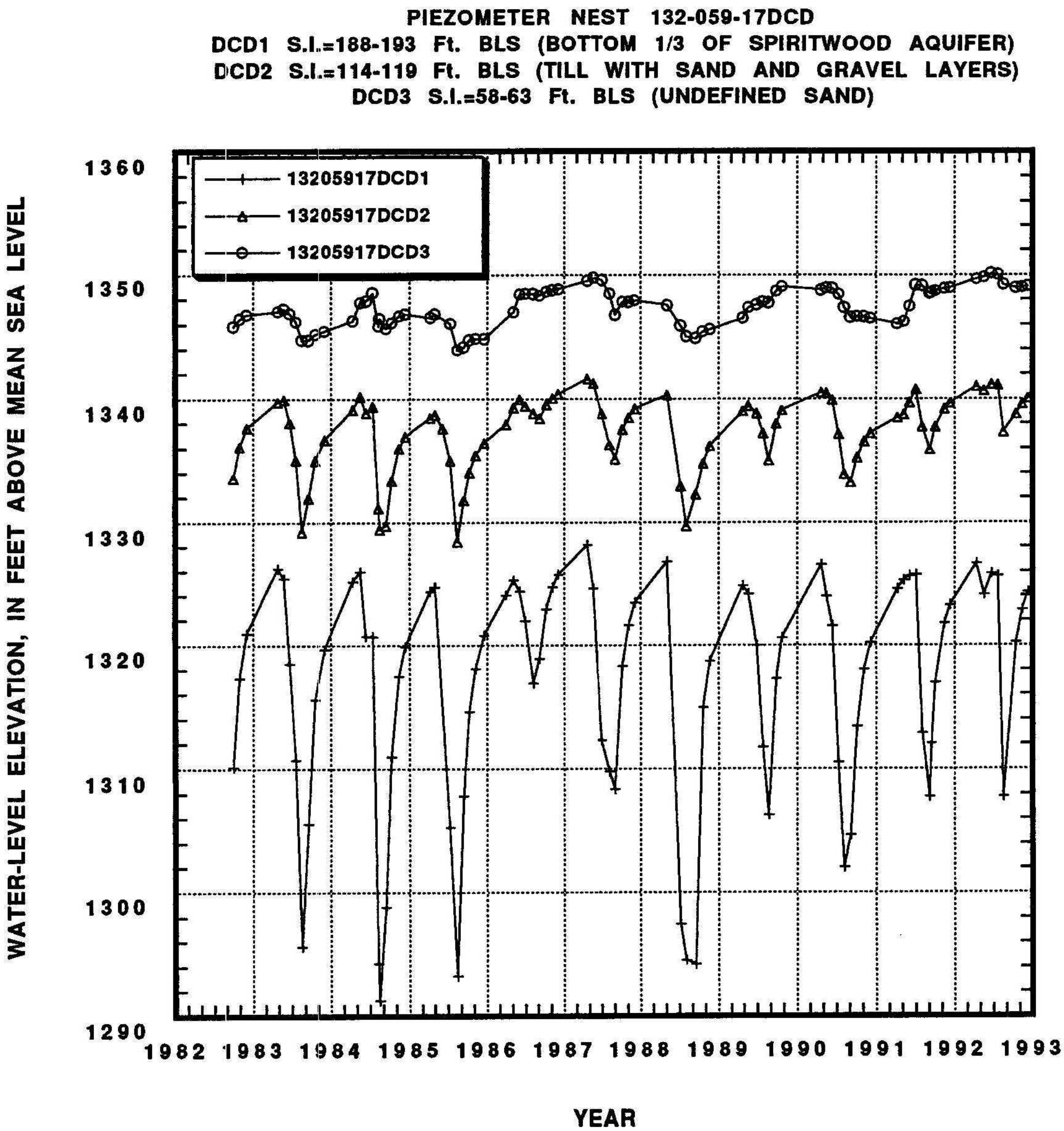


Figure 15.-- Hydrographs showing water levels at piezometer nest 132-059-17DCD

the fall, winter, and spring. Declining water levels during the summer in piezometers 17DCD1 were the result of irrigation withdrawals from the Spiritwood aquifer. The pattern of water-level fluctuations in 17DCD2 and to a lesser extent DCD3 are similar to those of 17DCD1, indicating upward propagation of drawdown and recovery into the till and undefined sand. The summer drawdown periods in 17DCD3 probably resulted from natural ground-water discharge at or near land surface and upward propagation of drawdown caused by irrigation pumping in the Spiritwood aquifer. Note that the magnitude of fall and winter recovery in 17DCD3 was much more subdued than that shown in 17DCD2. The magnitude of spring recovery in DCD3 is greater than that shown in 17DCD2. Both trends suggest that 17DCD3 was more responsive to surface and near surface recharge and discharge processes.

The previously described method of Bredehoeft and Hanshaw (1968) was used to estimate aquitard hydraulic diffusivity using water-level response in piezometer 17DCD2 (till) and piezometer 17DCD1 (bottom one-third of Spiritwood aquifer). The 1983 summer irrigation season was selected to apply this method because drawdown was relatively large in both piezometers. It was assumed that the maximum irrigation season drawdown 9.32 m (30.56 ft.) occurred as an "instantaneous" step drawdown (H_o) at time $t = 0$ (beginning of irrigation season). In reality the maximum drawdown 9.32 m (30.56 ft.) was not instantaneous as shown by the water-level hydrograph of piezometer 17DCD1 (fig.15). A more realistic H_o would be smaller than 9.32 m (30.56 ft). Using a larger H_o yields a more conservative (smaller) value of hydraulic diffusivity.

The calculated drawdown profile in the till aquitard above the Spiritwood aquifer at 132-039-17DCD is shown in figure 16. The actual maximum drawdown measured at piezometer 17DCD2 was 3.26 m (10.70 ft.) and was approximated analytically using a hydraulic diffusivity of 9.3 x 10^{-6} m^2/sec (8.75 $ft.^2$ day) (fig. 16). This hydraulic diffusivity is about 4.5 times the largest value in the range of hydraulic diffusivity reported by Van der Kamp and Maathius, (1986) (Table 3). The geologic log of 17CDD1 (Appendix I) indicates numerous sand and gravel layers in the till between 37.2 and 41.8 m (122 and 137 ft). The specific storage of this till interval would be smaller due to the occurrence of sand and gravel layers. In addition, if the sand and gravel layers are hydraulically connected, the vertical hydraulic conductivity would be larger. The combination of a larger hydraulic conductivity and a smaller specific storage could account for the above normal till hydraulic diffusivity calculated at this piezometer nest site.

A regression analysis of maximum annual (irrigation season) aquifer drawdown and aquitard drawdown is shown in figure 17. The analysis indicates that an instantaneous head change of at least 1.88 m (6.16 ft.) over a 100-day period in the Spiritwood aquifer is required to produce a head change at 17DCD2, 11.3 m (37 ft.) above the top of the Spiritwood aquifer.

The slope and y-intercept of the regression equation in figure 17 (piezometer nest 132-059-17DCD) are larger than those of the regression equation in figure 8 (piezometer nest 133-060-02CDD). This supports the anomalously large hydraulic diffusivity calculated at 133-060-02CDD. However, lithologic data at both piezometer nest sites suggests that the till hydraulic diffusivity at 133-060-02CDD should be

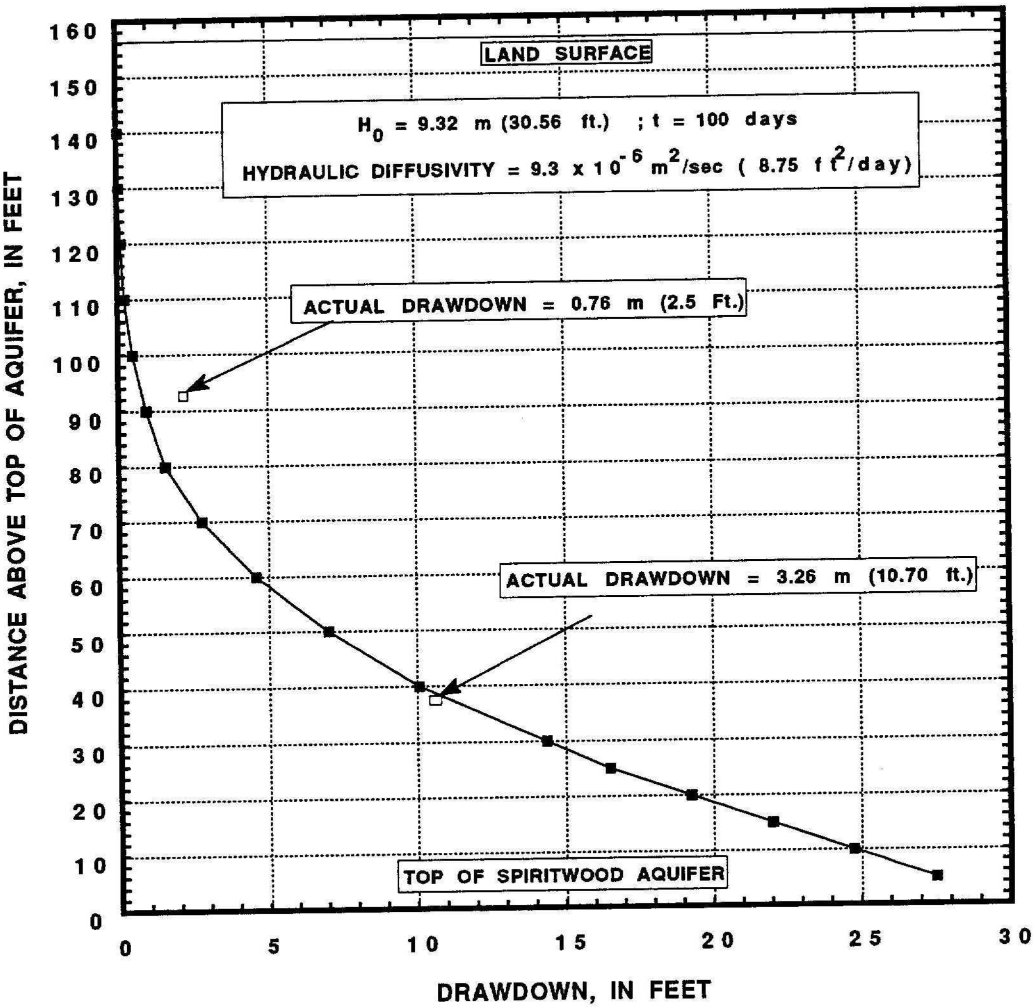


Figure 16. -- Vertical drawdown distribution in till at piezometer nest 132-059-17DCD computed using the stepped-drawdown analytical approach

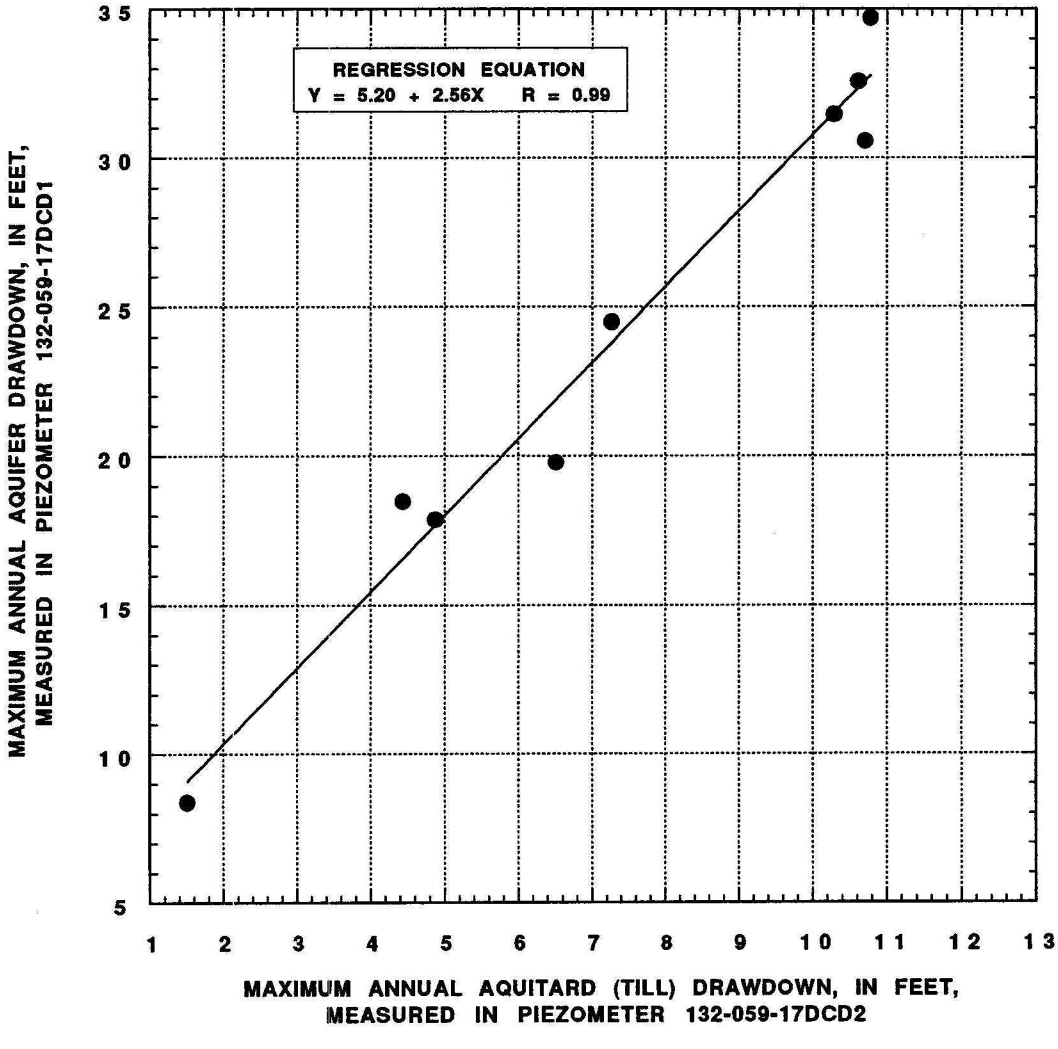


Figure 17.-- Regression analysis of measured drawdown response in the Spiritwood aquifer and overlying till at piezometer nest 132-059-17DCD

significantly less than that at 132-059-17DCD. The till at 133-060-02CDD, between 36.6 and 58.5 m (120 and 192 ft.) contains significantly fewer sand and gravel layers as compared to the till between 34.8 and 47.6 m (114 and 156 ft.) at 132-059-17DCD. The large apparent drawdown in the till at 133-060-02CDD3 and associated large apparent hydraulic diffusivity probably are the result of an ineffective annular seal for observation well 133-060-02CDD1. As previously mentioned, cement/bentonite grout was not injected into the annular area of this well. This open annular area may act as a large-transmissivity conduit that short circuits the till between piezometers 2CDD2 and 2CDD3. Observation well 133-060-02CDD1 should be reamed and re-drilled, and a piezometer should be installed in the same hole with a proper annular seal.

Water Chemistry

The relative distribution of cations and anions in piezometer nest 1323-059-17DCD is shown in figure 18, and the absolute distribution of cations and anions is shown in figure 19. Water in the upper, undefined sand (17DCD3) is a calcium-bicarbonate type with a mean-dissolved solids concentration of 631 mg/L (20 analyses). This hydrochemical facies is typical of shallow, glaciofluvial aquifers in Dickey, LaMoure, and Sargent Counties (Shaver, 1984; Shaver and Schuh, 1990).

The till at piezometer 17DCD2 is characterized by a mixed cation, bicarbonate type water with a mean dissolved-solids concentration of 796 mg/L (fig. 18). Dissolved-solids concentrations in this well are smaller than those associated with the deep till wells in piezometer nests 133-060-02CDD (CDD3) and 133-060-36DDD (DDD3). The deep till wells at

PIEZOMETER NEST 132-059-17DCD
DCD1 S.I.=188-192 Ft. BLS (BOTTOM 1/3 OF SPIRITWOOD AQUIFER)
DCD2 S.I.=114-119 Ft. BLS (TILL WITH SAND AND GRAVEL LAYERS)
DCD3 S.I.=58-63 Ft. BLS (UNDEFINED SAND)

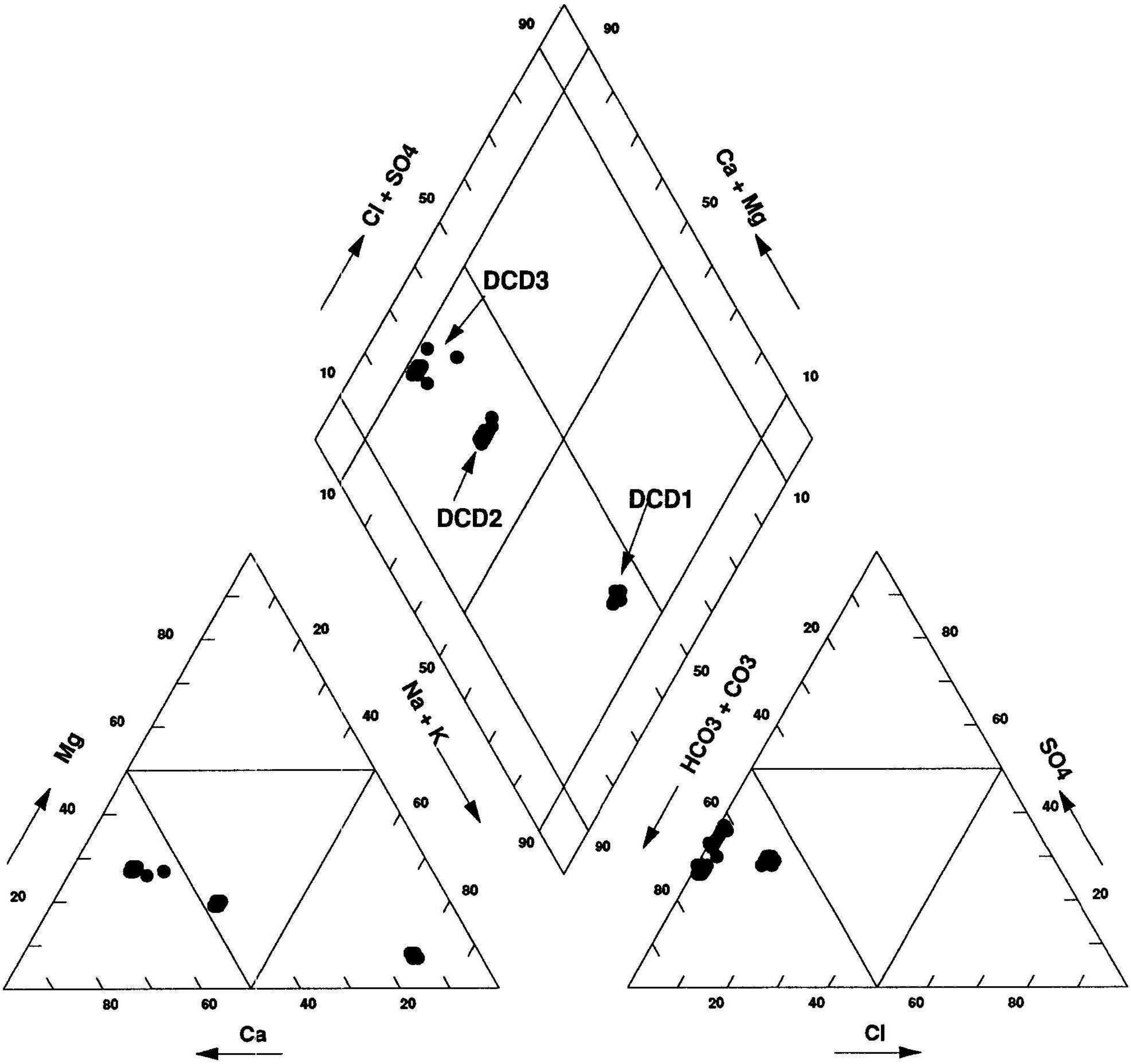


Figure 18.-- Piper trilinear diagram showing range in water chemistry at piezometer nest 132-059-17DCD

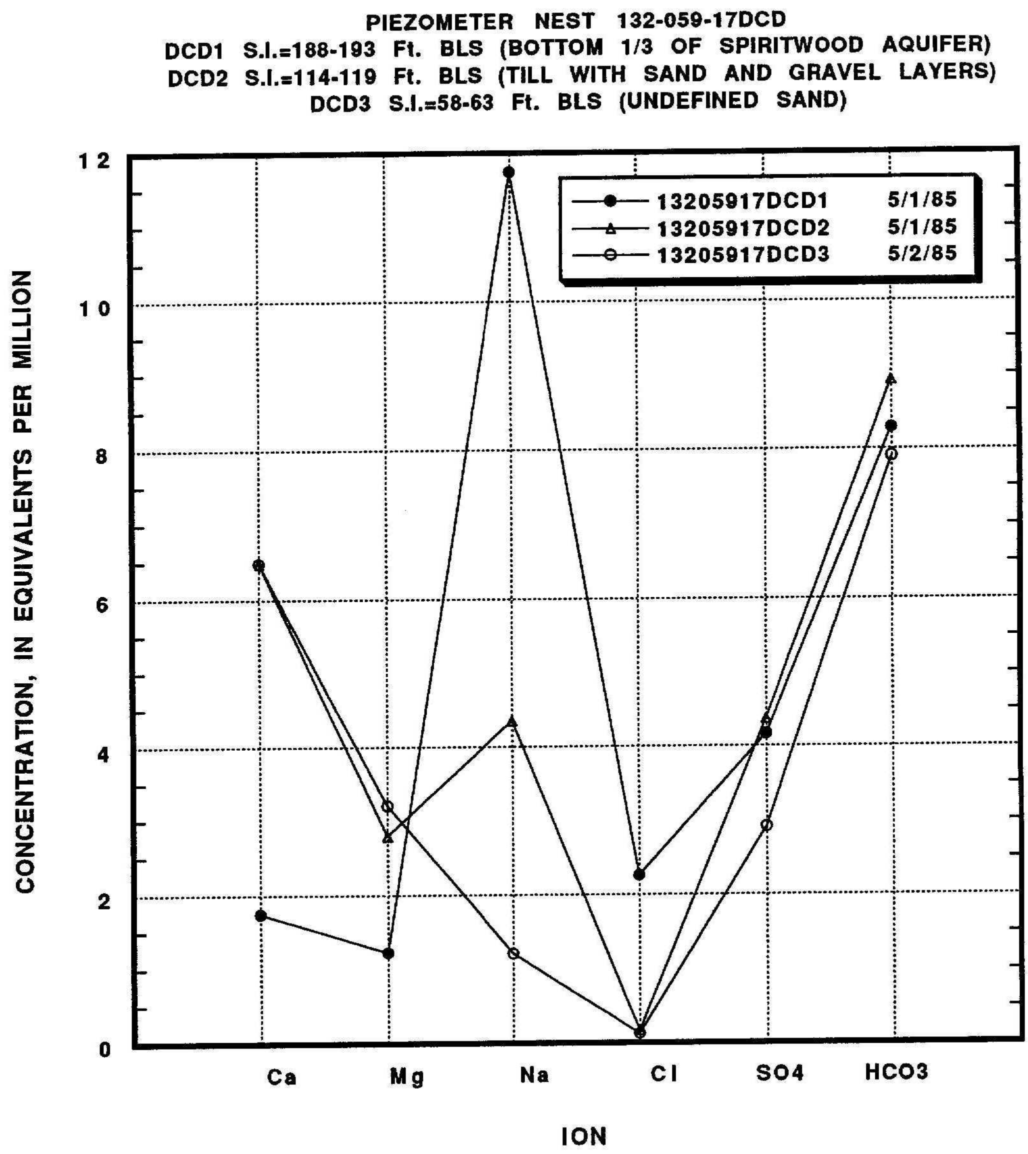


Figure 19.-- Schoeller diagram showing concentrations of selected ions at piezometer nest 132-059-17DCD

02CDD3 and 36DDD3 have larger sodium and sulfate concentrations than 17DCD2. In addition, the till wells at 02CDD3 and 36DDD3 are sulfate type waters. Except for the large difference in sodium between 17DCD2 and 17DCD3, the water chemistries are similar. Increased sodium from 17DCC1 to 17DCD2 may be due to cation exchange of calcium for sodium in the clays in the clayey silts and/or till. The fact that calcium concentrations are about the same in both piezometers does not negate cation exchange. Removal of calcium from solution during the exchange process can cause the solution to be undersaturated with respect to calcite. As a result, calcite, which is ubiquitous in the drift, may dissolve until saturation is attained. Calcite saturation is indicated by the saturation indices shown in Table 7. The increase in sulfate from 17DCD1 to 17DCD2 may be due to gypsum dissolution. Gypsum dissolution is thermodynamically plausible as indicated by the saturation indices in Table 7.

Unfortunately, a piezometer was not installed at the top of the Spiritwood aquifer at this nest site to compare water chemistry with that in the overlying till. Construction of a piezometer at the top of the Spiritwood Aquifer is planned for the 1994 field season.

The bottom one-third of the Spiritwood aquifer (17DCD1) is characterized by a sodium-bicarbonate type water with a mean dissolved-solids concentration of 899 mg/L (fig.18). The large sodium and chloride concentrations probably reflect upward movement of ground water into the bottom of the Spiritwood aquifer from the underlying Niobrara shale.

The occurrence of sandy, clayey, silts and numerous sand and gravel layers in the till at this nest site indicate a potential for more rapid downward ground-water movement to the Spiritwood aquifer. Both

Table 7. -- Calcite and gypsum saturation indices for piezometer nest 132-059-17DCD

PIEZOMETER	SCREENED INTERVAL (Ft. BLS)	SAMPLED 4/2/87		SAMPLED 5/4/87		SAMPLED 6/11/87	
		S.I. CALCITE	S.I. GYPSUM	S.I. CALCITE	S.I. GYPSUM	S.I. CALCITE	S.I. GYPSUM
132-059-17DCD1 BOTTOM 1/3 OF SPIRITWOOD AQUIFER	188-193	-0.698*	-1.666	0.122	-1.648	0.185	-1.648
132-059-17DCD2 TILL WITH SAND and GRAVEL LAYERS	114-119	0.353*	-1.146	0.029	-1.088	0.029	-1.088
132-059-17DCD3 UNDEFINED SAND	58-63	0.252*	-1.234	-0.095	-1.241	0.065	-1.246

[* possible pH meter malfunction and/or faulty pH reading]

[S.I. = Saturation Index]

drawdown response and minor differences in water chemistry at piezometers 17DCD2 and 17DCD3 support relatively rapid downward ground-water movement.

Piezometer nest 132-059-27CDC

Water-Level Response

Piezometer 131-059-27CDC1 is screened from 63.7 to 65.2 m (209 to 214 ft.) below land surface in the base of the Spiritwood aquifer, piezometer 27CDC2 is screened from 32.0 to 33.5 m (105 to 110 ft.) in the till, and piezometer 27CDC3 is screened from 45.7 to 47.3 m (150 to 155 ft.) in the top of the Spiritwood aquifer. Observation well 132-059-27CDD is screened in surficial Bear Creek valley alluvium (sand and gravel) about one-quarter of a mile east of piezometer nest 132-057-27CDC.

Hydrographs of the three piezometers are shown in figure 20. Water levels decreased with increasing depth through the till to the top of the Spiritwood aquifer. The water level in piezometer 27CDC3 (top of Spiritwood aquifer) generally was between 0.03 and 0.05 feet higher than that measured in piezometer 27CDC1 (bottom of Spiritwood aquifer). This head difference was within measurement and survey elevation error. Based on water levels measured on April 22, 1987, the vertical hydraulic gradient between 27CDC2 and 27CDC3 was 0.33, which is somewhat below the mid-range of values of non-weathered till shown in Table 4.

The hydrographs of piezometers 27CDC1 and 27CDC3 were characterized by declining water levels during the summer and rising water levels during the fall, winter and spring. Declining water levels during the summer were the result of irrigation withdrawals from the

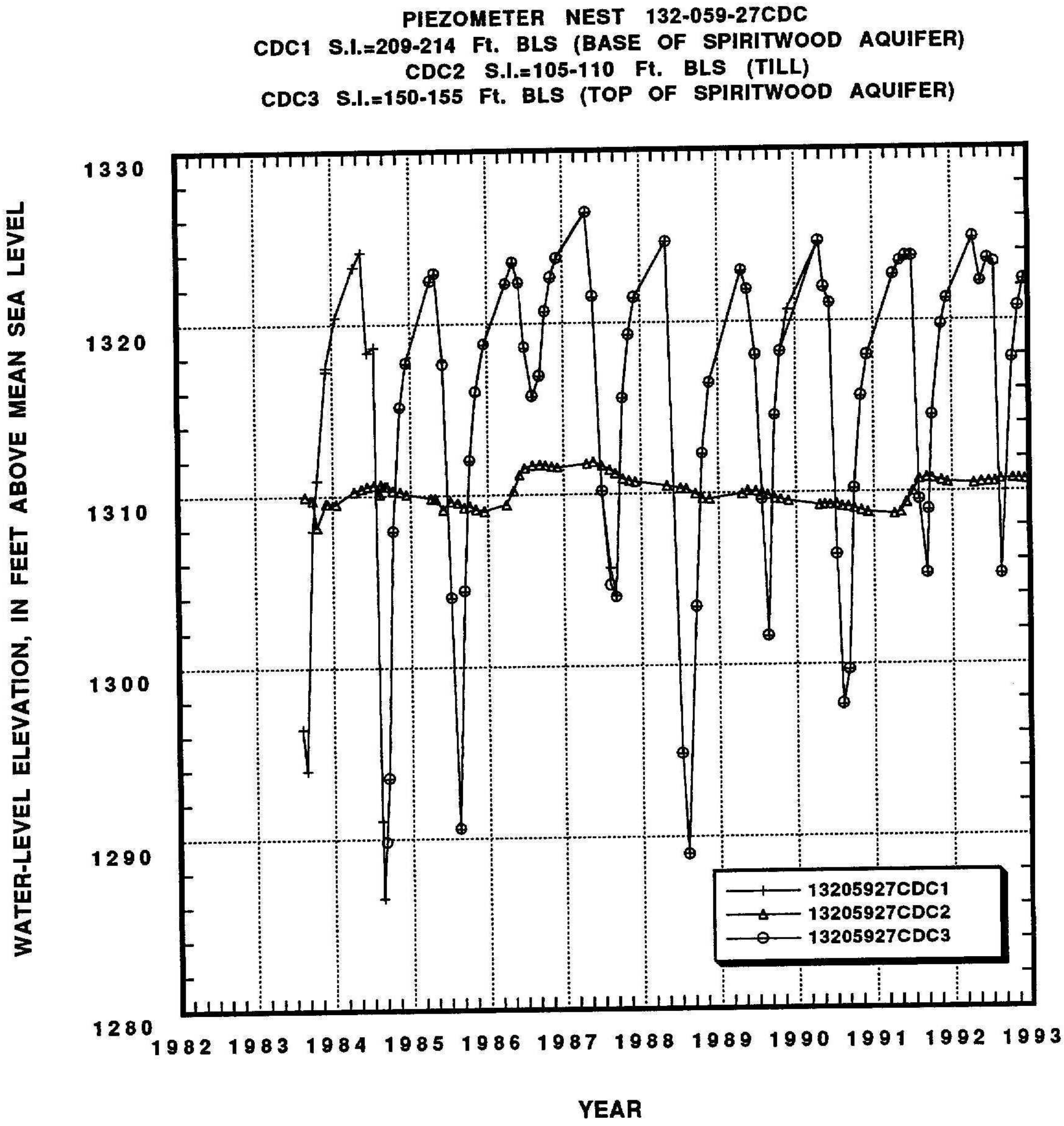


Figure 20.-- Hydrographs showing water levels at piezometer nest 132-059-27CDC

Spiritwood aquifer. The pattern of water-level fluctuation in 27CDC2 (till) was very different from that in piezometers 27CDC1 and 27CDC3 (Spiritwood aquifer). The upward propagation of the drawdown/recovery cycles in the Spiritwood aquifer was not evident in piezometer 27CDC2. This suggests a relatively small till hydraulic diffusivity between 32.0 and 44.8 m (105 and 147 ft.) below land surface.

The previously described method of Bredehoeft and Hanshaw (1968) was used to estimate the maximum till hydraulic diffusivity that would produce zero drawdown at 27CDC2 based on an H_0 of 11.9 m (39 ft.) and a 100-day pumping period. The calculated maximum hydraulic diffusivity is about 1.0 x 10-6 m^2/sec. (0.93 ft^2/day). This value is close to the upper limit of values reported by Van der Kamp and Maathius (1986).

Water Chemistry

The relative distribution of cations and anions in piezometer nest 132-059-27CDC and observation well 132-059-27CDD are shown in figures 21 and 22. The bottom of the Spiritwood aquifer (27CDC1) is characterized by a sodium-mixed anion type water with relatively large chloride concentrations. Sodium, and chloride occur in larger concentrations in piezometer 27CDC1 as compared with other piezometers in this nest. Ground water from the Niobrara Shale is a sodium-chloride-bicarbonate type (Shaver, 1984). The large sodium and chloride concentrations in piezometer 27CDC1 suggest upward movement of ground water into the bottom of the Spiritwood aquifer from the underlying Niobrara Shale.

PIEZOMETER NEST 132-059-27CDC
CDC1 S.I.=209-214 Ft. BLS (BASE OF SPIRITWOOD AQUIFER)
CDC2 S.I.=105-110 Ft. BLS (TILL)
CDC3 150-155 Ft. BLS (TOP OF SPIRITWOOD AQUIFER)
CDD S.I.= 49-54 Ft. BLS (BEAR CREEK VALLEY ALLUVIUM)

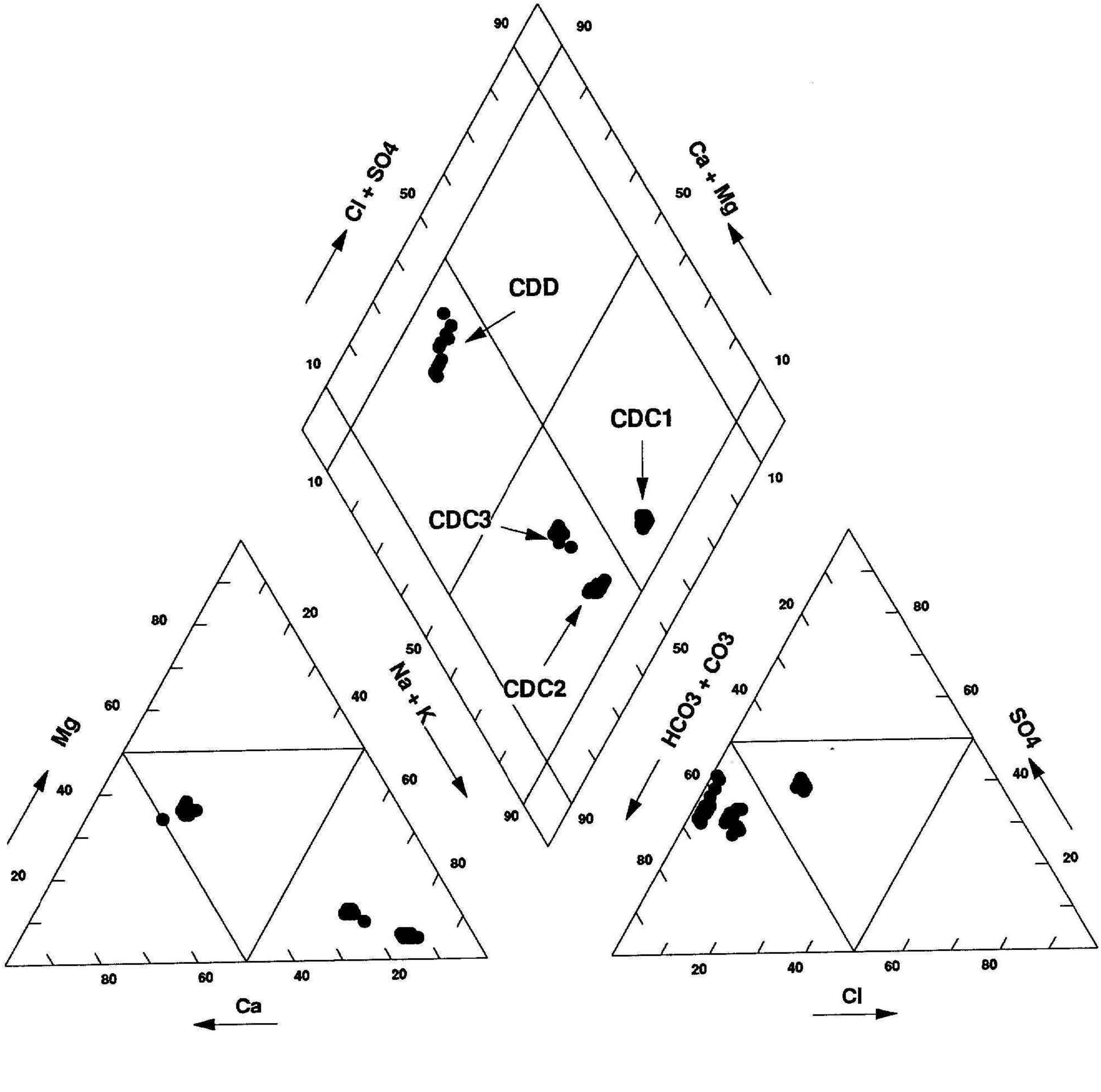


Figure 21.-- Piper trilinear diagram showing range in water chemistry at piezometer nest 132-059-27CDC and observation well 132-059-27CDD

PIEZOMETER NEST 132-059-27CDC
CDC1 S.I.=209-214 Ft. BLS (BASE OF SPIRITWOOD AQUIFER)
CDC2 S.I.=105-110 Ft. BLS (TILL)
CDC3 S.I.=150-155 Ft. BLS (TOP OF SPIRITWOOD AQUIFER)
CDD S.I.=49-54 Ft. BLS (BEAR CREEK VALLEY ALLUVIUM)

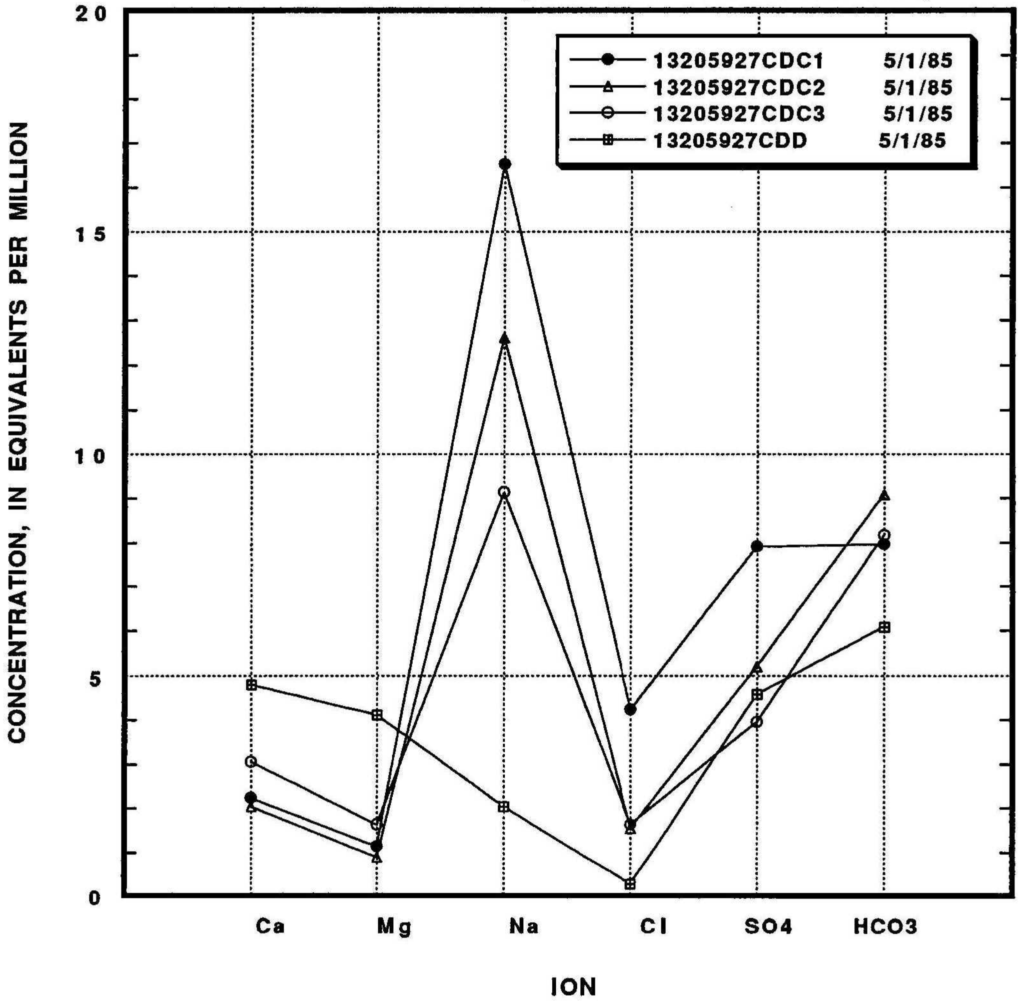


Figure 22.-- Schoeller diagram showing concentrations of selected ions at piezometer nest 132-059-27CDC

The top of the Spiritwood aquifer (27CDC3) is characterized by a sodium-bicarbonate type water. Both relative and absolute chloride are larger as compared to the top of the Spiritwood aquifer at other nest sites. Chloride diffusion from the bottom to the top of the Spiritwood aquifer at this nest site probably is the source of the relatively large chloride concentration at the top of the Spiritwood aquifer. Advection is not considered likely because the vertical hydraulic gradient, although very small, is downward from top to bottom in the Spiritwood aquifer at this nest site.

The till at 27CDC2 overlying the Spiritwood aquifer is characterized by a sodium-bicarbonate type water (fig. 21). Sodium concentration is larger than that in piezometer 27CDC3. Chloride concentration is about the same as that in piezometer 27CDC3. The chloride concentration in 27CDC2 is larger than that associated with other till piezometers at equivalent depths in the study area. This trend coupled with the direction of the hydraulic gradient between 27CDC3 and 27CDC2 indicate upward ground-water flow between these two piezometers.

Piezometer nest 132-059-27CDC is located about one-fourth mile east of Bear Creek. The elevation of Bear Creek, due west of 27CDC, is about 1290 feet above mean sea level. The potentiometric surface of the Spiritwood aquifer at 27CDC is about 1325 feet above mean sea level. Thus, Bear Creek represents a local discharge area to the Spiritwood aquifer (Shaver, 1984). Discharge to Bear Creek probably is small in relation to recharge from spring snowmelt and runoff. The Bear Creek valley alluvium at 27CDD is characterized by a mixed cation-bicarbonate type water with a mean dissolved-solids concentration (20 samples) of 582 mg/L. Chloride concentration is less than that in the till and top of the Spiritwood aquifer at piezometer nest 27CDC. The difference in water chemistry between Bear Creek valley alluvium and the till and top of the Spiritwood aquifer indicates that upward flow into Bear Creek valley from the underlying till is small.

Piezometer Nest 131-059-05BAA

Water-Level Response

Piezometer nest 131-059-05BAA3 was completed in 1982. Cement was injected into the annular areas of the piezometers using tremie pipes. Piezometer BAA1 is screened from 50.6 to 52.1 m (166 to 171 ft.) in the bottom one-third of the Spiritwood aquifer (which includes the cobbly, sand and gravel interbedded with clay or till); piezometer 5BAA2 is screened from 29.9 to 31.4 m (98 to 103 ft.) in till; and piezometer 5BAA3 is screened from 15.9 to 17.4 m (52 to 57 ft.) in a layer of very fine to medium sand.

Hydrographs of the three piezometers are shown in figure 23. Water-level elevations decrease with increasing depth indicating downward ground-water flow. The vertical hydraulic gradient measured on 4/87 between 05BAA2 and 05BAA3 was 0.03. These values are typical of vertical hydraulic gradients reported for fractured, weathered tills, generally less than 25 feet deep (Table 4). The pattern of water-level fluctuations in 5BAA2 and 5BAA3 are almost the same. The small vertical hydraulic gradient coupled with the similar pattern of water-level response suggest a hydraulic "short circuit" possibly caused by a faulty (leaky) annular well seal. The vertical hydraulic gradient measured on 4/87 between 5BAA2 and 5BAA1 ranged from 0.21 to 0.32. The smaller value (0.21) was calculated by adding 1.8 m (6 ft.) to the measured water

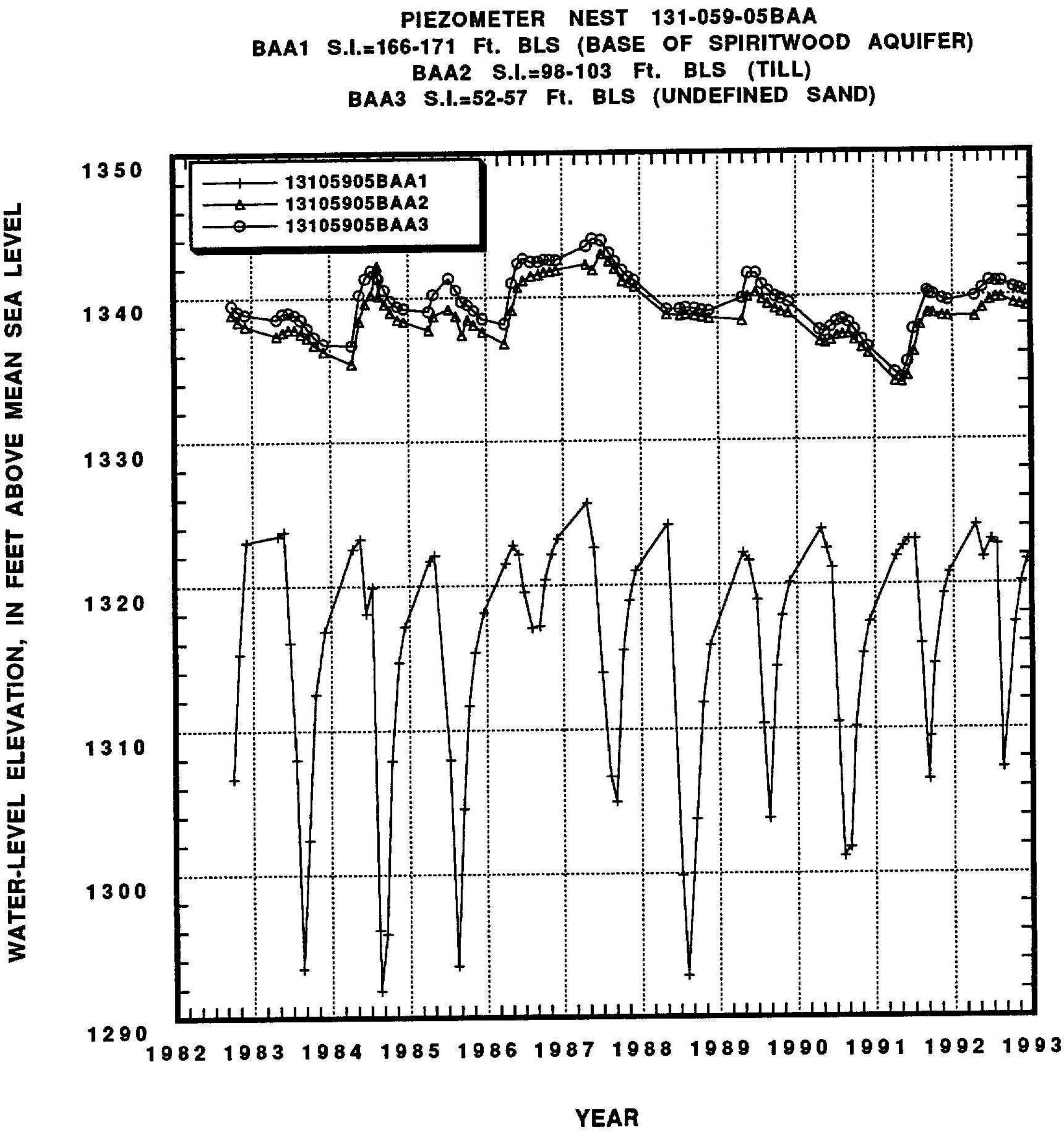


Figure 23.-- Hydrographs showing water levels at piezometer nest 131-059-05BAA

level in BAA1. The Spiritwood aquifer in this area has about 1.8 m (6 ft.) of residual drawdown since irrigation development began in 1975.

The hydrograph of piezometer 05BAA1 (Spiritwood aquifer) is characterized by declining water levels during the summer and rising water levels during the fall, winter, and spring. Declining water levels during the summer were the result of irrigation withdrawals from the Spiritwood aquifer. Till hydraulic diffusivity between the top of the Spiritwood aquifer and piezometer 5BAA2, based on water-level response in 5BAA2 was not considered valid because of the inferred leak in well annular area seals.

Water Chemistry

The relative distribution of cations and anions from water samples in piezometer nest 131-059-05BAA is shown in figure 24 and the absolute distribution of cations and anions is shown in figure 25. The upper, undefined sand (5BAA3) is characterized by a mixed cation-bicarbonate type water, with a mean dissolved-solids concentration (17 samples) of 486 mg/L. The deeper till (5BAA2) is characterized by a sodium-bicarbonate type water with a mean dissolved-solid concentration of 1,011 mg/L. The base of the Spiritwood aquifer (BAA1) is characterized by a sodium-bicarbonate type water with a mean dissolved-solids concentration of 795 mg/L.

The difference in water chemistry between piezometers 5BAA2 and 5BAA3 does not support an annular area/hydraulic "short circuit" between piezometers 5BAA2 and 5BAA3. The water chemistry of the deeper till (5BAA2) is similar to that in other deeper till piezometers that are characterized by smaller hydraulic diffusivities (i.e. drawdown/

PIEZOMETER NEST 131-059-05BAA
BAA1 S.I.=166-171 Ft. BLS (BASE OF SPIRITWOOD AQUIFER)
BAA2 S.I.=98-103 Ft. BLS (TILL)
BAA3 S.I.=52-57 Ft. BLS (UNDEFINED SAND)

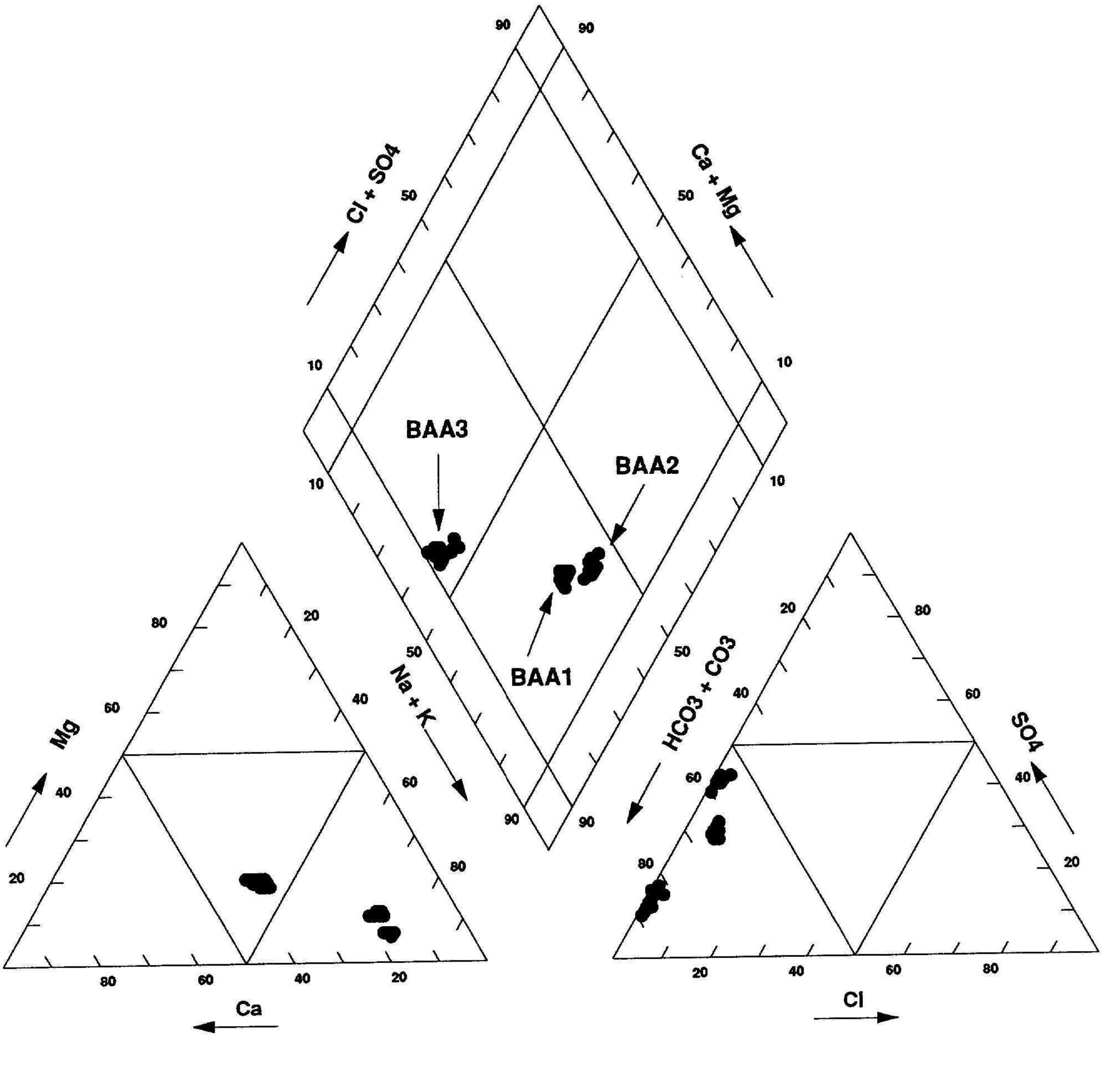


Figure 24.-- Piper trilinear diagram showing range in water chemistry at piezometer nest 131-059-05BAA

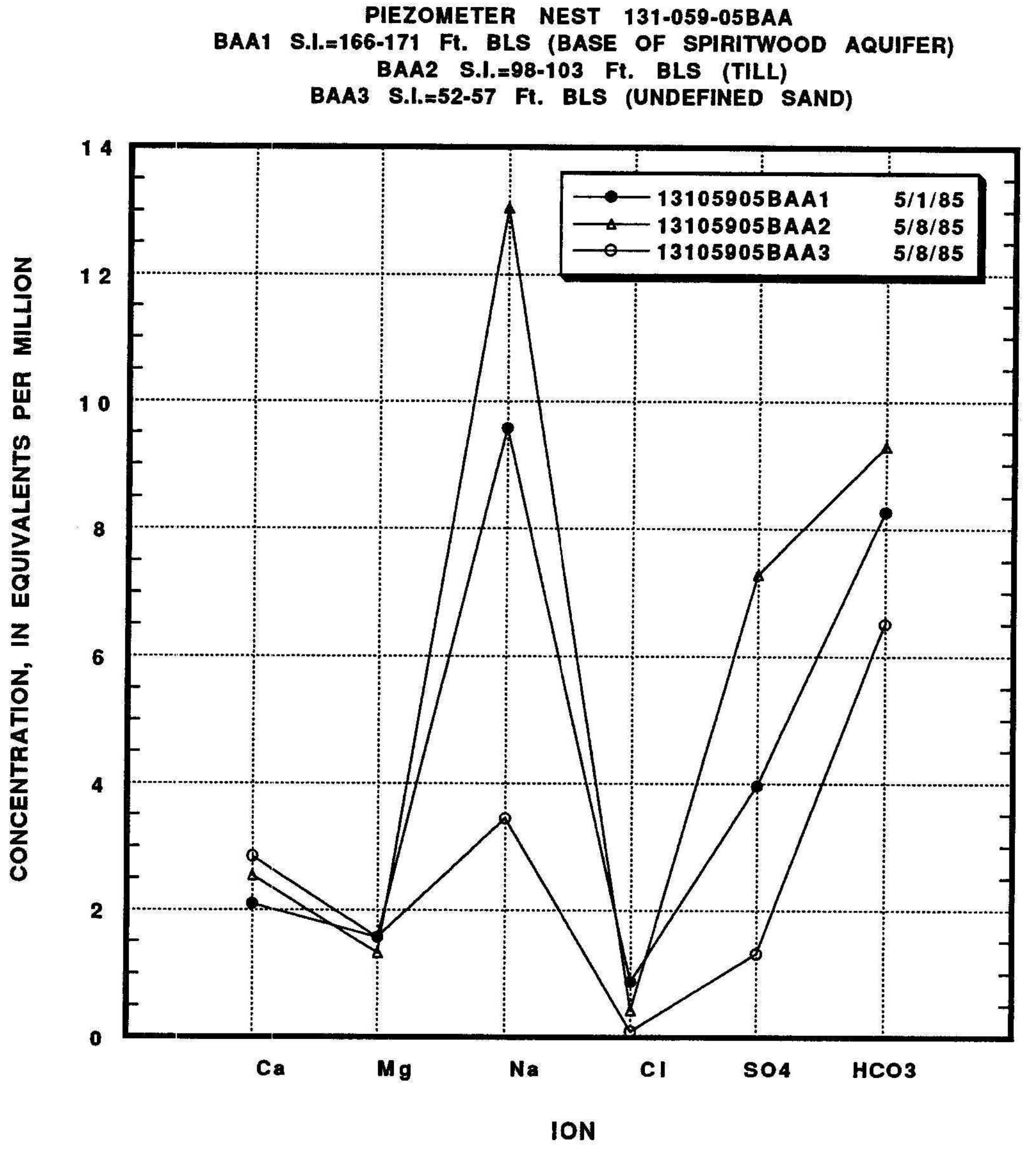


Figure 25.-- Schoeller diagram showing concentrations of selected ions at piezometer nest 131-059-05BAA

recovery in Spiritwood aquifer does not propagate upward into these till piezometers).

The difference in water chemistry between piezometers 5BAA2 (till) and 5BAA3 (bottom of Spiritwood aquifer) indicate that recharge to the Spiritwood aquifer from the overlying till at this site is relatively minor. From 5BAA2 to 5BAA1, dissolved solids concentrations decrease from about 1,011 mg/L to 795 mg/L. Both sodium and sulfate significantly decrease in concentration from 5BAA2 to 5BAA1 (fig. 25). Sinks for sodium and sulfate are not thermodynamically plausible (Table 8). As with other nest sites, sulfate reduction also is not considered plausible. At this site, the lower salinity water of the Spiritwood aquifer probably reflects the dominance of downward ground-water flow through relatively highly transmissive inhomogeneities in the overlying drift up-gradient from this piezometer nest.

Piezometer Nest 131-058-20DDD

Water-Level Response

Piezometer nest 131-058-20DDD was completed in the fall of 1989. Powdered bentonite, mixed with water to form a slurry, was injected into the annular areas of each piezometer to form a seal. Piezometer 20DDD1 is screened from 46.3 to 47.9 m (152 to 157 ft.) below land surface in the top of the Spiritwood aquifer, piezometer 20DDD2 is screened from 29.9 to 31.4 m (98 to 103 ft.) below land surface in till, and piezometer 20DDD3 is screened from 16.8 to 18.3 m (55 to 60 ft.) in an undefined esker comprised of sand and gravel.

Hydrographs of the three piezometers are shown in figure 26. During the spring, the water-level elevation in piezometer 20DDD3 was

Table 8. – Calcite and gypsum saturation indices for piezometer nest 131-059-05BAA

PIEZOMETER	SCREENED INTERVAL (Ft. BLS)	SAMPLED 4/2/87		SAMPLED 5/13/87		SAMPLED 6/10/87	
		S.I. CALCITE	S.I. GYPSUM	S.I. CALCITE	S.I. GYPSUM	S.I. CALCITE	S.I. GYPSUM
131-059-05BAA1 BOTTOM OF SPIRITWOOD AQUIFER	166-171	0.204	-1.580	0.117	-1.614	0.212	-1.610
131-059-05BAA2 TILL	98-103	0.243	-1.343	-0.034	-1.363	0.278	-1.360
131-059-05BAA3 UNDEFINED SAND	52-57	0.256	-1.936	0.249	-1.950	0.375	-1.907

[S.I. = Saturation Index]

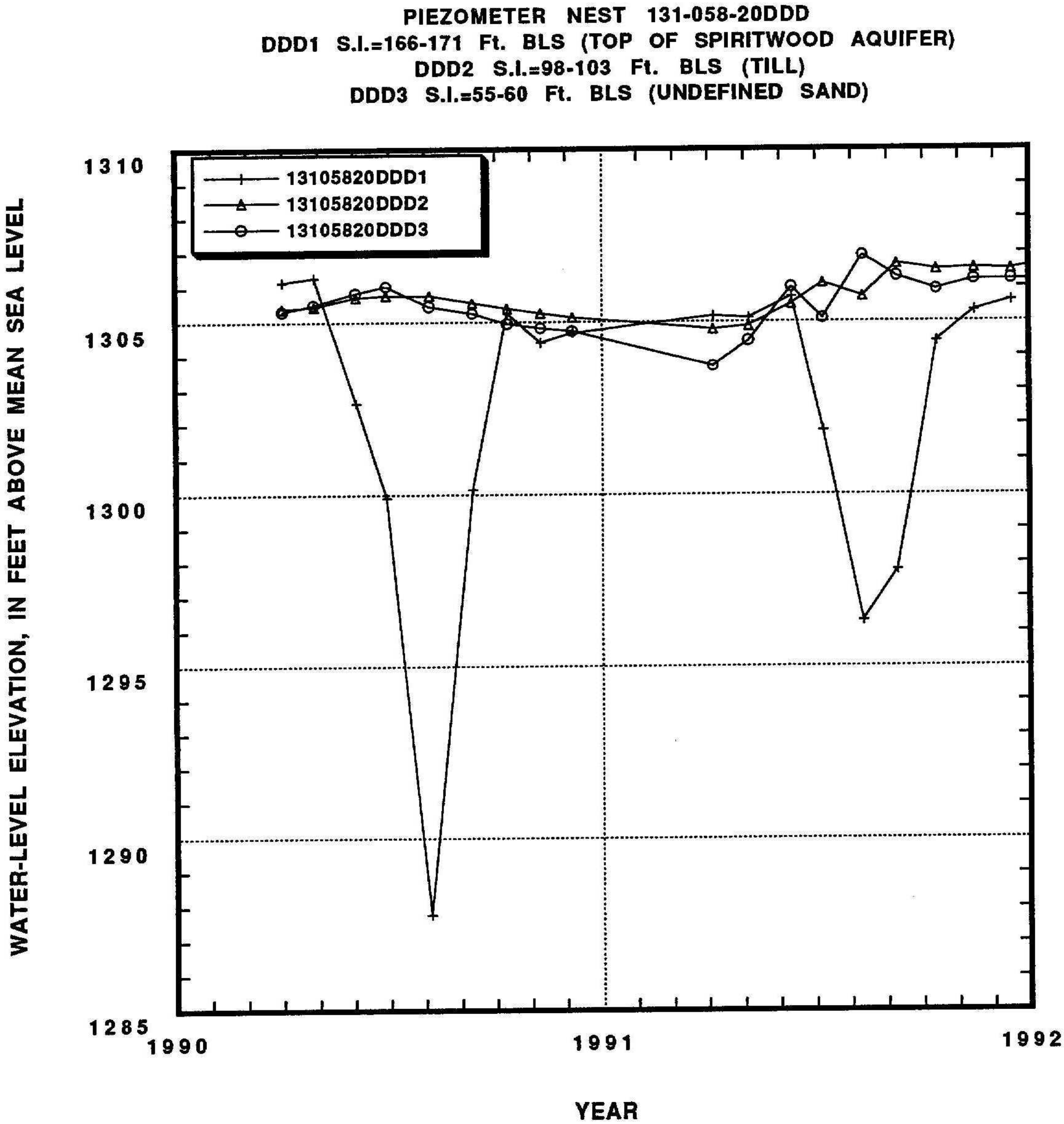


Figure 26.-- Hydrographs showing water levels at piezometer nest 131-058-20DDD

slightly higher than that in piezometer 20DDD2, indicating downward ground-water flow. During the summer, fall, and winter, the water-level elevation in piezometer 20DDD3 fell below that of piezometer 20DDD2 indicating upward ground-water flow. The maximum downward vertical hydraulic gradient was 0.028 measured on August 11, 1991 and the maximum upward vertical hydraulic gradient measured on April 6, 1991 was 0.024. These values fall within the range of hydraulic gradients reported for weathered, fractured tills less than about 15.2 m (50 ft.) deep. The change in direction of vertical hydraulic gradient between the two piezometers coupled with the relatively small absolute values of hydraulic gradient suggest that the volume of downward and upward ground-water flow through the till interval between 18.9 and 30.5 m (62 and 100 ft.) is small.

During the spring, the water-level elevation in piezometer 20DDD1 was slightly higher than that in piezometer 20DDD2 indicating upward ground-water flow. During the summer, when pumping for irrigation begins, the water-level elevation in piezometer 20DDD1 fell well below that in piezometer 20DDD2 indicating downward ground-water flow. Prior to irrigation development in the mid 1970s the water-level elevation in the Spiritwood aquifer probably was consistently above those in piezometers 20DDD2 and 20DDD3, indicating upward ground-water flow.

The drawdown/recovery cycles in 20DDD1 (Spiritwood aquifer) caused by irrigation pumping did not propagate upward to any significant degree in piezometer 20DDD2 (till). The previously described method of Bredehoeft and Hanshaw (1968) was used to estimate the maximum till hydraulic diffusivity that would produce zero drawdown at

20DDD2 based on an H_o of 5.6 m (18.5 ft.) and a 100-day pumping period. The calculated maximum hydraulic diffusivity is 1.7 x 10^{-6} m^2/sec (1.58 ft^2/day). This value is just above the high end of the range in values reported by Van der Kamp and Maathius (1986) (Table 3).

Water Chemistry

The relative distribution of cations and anions in piezometer nest 131-058-20DDD is shown in figure 27 and the absolute distribution of cations and anions is shown in figure 28. The surficial, eskerine sand and gravel (20DDD3) is characterized by a mixed cation-bicarbonate type water with a dissolved-solids concentration of 667 mg/L. The till at 20DDD2 is characterized by a sodium-sulfate-bicarbonate type water with a dissolved solids concentration of 1080 mg/L. The top of the Spiritwood aquifer is characterized by a sodium-bicarbonate type water with a dissolved-solids concentration of 602 mg/L.

The difference in hydrochemical facies between the till (20DDD2) and the top of the Spiritwood aquifer (20DDD1) indicates downward movement of water through the till matrix into the Spiritwood aquifer is relatively minor in this area. From 20DDD2 to 20DDD1, sulfate decreases about 5 epm. As with piezometer nest 133-060-36DDD, neither gypsum precipitation (Table 9) or sulfate reduction is a plausible mechanism to account for the decreased sulfate. From 20DDD2 to 20DDD1, sodium decreases about 8 epm. Precipitation of highly soluble sodium sulfate and chloride minerals is not a plausible mechanism to account for the decreased sodium. An up-gradient recharge area probably provides the low dissolved-solids concentration water in the Spiritwood aquifer at 20DDD1.

PIEZOMETER NEST 131-058-20DDD
DDD1 S.I.=152-157 Ft. BLS (TOP OF SPIRITWOOD AQUIFER)
DDD2 S.I.=98-103 Ft. BLS (TILL)
DDD3 S.I.=55-60 Ft. BLS (UNDEFINED SAND)

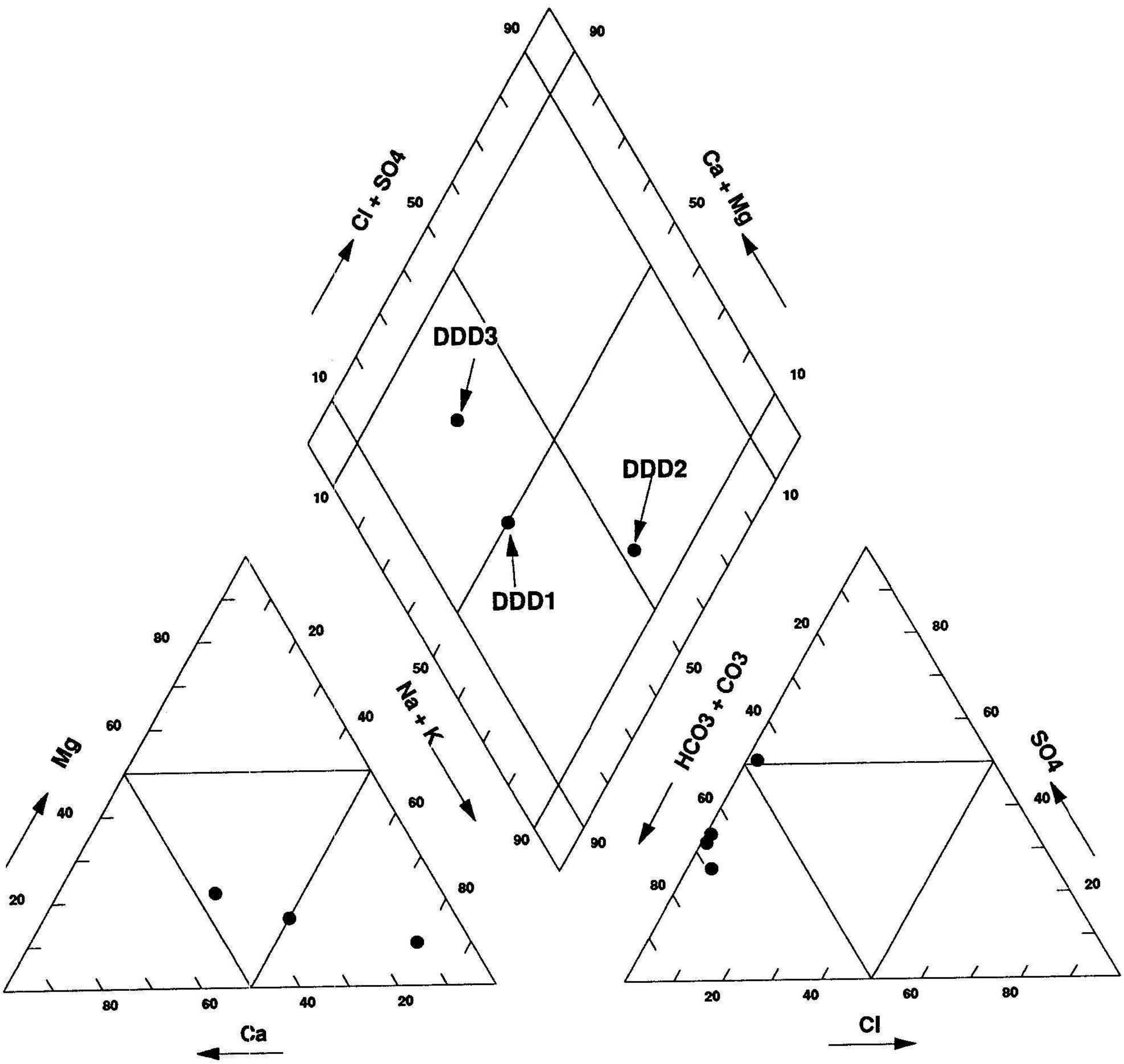


Figure 27.-- Piper trilinear diagram showing range in water chemistry at piezometer nest 131-058-20DDD

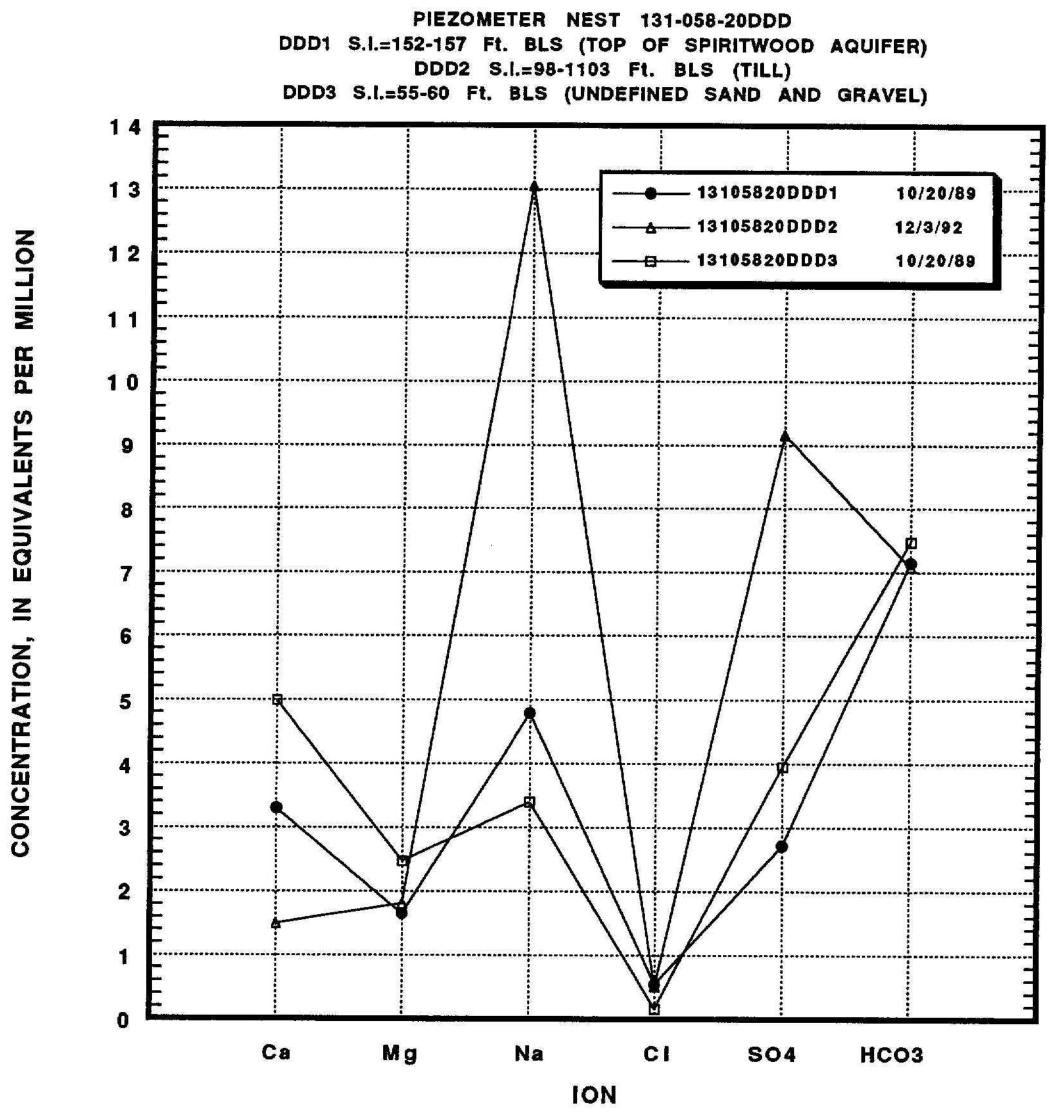


Figure 28.-- Schoeller diagram showing concentrations of selected ions at piezometer nest 131-058-20DDD

Table 9. -- Gypsum saturation indices for piezometer nest 131-058-20DDD

PIEZOMETER	SCREENED INTERVAL (Ft. BLS)	S.I. GYPSUM
131-058-20DDD1 TOP OF SPIRITWOOD AQUIFER	152-157	-1.562
131-058-20DDD2 TILL	98-103	-1.523
131-058-20DDD3 UNDEFINED SAND and GRAVEL	55-60	-1.272

[S.I. = Saturation Index]

Piezometer Nest 131-058-25CCC

Water-Level Response

A bentonite grout slurry was injected into the annular space of the piezometers at 131-058-25CCC using 3.18 cm (1 1/4 in.) diameter PVC tremie pipe. Piezometer 25CCC1 is screened from 62.5 to 64.0 m (205 to 210 ft.) at the base of the Spiritwood aquifer; piezometer 25CCC2 is screened from 50.6 to 52.1 m (166 to 171 ft.) near the top of the Spiritwood aquifer; piezometer 25CCC3 is screened from 31.1 to 32.6 m (102 to 107 ft.) in a sequence of sandy, clayey, silts and sandy, silty, clays; and piezometer 25CCC4 is screened from 5.5 to 7.0 m (18 to 23 ft.) at the till/silty clay contact. Till only occurs from land surface to between 4.6 to 6.1 m (15 to 20 ft.). Otherwise, the Spiritwood aquifer is overlain predominantly by the sandy, silty, clay/sandy, clayey, silt sequence at this site.

Hydrographs of the four piezometers are shown in figure 29. Water-level elevations decrease with increasing depth indicating downward ground-water flow. Based on water levels measured on June 11, 1991, the vertical hydraulic gradient between 25CCC4 and 25CCC3 was 0.03 and the vertical hydraulic gradient between 25CCC3 and 25CCC2 was 0.05. Both values fall within the range reported by Simpkins and Bradbury (1992), for a weathered and fractured till less than 10 meters deep. The relatively small vertical hydraulic gradients at this nest site with depth probably were not caused by fractures but rather the relatively large primary hydraulic conductivity associated with the sandy, clayey, silt/sandy, silty, clay sequence.

The hydrographs of piezometers 25CCC1 and 25CCC2 are characterized by declining water levels during the summer and rising

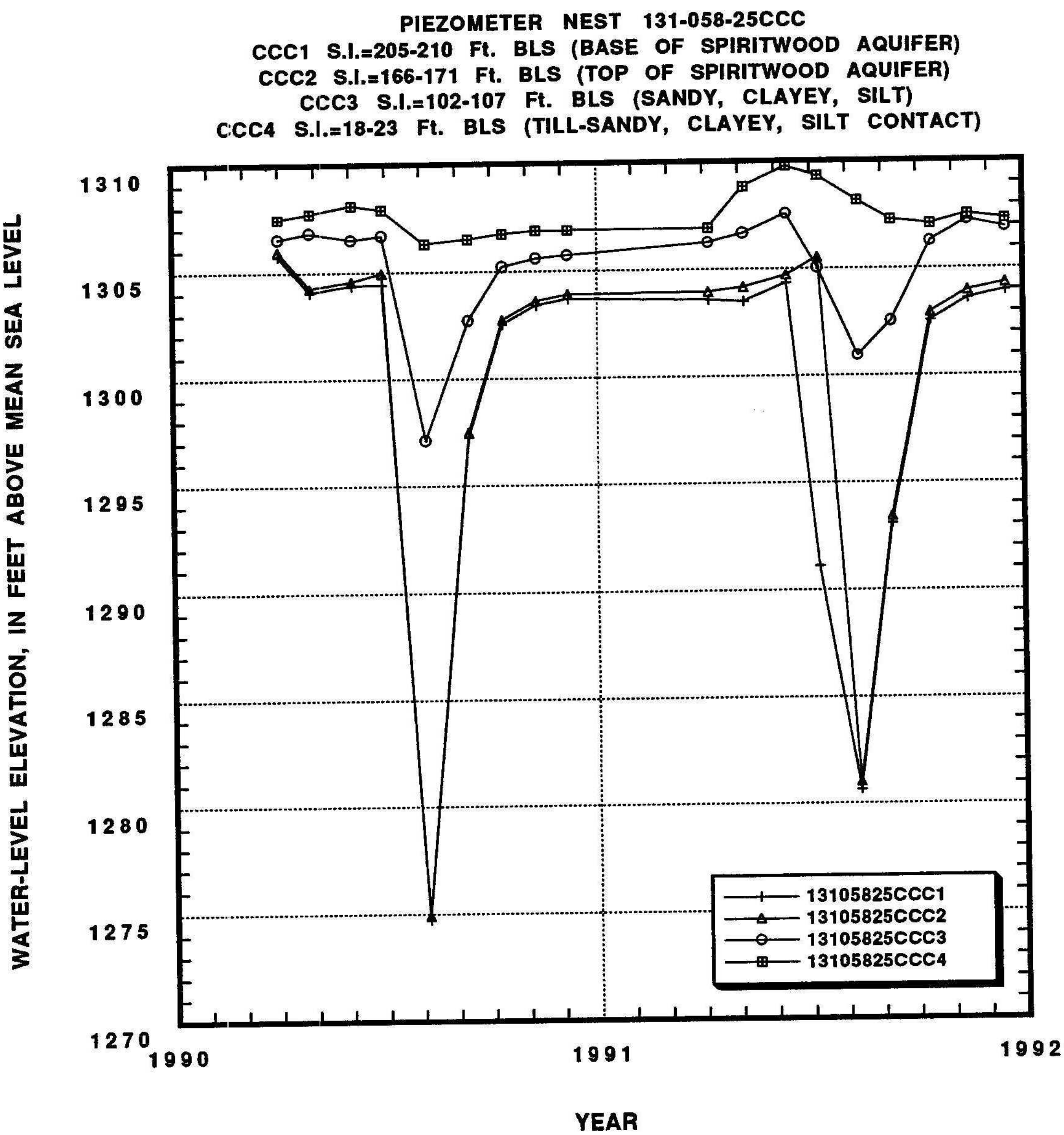


Figure 29.-- Hydrographs showing water levels at piezometer nest 131-058-25CCC

water levels during the fall, winter, and spring. Declining water levels during the summer were the result of irrigation withdrawals from the Spiritwood aquifer. The pattern of water-level fluctuations in 25CCC3 suggests a relatively large hydraulic diffusivity between 32.6 and 49.1 m (107 and 161 ft.).

The previously described methods of Bredehoeft and Hanshaw (1968) was used to estimate aquitard hydraulic diffusivity using water-level response in piezometer 25CCC2 (top of Spiritwood aquifer) and piezometer 25CCC3 (sandy, clayey, silt/sandy, silty, clay). The 1990 summer irrigation season was selected to apply this method because the drawdown was the largest in both piezometers (fig. 29). It was assumed that the maximum irrigation season drawdown 9.15 m (30.02 ft.) occurred as an "instantaneous" step drawdown (H_0) at time $t = 0$ (beginning of irrigation season). In reality, the maximum drawdown 9.15 m (30.02 ft.) was not instantaneous as shown by the water-level hydrograph of piezometer 25CCC2 (fig. 29). A more realistic H_0 would be smaller than 9.15 m (30.02 ft.). Using a larger H_0 yields a more conservative (smaller) value of hydraulic diffusivity.

The calculated drawdown profile in the sandy, clayey, silt/sandy, silty, clay aquitard above the Spiritwood aquifer at 131-058-25CCC is shown in figure 30. The actual maximum drawdown measured at piezometer 25CCC3 was 2.96 m (9.72 ft.) and was approximated analytically using a hydraulic diffusivity of 1.81×10^{-5} m^2/sec (16.8 ft^2/ day). This value is about one-half the value for till reported by Keller (1985) and about one order of magnitude larger than the value for till reported by Van der Kamp and Maathius, (1986) (Table 3). The larger calculated hydraulic diffusivity probably reflects the larger primary

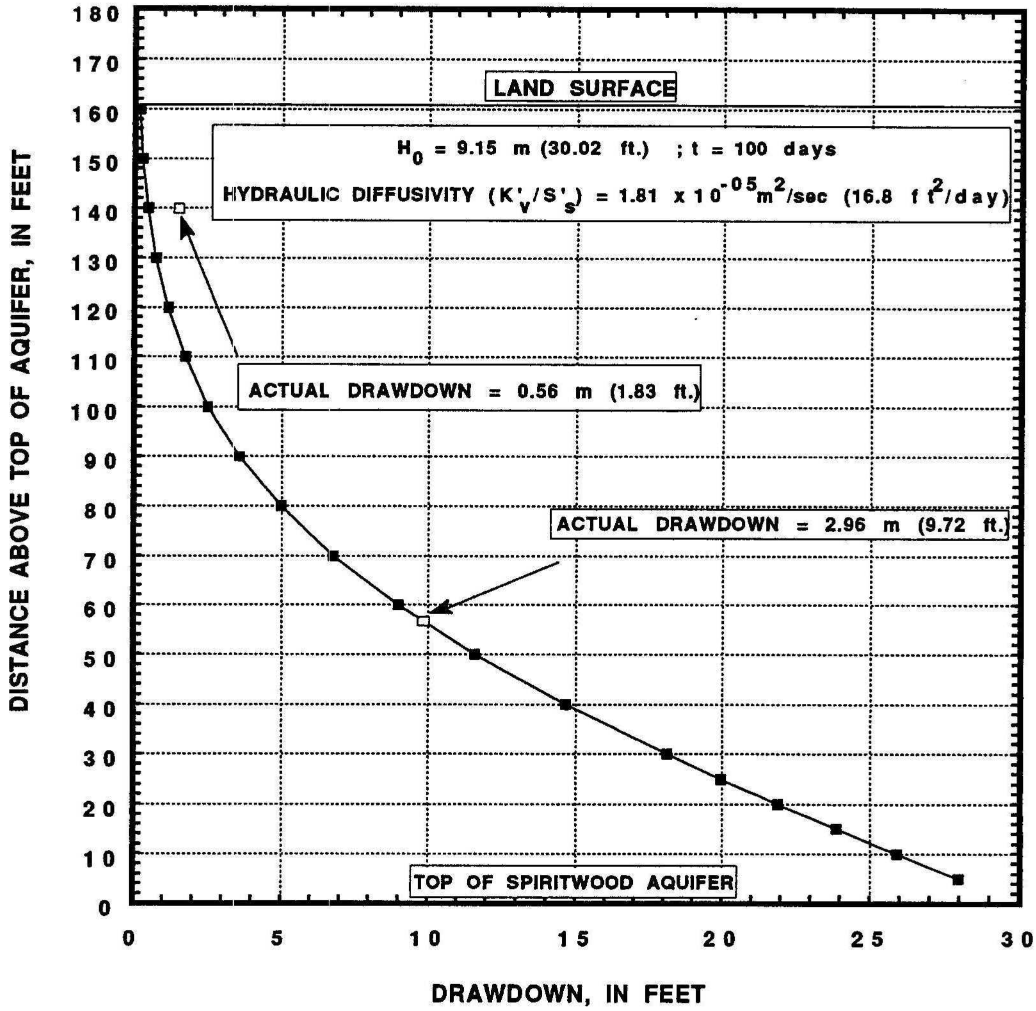


Figure 30. -- Vertical drawdown distribution in till at piezometer nest 131-058-25CCC computed using the stepped-drawdown analytical approach

hydraulic conductivity associated with the sandy, clayey, silt/sandy, silt, clay sequence.

The magnitude of drawdown in piezometer 25CCC4 was larger than the calculated drawdown using the previously described analytical method (fig. 30). The pattern of water-level fluctuations in 25CCC4 to a large extent is controlled by recharge/discharge processes that occur at or near land surface and as a result probably mask the small drawdown/recovery component propagating upward from the Spiritwood aquifer.

Water Chemistry

The relative distribution of cations and anions in piezometer nest 131-058-25CCC is shown in figure 31 and the absolute distribution of cations and anions is shown in figure 32. The shallow till and sandy clayey silt/silty clay contact at piezometer 25CCC4 is characterized by a calcium-sulfate type water with a dissolved-solids concentration of 1,600 mg/L. The sandy, clayey, silt at 25CCC3 is characterized by a calcium-bicarbonate type water with a dissolved-solids concentration of 755 mg/L. Water from 25CCC3 had 6.98 epm less calcium, 5.99 epm has less magnesium, and 14.57 epm less sulfate. Significant downward movement of ground water from 25CCC4 to 25CCC3 is not plausible based on the differences in water chemistry. The decrease of 14.57 epm sulfate is not due to precipitation of gypsum or other more soluble gypsum minerals because water in 25CCC3 and 25CCC4 is undersaturated with respect to gypsum (Table 10). In addition, sulfate reduction is not considered plausible because a large increase in calcium and bicarbonate does not occur. Piezometer 25CCC4 probably is

PIEZOMETER NEST 131-058-25CCC
CCC1 S.I.=205-210 Ft. BLS (BASE OF SPIRITWOOD AQUIFER)
CCC2 S.I.=166-171 Ft. BLS (TOP OF SPIRITWOOD AQUIFER)
CCC3 S.I.=102-107 Ft. BLS (SANDY, CLAYEY, SILT)
CCC4 S.I.=18-23 Ft. BLS (CONTACT BETWEEN TILL AND SANDY, CLAYEY, SILT)

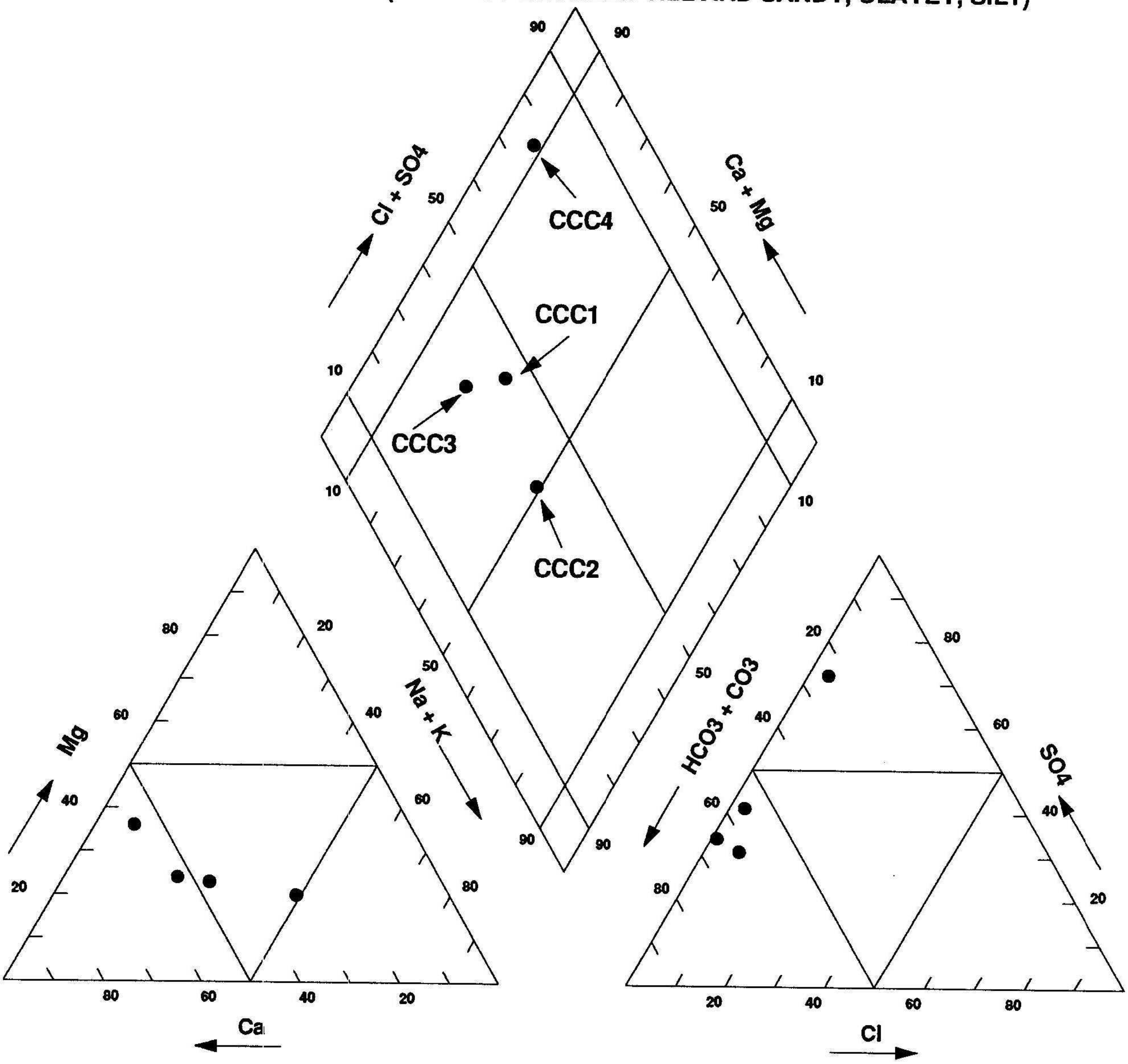


Figure 31.-- Piper trilinear diagram showing range in water chemistry at piezometer nest 131-058-25CCC

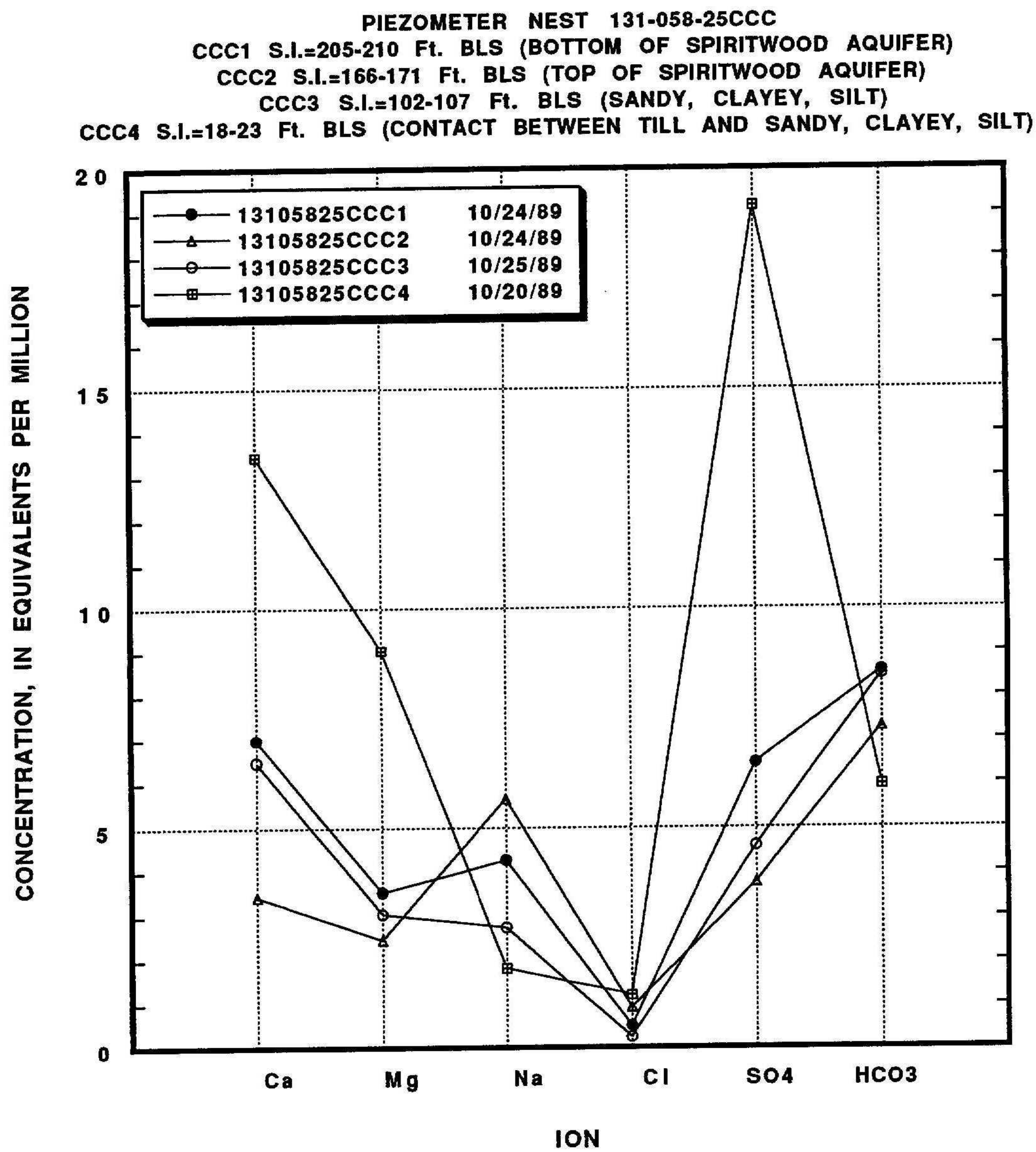


Figure 32.-- Schoeller diagram showing concentrations of selected ions at piezometer nest 131-058-25CCC

Table 10. -- Gypsum saturation indices for piezometer nest 131-058-25CCC

PIEZOMETER	SCREENED INTERVAL (Ft. BLS)	SAMPLED 4/2/87 S.I. GYPSUM
131-058-25CCC1 BOTTOM OF SPIRITWOOD AQUIFER	205-210	-0.971
131-0058-25CCC2 TOP OF SPIRITWOOD AQUIFER	166-171	-1.377
131-058-25CCC3 SANDY, CLAYEY, SILT	102-107	-1.114
131-058-25CCC4 TILL - SANDY, CLAYEY, SILT CONTACT	18-23	-0.415

[S.I. = Saturation Index]

completed in a shallow flow system that is uncoupled from the intermediate depth flow system in which piezometer 25CCC3 is completed. The local ground-water flow system may be similar to the schematic diagram shown in figure 14, for piezometer nest 133-060-36DDD.

The water chemistry in piezometer 25CCC1 (base of the Spiritwood aquifer) is more similar to 25CCC3 (overlying sandy, clayey, silt/silty, clay) than 25CCC2 (top of the Spiritwood aquifer) (figs. 31 and 32). In addition, the chloride concentration in 25CCC2 is larger than that in 25CCC1. Piezometers completed at the base of the Spiritwood aquifer generally show larger chloride concentrations due to upward ground-water flow through bedrock shale. No explanation for this water chemistry pattern is apparent.

Summary of Vertical Hydraulic Gradients, Hydraulic Diffusivity, and Water Chemistry in Piezometer Nests

Vertical Hydraulic Gradients

Except for land-surface topographic low areas (Bear Creek valley, Lake Taayer, Dill and Pickell Sloughs) vertical hydraulic gradients in unoxidized, non-weathered till and other clayey aquitards overlying the Spiritwood aquifer were downward (Table 11). In areas characterized by downward flow, vertical hydraulic gradients generally were greater than 0.10 and correspond to the lower range of values reported by other investigators for non-weathered till (Table 4).

The smaller vertical hydraulic gradient in the upper till at site 131-059-05BAA may be due to lateral flow components or a leak in one or more of the piezometer annular areas. The smaller vertical hydraulic

Table 11. -- Vertical hydraulic gradients in aquitards overlying the Spiritwood aquifer study area

PIEZOMETER NEST	PIEZOMETERS USED TO COMPUTE GRADIENTS	LITHOLOGIES ACROSS WHICH GRADIENT MEASURED	DATE MEASURED	VERTICAL HYDRAULIC GRADIENT
134-061-13DAD	DAD2 - DAD3	TILL	5/87	0.34
133-060-02CDD	CDD4 - CDD3	TILL	5/87	0.28
	CDD3 - CDD2	TILL	5/87	0.20* and 0.27
133-060-36DDD	DDD5 - DDD3	TILL	4/87	0.15
	DDD3 - DDD1	TILL	4/87	0.20* and 0.27
132-059-17DCD	DCD3 - DCD2	SANDY, CLAYEY, SILT/ SILTY CLAY	4/87	0.14
	DCD2 - DCD1	TILL WITH SAND AND GRAVEL LAYERS	4/87	0.10* and 0.18
132-059-27CDC	CDC2 - CDC3	TILL AND SANDY, SILTY, CLAY	4/87	-0.33 and -0.45*
131-059-05BAA	BAA3 - BAA2	TILL AND CLAYEY SILT/ SILTY CLAY	4/87	0.03
	BAA2 - BAA1	TILL	4/87	0.21* and 0.32
131-058-20DDD	DDD3 - DDD2	TILL	6/91 and 8/91	0.03 and -0.02
	DDD2 - DDD1	TILL	4/87	-0.02 and -0.11**
131-058-25CCC	CCC4 - CCC3	SANDY, CLAYEY, SILT/ SILTY CLAY	6/91	0.03
	CCC3 - CCC2	SANDY, CLAYEY, SILT/ SILTY CLAY	6/91	0.05 and -0.02**

[NEGATIVE VALUES INDICATE UPWARD GRADIENTS]

* POTETIOMETRIC SURFACE ELEVATION OF SPIRITWOOD AQUIFER CORRECTED FOR A 6 -FOOT RESIDUAL DRAWDOWN

** POTENTIOMETRIC SURFACE ELEVATION OF SPIRITWOOD AQUIFER CORRECTED FOR A 4-FOOT RESIDUAL DRAWDOWN gradient between the surficial sand and upper till at site 131-058-20DDD may be due to lateral flow components within the surficial sand. The surficial sand is an eskerine feature situated in a land-surface topographic low area and is characterized by a relatively large transmissivity. Rapid discharge from evapotranspiration probably causes lower water levels in relation to the surrounding till. The smaller vertical hydraulic gradient associated with the deeper till at 131-058-20DDD may also be indicative of very small upward and downward ground-water flow. Surficial recharge probably is diverted laterally along the narrow eskerine sand thereby reducing downward flow through the till. Finally, the smaller vertical hydraulic gradient in the upper till at site 131-058-25CCC also probably is caused by lateral flow components in the surficial sandy, silty, clay/sandy, clayey, silt. The larger salinity water at the top of the sandy, silty, clay/sandy, clayey, silt unit supports this conclusion.

Hydraulic Diffusivity

Calculated hydraulic diffusivity values at each piezometer nest site are shown in Table 12. Three of the seven deeper aquitard piezometers respond to pumping and recovery in the underlying Spiritwood aquifer. The anomalously large drawdown/recovery response and associated large hydraulic diffusivity at 133-060-02CDD3 probably are due to a leaky annular area in a nearby observation well in the piezometer nest. The large hydraulic diffusivity at 132-060-17DCD probably is the result of sand and gravel layers in the till. These sand and gravel layers may provide a better hydraulic connection to the underlying Spiritwood aquifer. Finally, the larger hydraulic diffusivity at 131-058-25CCC

Table 12. -- Hydraulic diffusivity of overlying aquitards in the Spiritwood aquifer study area

PIEZOMETER NEST	PIEZOMETER	LITHOLOGY	HYDRAULIC DIFFUSIVITY
133-060-02CDD	02CDD3	TILL	8.3 E-05 m2/sec ** (77.5 ft2/day)
133-060-36DDD	36DDD3	TILL	< 5.1 E-06 m2/sec (<4.7 ft2/day)
132-059-17DCD	17DCD2	TILL with SAND and GRAVEL LAYERS	9.3 E-06 m2/sec (8.7 ft2/day)
132-059-27CDC	27CDC2	TILL	<1 E-06 m2/sec (<0.9 ft2/day)
131-059-05BAA	05BAA2	TILL	<1.7 E-06 m2/sec (<1.6 ft2/day)
131-058-20DDD	20DDD2	TILL	<1.7 E-06 m2/sec (<1.6 ft2/day)
131-058-25CCC	25CCC3	SANDY, CLAYEY, SILT/ SILTY, SANDY, CLAY	1.8 E-05 m2/sec (16.8 ft2/day)

** This value is anomalously large and probably is due to a leaky annular area in observation well 02CDD1.

probably reflects the larger hydraulic conductivity associated with a sandy, clayey, silt/sandy, silty, clay sequence.

Maximum hydraulic diffusivities were calculated at the four till piezometers that did not respond to pumping in the Spiritwood aquifer. These hydraulic diffusivities represent the maximum values that would produce a zero drawdown in the deepest piezometer till with a stepped-head decline equal to the 100-day decline (H_0) in the underlying Spiritwood aquifer. They are within the range of hydraulic diffusivities reported by Van der Kamp and Maathius (1986) shown in Table 3.

Water Chemistry

In areas where the till is relatively homogeneous and characterized by downward vertical hydraulic gradients, greater than about 0.10, ground-water sulfate concentrations are significantly larger in the till as compared to the underlying Spiritwood aquifer (Table 13). In addition, dissolved-solids concentrations at the top of the Spiritwood aquifer are less than dissolved-solids concentrations in the overlying till (Table 13). This suggests recharge through the till matrix is small and that recharge to the Spiritwood aquifer occurs primarily through larger transmissivity conduits that "short circuit" the till.

ANALYSIS OF THE POTENTIOMETRIC SURFACE IN THE SPIRITWOOD AQUIFER STUDY AREA

Analysis of the shape and configuration of a potentiometric surface in an aquifer can be useful in locating transmissivity discontinuities (Shaver and Pusc, 1992), changes in transmissivity, recharge and discharge areas. In addition, potentiometric data coupled with aquifer

Table 13. -- Mean dissolved-solids and sulfate concentration in the top of the Spiritwood aquifer and overlying till

PIEZOMETER NEST	SPIRITWOOD AQUIFER PIEZOMETER	DISSOLVED SOLIDS	SULFATE	TILL PIEZOMETER	DISSOLVED SOLIDS	SULFATE
133-060-02CDD	CDD2	885	291	CDD3	959	397
133-060-36DDD	DDD1	547	81	DDD3	1121	484
131-059-05BAA	BAA1	795	191	BAA2	1011	332
131-059-20DDD	DDD1	602	130	DDD2	1080	440

geometry and hydraulic conductivity data can be used to calculate recharge or discharge using the Darcy approach ($Q = KIA$).

Hydraulic properties in the Spiritwood aquifer study area are summarized in Table 14. These values were calculated using aquifer test analytical methods and are the basis for the following Darcy analyses.

Between LaMoure and Verona, the Spiritwood aquifer consists of two discrete buried valleys separated by a narrow bedrock shale divide. The predominant direction of ground-water flow is southeast (figs. 33 and 34). Southeast of Twin Lakes to about the center of Township 133 North, the horizontal hydraulic gradient in both buried valley aquifers is small. In the western buried valley aquifer, the hydraulic gradient between 134-60-32DDD and 133-59-19ABB is about 7.1×10^{-6}. In the eastern buried valley aquifer, the hydraulic gradient between 134-060-26DCC and 133-059-15AAA is about 2.3×10^{-5}. The small hydraulic gradients in these areas of the Spiritwood aquifer suggest that recharge to the aquifer is small.

Assuming an average hydraulic gradient of 7.1×10^{-6} on the upper reach of the western buried valley aquifer, an average valley width of about 3.6 km (2.2 mi.) an average aquifer thickness of 10.7 m (35 ft.), and an average aquifer hydraulic conductivity of about 143 m/day (470 ft/day), the cross-sectional flow (perpendicular to principal flow direction) is about 40 m^3/day (1,400 ft^3/day).

The contributing recharge area overlying this part of the aquifer is estimated at about 41 km^2 (16 mi^2). Assuming a total flux of 40 m^3/day (1,400 ft^3/day) over a 41 km^2 (16 mi^2) area with a vertical hydraulic gradient of 0.2 through the overlying till, the Darcy equation ($K = Q/IA$) yields a vertical till hydraulic conductivity of 5.4×10^{-11} m/sec (1.5 x

Table 14. -- Hydraulic properties calculated from aquifer tests in the Spiritwood aquifer study area

TEST SITE	AQUIFER THICKNESS (FT)	TRANSMISSIVITY (FT2/DAY)	HYDRAULIC CONDUCTIVITY (FT/DAY)	STORAGE COEFFICIENT	SPECIFIC STORAGE (FT-1)
JOHN VCULEK RESPONSE TEST 131-059-11AAC	37	20,000	540	0.00024	6.5 E-06
DENNIS RONEY AQUIFER TEST 131-059-22BDA	42	25,000	595	0.0002	4.8 E-06
ORIN STREICH RESPONSE TEST 131-059-16CCC	43	18,000	419	0.0002	4.7 E-06
CURT KNUTSON AQUIFER TEST 132-059-21CBD	90	37,700	420	0.0002	2.2 E -06
WILLIAM HUETHER AQUIFER TEST 134-060-36CCB	49	18,500	380	0.0004	8.2 E-06
AVERAGE VALUES	52	24,000	470	0.00025	5.3 E-06

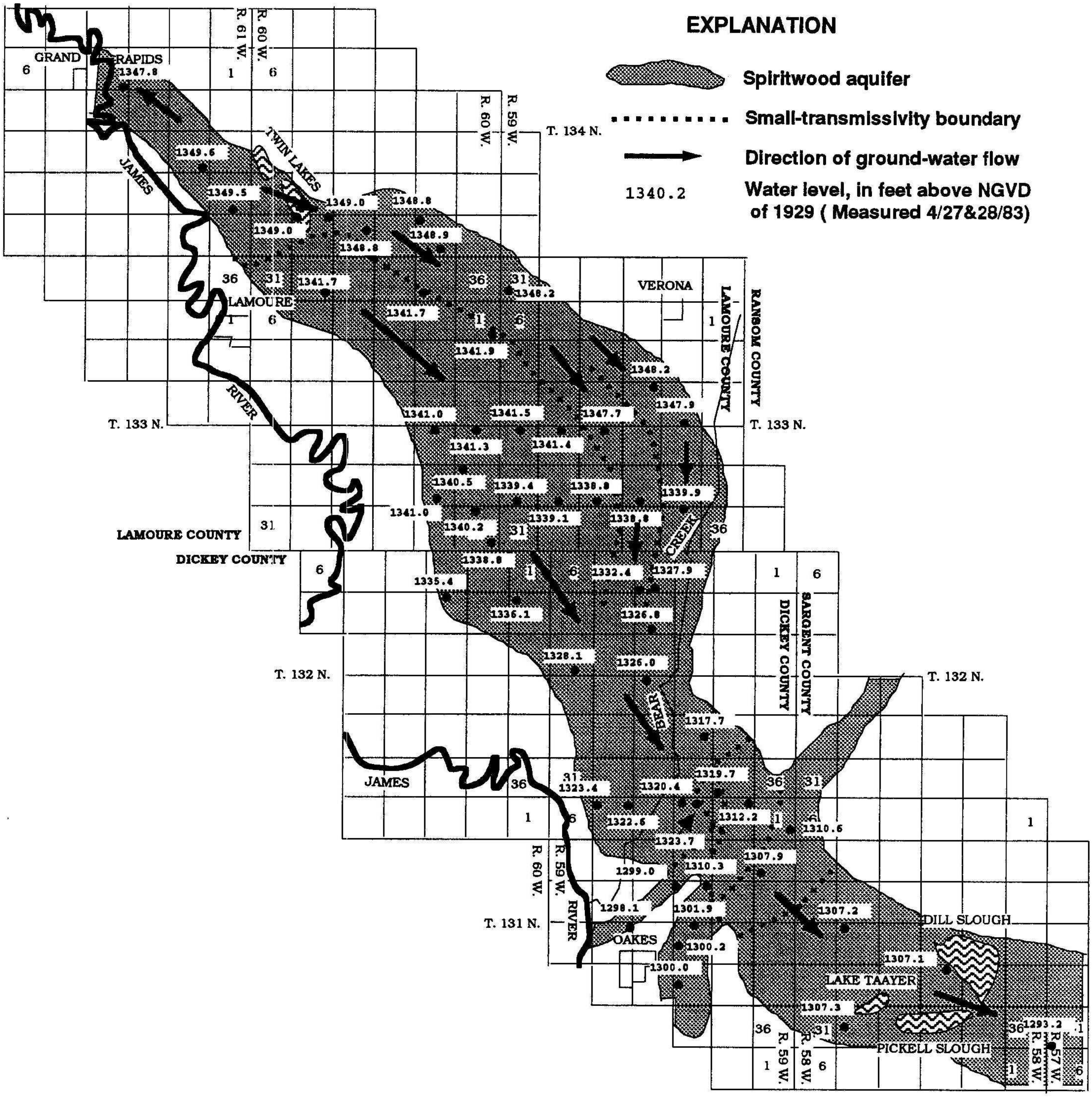


Figure 33. -- Elevation of potentiometric surface and direction of ground-water flow in the Spiritwood aquifer study area

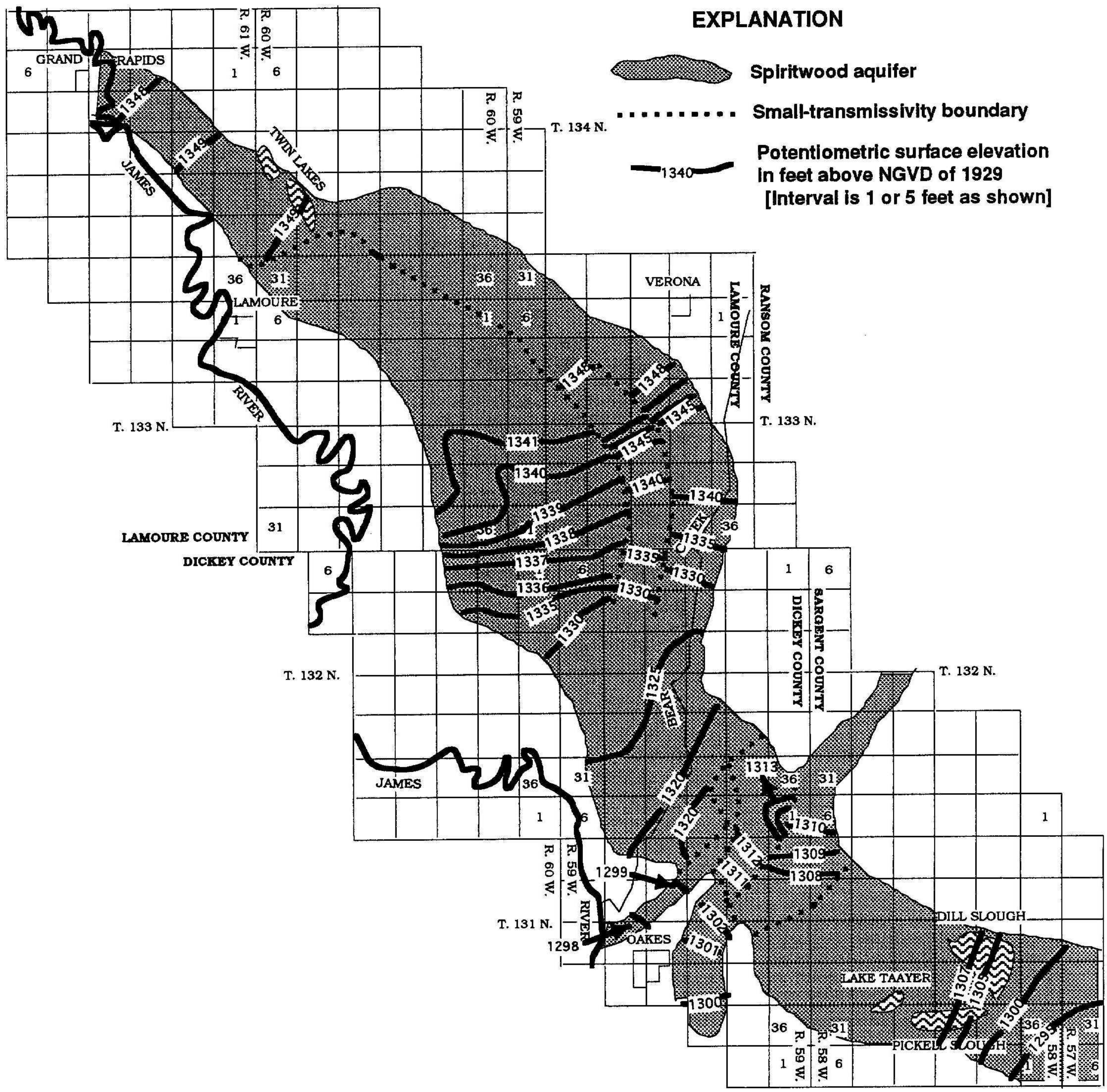


Figure 34. -- Shape and configuration of the potentiometric surface in the Spiritwood aquifer study area

10^{-5} ft/day). This till hydraulic conductivity value is at the low end of values shown on Table 1. Based on the above, it is concluded that the glacial drift overlying this area of the Spiritwood aquifer at depths greater than about 18 m (60 ft.) consists of non-fractured till or fractured till in which fractures do not contribute to bulk hydraulic conductivity. In addition, interconnected fluvial inhomogeneities that enhance recharge are not significant in this area of the Spiritwood aquifer.

Assuming an average hydraulic gradient of 2.3×10^{-5} in the upper reach of the eastern buried channel of the Spiritwood aquifer, an average valley width of 2.7 km (1.7 mi.), an average aquifer thickness of 11 m of (36 ft.), and an average aquifer hydraulic conductivity of 143 m/day (470 ft/day), the cross-sectional flow (perpendicular to the principal flow direction) is about 96 m^3/day (3,400 ft^3/day).

The contributing recharge area overlying this part of the aquifer is estimated at about 36 km^2 (14 mi^2). Assuming a total flux of about 96 m^3/day (3,400 ft^3/day) over a 36/km^2 (14 mi^2) area, with a vertical hydraulic gradient of 0.2 through the overlying till, the Darcy equation ($K = Q/IA$) yields a vertical till hydraulic conductivity of $1.5 \times {}^{-10}$ m/sec (4.3×10^{-5} ft/day). This till hydraulic conductivity is at the low end of values shown on Table 1. Based on the above, it is concluded that the glacial drift overlying this area of the Spiritwood aquifer is similar to that described overlying the western buried channel of the Spiritwood aquifer.

It is important to note that if the product of the cross-sectional area and aquifer hydraulic conductivity is increased by one order of magnitude, the calculated vertical till hydraulic conductivity would also increase by one order of magnitude. The increased vertical till hydraulic conductivities would range from 5×10^{-10} to 1.5×10^{-9} m/sec which still corresponds to small values characteristic of unfractured till. These calculations support the conclusion that deeper tills (> about 18 m; 60 ft.) are either unfractured or if fractured, the apperatures are effectively closed due to overburden pressure and, therefore, do not contribute to bulk hydraulic conductivity. As a result, areas in the Spiritwood aquifer characterized by increased recharge (increased horizontal hydraulic gradients and/or abrupt changes in water chemistry) probably are due to fluvial inhomogeneities in the overlying drift and not till fractures. For depths greater than about 18 m (60 ft.), it is difficult to conceive a mechanism that would allow till fractures to contribute to bulk hydraulic conductivity in some areas and not in others.

Near the Dickey-LaMoure County line, the hydraulic gradient in the western buried channel of the Spiritwood aquifer increases to about 2.6×10^{-4} (measured between 133-059-19BAA and 132-060-12BBB). This represents almost a two-order of magnitude increase in hydraulic gradient along the principal ground-water flow path. Assuming a hydraulic gradient of 2.6×10^{-4}, a hydraulic conductivity of 143 m/day (470 ft/day), an average aquifer thickness of 9.2 m (30 ft.) and cross-section width of 6.9 km (4.3 mi.), the cross-sectional flow is about 2,350 m^3/day (83,000 ft^3/day). There is no geohydrologic evidence to indicate that an almost two order of magnitude increase in hydraulic gradient is caused solely by a decrease in cross-sectional transmissivity. It appears that increased recharge (up to about 2,350 m^3/day; 82,000 ft^3/day) to the Spiritwood aquifer occurs in this area from the overlying glacial drift.

The contributing area between 133-059-19BAA and 132-060-12BBB is about 44 km^2 (17 mi^2). Assuming a total flux of 2,350 m^3/day (82,000 ft^3/day) over a 44 km^2 (17 mi^2) area, with a vertical hydraulic gradient of 0.2 through the overlying till, the Darcy equation ($K = Q/IA$) yields a vertical till hydraulic conductivity of 3.1×10^{-9} m/sec (8.7×10^{-3} ft/day). The till hydraulic conductivity value of 3.1×10^{-9} m/sec used to calculate the 2,350 m^3 (82,000 ft^3) of flow is about two orders of magnitude larger than the previously estimated till hydraulic conductivities. This value is on the low to middle range of till values shown on Table 2.

Geohydrologic data suggests that the increased hydraulic gradient and recharge near the county line in the western channel aquifer is not the result of increased till bulk hydraulic conductivity, but rather the occurrence of relatively large transmissivity inhomogeneities (fluvial units) within the till. The irregular shape of the potentiometric surface near 133-060-25, coupled with the abrupt decrease in dissolved-solids concentrations in this area of the Spiritwood aquifer, suggest a localized increase in recharge (Shaver, 1984).

About 7 km (4 mi.) north of the Dickey-LaMoure County line, the eastern channel of the Spiritwood aquifer bifurcates and the two narrower buried valleys are separated by a narrow bedrock shale divide (fig. 33). About 1.6 km (1 mi.) south of this divide, the hydraulic gradient in both buried valley aquifers increases.

Assuming a hydraulic gradient between 133-059-21ABB and 133-059-27CDD of 8.0×10^{-4}, an average valley width of 1.6 km (1 mi.), an average aquifer thickness of 11 m of (35 ft.), and an average hydraulic conductivity of 143 m/day (470 ft/day), the cross-sectional flow is about 1,970 m^3/day (69,500 ft^3/day).

Assuming a hydraulic gradient between 133-059-14DCC and 133-059-35ABB of 7.6×10^{-4}, an average valley width of 1.6 km (1 mi.), an average aquifer thickness of 9 m (30 ft.), and an average aquifer hydraulic conductivity of 143 m/day (470 ft/day), the cross-sectional flow is about 1,600 m^3/day (56,600 ft^3/day). The contributing recharge area overlying these two narrow channels of the Spiritwood aquifer is estimated at about 14 km^2 (5.5 mi^2). Assuming a total flux of 1,970 m^3/day (69,500 ft^3/day) over a 14 km^2 (5.5 mi^2) area with a vertical hydraulic gradient of 0.2 through the overlying till, the Darcy equation ($K = Q/IA$) yields a vertical till hydraulic conductivity of 1.5×10^{-8} m/sec (4×10^{-3} ft/day). This till hydraulic conductivity value is at the middle to high end of the range of values shown in Table 1.

Assuming no change in cross-sectional flow area and aquifer hydraulic conductivity, the increased hydraulic gradient in the eastern channel of the Spiritwood aquifer (southeast of the bifurcation) amounts to a 37-fold increase in flow volume. To maintain a cross-sectional flow of 96 m^3/day (3,400 ft^3/day) (upgradient in the eastern channel) across this area of gradient change would require a decrease in hydraulic conductivity from 143 to 3.9 m/day (470 to 12.7 ft/day) or a decrease in cross-section area from 1.6 to 0.017 km (1 to 0.027 mi). Test-drilling data do not indicate a significant decrease in aquifer transmissivity in this area. The increased hydraulic gradient in the Spiritwood aquifer in this area may be caused by increased recharge from fluvial inhomogeneities in the overlying drift. However, no significant change in water chemistry in the aquifer is indicated. It is possible that the additional recharge may occur from an intermediate depth fluvial unit with a similar hydrochemical signature. Based on available data, the mechanism(s) causing the increased hydraulic gradient in this area of the Spiritwood aquifer are not defined.

About 3 km (2 mi.) south of the Dickey-LaMoure County line the two narrow eastern buried-valley aquifers merge with the western buried-valley aquifer. The cross-sectional area in this part of the aquifer and southeast toward Oakes is not well defined. In addition, northeast of Oakes, the Spiritwood aquifer is characterized by numerous linear hydraulic head discontinuities caused by linear zones of decreased hydraulic conductivity. Based on the complex geologic setting, potentiometric analysis of recharge using available data is not considered valid in this area of the Spiritwood aquifer.

The area of the Spiritwood aquifer between the southeastern most linear zone of small transmissivity (fig. 33) and Dill and Pickell Sloughs is characterized by a relatively small hydraulic gradient. The hydraulic gradient between 131-058-20BBB and 131-058-27AAB is 6.8×10^{-6}. Assuming a valley width of three miles, a hydraulic conductivity of 143 m/day (470 ft/day), and an average aquifer thickness of 11 m (35 ft.), the cross-sectional flow is about 51 m^3/day (1,800 ft^3/day). The contributing recharge area overlying this part of the aquifer is estimated at about 39 km^2 (15 mi^2). Assuming a total flux of about 51 m^3/day (1,800 ft^3/day) over a 39 km^2 (15 mi^2) area with a vertical hydraulic gradient of 0.2 through the overlying till, the Darcy equation ($K = Q/IA$) yields a vertical till hydraulic conductivity of 7.5×10^{-11} m/sec (2.1×10^{-5} ft/day). This till hydraulic conductivity is at the low end of values shown on Table 1 and is within the range of values calculated in the northwestern part of the study area southeast of Twin Lakes. Based on the available data, it is concluded that the glacial drift overlying this area of the Spiritwood aquifer, at depths greater than about 18 m (60 ft.), consists of non-fractured till with little or no interconnected fluvial inhomogeneities that enhance aquifer recharge.

Southeast of Dill and Pickell sloughs, the horizontal hydraulic gradient in the Spiritwood aquifer increases. The hydraulic gradient between 131-058-27AAB and 131-057-31CCC is 8.5×10^{-4}. Test-drilling data is insufficient in this area to determine if the increased hydraulic gradient is caused by a decrease in aquifer transmissivity or an increase in recharge. However, the lithologic log of 131-058-25CCC1 indicates an interval of clayey, sandy, silt from 4.6 to 49 m (15 to 161 ft.) directly overlying the Spiritwood aquifer. This fluvial unit may occupy a narrow valley that truncates the Spiritwood aquifer in this area and functions as a line-source to the Spiritwood aquifer.

Conclusions of Potentiometric Analysis

In areas of the Spiritwood aquifer characterized by small horizontal hydraulic gradients (western and eastern buried valleys southeast of Twin Lakes; Lake Taayer area) the calculated vertical till hydraulic conductivities were in the range of 10^{-10} to 10^{-11} m/sec. These values are typical of non-weathered, unfractured till reported in Table 1, and probably are representative of deeper till (greater than about 18 m; 60 feet) over the entire study area. Fractures, if present in the deeper till, probably do not affect the bulk hydraulic conductivity of the till because the apperatures are effectively closed due to large overburden pressures.

Due to uncertainty with regard to aquifer geometry and hydraulic conductivity (cross-sectional transmissivity) it is not possible to determine if areas of increased hydraulic gradient are caused by decreased cross-sectional transmissivity or increased recharge to the aquifer through the overlying glacial drift. In one such area, increased recharge to the Spiritwood aquifer through the overlying drift was indicated by a meteoric water signature in the Spiritwood aquifer. However, quantification of this local increase in recharge using the Darcy equation was not possible because of uncertainty with regard to aquifer cross-sectional transmissivity. In areas of the Spiritwood aquifer characterized by increased horizontal hydraulic gradients, additional detailed test drilling is necessary to verify potential increases in recharge and/or changes in cross-sectional aquifer transmissivity.

WATER USE AS RELATED TO RESIDUAL DRAWDOWN IN THE SPIRITWOOD AQUIFER STUDY AREA

The largest withdrawals in the Spiritwood aquifer study area are for irrigation use. Minor withdrawals occur from rural domestic and stock wells. There are no municipal or industrial wells in the Spiritwood aquifer study area.

Center-pivot irrigation development began in the Spiritwood aquifer study area in 1973. From 1973 through 1991, about 3,085 ha-m (25,000 ac-ft.) of ground water has been pumped for supplemental irrigation. The pattern of annual irrigation water use from 1973 through 1991 is shown in figure 35. Except for 1986 (wet growing season) and 1988 (dry growing season), annual water use since 1981 has remained relatively constant varying between about 185 and 247 ha-m (1,500 and 2,000 ac-ft.).

The locations of approved and pending irrigation water use permits are shown in figure 36. Many of the permits are concentrated in the Oakes area. The Oakes area is characterized by light-textured (sandy) soils with relatively low moisture-holding capacities that require

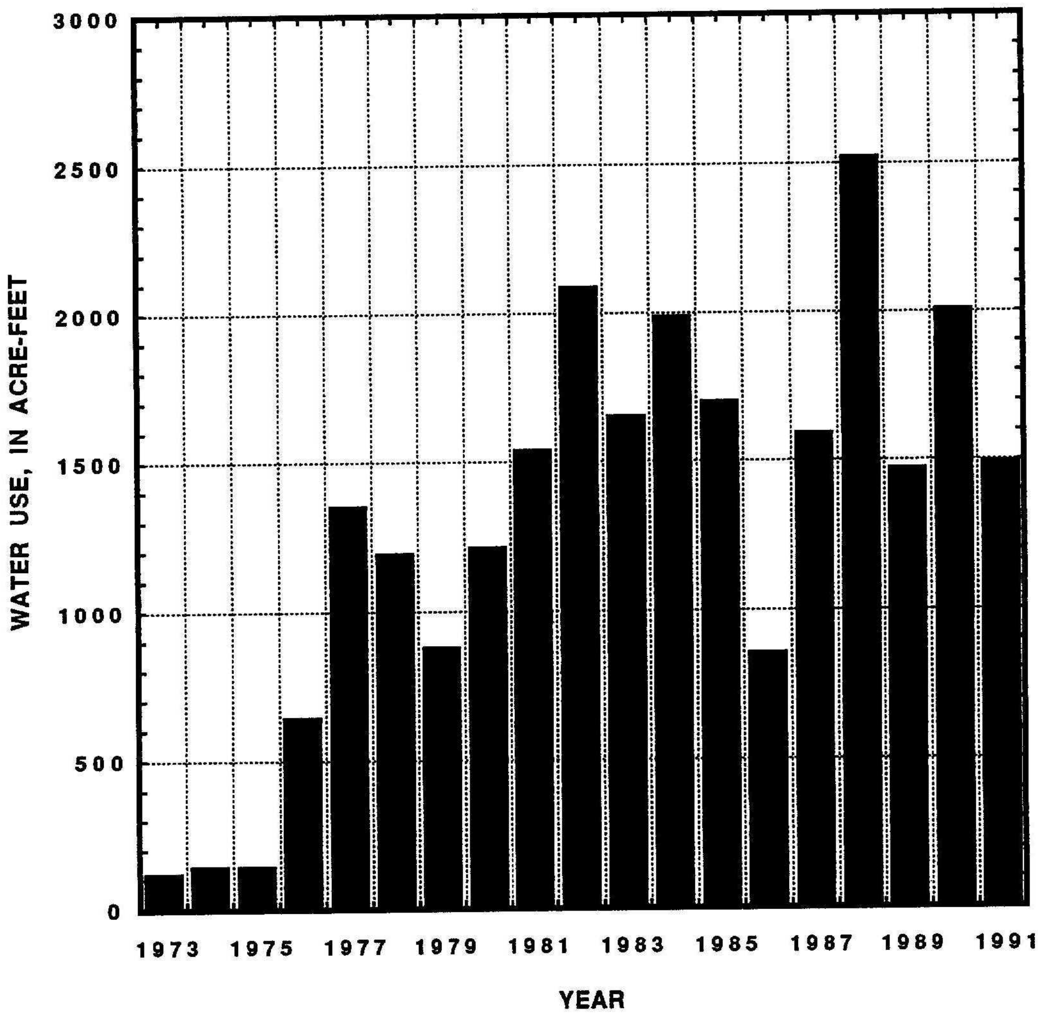


Figure 35. -- Annual water use in the Spiritwood aquifer study area

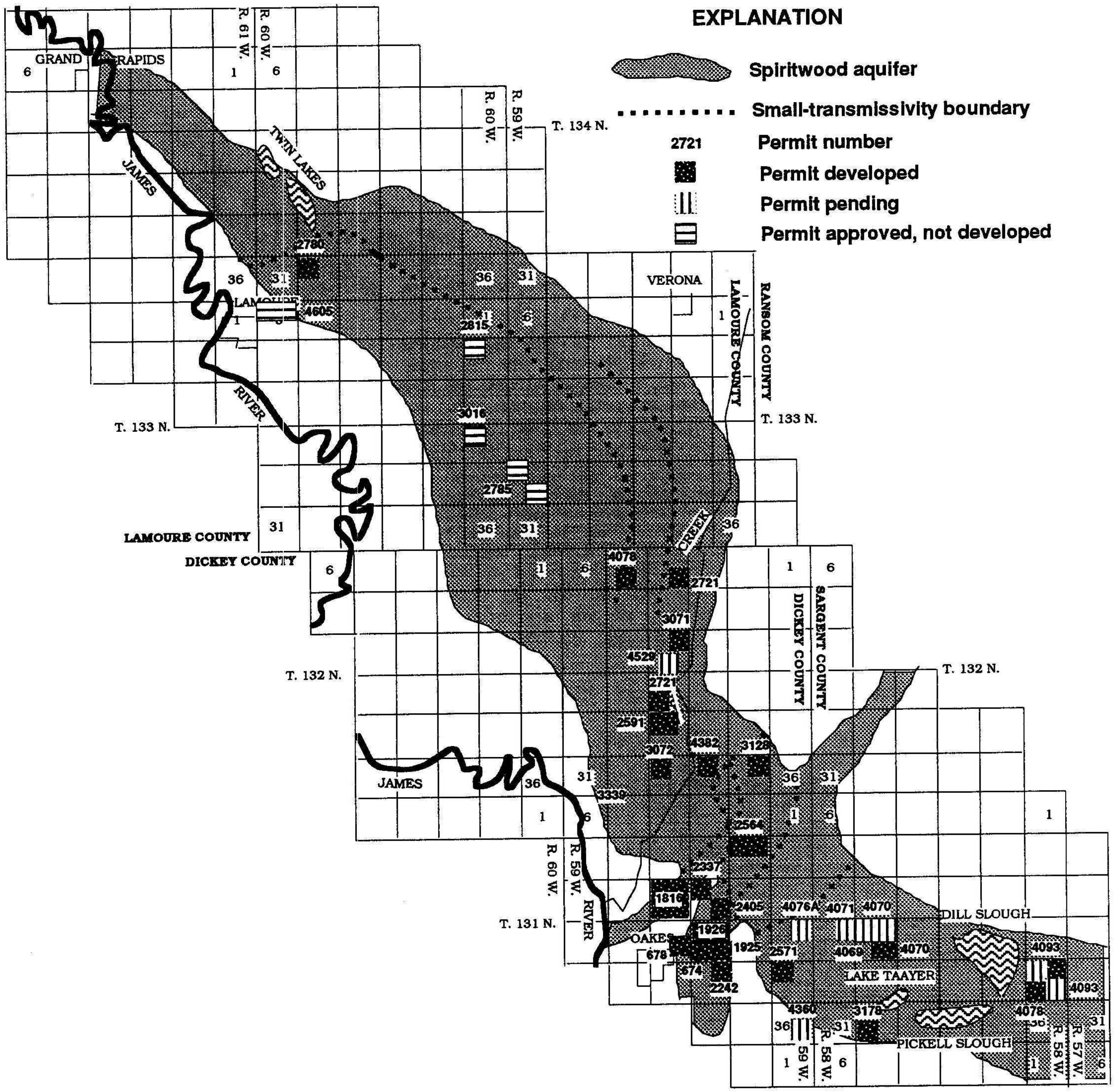


Figure 36.-- Location of water permits in the Spiritwood aquifer study area

supplemental irrigation for crop growth. Most other areas of the Spiritwood aquifer study area are characterized by heavier textured soils with larger moisture-holding capacities that are not as desirable to irrigate.

The Spiritwood aquifer study area is divided into three "similar hydrologic response" areas (fig. 37). Area A is the largest area and extends from the Twin Lakes area southeast to the furthest southeast small-transmissivity boundary east of Oakes. The developed irrigation water use permits in this area include, No. 2564, No. 3128, No. 3072, No. 2721, No. 3071, No. 4078, and No. 2780 (Figs. 36 and 37). Irrigation development in Area A began in 1977. From 1977 through 1991, total irrigation water use was 1,145 ha-m (9,280 ac-ft.).

The residual drawdown distribution in the Spiritwood aquifer study area is shown in figure 37. Water-level hydrographs for the observation wells/piezometers shown in figure 37 are in Appendix 4. The average residual drawdown in Area A from either the spring of 1975 or 1976 through the spring of 1992 is 2.3 m (7.4 ft.). The Spiritwood aquifer in Area A occupies about 259 km^2 (100 mi^2). Assuming an aquifer storage coefficient of 0.00025 (Table 13) over a 259 km^2 (100 mi^2) area characterized by an average residual drawdown of 2.3 m (7.4 ft.) amounts to about 15 ha-m (118 ac-ft.) of water. The amount of water pumped from the Spiritwood aquifer over this time period is close to two orders of magnitude larger than the estimated residual volume. The irrigation withdrawals are primarily derived from leakage through the overlying glacial drift and not from storage in the Spiritwood aquifer. Water-level hydrographs of observation wells/piezometers in Area A show little change in residual drawdown from 1983 through 1992. This

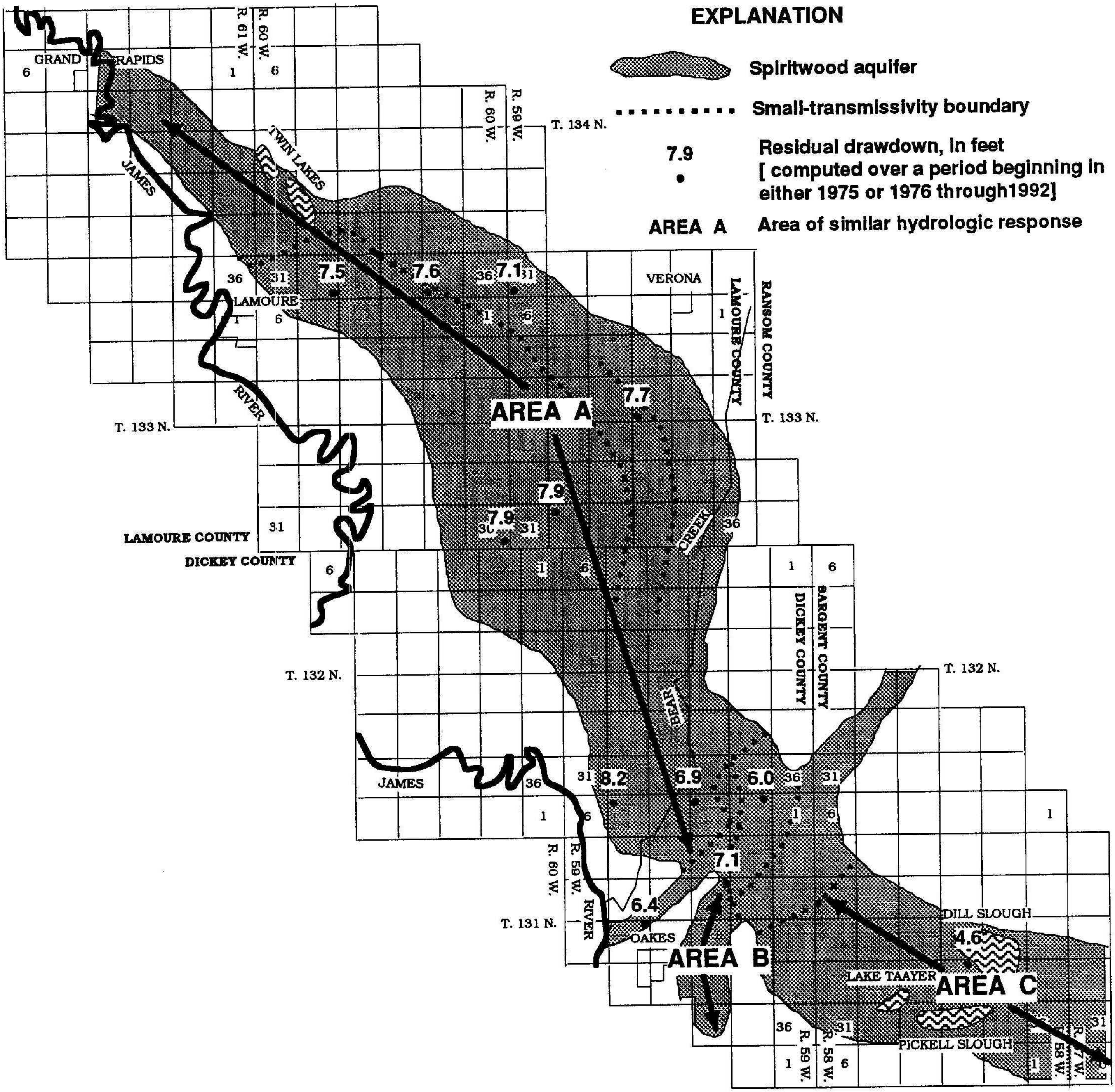


Figure 37.-- Distribution of residual drawdown in the Spiritwood aquifer study area

indicates that leakage from the overlying glacial drift has sustained annual withdrawals of between 185 and 370 ha-m (1,500 and 3,000 ac-ft.) for about the past 10 years.

Area B is the smallest "similar hydrologic response" area and occupies about five square miles in a relatively narrow buried tributary channel just east of Oakes (fig. 37). In this area, the Spiritwood aquifer is directly overlain by a sequence of sandy, silty, clays and sandy, clayey silts which is, in turn, overlain by sand and gravel deposits of the surficial Oakes aquifer (Shaver, 1984). The sandy, silty, clay/sandy, clayey, silt sequence is very leaky (North Dakota State Water Commission Aquifer Test Reports, (Dennis Roney Aquifer Test, 1976).

The developed irrigation water use permits in Area B include, No. 674, No. 678, No. 1925, No. 1926, No. 2242, No. 2337, and No. 2405 (Figs. 36 and 37). Irrigation water-use permit No. 1816 is not included in Area B because this permit occupies a relatively small, discrete hydrologic unit (buried-tributary channel). From 1973, when irrigation development began, through 1991, about 1,455 ha-m (11,800 ac-ft.) of ground water has been pumped for supplemental irrigation. Assuming an aquifer storage coefficient of 0.00025, an area of 13 km^2 (5 mi^2) characterized by a 2.1 m (7 ft.) residual drawdown amounts to only about one acre-foot of water. The amount of ground water pumped from Area B (1,455 ha-m; 11,800 acre-feet) is about four orders of magnitude larger than the estimated residual volume (one acre-foot). Again, irrigation withdrawals are primarily derived from leakage through the overlying sandy, silty, clay/sandy, clayey, silt sequence and the Oakes aquifer and not from storage in the Spiritwood aquifer. Water-level hydrographs of observation wells 131-059-22CBB1 and 131-059-27CBB1 (Appendix 4) in Area B, show little change in residual drawdown from 1989 through 1992. This indicates that leakage from the overlying sediments has sustained annual irrigation withdrawals of between 62 to 74 ha-m (500 to 600 ac-ft.) for the past three years. Assuming a vertical hydraulic gradient of 0.01, an average vertical flux of 74 ha-m (600 ac-ft.) per year over a 13 km^2 (5 mi^2) area, the rearranged Darcy equation ($K = Q/IA$) yields a vertical hydraulic conductivity of 1.8×10^{-7} m/sec (5.1×10^{-2} ft/day). This value is plausible for a sandy, silty, clay/sandy, clayey, silt sequence.

Area C occupies about 104 km^2 (40 mi^2) from the southern most small-transmissivity boundary (east of Oakes) to Meszaroes Slough which is located about three miles south of the southeast margin of the aquifer shown on figure 37. In the northwest part of Area C, the Spiritwood aquifer is overlain predominantly by till. To the southeast, the Spiritwood aquifer is overlain in some areas by a sequence of sandy, silty, clays and sandy, clayey, silts.

The developed irrigation water-use permits in Area C include No. 2571, No. 3178, No. 4070, No. 4078, and No. 4093 (Figs. 36 and 37). From 1978, when irrigation development began, through 1991, about 440 ha-m (3,600 ac-ft.) of ground water has been pumped for supplemental irrigation. Assuming a aquifer storage coefficient of 0.00025, an area of 104 km^2 (40 mi^2) characterized by a 1.5 m (5 ft.) residual drawdown amounts to only 4 ha-m (32 ac-ft.) of water. As with Areas A and B, irrigation withdrawals are primarily derived from leakage through the overlying drift sequence and not from storage in the Spiritwood aquifer. As with Area A, leakage primarily occurs through local inhomogeneities in the overlying drift. Because the areal extent of these inhomogeneities is not well defined, it is not possible to estimate associated vertical hydraulic conductivities using the Darcy approach.

The most important conclusion obtained from the water use/residual drawdown analysis, is that up to this point in time, leakage from the overlying glacial drift has sustained irrigation withdrawals from the Spiritwood aquifer study area. The large volume of leakage would not be possible through a deep, non-weathered till characterized by vertical hydraulic conductivities in the range of 10^{-11} to 10^{-10} m/sec and vertical hydraulic gradients ranging from 0.1 to 0.3, which appear to be typical values for till in this study area. Therefore, it is concluded that more localized inhomogeneities (fluvial units) are scattered throughout the overlying till, and these units provide most of the recharge to the Spiritwood aquifer.

CONCEPTUAL MODEL OF GROUND-WATER FLOW IN THE TILL AQUITARD OVERLYING THE SPIRITWOOD AQUIFER STUDY AREA

Based on previous investigations and available data from the Spiritwood aquifer study area, the following conclusions are considered relevant to buried-valley aquifer flow systems in North Dakota (fig. 38):

1. Till is the dominate lithology overlying most buried-valley aquifers.
2. Fractures are ubiquitous in the weathered till.
3. Fractures also occur in underlying non-weathered till but are less frequent, more widely spaced, and probably affect bulk hydraulic conductivity to depths of no more than about 18 m (60 ft.). Increased overburden pressure with depth probably effectively closes fractures.

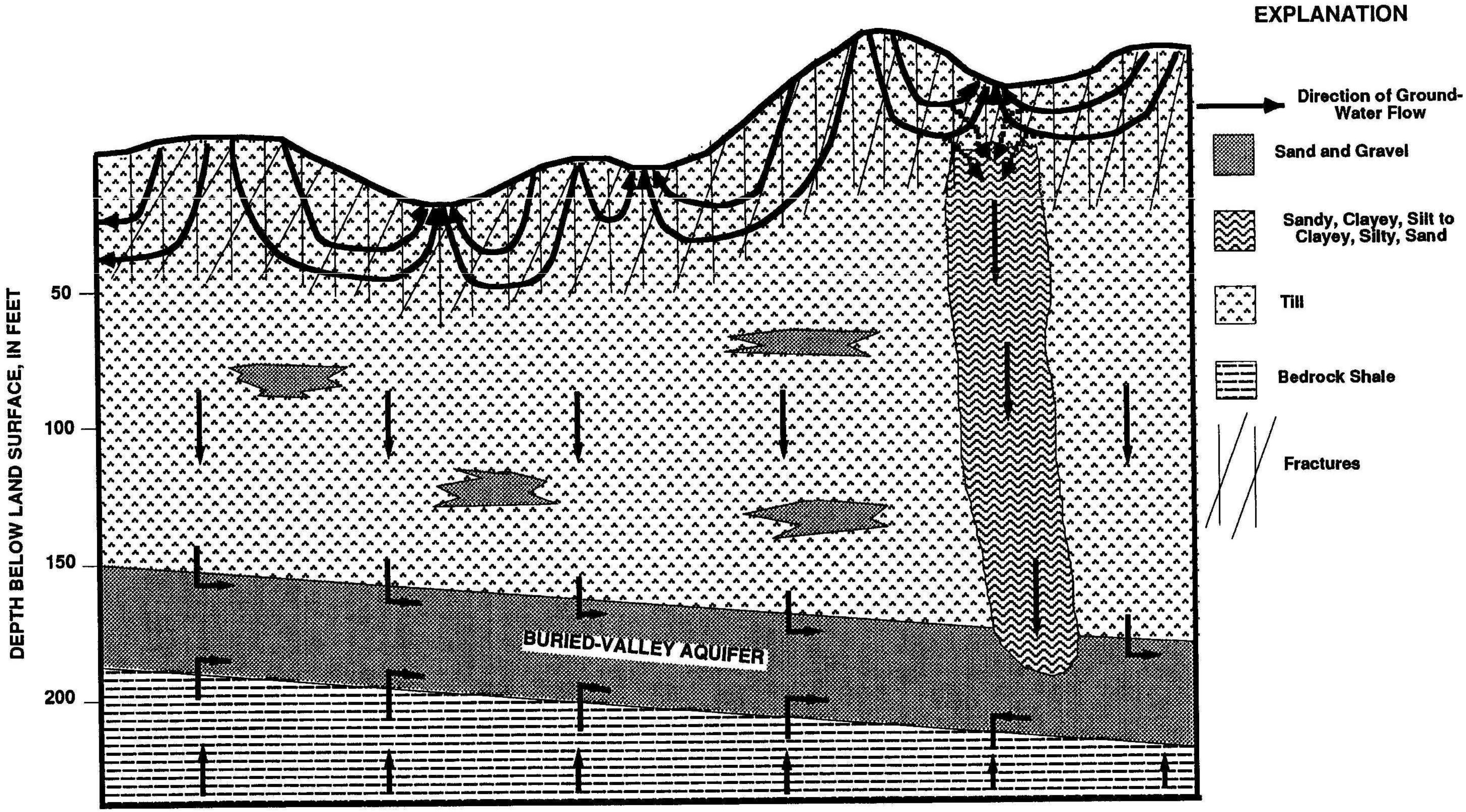


Figure 38.-- Schematic diagram of ground - water flow for buried - valley aquifer systems in areas characterized by downward hydraulic gradients in the overlying glacial drift

4. Due to fractures, the bulk hydraulic conductivity of shallow till may be one to three orders of magnitude greater than that of the deeper till. This large difference in hydraulic conductivity creates two distinct ground-water flow systems in the till profile.
5. The upper, shallow flow system associated with fractured till is more dynamic. Ground-water flow paths are shorter and in many areas, lateral flow components are dominant. Although fractures enhance recharge, they also enhance surface discharge (primarily by evapotranspiration) because they provide highly conductive flow paths that more efficiently link local surficial recharge and discharge areas. As a result, much of the surface recharge is diverted away from the deeper till flow system. Bulk hydraulic conductivities range from about 1×10^{-9} to 1×10^{-6} m/sec in shallow, fractured till.
6. The ground-water flow system associated with the deeper till is, for the most part, less dynamic than the shallow flow system. Flow paths are longer and vertical flow components dominate. The bulk hydraulic conductivity of the till is about equal to the matrix hydraulic conductivity of the till. Matrix hydraulic conductivities range from about 1×10^{-11} to 1×10^{-9} m/sec.
7. Vertical hydraulic gradients in the deeper non-weathered till in the Spiritwood aquifer study area range from about 0.1 to 0.3.

8. Based on a range in hydraulic conductivity of 1×10^{-11} to 1×10^{-9} m/sec and a range in vertical hydraulic gradient of 0.1 to 0.3, the estimated range in recharge to the Spiritwood aquifer through the deeper till flow system is from 3.2×10^{-5} m/yr (1×10^{-4} ft/yr) to 1×10^{-3} m/yr (0.03 ft/yr).
9. Fluvial inhomogeneities are common in the till sequence overlying the Spiritwood aquifer study area. Some fluvial inhomogeneities appear to extend through the shallow fractured till, downward to the top of the Spiritwood aquifer. These "hydraulic short circuits" in the till sequence probably provide most of the recharge to the Spiritwood aquifer.
10. Fluvial inhomogeneities that "short circuit" the till sequence tend to be relatively local in extent. As a result, they are difficult to detect by test-drilling methods. In some cases, these features can be inferred by local anomalies in the potentiometric surface of the buried-valley aquifer and/or abrupt changes in aquifer water chemistry.

APPROACH TO MONITORING AND EVALUATING BURIED-VALLEY AQUIFER SYSTEMS

An important conclusion of this investigation is that recharge to buried-valley aquifers through till at depths greater than about 18 m (60 ft.) is minor. In areas of buried-valley aquifers where recharge is relatively large, inhomogeneities in the overlying glacial drift are the primary avenues of recharge. These inhomogeneities, most of which probably are of fluvial origin, can be viewed as highly transmissive "short circuits" scattered throughout till. The geometry and plumbing (interconnectedness) of these inhomogeneities are complex and highly variable making it virtually impossible to map these features.

At present, it appears that one can only indirectly estimate cumulative (total) recharge through drift over large aquifer areas by a rather simple Darcy analysis and/or water-budget analysis as described in this text. For these analyses, aquifer geometry (average thickness and width) coupled with average hydraulic conductivity, hydraulic gradients, and water use data are required. These data are available in many buried-valley aquifer study areas. The volume of cross-sectional flow in the aquifer computed using the Darcy equation can be compared with the vertical Darcy flow over the contributing area of aquifer recharge. If vertical hydraulic gradients in the overlying drift are known, then a good estimate of average drift vertical hydraulic conductivity can be made. Computed vertical hydraulic conductivities in the 10^{-11} to 10^{-10} m/sec range indicate recharge primarily through a till matrix. Larger computed average vertical hydraulic conductivity values probably reflect significant recharge through inhomogeneities in the drift.

Based on the above, more data are needed to define vertical hydraulic gradients in the overlying drift. This will require installation of piezometer nests throughout buried-valley aquifer study areas. These piezometers should become permanent water-level monitoring sites.

In addition, single-well response tests should be performed in piezometers completed in low transmissivity drift deposits such as till, silty clays, and clayey silts. Assuming isotropy, hydraulic conductivities computed for these tests can be compared with hydraulic conductivities computed using the Darcy analysis.

Areas of the buried-valley aquifer characterized by significant changes in horizontal hydraulic gradient should be examined in more detail. Increased hydraulic gradients may be caused by increased recharge or decreased cross-sectional transmissivity. Abrupt changes in water chemistry in these areas indicate increased recharge. Additional test drilling probably will be required in these areas to define drift inhomogeneities or changes in cross-sectional transmissivity. Keep in mind that a doubling of the horizontal hydraulic gradient (which is common in many areas of buried-valley aquifers) requires a halving of aquifer cross-sectional transmissivity (assuming no recharge). A major trend like this may not be that difficult to identify using standard test drilling techniques.

Available data in all buried-valley aquifers in North Dakota indicates sand/or sand and gravel "lenses" scattered throughout the overlying till. Piezometers should be installed in these "lenses" at selected sites that also include till piezometers. As compared to piezometers completed in till, piezometers completed in sand and gravel "lenses" offer two important advantages:

1. Well development is more efficient and, for the most part, water samples for standard chemical analysis are more easily obtained because of increased transmitting capacity.

2. Sand or sand and gravel "lenses" for all practical purposes, function as large-diameter monitoring wells. The larger the areal extent of the "lenses," the larger the effective area of monitoring. If fractures occur in till at depth but are less

widespread (larger spacing), till piezometer intake areas may not intersect fractures. Sand and gravel lenses may intersect these fractures and their effect on bulk hydraulic conductivity of till can be more readily evaluated. In addition, these "lenses" may be hydraulically connected to other fluvial inhomogeneities which "short circuit" the till. Comparison of water-level response in till and "lense" piezometers may aid in identifying the spatial distribution of these inhomogeneities.

Based on the literature search presented at the beginning of this report, little data are available on specific storage of till and other clayey, silty deposits that occur in the drift overlying buried-valley aquifers. Studies that report specific storage values for these lithologies in North Dakota do not exist. As a result, more till/silty clay specific storage value should be measured at selected sites in buried-valley aquifer study areas throughout North Dakota. This can be accomplished using analytical methods and/or calibration of 1-dimensional ground-water flow models. These methods would require water-level monitoring in both the pumped aquifer and overlying till/silty clay aquitards (piezometer nests).

Most analytical methods for aquifer test analysis are not applicable because of complex boundary conditions associated with buried-valley aquifers. The stepped-head analytical method, as described in this report, can be applied in such a way as to mitigate the effect of parallel barrier boundaries that contain hydraulic response in buried-valley aquifers.

The ultimate objective of the stepped-head analytical method is to calculate aquitard hydraulic diffusivity (K_V'/S_S'). Vertical hydraulic conductivity must be known to solve for specific storage. Prior to or after conducting the stepped-head test, single-well response tests can be performed in individual aquitard piezometers to calculate horizontal hydraulic conductivity. Assuming aquitard isotropy, the horizontal hydraulic conductivity can be used in the hydraulic diffusivity expression to solve for specific storage.

Probably the best approach for evaluating aquitard specific storage will be 1-dimensional ground-water flow models of the aquifer/aquitard piezometer nest sites. Water-level response from both aquifer and aquitard will be used to evaluate till/silty clay hydraulic conductivity and specific storage. Model input (K_V' and S_S') will be initialized based on typical reported values in the literature and obtained in this study. Single-well response tests should be performed in aquitard piezometers in the modeled areas to compare with initial values.

Stable isotope analyses (oxygen-18, deuterium) of water from piezometer nests may also provide evidence regarding ground-water residence times, velocity, and associated vertical hydraulic conductivities in overlying drift. Changes in stable isotope signature can be indicative of changing climatic and recharge patterns. It is important to evaluate stable isotope signatures of meteoric water and their relation to the local meteoric water line prior to analyzing deeper, complex ground-water flow systems. This first step has been undertaken in the Oakes aquifer and published results will be available in 1994.

Given that recharge to buried-valley aquifers predominantly occurs through fluvial inhomogeneities scattered throughout overlying drift, it may become necessary to map the distribution and interconnectedness of these inhomogeneities. The ultimate goal is to predict the ability of inhomogeneities to sustain recharge under various aquifer ground-water withdrawal scenarios. This goal may not be achievable using contemporary "state of the art" techniques.

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APPENDIX 1

LITHOLOGIC LOGS OF PIEZOMETER NESTS IN THE SPIRITWOOD AQUIFER STUDY AREA

(Abbreviations)

PVC -	polyvinylchloride
L.S. -	land surface
NDSW -	North Dakota State Water Commission
dia. -	diameter

134-061-13DAD1

NDSWC 6259

Date Completed:	8/16/83	Well Type:	Observation
Depth Drilled (ft):	312	Source of Data:	NDSWC
Screened Interval (ft):	257-262	Principal Aquifer :	Spiritwood
Casing size (in) & Type:	1/1/4" Dia PVC	L.S. Elevation (ft)	1413.79

Lithologic Log

Unit	Description	Depth (ft)
TOPSOIL		0-1
CLAY	silty, interbedded with medium to coarse sands, gravelly, yellow brown, oxidized	1-22
SAND	gravelly, medium to coarse sand, subrounded to rounded, predom. detrital shale, some silicates and carbonates, oxidized	22-39
TILL	clay, silty, sandy, pebbly, some detrital lignite fragments	39-64
SAND	gravelly, subrounded to rounded, 70% detrital shale, minor silicates and carbonates	64-72
TILL	clay, silty, sandy, pebbly, layer of fine sand and silt from 104 to 106 ft.	72-112
SAND	fine to medium, very silty and clayey, subrounded to well rounded, predom. detrital shale, some carbonates and silicates	112-137
GRAVEL	fine to pea size gravel, and medium to coarse sand, subrounded to well rounded, 50% detrital shale, 30% quartz, some silicates, carbonates and lignite, clean section	137-160
GRAVEL	pea size, and coarse sand, lots of detrital lignite, subrounded to well rounded, drills as stratified, composition as above	160-260
GRAVEL	pea to marble size, cobbly, rough drilling, takes water	260-279
CLAY	brownish black, slightly silty, plastic, some bentonite, (Pierre Formation ?)	279-312

134-061-13DAD2

NDSWC 11470

Date Completed:	8/28/84	Well Type:	Piezometer
Depth Drilled (ft):	140	Source of Data:	NDSWC
Screened Interval (ft):	132-137	Principal Aquifer :	Spiritwood
Casing size (in) & Type:	1 1/4" Dia PVC	L.S. Elevation (ft)	1416.1

Lithologic Log

Unit	Description	Depth (ft)
TILL	silty, sandy, pebbly, pale yellow brown with red-yellow stringers, oxidized	0-18
SAND	very fine to medium, predom. fine, silty, yellow stained, oxidized	18-27
SAND	60-70%, very fine to very coarse, predom. medium to coarse, gravelly, subangular to well rounded, predom. shale and carbonates, some silicates and lignite, yellow stained, oxidized	27-37
TILL	clay, silty, sandy, gravelly, pebbly, olive gray, hard, slightly brittle	37-62
SAND	50-60%, very fine to very coarse, predom. coarse, subangular to well rounded, gravelly, predom. shale and carbonates, some silicates	62-73
TILL	clay, silty, sandy, gravelly, pebbly, olive gray	73-110
SAND	90-95%, very fine to very coarse, predom. medium, gravelly, subangular to well rounded, lots of shale and carbonates, some silicates and quartz, slight bit chatter, takes water, clean section	110-140

134-061-13DAD3

NDSWC 11471

Date Completed:	8/29/84	Well Type:	Piezometer
Depth Drilled (ft):	75	Source of Data:	NDSWC
Screened Interval (ft):	68-73	Principal Aquifer :	Undefined
Casing size (in) & Type:	1 1/4" Dia PVC	L.S. Elevation (ft)	1416.5

Lithologic Log

Unit	Description	Depth (ft)
TILL	clay, silty, sandy, gravelly, pebbly, pale yellow brown with red-yellow stringers, oxidized	0-18
SAND	60-70%, very fine to very coarse, predom. medium, gravelly, subangular to well rounded, lots of shale, carbonates, silicates, lignite, yellow stained, oxidized	18-36
TILL	clay, silty, sandy, gravelly, olive gray, sand and gravel layers from 65-66 ft. and 70-72 ft.	38-75

133-060-02CDD1

NDSWC 6246

Date Completed:	7/27/83	Well Type:	Observation
Depth Drilled (ft):	282	Source of Data:	NDSWC
Screened Interval (ft):	255-260	Principal Aquifer :	Spiritwood
Casing size (in) & Type:	1 1/4" Dia PVC	L.S. Elevation (ft)	1398.12

Lithologic Log

Unit	Description	Depth (ft)
TOPSOIL		0-1
GRAVEL	up to 1/4- inch diam., sandy, oxidized	1-2
TILL	clay, silty, sandy, gravelly, pebbly, yellow brown, soft, oxidized	2-18
TILL	as above, olive gray, unoxidized	18-27
SAND	fine, well sorted, 50% quartz and 50% detrital lignite	27-32
TILL	clay, silty, sandy, gravelly, olive gray, soft, sand lenses from 42-43 ft., and from 101-105 ft.	32-193
SAND	very coarse and gravel, angular to well rounded, 60% quartz, 20% carbonates, 20% shale and lignite	193-200
GRAVEL	up to 1/8-inch diam., and very coarse sand, rounded, comprised of quartz, carbonates, silicates, shale, lignite, drills as stratified	200-261
SHALE	clay, silty, brown, with light gray specks (Niobrara Formation)	261-282

133-060-02CDD2

NDSWC 11463

Date Completed:	8/23/84	Well Type:	Piezometer
Depth Drilled (ft):	200	Source of Data:	NDSWC
Screened Interval (ft):	195-200	Principal Aquifer :	Spiritwood
Casing size (in) & Type:	1 1/4" Dia PVC	L.S. Elevation (ft)	1397.45

Lithologic Log

Unit	Description	Depth (ft)
CLAY	silty, slightly sandy, soft, yellow brown, oxidized	0-5
SAND & GRAVEL	yellow stained, oxidized	5-6
TILL	clay, silty, sandy, pebbly, pale yellow brown with red-yellow stringers, oxidized	6-15
TILL	as above, olive gray, soft, unoxidized	15-30
CLAY	slightly silty, greenish gray, soft	30-34
TILL	clay, silty, sandy, pebbly, olive gray,soft	34-192
SAND	70-80%, very fine to very coarse, predom. medium to coarse, gravelly, subangular to well rounded, comprised of shield silicates, quartz, carbonates, shale and lignite, clean section	192-200

133-060-02CDD3

NDSWC 11464

Date Completed:	8/23/84	Well Type:	Piezometer
Depth Drilled (ft):	125	Source of Data:	NDSWC
Screened Interval (ft):	117-122	Principal Aquifer :	Till
Casing size (in) & Type:	1 1/4" Dia PVC	L.S. Elevation (ft)	1398.12

Lithologic Log

Unit	Description	Depth (ft)
TILL	clay, silty, sandy, pebbly, pale yellow brown with red-yellow stringers, oxidized	0-18
TILL	as above, olive gray, unoxidized, sand and gravel layers from 21-22 ft., and 24-29 ft., 90% sand, lots of shale and carbonates, minor silicates	18-32
CLAY	silty, greenish gray, soft	32-36
TILL	clay, as above, sand and gravel layers from 41-46 ft., 91-93 ft., and 102-106 ft.	36-125

133-060-02CDD4

NDSWC 11465

Date Completed:	8/24/84	Well Type:	Piezometer
Depth Drilled (ft):	46	Source of Data:	NDSWC
Screened Interval (ft):	26-31	Principal Aquifer :	Undefined
Casing size (in) & Type:	1 1/4" Dia PVC	L.S. Elevation (ft)	1397.94

Lithologic Log

Unit	Description	Depth (ft)
TILL	clay, silty, sandy, pebbly, pale yellow brown with red-yellow stringers, oxidized	0-17
TILL	clay, as above, olive gray	17-25
SAND	very fine to medium, predom. fine, lots of shale and carbonates, some silicates and lignite, subangular to rounded	25-31
CLAY	silty, greenish gray, soft	31-37
TILL	clay, as above	37-46

133-060-36DDD1

NDSWC 9448

Date Completed:	9/23/75	Well Type:	Observation
Depth Drilled (ft):	260	Source of Data:	NDSWC
Screened Interval (ft):	212-215	Principal Aquifer :	Spiritwood
Casing size (in) & Type:	1 1/4" Dia PVC	L.S. Elevation (ft)	1383.1

Lithologic Log

Unit	Description	Depth (ft)
TILL	clay, silty, sandy, pebbly, yellow stained, oxidized	0-17
TILL	clay, as above, olive gray, unoxidized	17-34
CLAY	sandy, silty, medium dark gray, sticky	34-40
TILL	clay, silty, sandy, gravelly, pebbly, olive gray, some thin interbedded sand and gravel layers	40-204
SAND	75%, very fine to very coarse, gravelly, subangular to subrounded, comprised of quartz, carbonates, shale, silicates, and lignite (Spiritwood Aquifer)	204-243
SHALE	clay, sandy, silty, brownish gray, acid residue brown, (Niobrara Formation)	243-260

133-060-36DDD2

NDSWC 11459

Date Completed:	8/22/84	Well Type:	Piezometer
Depth Drilled (ft):	249	Source of Data:	NDSWC
Screened Interval (ft):	236-241	Principal Aquifer :	Spiritwood
Casing size (in) & Type:	1 1/4" Dia PVC	L.S. Elevation (ft)	1383.1

Lithologic Log

Unit	Description	Depth (ft)
TILL	clay, silty, sandy, gravelly, pale yellow brown with red-yellow stringers, oxidized	0-19
TILL	clay, as above, olive gray, unoxidized	19-24
CLAY	silty, greasy, olive gray	24-38
TILL	clay, as above, sand layers from 126-127 ft., 132-133 ft., and 136-140 ft., and sand and gravel layers from 151-152 ft., and 200-201 ft.	38-206
SAND	60-70%, very fine to very coarse, predom. medium to coarse, gravelly, subangular to well rounded, comprised of silicates, carbonates, quartz, shale, and lignite, drills as stratified, (Spiritwood Aquifer)	206-243
SHALE	clay, medium brown with light gray specks, calcareous, (Niobrara Formation)	243-249

133-060-36DDD3

NDSWC 11460

Date Completed:	8/22/84	Well Type:	Piezometer
Depth Drilled (ft):	125	Source of Data:	NDSWC
Screened Interval (ft):	120-125	Principal Aquifer :	Till
Casing size (in) & Type:	1 1/4" Dia PVC	L.S. Elevation (ft)	1383.3

Lithologic Log

Unit	Description	Depth (ft)
TILL	clay, silty, sandy, gravelly, pale yellow brown with red-yellow stringers, oxidized	0-19
TILL	clay, as above, olive gray, unoxidized	19-26
CLAY	silty, greasy, olive gray to greenish gray	26-38
TILL	clay, as above, cobbles at 65, 70, 97, and 106 ft.	38-125

133-060-36DDD5

NDSWC 11462

Date Completed:	8/22/84	Well Type:	Piezometer
Depth Drilled (ft):	45	Source of Data:	NDSWC
Screened Interval (ft):	40-45	Principal Aquifer :	Till
Casing size (in) & Type:	1 1/4" Dia PVC	L.S. Elevation (ft)	1383.8

Lithologic Log

Unit	Description	Depth (ft)
TILL	clay, silty, sandy, pebbly, pale yellow brown with red-yellow stringers, oxidized	0-21
TILL	clay, as above, olive gray, unoxidized	21-26
CLAY	silty, olive gray to greenish gray, soft, greasy	26-36
TILL	clay, as above	36-45

132-059-17DCD1

NDSWC 11969A

Date Completed:	9/3/82	Well Type:	Piezometer
Depth Drilled (ft):	220	Source of Data:	NDSWC
Screened Interval (ft):	188-193	Principal Aquifer :	Spiritwood
Casing size (in) & Type:	1 1/4" Dia PVC	L.S. Elevation (ft)	1371.1

Lithologic Log

Unit	Description	Depth (ft)
TILL	clay, silty, sandy, pebbly, pale yellow brown with red-yellow stringers, soft, oxidized	0-21
CLAY	as above, olive gray, unoxidized	21-31
SILT	clayey, greenish gray	31-35
SAND & GRAVEL	predom. shale and carbonates	35-36
TILL	clay, silty, sandy, pebbly, olive gray, silty sand layer from 52-54 ft.	36-58
SAND	very fine to medium, predom. fine to very fine, silty, lots of quartz, some silicates, carbonates, shale, and lignite	58-69
SILT	clayey to clay silty, occas, sandy interval, drills fast and smooth, most into suspension, suggests mostly silt, occas. sand-sized lignite grain	69-116
TILL	clay, silty, sandy, pebbly, olive gray	116-122
SAND & GRAVEL	interbedded with till, sand and gravel layers from 122-124,125-126, 128-131, 132-135, and 135-137 ft., cobbles from 131-132 ft.	122-137
TILL	as above, sand and gravel layer from 143-146 ft.	137-156
SAND	80-90%, very fine to very coarse, predom. medium to coarse, gravelly, comprised of shield silicates, quartz, carbonates, shale, and lignite, subangular to well rounded, drills as stratified, (Spiritwood Aquifer)	156-193
SAND & GRAVEL	with cobbles and boulders, interbedded with clay? or till?, very tough drilling	193-212
SHALE	clay, medium brown with light gray specks, acid residue dark brown, (Niobrara Formation)	212-220

132-059-17DCD2

NDSWC 11969B

Date Completed:	9/7/82	Well Type:	Piezometer
Depth Drilled (ft):	120	Source of Data:	NDSWC
Screened Interval (ft):	114-119	Principal Aquifer :	Till
Casing size (in) & Type:	1 1/4" Dia PVC	L.S. Elevation (ft)	1371.2

Lithologic Log

Unit	Description	Depth (ft)
TILL	clay, silty, sandy, gravelly, pale yellow brown with red-yellow stringers, oxidized	0-23
SAND	very fine to medium, silty, yellow stained, oxidized	23-24
TILL	clay, as above, olive gray, unoxidized	24-26
GRAVEL		26-27
CLAY	silty, greenish gray, soft, drills smooth and fast, good sample recovery	27-37
TILL	clay, as above, very hard, somewhat brittle	37-56
SAND	very fine to medium, predom. very fine to fine, silty, lots of quartz, some lignite	56-67
SAND	as above, probably very silty, drills slower than above, possibly clayey	67-88
CLAY	silty to silt, clayey, with some very greasy clays, greenish gray, good recovery	88-97
TILL	clay, as above	97-100
SILT	very sandy, slightly clayey, greenish gray, good sample recovery, drills fast	100-113
TILL	interbedded with 6-inch thick gravel layers	113-120

132-059-17DCD3

NDSWC 11969C

Date Completed:	9/7/82	Well Type:	Piezometer
Depth Drilled (ft):	66	Source of Data:	NDSWC
Screened Interval (ft):	58-63	Principal Aquifer :	Undefined
Casing size (in) & Type:	1 1/4" Dia PVC	L.S. Elevation (ft)	1371.1

Lithologic Log

Unit	Description	Depth (ft)
TILL	clay, silty, sandy, pebbly, pale yellow brown with red-yellow stringers, soft, oxidized	0-18
TILL	clay, as above, olive gray, unoxidized	18-23
SILT	clayey, very slightly sandy, drills fast and smooth	23-31
TILL	clay, as above	31-34
SILT	clayey, greenish gray, soft, smooth drilling	34-38
TILL	clay, as above, hard, slightly brittle, slower drilling than above	38-57
SAND	very fine to medium, predom. very fine to fine, silty, lots of quartz, some lignite	57-66

132-059-27CDC1

NDSWC 12260

Date Completed:	7/28/83	Well Type:	Piezometer
Depth Drilled (ft):	260	Source of Data:	NDSWC
Screened Interval (ft):	209-214	Principal Aquifer :	Spiritwood
Casing size (in) & Type:	1 1/4" Dia PVC	L.S. Elevation (ft)	1332.42

Lithologic Log

Unit	Description	Depth (ft)
TOPSOIL		0-1
SAND	very fine to coarse, predom. fine to medium, oxidized	1-12
GRAVEL	very fine to very coarse, predom. fine to medium, some cobbles, oxidized	12-25
TILL	clay, silty, sandy, pebbly,olive brown, oxidized	25-26
TILL	clay, as above, olive gray, unoxidized	26-38
SILT	clayey, olive gray, soft	38-81
TILL	clay, sandy, silty, pebbly, olive gray	81-83
SILT	clayey, olive gray, soft	83-89
TILL	clay, as above, cobbles at 113-114 ft.	89-121
CLAY	silty, interbedded with sand, silt, and sandy clay	121-141
TILL	clay, silty, sandy, pebbly, olive gray	141-147
SAND	50%, coarse to very coarse, and gravel, 50%, very fine to fine pebble, subangular to subrounded, lignite fragments	147-194
GRAVEL	and cobbles	194-195
GRAVEL	very fine to very coarse, and 25% very coarse sand	195-213
GRAVEL	cobbles, and boulders	213-218
SHALE	clay, medium gray, soft, greasy, white specks, (Niobrara Formation)	218-260

132-059-27CDC2

NDSWC 12261

Date Completed:	7/28/83	Well Type:	Piezometer
Depth Drilled (ft):	111	Source of Data:	NDSWC
Screened Interval (ft):	105-110	Principal Aquifer :	Till
Casing size (in) & Type:	1 1/4" Dia PVC	L.S. Elevation (ft)	1332.87

Lithologic Log

Unit	Description	Depth (ft)
TOPSOIL		0-1
SAND	very fine to coarse, predom. fine to medium, oxidized	1-16
GRAVEL	very fine to coarse pebble, predom. very fine to fine pebble, 25-50% coarse to very coarse sand	16-22
TILL	clay, silty, sandy, pebbly, olive brown, oxidized	22-26
TILL	clay, as above, olive gray, unoxidized	26-36
SILT	clayey, olive gray, soft	36-71
TILL	clay, as above	71-79
SILT	clayey, olive gray, soft	79-89
TILL	clay, as above	89-96
TILL	clay, as above, interbedded with shale gravel	96-101
TILL	clay, silty, sandy, pebbly, olive gray	101-111

132-059-27CDC3

NDSWC 11457

Date Completed:	8/21/84	Well Type:	Piezometer
Depth Drilled (ft):	160	Source of Data:	NDSWC
Screened Interval (ft):	150-155	Principal Aquifer :	Spiritwood
Casing size (in) & Type:	1 1/4" Dia PVC	L.S. Elevation (ft)	1333.1

Lithologic Log

Unit	Description	Depth (ft)
CLAY	silty, slightly sandy, pale yellow brown with red-yellow stringers, oxidized	0-3
SAND	70-80%, very fine to very coarse, predom. medium to coarse, and gravel, subangular to well rounded, lots of carbonates, silicates, quartz, some shale, yellow stained, oxidized	3-22
TILL	clay, silty, sandy, pebbly, yellow brown, oxidized	22-25
TILL	clay, very silty, very sandy, slightly pebbly, olive gray, slightly brittle, hard	25-38
CLAY	silty, greenish gray, very slightly brittle	38-83
TILL	clay, silty, sandy, pebbly, olive gray, slightly brittle	83-113
SAND	very fine to fine, silty, poor sample recovery, most into suspension	113-118
TILL	clay, silty, sandy, pebbly, olive gray, sand and gravel layers at 125-127 and 128-130 ft.	118-149
SAND	very fine to very coarse, predom. medium to coarse, and gravel, subangular to well rounded, lots of silicates, carbonates, and quartz, drills as stratified	149-160

132-059-27CDD

NDSWC 6154

Date Completed:	9/22/82	Well Type:	Observation
Depth Drilled (ft):	82	Source of Data:	NDSWC
Screened Interval (ft):	49-54	Principal Aquifer :	Undefined
Casing size (in) & Type:	1 1/4" Dia PVC	L.S. Elevation (ft)	1317.28

Lithologic Log

Unit	Description	Depth (ft)
TOPSOIL		0-1
SILT	clayey, yellow brown to dark yellow orange, oxidized	1-17
SILT	clayey, olive gray	17-19
SAND	coarse to medium gravel, rounded	19-22
SILT		22-26
SAND	coarse to medium gravel, rounded	26-60
TILL	clay, silty, pebbly, interbedded with silt	60-82

131-059-05BAA1

NDSWC 11970A

Date Completed:	9/8/82	Well Type:	Piezometer
Depth Drilled (ft):	185	Source of Data:	NDSWC
Screened Interval (ft):	166-171	Principal Aquifer :	Spiritwood
Casing size (in) & Type:	1 1/4" Dia PVC	L.S. Elevation (ft)	1351.5

Lithologic Log

Unit	Description	Depth (ft)
TILL	clay, silty, sandy, pebbly, pale yellow brown with red-yellow stringers, oxidized, soft	0-18
TILL	clay, as above, olive gray, unoxidized	18-43
SILT	clayey, pale greenish gray, good sample recovery, not much into suspension	43-66
TILL	clay, as above	66-107
GRAVEL	80%, and sand, with cobbles, predom. shale and carbonates, less than 10% silicates, angular to rounded	107-116
TILL	clay, as above, sand and gravel layers from 131-132 and 133 to 135 ft.	116-151
SAND	80%, very fine to very coarse, predom. medium to coarse, and gravel, subangular to rounded, comprised of shield silicates, carbonates, shale, quartz, and lignite, drills as stratified (Spiritwood Aquifer)	151-174
BOULDERS	cobbles, and gravel, very hard drilling	174-182
SHALE	clay, medium brown with light gray specks, calcareous, acid residue dark brown	182-185

131-059-05BAA2

NDSWC 10970B

Date Completed:	9/8/82	Well Type:	Piezometer
Depth Drilled (ft):	104	Source of Data:	NDSWC
Screened Interval (ft):	98-103	Principal Aquifer :	Till
Casing size (in) & Type:	1 1/4" Dia PVC	L.S. Elevation (ft)	1351.8

Lithologic Log

Unit	Description	Depth (ft)
TILL	clay, silty, sandy, pebbly, pale yellow brown with red-yellow stringers, soft, oxidized	0-18
TILL	clay, as above, olive gray, unoxidized	18-43
SILT	very clayey, pale greenish gray, soft, good recovery, drills smooth	43-70
TILL	clay, as above	70-104

131-059-05BAA3

NDSWC 11970C

Date Completed:	9/8/82	Well Type:	Piezometer
Depth Drilled (ft):	60	Source of Data:	NDSWC
Screened Interval (ft):	52-57	Principal Aquifer :	Undefined
Casing size (in) & Type:	1 1/4" Dia PVC	L.S. Elevation (ft)	1351.5

Lithologic Log

Unit	Description	Depth (ft)
TILL	clay, silty, sandy, pebbly, pale yellow brown with red-yellow stringers, oxidized	0-15
TILL	clay, as above, olive gray, unoxidized	15-45
SILT	vary clayey, pale greenish gray, good sample recovery, smooth drilling	45-54
SAND	very fine to very coarse, predom. fine to medium, subrounded to rounded, predom. shale and carbonates	54-57
TILL	clay, as above	57-60

131-058-20DDD1

NDSWC 12405

Date Completed:	10/3/89	Well Type:	Piezometer
Depth Drilled (ft):	200	Source of Data:	NDSWC
Screened Interval (ft):	152-157	Principal Aquifer :	Spiritwood
Casing size (in) & Type:	2" Dia PVC	L.S. Elevation (ft)	1319.06

Lithologic Log

Unit	Description	Depth (ft)
CLAY	silty, light gray, soft	0-2
ROCK		2-3
SAND	very fine to very coarse, predom. coarse, gravelly, fine to coarse, angular to rounded, predom. sahle and carbonates, some shield silicates and quartz, yellow stained, oxidized	3-18
SAND	as above, unoxidized, less gravelly with depth, sand becomes fine to medium	18-62
TILL	clay, silty, sandy, pebbly, olive gray,	62-149
SAND	very fine to verty coarse, predom. medium, gravelly, subangular to rounded, comprised of carbonates, shale,shield silicates,quartz, lignite	149-161
SAND & GRAVEL	as above but interbedded with till, good sample recovery	161-186
SAND & GRAVEL	as above, clean section	186-190
SAND & GRAVEL	as above, interbedded with thin till layers	190-197
SHALE	clay, slightly silty, medium brown with light gray specks, calcareous, soft, (Niobrara Fm.)	197-200

131-058-20DDD2

NDSWC 12406

Date Completed:	10/4/89	Well Type:	Piezometer
Depth Drilled (ft):	105	Source of Data:	NDSWC
Screened Interval (ft):	98-103	Principal Aquifer :	Till
Casing size (in) & Type:	2" Dia PVC	L.S. Elevation (ft)	1319.07

Lithologic Log

Unit	Description	Depth (ft)
TILL	clay, silty, sandy, pebbly, pale yellow brown with red yellow stringers, oxidized,	0-3
SAND	very fine to very coarse, predom. coarse, gravelly, fine to coarse, rounded, comprised of shale , carbonates, some shield silicates and quartz, yellow stained, oxidized	3-17
SAND	as above, unoxidized, less gravelly with depth, sand becomes fine to medium	17-63
TILL	clay, silty, sandy, pebbly, olive gray,	63-105

131-058-20DDD3

NDSWC 12407

Date Completed:	10/4/89	Well Type:	Piezometer
Depth Drilled (ft):	60	Source of Data:	NDSWC
Screened Interval (ft):	55-60	Principal Aquifer :	Unnamed
Casing size (in) & Type:	2" Dia PVC	L.S. Elevation (ft)	1319.05

Lithologic Log

Unit	Description	Depth (ft)
TILL	clay, silty, sandy, pebbly,	0-3
GRAVEL	coarse to medium pebble, oxidized	3-17
GRAVEL	as above, gray	17-20
GRAVEL	sandy, fine to very coarse sand, lots of detrital shale, becomes finer with depth	20-60

131-058-25CCC1

NDSWC 12401

Date Completed:	10/2/89	Well Type:	Piezometer
Depth Drilled (ft):	217	Source of Data:	NDSWC
Screened Interval (ft):	205-210	Principal Aquifer :	Spiritwood
Casing size (in) & Type:	12" Dia PVC	L.S. Elevation (ft)	1312.73

Lithologic Log

Unit	Description	Depth (ft)
CLAY	silty, dark black, soft	0-5
TILL	clay, silty, sandy, pebbly, pale yellow brown with red yellow stringers, oxidized, soft,	5-15
SILT	slightly clayey to very clayey with depth, slight to moderately sandy, very fine sand, pale greenish gray, soft	15-161
SAND	very fine to very coarse, slightly gravelly, subangular to rounded, lots of shale, carbonates, shield silicates, and lignite	161-171
SAND	as above but very gravelly, clean	171-180
TILL	clay, silty, sandy, pebbly, olive gray,	180-190
SAND	as above, very gravelly, interbedded with thin till or silty clay layers	190-212
SHALE	clay, dark black, hard, very sticky, noncalcareous, (Carlile Fm.)	212-217

131-058-25CCC2

NDSWC 12402

Date Completed:	10/3/89	Well Type:	Piezometer
Depth Drilled (ft):	170	Source of Data:	NDSWC
Screened Interval (ft):	166-171	Principal Aquifer :	Spiritwood
Casing size (in) & Type:	2" Dia PVC	L.S. Elevation (ft)	1312.95

Lithologic Log

Unit	Description	Depth (ft)
CLAY	silty, dark black, soft	0-5
TILL	clay, silty, sandy, pebbly, pale yellow brown with red yellow stringers, oxidized,	5-12
TILL	clay, silty, sandy, pebbly, olive gray,	12-20
SILT	slightly sandy, very fine sand, very slightly clayey, greenish gray, most sample returns into suspension	20-159
SAND	very fine to very coarse, slightly gravelly, subangular to rounded, comprised of carbonates, shale, shield silicates, and lignite	159-170

131-058-25CCC3

NDSWC 12403

Date Completed:	10/3/89	Well Type:	Piezometer
Depth Drilled (ft):	107	Source of Data:	NDSWC
Screened Interval (ft):	102-107	Principal Aquifer :	Unnamed
Casing size (in) & Type:	2" Dia PVC	L.S. Elevation (ft)	1312.82

Lithologic Log

Unit	Description	Depth (ft)
CLAY	silty, dark black	0-5
TILL	clay, silty, sandy, pebbly, pale yellow brown with red yellow stringers, oxidized,	5-12
TILL	clay, silty, sandy, pebbly, olive gray, soft,	12-19
SILT	slight to moderately sandy, slightly clayey, pale greenish gray, poor sample recovery, most into suspension	19-107

131-058-25CCC4

NDSWC 12404

Date Completed:	10/3/89	Well Type:	Piezometer
Depth Drilled (ft):	23	Source of Data:	NDSWC
Screened Interval (ft):	18-23	Principal Aquifer :	Unnamed
Casing size (in) & Type:	2" Dia PVC	L.S. Elevation (ft)	1312.59

Lithologic Log

Unit	Description	Depth (ft)
CLAY	silty, dark black, soft	0-5
TILL	clay, silty, sandy, pebbly, pale yellow brown with red yellow stringers, oxidized,	5-12
TILL	clay, silty, sandy, pebbly, olive gray,	12-19
SILT	very slightly to moderately sandy, slightly clayey, pale greenish gray, soft, most into suspension	19-23

APPENDIX 2

WATER LEVELS MEASURED AT PIEZOMETER NESTS IN THE SPIRITWOOD AQUIFER STUDY AREA

(Abbreviations)

LS Elev. -	land surface elevation
msl -	mean sea level
SI -	screened interval
WL Elev. -	water level elevation

134-061-13DAD1 LS Elev (msl,ft)=1413.79

Spiritwood Aquifer SI (ft.)=257-262

Date	Depth to Water (ft)	WL Elev (msl, ft)	Date	Depth to Water (ft)	WL Elev (msl, ft)
09/20/83	68.05	1346.74	04/24/89	66.06	1348.73
12/02/83	67.87	1346.92	05/22/89	65.88	1348.91
			06/29/89	65.88	1348.91
04/13/84	66.10	1348.69	07/26/89	66.09	1348.70
05/17/84	65.89	1348.90	08/22/89	67.03	1347.76
06/14/84	65.72	1349.07	09/26/89	67.50	1347.29
07/12/84	65.66	1349.13	10/24/89	67.47	1347.32
08/13/84	67.00	1347.79			
09/13/84	68.58	1346.21	05/16/90	65.98	1348.81
10/09/84	68.91	1345.88	06/14/90	65.95	1348.84
11/14/84	68.57	1346.22	07/12/90	66.47	1348.32
12/11/84	68.30	1346.49	08/08/90	68.69	1346.10
			09/06/90	70.97	1343.82
04/09/85	67.04	1347.75	10/03/90	71.10	1343.69
04/28/85	66.90	1347.89	11/05/90	70.82	1343.97
04/30/85	66.90	1347.89	12/03/90	70.32	1344.47
06/06/85	66.57	1348.22			
07/11/85	66.91	1347.88	04/08/91	68.17	1346.62
08/15/85	68.20	1346.59	05/08/91	67.62	1347.17
09/12/85	69.12	1345.67	06/04/91	67.11	1347.68
10/07/85	69.15	1345.64	07/02/91	66.68	1348.11
11/06/85	69.13	1345.66	07/30/91	68.22	1346.57
12/17/85	67.61	1347.18	09/04/91	70.27	1344.52
			09/11/91	70.38	1344.41
04/02/86	67.25	1347.54	10/01/91	70.02	1344.77
05/06/86	66.57	1348.22	11/13/91	68.96	1345.83
06/04/86	66.44	1348.35	12/09/91	68.45	1346.34
07/02/86	66.26	1348.53			
08/07/86	66.35	1348.44	04/15/92	66.55	1348.24
09/05/86	66.80	1347.99	05/19/92	66.29	1348.50
10/07/86	66.41	1348.38	06/22/92	66.14	1348.65
11/05/86	66.10	1348.69	07/22/92	66.63	1348.16
12/03/86	65.75	1349.04	08/18/92	67.98	1346.81
			09/15/92	68.26	1346.53
04/23/87	64.32	1350.47	10/13/92	68.23	1346.56
05/20/87	64.21	1350.58	11/12/92	67.72	1347.07
07/01/87	65.29	1349.50	12/08/92	67.27	1347.52
08/06/87	63.98	1350.81			
09/03/87	65.59	1349.20	04/13/93	65.66	1349.13
10/07/87	65.70	1349.09	05/11/93	65.40	1349.39
11/05/87	65.26	1349.53	06/10/93	65.30	1349.49
12/03/87	65.33	1349.46	07/07/93	64.93	1349.86
			08/19/93	65.80	1348.99
05/04/88	64.15	1350.64	09/08/93	65.30	1349.49
07/07/88	64.84	1349.95	10/12/93	65.23	1349.56
08/03/88	66.05	1348.74	11/08/93	64.94	1349.85
09/16/88	67.86	1346.93	12/14/93	64.48	1350.31
10/19/88	67.90	1346.89			
11/22/88	67.77	1347.02	04/20/94	62.99	1351.80

134-061-13DAD2 LS Elev (msl,ft)=1416.1

Spiritwood Aquifer SI (ft.)=132-137

Date	Depth to Water (ft)	WL Elev (msl, ft)
08/30/84	69.59	1348.91
09/13/84	70.20	1348.30
10/09/84	70.53	1347.97
11/14/84	70.17	1348.33
12/11/84	69.93	1348.57
04/09/85	68.67	1349.83
04/30/85	68.53	1349.97
07/11/85	68.54	1349.96
08/15/85	69.42	1349.08
09/12/85	70.75	1347.75
10/07/85	70.78	1347.72
11/06/85	70.75	1347.75
12/17/85	70.24	1348.26
04/02/86	69.03	1349.47
05/06/86	68.20	1350.30
06/04/86	68.05	1350.45
07/02/86	67.90	1350.60
08/07/86	67.97	1350.53
09/05/86	68.45	1350.05
10/07/86	68.05	1350.45
11/05/86	67.77	1350.73
12/03/86	67.38	1351.12
04/23/87	65.98	1352.52
05/20/87	65.85	1352.65
07/01/87	65.95	1352.55
08/06/87	66.63	1351.87
09/03/87	67.31	1351.19
10/07/87	67.53	1350.97
11/05/87	67.37	1351.13
12/03/87	67.08	1351.42
05/04/88	65.92	1352.58
07/07/88	66.60	1351.90
08/03/88	67.85	1350.65
09/16/88	69.50	1349.00
10/19/88	69.65	1348.85
11/22/88	69.37	1349.13
04/24/89	67.80	1350.70
05/22/89	67.60	1350.90
06/29/89	67.61	1350.89
07/26/89	67.85	1350.65
08/22/89	68.74	1349.76
09/26/89	69.26	1349.24
10/24/89	69.23	1349.27
11/28/89	69.12	1349.38
04/23/90	67.76	1350.74
05/16/90	67.77	1350.73
06/14/90	67.72	1350.78
07/12/90	68.29	1350.21
08/08/90	70.46	1348.04
09/06/90	72.73	1345.77
10/03/90	72.89	1345.61
11/05/90	72.59	1345.91
12/03/90	72.10	1346.40
04/08/91	69.95	1348.55
05/08/91	69.40	1349.10
06/04/91	68.79	1349.71
07/02/91	68.46	1350.04
07/30/91	69.92	1348.58
09/04/91	72.06	1346.44
09/11/91	72.17	1346.33
10/01/91	71.80	1346.70
11/13/91	70.63	1347.87
12/09/91	70.26	1348.24
04/15/92	68.34	1350.16
05/19/92	68.05	1350.45
06/22/92	67.93	1350.57
07/22/92	68.33	1350.17
08/18/92	69.76	1348.74
09/15/92	70.05	1348.45
10/13/92	69.99	1348.51
11/12/92	69.50	1349.00
12/08/92	69.06	1349.44
04/13/93	67.45	1351.05
05/11/93	67.19	1351.31
06/10/93	67.09	1351.41
07/07/93	66.71	1351.79
08/19/93	66.70	1351.80
09/08/93	67.09	1351.41
10/25/93	67.01	1351.49
11/08/93	66.73	1351.77
12/14/93	66.20	1352.30
04/20/94	64.76	1353.74

134-061-13DAD3 LS Elev (msl,ft)=1416.5

Unnamed Aquifer SI (ft.)=68-73

Date	Depth to Water (ft)	WL Elev (msl, ft)
09/13/84	43.66	1374.34
10/09/84	44.27	1373.73
11/14/84	44.58	1373.42
12/11/84	44.75	1373.25
04/09/85	44.80	1373.20
04/30/85	44.71	1373.29
06/06/85	44.63	1373.37
07/11/85	44.77	1373.23
08/15/85	45.30	1372.70
09/12/85	45.68	1372.32
10/07/85	45.74	1372.26
11/06/85	45.62	1372.38
12/17/85	45.60	1372.40
04/02/86	45.42	1372.58
05/06/86	44.86	1373.14
06/04/86	44.60	1373.40
07/02/86	44.48	1373.52
08/07/86	44.30	1373.70
09/05/86	44.39	1373.61
10/07/86	44.17	1373.83
11/05/86	44.06	1373.94
12/03/86	43.91	1374.09
04/23/87	43.43	1374.57
05/20/87	43.32	1374.68
07/01/87	43.41	1374.59
08/06/87	43.69	1374.31
09/03/87	44.11	1373.89
10/07/87	44.33	1373.67
11/05/87	44.58	1373.42
12/03/87	44.57	1373.43
05/04/88	45.93	1372.07
07/07/88	46.89	1371.11
08/03/88	47.67	1370.33
09/16/88	49.07	1368.93
10/19/88	49.49	1368.51
11/22/88	49.82	1368.18
04/24/89	50.98	1367.02
05/22/89	50.89	1367.11
06/29/89	50.53	1367.47
07/26/89	49.98	1368.02
08/22/89	49.40	1368.60

Date	Depth to Water (ft)	WL Elev (msl, ft)
09/26/89	48.09	1369.91
10/24/89	46.59	1371.41
11/28/89	44.79	1373.21
04/23/90	42.93	1375.07
05/16/90	42.75	1375.25
06/14/90	42.63	1375.37
07/12/90	42.73	1375.27
08/08/90	43.16	1374.84
09/06/90	43.58	1374.42
10/03/90	43.68	1374.32
11/05/90	43.59	1374.41
12/03/90	43.59	1374.41
04/08/91	43.23	1374.77
05/08/91	43.06	1374.94
06/04/91	42.77	1375.23
07/02/91	42.50	1375.50
07/30/91	42.50	1375.50
09/04/91	42.86	1375.14
09/11/91	43.87	1374.13
10/01/91	42.90	1375.10
11/13/91	42.70	1375.30
12/09/91	42.61	1375.39
04/15/92	42.19	1375.81
05/19/92	42.10	1375.90
06/22/92	41.94	1376.06
07/22/92	41.98	1376.02
08/18/92	42.15	1375.85
09/15/92	42.09	1375.91
10/13/92	42.22	1375.78
11/12/92	42.14	1375.86
12/08/92	42.14	1375.86
04/13/93	41.87	1376.13
05/11/93	41.71	1376.29
06/10/93	41.52	1376.48
07/07/93	41.27	1376.73
08/19/93	40.87	1377.13
09/08/93	40.94	1377.06
10/12/93	40.97	1377.03
11/08/93	40.90	1377.10
12/14/93	40.71	1377.29
04/20/94	40.37	1377.63

133-060-02CDD2
Spiritwood Aquifer

LS Elev (msl,ft)=1397.45
SI (ft.)=195-200

Date	Depth to Water (ft)	WL Elev (msl, ft)
09/13/84	63.40	1335.45
10/09/84	64.25	1334.60
11/14/84	62.93	1335.92
12/11/84	62.01	1336.84
04/09/85	59.15	1339.70
04/28/85	58.86	1339.99
04/30/85	58.83	1340.02
06/06/85	58.67	1340.18
07/11/85	59.06	1339.79
08/15/85	61.79	1337.06
09/12/85	63.76	1335.09
10/07/85	63.48	1335.37
11/06/85	62.79	1336.06
12/17/85	61.60	1337.25
04/02/86	59.30	1339.55
05/06/86	58.33	1340.52
06/04/86	57.98	1340.87
07/02/86	57.77	1341.08
08/06/86	57.61	1341.24
09/05/86	57.90	1340.95
10/07/86	57.77	1341.08
11/05/86	57.52	1341.33
12/03/86	57.09	1341.76
04/22/87	55.34	1343.51
05/20/87	55.13	1343.72
07/01/87	55.72	1343.13
08/06/87	56.64	1342.21
09/03/87	57.95	1340.90
10/07/87	58.73	1340.12
11/05/87	57.73	1341.12
12/03/87	57.90	1340.95
05/04/88	55.79	1343.06
07/07/88	56.52	1342.33
08/03/88	59.44	1339.41
09/16/88	62.86	1335.99
10/19/88	62.59	1336.26
11/22/88	61.54	1337.31
04/25/89	58.18	1340.67
05/22/89	57.80	1341.05
06/29/89	57.81	1341.04
07/26/89	58.08	1340.77
08/22/89	58.97	1339.88

Date	Depth to Water (ft)	WL Elev (msl, ft)
09/26/89	60.33	1338.52
10/24/89	60.05	1338.80
11/28/89	59.48	1339.37
04/23/90	57.61	1341.24
05/16/90	57.54	1341.31
06/14/90	57.56	1341.29
07/12/90	60.92	1337.93
08/08/90	65.04	1333.81
09/06/90	66.77	1332.08
10/03/90	64.72	1334.13
11/05/90	63.66	1335.19
12/03/90	62.46	1336.39
04/08/91	59.23	1339.62
05/08/91	58.66	1340.19
06/05/91	58.15	1340.70
07/02/91	58.48	1340.37
07/30/91	62.27	1336.58
09/04/91	65.21	1333.64
09/11/91	64.86	1333.99
10/01/91	63.02	1335.83
11/14/91	61.00	1337.85
12/10/91	60.14	1338.71
04/15/92	57.44	1341.41
05/19/92	57.18	1341.67
06/22/92	56.96	1341.89
07/22/92	57.40	1341.45
08/18/92	61.00	1337.85
09/15/92	60.36	1338.49
10/13/92	60.06	1338.79
11/12/92	59.30	1339.55
12/08/92	58.68	1340.17
04/13/93	56.49	1342.36
05/11/93	56.19	1342.66
06/10/93	56.26	1342.59
07/07/93	55.60	1343.25
08/19/93	56.30	1342.55
09/08/93	56.95	1341.90
10/12/93	56.62	1342.23
11/08/93	56.18	1342.67
12/14/93	55.45	1343.40
04/20/94	53.78	1345.07

133-060-02CDD3 LS Elev (msl,ft)=1398.12

Till SI (ft.)=117-122

Date	Depth to Water (ft)	WL Elev (msl, ft)
08/29/84	38.01	1362.21
09/05/84	36.68	1363.54
09/13/84	37.32	1362.90
10/11/84	38.32	1361.90
11/14/84	37.76	1362.46
12/11/84	37.57	1362.65
04/09/85	36.89	1363.33
04/30/85	36.78	1363.44
06/06/85	37.79	1362.43
07/11/85	37.65	1362.57
08/15/85	38.79	1361.43
09/12/85	40.06	1360.16
10/07/85	39.92	1360.30
11/06/85	39.76	1360.46
12/17/85	39.16	1361.06
04/02/86	38.60	1361.62
05/06/86	37.64	1362.58
06/04/86	37.40	1362.82
07/02/86	37.13	1363.09
08/06/86	36.95	1363.27
09/05/86	36.97	1363.25
10/07/86	36.77	1363.45
11/05/86	36.66	1363.56
12/03/86	36.40	1363.82
04/22/87	35.42	1364.80
05/20/87	35.44	1364.78
07/01/87	35.57	1364.65
08/06/87	35.83	1364.39
09/03/87	36.37	1363.85
10/07/87	36.71	1363.51
11/05/87	36.71	1363.51
12/03/87	36.45	1363.77
05/04/88	35.83	1364.39
07/07/88	36.14	1364.08
08/03/88	37.19	1363.03
09/16/88	38.87	1361.35
10/19/88	38.91	1361.31
11/22/88	38.56	1361.66
04/25/89	37.36	1362.86
05/22/89	37.25	1362.97
06/29/89	37.38	1362.84

Date	Depth to Water (ft)	WL Elev (msl, ft)
07/26/89	37.50	1362.72
08/22/89	37.81	1362.41
09/26/89	38.46	1361.76
10/24/89	38.45	1361.77
11/28/89	37.79	1362.43
04/23/90	36.71	1363.51
05/16/90	36.73	1363.49
06/14/90	37.78	1362.44
07/12/90	38.90	1361.32
08/08/90	40.56	1359.66
09/06/90	41.82	1358.40
10/03/90	41.26	1358.96
11/05/90	40.88	1359.34
12/03/90	40.53	1359.69
04/08/91	39.36	1360.86
05/08/91	39.06	1361.16
06/05/91	38.04	1362.18
07/02/91	38.76	1361.46
09/04/91	41.15	1359.07
10/01/91	40.47	1359.75
11/14/91	39.44	1360.78
12/10/91	39.02	1361.20
04/15/92	37.67	1362.55
05/19/92	37.43	1362.79
06/22/92	37.19	1363.03
07/22/92	37.30	1362.92
08/18/92	38.59	1361.63
09/15/92	38.42	1361.80
10/13/92	38.30	1361.92
11/12/92	37.93	1362.29
12/08/92	37.66	1362.56
04/13/93	36.82	1363.40
05/11/93	36.68	1363.54
06/10/93	36.57	1363.65
07/07/93	36.24	1363.98
08/19/93	36.11	1364.11
09/08/93	36.26	1363.96
10/12/93	36.09	1364.13
11/08/93	35.82	1364.40
12/14/93	35.32	1364.90
04/20/94	34.50	1365.72

133-060-02CDD4 LS Elev (msl,ft)=1397.94

Undefined SI (ft.)=26-31

Date	Depth to Water (ft)	WL Elev (msl, ft)	Date	Depth to Water (ft)	WL Elev (msl, ft)
08/29/84	16.66	1383.38	09/26/89	13.67	1386.37
09/13/84	10.86	1389.18	10/24/89	13.71	1386.33
10/09/84	11.50	1388.54	11/28/89	13.70	1386.34
11/14/84	10.28	1389.76			
12/11/84	10.48	1389.56	04/23/90	15.41	1384.63
			05/16/90	15.56	1384.48
04/09/85	9.86	1390.18	06/14/90	15.73	1384.31
04/30/85	9.40	1390.64	07/12/90	15.33	1384.71
06/06/85	9.20	1390.84	08/08/90	15.11	1384.93
07/11/85	10.77	1389.27	09/06/90	14.99	1385.05
08/15/85	10.98	1389.06	10/03/90	14.90	1385.14
09/12/85	11.32	1388.72	11/05/90	14.93	1385.11
10/07/85	11.24	1388.80	12/03/90	15.01	1385.03
11/06/85	11.28	1388.76			
12/17/85	11.56	1388.48	04/08/91	16.29	1383.75
			05/08/91	16.24	1383.80
04/02/86	9.29	1390.75	06/05/91	14.75	1385.29
05/06/86	9.49	1390.55	07/02/91	11.20	1388.84
06/04/86	9.84	1390.20	07/30/91	11.30	1388.74
07/02/86	10.42	1389.62	09/04/91	11.93	1388.11
08/06/86	10.72	1389.32	09/11/91	11.93	1388.11
09/05/86	10.84	1389.20	10/01/91	12.35	1387.69
10/07/86	10.55	1389.49	11/14/91	12.30	1387.74
11/05/86	10.40	1389.64	12/10/91	12.27	1387.77
12/03/86	10.19	1389.85			
			04/15/92	12.10	1387.94
04/22/87	10.09	1389.95	05/19/92	11.89	1388.15
05/20/87	10.27	1389.77	06/22/92	11.43	1388.61
07/01/87	9.96	1390.08	07/22/92	11.08	1388.96
08/06/87	11.49	1388.55	08/18/92	11.28	1388.76
09/03/87	11.70	1388.34	09/15/92	11.57	1388.47
10/07/87	11.81	1388.23	10/13/92	11.96	1388.08
11/05/87	11.79	1388.25	11/12/92	12.01	1388.03
12/03/87	11.78	1388.26	12/08/92	12.08	1387.96
05/04/88	13.19	1386.85	04/13/93	12.46	1387.58
07/07/88	13.73	1386.31	05/11/93	11.36	1388.68
08/03/88	13.56	1386.48	06/10/93	10.65	1389.39
09/16/88	13.31	1386.73	07/07/93	9.98	1390.06
10/19/88	12.87	1387.17	08/19/93	9.26	1390.78
11/22/88	12.51	1387.53	09/08/93	9.21	1390.83
			10/12/93	9.44	1390.60
04/25/89	13.43	1386.61	11/08/93	9.57	1390.47
05/22/89	12.54	1387.50	12/14/93	9.51	1390.53
06/29/89	12.65	1387.39			
07/26/89	13.04	1387.00	04/20/94	9.03	1391.01
08/22/89	13.40	1386.64			

133-060-36DDD1

Spiritwood Aquifer

LS Elev (msl,ft)=1383.1

SI (ft.)=212-215

Date	Depth to Water (ft)	WL Elev (msl, ft)
11/05/75	38.22	1346.88
12/04/75	38.06	1347.04
03/09/76	37.88	1347.22
04/13/76	37.89	1347.21
05/04/76	37.80	1347.30
06/10/76	38.01	1347.09
07/07/76	38.15	1346.95
08/03/76	38.57	1346.53
09/08/76	38.94	1346.16
08/04/77	47.05	1338.05
08/09/77	48.01	1337.09
08/17/77	49.32	1335.78
08/22/77	49.87	1335.23
08/31/77	49.88	1335.22
09/06/77	50.93	1334.17
09/14/77	50.87	1334.23
09/20/77	50.55	1334.55
09/26/77	50.15	1334.95
10/06/77	49.74	1335.36
11/01/77	48.20	1336.90
12/12/77	46.10	1339.00
01/10/78	45.30	1339.80
03/22/78	43.50	1341.60
04/10/78	43.11	1341.99
05/09/78	42.70	1342.40
06/06/78	42.40	1342.70
06/23/78	42.76	1342.34
07/07/78	42.59	1342.51
06/21/79	42.09	1343.01
07/25/79	43.45	1341.65
08/09/79	44.30	1340.80
08/28/79	45.40	1339.70
09/12/79	46.36	1338.74
09/26/79	46.66	1338.44
10/09/79	46.28	1338.82
10/24/79	45.90	1339.20
11/15/79	44.93	1340.17
12/05/79	44.12	1340.98
04/01/80	42.02	1343.08
04/24/80	41.77	1343.33
05/21/80	42.10	1343.00
06/17/80	43.22	1341.88
07/15/80	44.98	1340.12
08/13/80	49.22	1335.88
09/10/80	48.54	1336.56
10/10/80	47.73	1337.37
11/07/80	46.28	1338.82
12/10/80	45.13	1339.97
04/16/81	42.80	1342.30
05/21/81	44.00	1341.10
06/11/81	45.09	1340.01
07/10/81	45.07	1340.03
08/07/81	48.13	1336.97
09/04/81	51.38	1333.72
09/30/81	50.35	1334.75
10/29/81	48.48	1336.62
11/24/81	47.37	1337.73
01/13/82	45.17	1339.93
04/14/82	43.84	1341.26
05/13/82	43.80	1341.30
06/08/82	43.48	1341.62
07/08/82	45.60	1339.50
08/05/82	51.35	1333.75
09/01/82	55.94	1329.16
09/30/82	55.00	1330.10
10/28/82	52.42	1332.68
12/02/82	50.34	1334.76
04/27/83	46.31	1338.79
05/25/83	45.97	1339.13
06/22/83	47.13	1337.97
07/20/83	49.35	1335.75
08/17/83	53.77	1331.33
09/15/83	55.10	1330.00
10/19/83	53.11	1331.99
11/30/83	50.98	1334.12
04/12/84	47.05	1338.05
05/16/84	46.50	1338.60
06/14/84	47.44	1337.66
07/12/84	47.39	1337.71
08/09/84	52.27	1332.83
08/14/84	53.50	1331.60
09/13/84	57.30	1327.80
10/09/84	55.66	1329.44
11/14/84	52.86	1332.24
12/11/84	51.50	1333.60
04/09/85	48.01	1337.09
04/30/85	47.70	1337.40
06/06/85	48.54	1336.56
07/11/85	49.56	1335.54
08/15/85	55.60	1329.50
09/12/85	55.76	1329.34
10/07/85	53.96	1331.14
11/06/85	52.48	1332.62
12/17/85	50.85	1334.25
04/02/86	48.20	1336.90
05/06/86	47.13	1337.97
06/04/86	46.78	1338.32
07/01/86	46.88	1338.22
08/06/86	47.10	1338.00
09/05/86	47.79	1337.31
10/07/86	47.14	1337.96
11/05/86	46.55	1338.55
12/03/86	46.01	1339.09
04/22/87	44.09	1341.01
05/20/87	44.09	1341.01
07/01/87	45.14	1339.96
08/06/87	48.09	1337.01
09/02/87	49.76	1335.34

133-060-36DDD1 **(Continued)** LS Elev (msl,ft)=1383.1

Spiritwood Aquifer SI (ft.)=212-215

Date	Depth to Water (ft)	WL Elev (msl, ft)	Date	Depth to Water (ft)	WL Elev (msl, ft)
10/07/87	49.09	1336.01	05/08/91	47.30	1337.80
11/05/87	48.15	1336.95	06/04/91	46.77	1338.33
12/03/87	47.20	1337.90	07/02/91	46.34	1338.76
			07/30/91	49.12	1335.98
05/04/88	44.58	1340.52	09/04/91	53.06	1332.04
07/07/88	48.44	1336.66	09/12/91	53.33	1331.77
08/03/88	53.23	1331.87	10/01/91	53.48	1331.62
09/16/88	55.07	1330.03	11/14/91	50.05	1335.05
10/19/88	53.08	1332.02	12/10/91	49.02	1336.08
11/22/88	51.27	1333.83			
			04/15/92	46.01	1339.09
04/25/89	47.09	1338.01	05/19/92	45.84	1339.26
05/22/89	46.79	1338.31	06/22/92	45.69	1339.41
06/29/89	47.23	1337.87	07/22/92	46.03	1339.07
07/26/89	48.47	1336.63	08/18/92	48.87	1336.23
08/22/89	50.72	1334.38	09/15/92	50.43	1334.67
09/26/89	50.69	1334.41	10/13/92	49.61	1335.49
10/24/89	49.61	1335.49	11/12/92	48.41	1336.69
11/28/89	48.59	1336.51	12/08/92	47.56	1337.54
04/23/90	46.06	1339.04	04/13/93	45.07	1340.03
05/16/90	45.94	1339.16	05/11/93	44.76	1340.34
06/14/90	46.42	1338.68	06/10/93	44.53	1340.57
07/12/90	48.05	1337.05	07/07/93	44.17	1340.93
08/08/90	52.23	1332.87	08/19/93	44.86	1340.24
09/06/90	55.92	1329.18	09/08/93	46.18	1338.92
10/03/90	54.86	1330.24	10/12/93	45.86	1339.24
11/05/90	53.05	1332.05	11/08/93	45.11	1339.99
12/03/90	51.71	1333.39	12/14/93	44.17	1340.93
04/08/91	48.00	1337.10	04/20/94	42.31	1342.79

133-060-36DDD2 LS Elev (msl,ft)=1383.1

Spiritwood Aquifer SI (ft.)=236-241

Date	Depth to Water (ft)	WL Elev (msl, ft)
08/29/84	55.64	1329.36
09/13/84	57.18	1327.82
10/09/84	55.56	1329.44
11/14/84	52.73	1332.27
12/11/84	51.39	1333.61
04/09/85	47.91	1337.09
04/28/85	47.61	1337.39
04/30/85	47.60	1337.40
06/06/85	48.42	1336.58
07/11/85	49.19	1335.81
08/15/85	55.45	1329.55
09/12/85	55.68	1329.32
10/07/85	53.85	1331.15
11/06/85	52.38	1332.62
12/17/85	50.74	1334.26
04/02/86	48.10	1336.90
05/06/86	47.03	1337.97
06/04/86	46.67	1338.33
07/01/86	46.77	1338.23
08/06/86	46.99	1338.01
09/05/86	47.67	1337.33
10/07/86	47.04	1337.96
11/05/86	46.45	1338.55
12/03/86	45.91	1339.09
04/22/87	43.97	1341.03
05/20/87	44.00	1341.00
07/01/87	45.10	1339.90
08/06/87	47.97	1337.03
09/02/87	49.60	1335.40
10/07/87	48.95	1336.05
11/05/87	48.02	1336.98
12/03/87	47.11	1337.89
05/04/88	44.53	1340.47
07/07/88	48.34	1336.66
08/03/88	53.14	1331.86
09/16/88	54.98	1330.02
10/19/88	52.98	1332.02
11/22/88	51.18	1333.82
04/25/89	47.00	1338.00
05/22/89	46.70	1338.30
06/29/89	47.15	1337.85
07/26/89	48.38	1336.62
08/22/89	50.64	1334.36
09/26/89	50.59	1334.41
10/24/89	49.53	1335.47
04/23/90	45.94	1339.06
05/16/90	45.85	1339.15
06/14/90	46.33	1338.67
07/12/90	47.94	1337.06
08/08/90	52.16	1332.84
09/06/90	55.83	1329.17
10/03/90	54.80	1330.20
11/05/90	52.90	1332.10
12/03/90	51.62	1333.38
04/08/91	47.90	1337.10
05/08/91	47.20	1337.80
06/04/91	46.69	1338.31
07/02/91	46.24	1338.76
07/30/91	49.00	1336.00
09/04/91	52.94	1332.06
09/12/91	53.22	1331.78
10/01/91	53.36	1331.64
11/14/91	49.96	1335.04
12/10/91	48.89	1336.11
04/15/92	45.88	1339.12
05/19/92	45.73	1339.27
06/22/92	45.58	1339.42
07/22/92	45.69	1339.31
08/18/92	48.76	1336.24
09/15/92	50.33	1334.67
10/13/92	49.50	1335.50
11/12/92	48.31	1336.69
12/08/92	47.46	1337.54
04/13/93	44.98	1340.02
05/11/93	44.67	1340.33
06/10/93	44.43	1340.57
07/07/93	44.07	1340.93
08/19/93	44.72	1340.28
09/08/93	46.03	1338.97
10/12/93	45.74	1339.26
11/08/93	45.02	1339.98
12/14/93	44.08	1340.92
04/20/94	42.21	1342.79

133-060-36DDD3 LS Elev (msl,ft)=1383.3

Till with Sand and Gravel Layers SI (ft.)=120-125

Date	Depth to Water (ft)	WL Elev (msl, ft)
09/05/84	24.42	1360.58
09/13/84	24.44	1360.56
10/09/84	24.56	1360.44
11/14/84	24.59	1360.41
12/11/84	24.72	1360.28
04/09/85	25.06	1359.94
04/30/85	25.13	1359.87
06/06/85	25.40	1359.60
07/11/85	25.03	1359.97
08/15/85	25.12	1359.88
09/12/85	25.38	1359.62
10/07/85	25.44	1359.56
11/06/85	25.73	1359.27
12/17/85	25.88	1359.12
04/02/86	26.25	1358.75
05/06/86	25.39	1359.61
06/04/86	24.75	1360.25
07/01/86	24.02	1360.98
08/06/86	23.24	1361.76
09/05/86	22.84	1362.16
10/07/86	22.40	1362.60
11/05/86	22.19	1362.81
12/03/86	21.93	1363.07
04/22/87	21.58	1363.42
05/20/87	21.52	1363.48
07/01/87	21.32	1363.68
08/06/87	21.15	1363.85
09/02/87	21.41	1363.59
10/07/87	21.70	1363.30
11/05/87	21.07	1363.93
12/03/87	22.15	1362.85
05/04/88	23.08	1361.92
07/07/88	23.28	1361.72
08/03/88	23.28	1361.72
09/16/88	23.95	1361.05
10/19/88	24.19	1360.81
11/22/88	24.36	1360.64
04/25/89	24.64	1360.36
05/22/89	24.44	1360.56
06/29/89	24.09	1360.91
07/26/89	23.71	1361.29
08/22/89	23.55	1361.45
09/26/89	23.36	1361.64
10/24/89	23.31	1361.69
11/28/89	23.21	1361.79
04/23/90	23.54	1361.46
05/16/90	23.49	1361.51
06/14/90	23.47	1361.53
07/12/90	23.36	1361.64
08/08/90	23.38	1361.62
09/06/90	23.51	1361.49
10/03/90	23.69	1361.31
11/05/90	24.08	1360.92
12/03/90	24.35	1360.65
04/08/91	24.90	1360.10
05/08/91	24.76	1360.24
06/04/91	23.78	1361.22
07/02/91	23.35	1361.65
07/30/91	22.69	1362.31
09/04/91	22.23	1362.77
10/01/91	23.93	1361.07
11/14/91	21.63	1363.37
12/10/91	21.54	1363.46
04/15/92	21.28	1363.72
05/19/92	21.02	1363.98
06/22/92	20.70	1364.30
07/22/92	20.59	1364.41
08/18/92	20.65	1364.35
09/15/92	20.59	1364.41
10/13/92	20.84	1364.16
11/12/92	20.93	1364.07
12/08/92	21.05	1363.95
04/13/93	21.44	1363.56
05/11/93	21.37	1363.63
06/10/93	20.89	1364.11
07/07/93	20.40	1364.60
08/19/93	19.40	1365.60
09/08/93	19.03	1365.97
10/12/93	18.80	1366.20
11/08/93	18.64	1366.36
12/14/93	18.40	1366.60
04/20/94	18.17	1366.83

133-060-36DDD5 LS Elev (msl,ft)=1383.8

Till SI (ft.)=40-45

Date	Depth to Water (ft)	WL Elev (msl, ft)	Date	Depth to Water (ft)	WL Elev (msl, ft)
09/05/84	13.23	1372.67	08/22/89	11.65	1374.25
09/13/84	13.46	1372.44	09/26/89	11.71	1374.19
10/09/84	14.03	1371.87	10/24/89	11.85	1374.05
11/14/84	13.63	1372.27	11/28/89	11.64	1374.26
12/11/84	13.63	1372.27			
			04/23/90	13.46	1372.44
04/09/85	14.36	1371.54	05/16/90	12.33	1373.57
04/30/85	13.93	1371.97	06/14/90	11.75	1374.15
06/06/85	13.71	1372.19	07/12/90	11.75	1374.15
07/11/85	13.68	1372.22	08/08/90	12.41	1373.49
08/15/85	14.53	1371.37	09/06/90	13.16	1372.74
09/12/85	15.05	1370.85	10/03/90	13.62	1372.28
10/07/85	15.18	1370.72	11/05/90	13.90	1372.00
11/06/85	15.32	1370.58	12/03/90	14.02	1371.88
12/17/85	15.56	1370.34			
			04/08/91	14.53	1371.37
04/02/86	14.75	1371.15	05/08/91	13.16	1372.74
05/06/86	11.08	1374.82	06/04/91	10.50	1375.40
06/04/86	10.18	1375.72	07/02/91	9.41	1376.49
07/01/86	10.54	1375.36	07/30/91	9.41	1376.49
08/06/86	11.02	1374.88	09/04/91	9.86	1376.04
09/05/86	11.34	1374.56	10/01/91	10.37	1375.53
10/07/86	11.16	1374.74	11/14/91	10.53	1375.37
11/05/86	11.18	1374.72	12/10/91	10.44	1375.46
12/03/86	11.18	1374.72			
			04/15/92	9.73	1376.17
04/22/87	10.47	1375.43	05/19/92	9.48	1376.42
05/20/87	10.52	1375.38	06/22/92	9.46	1376.44
07/01/87	10.90	1375.00	07/22/92	9.75	1376.15
08/06/87	11.96	1373.94	08/18/92	10.37	1375.53
09/02/87	12.62	1373.28	09/15/92	10.53	1375.37
10/07/87	13.30	1372.60	10/13/92	9.96	1375.94
11/05/87	13.54	1372.36	11/12/92	10.95	1374.95
12/03/87	13.67	1372.23	12/08/92	10.74	1375.16
05/04/88	13.81	1372.09	04/13/93	10.38	1375.52
07/07/88	13.98	1371.92	05/11/93	9.37	1376.53
08/03/88	13.97	1371.93	06/10/93	8.90	1377.00
09/16/88	14.86	1371.04	07/07/93	8.30	1377.60
10/19/88	15.05	1370.85	08/19/93	7.66	1378.24
11/22/88	15.00	1370.90	09/08/93	7.98	1377.92
			10/12/93	8.65	1377.25
04/25/89	12.63	1373.27	11/08/93	8.89	1377.01
05/22/89	11.69	1374.21	12/14/93	8.83	1377.07
06/29/89	11.63	1374.27			
07/26/89	11.35	1374.55	04/20/94	7.53	1378.37

132-059-17DCD1 LS Elev (msl,ft)=1371.1

Spiritwood Aquifer SI (ft.)=188-193

Date	Depth to Water (ft)	WL Elev (msl, ft)
09/29/82	62.92	1310.18
10/28/82	55.75	1317.35
12/01/82	52.14	1320.96
04/27/83	46.86	1326.24
05/24/83	47.66	1325.44
06/22/83	54.57	1318.53
07/20/83	62.37	1310.73
08/17/83	77.42	1295.68
09/15/83	67.50	1305.60
10/18/83	57.47	1315.63
11/30/83	53.45	1319.65
04/12/84	47.94	1325.16
05/16/84	47.10	1326.00
06/13/84	52.33	1320.77
07/12/84	52.38	1320.72
08/09/84	78.83	1294.27
08/14/84	81.80	1291.30
09/13/84	74.25	1298.85
10/09/84	62.11	1310.99
11/14/84	55.61	1317.49
12/11/84	53.24	1319.86
04/09/85	48.76	1324.34
04/28/85	48.40	1324.70
04/30/85	48.37	1324.73
07/11/85	67.80	1305.30
08/15/85	79.82	1293.28
09/11/85	65.27	1307.83
10/07/85	58.50	1314.60
11/07/85	54.99	1318.11
12/17/85	52.32	1320.78
04/02/86	49.02	1324.08
05/06/86	47.81	1325.29
06/04/86	48.72	1324.38
07/01/86	51.14	1321.96
08/06/86	56.18	1316.92
09/05/86	54.19	1318.91
10/07/86	50.15	1322.95
11/05/86	48.40	1324.70
12/03/86	47.38	1325.72
04/22/87	44.92	1328.18
05/20/87	48.52	1324.58
07/01/87	60.79	1312.31
08/06/87	63.29	1309.81
09/02/87	64.69	1308.41
10/07/87	54.77	1318.33
11/05/87	51.50	1321.60
12/03/87	49.67	1323.43
05/04/88	46.30	1326.80
07/07/88	75.64	1297.46
08/03/88	78.53	1294.57
09/16/88	78.86	1294.24
10/19/88	58.15	1314.95
11/22/88	54.39	1318.71
04/25/89	48.29	1324.81
05/22/89	48.96	1324.14
06/29/89	53.12	1319.98
07/26/89	61.32	1311.78
08/22/89	66.76	1306.34
09/26/89	55.79	1317.31
10/24/89	52.50	1320.60
04/23/90	46.55	1326.55
05/16/90	49.17	1323.93
06/14/90	51.54	1321.56
07/12/90	62.56	1310.54
08/07/90	71.03	1302.07
09/05/90	68.40	1304.70
10/03/90	59.69	1313.41
11/05/90	55.03	1318.07
12/04/90	52.94	1320.16
04/08/91	48.53	1324.57
05/08/91	47.83	1325.27
06/05/91	47.45	1325.65
07/02/91	47.39	1325.71
07/30/91	60.22	1312.88
09/04/91	65.31	1307.79
09/12/91	61.02	1312.08
10/01/91	56.10	1317.00
11/14/91	51.32	1321.78
12/10/91	49.87	1323.23
04/15/92	46.47	1326.63
05/19/92	49.01	1324.09
06/22/92	47.30	1325.80
07/22/92	47.46	1325.64
08/18/92	65.29	1307.81
09/15/92	57.38	1315.72
10/13/92	52.85	1320.25
11/12/92	50.21	1322.89
12/08/92	48.78	1324.32
04/13/93	45.68	1327.42
05/11/93	45.33	1327.77
06/10/93	45.44	1327.66
07/07/93	45.49	1327.61
08/19/93	52.67	1320.43
09/08/93	53.25	1319.85
10/12/93	48.20	1324.90
11/08/93	46.45	1326.65
12/14/93	45.02	1328.08
04/20/94	42.90	1330.20

132-059-17DCD2 LS Elev (msl,ft)=1371.2

Till SI (ft.)=114-119

Date	Depth to Water (ft)	WL Elev (msl, ft)
09/29/82	39.60	1333.60
10/28/82	37.04	1336.16
12/01/82	35.52	1337.68
04/27/83	33.46	1339.74
05/24/83	33.28	1339.92
06/22/83	35.12	1338.08
07/20/83	38.12	1335.08
08/17/83	43.99	1329.21
09/15/83	41.25	1331.95
10/18/83	38.18	1335.02
11/30/83	36.51	1336.69
04/12/84	34.05	1339.15
05/16/84	33.00	1340.20
06/13/84	34.33	1338.87
07/12/84	33.83	1339.37
08/09/84	42.02	1331.18
08/14/84	43.78	1329.42
09/13/84	43.46	1329.74
10/09/84	39.80	1333.40
11/14/84	37.22	1335.98
12/11/84	36.27	1336.93
04/09/85	34.71	1338.49
04/30/85	34.48	1338.72
06/06/85	35.62	1337.58
07/11/85	38.20	1335.00
08/15/85	44.77	1328.43
09/11/85	41.41	1331.79
10/07/85	39.13	1334.07
11/07/85	37.76	1335.44
12/17/85	36.75	1336.45
04/02/86	35.29	1337.91
05/06/86	33.90	1339.30
06/04/86	33.25	1339.95
07/01/86	33.79	1339.41
08/06/86	34.39	1338.81
09/05/86	34.76	1338.44
10/07/86	33.68	1339.52
11/05/86	33.14	1340.06
12/03/86	32.82	1340.38
04/22/87	31.56	1341.64
05/20/87	31.94	1341.26
07/01/87	34.40	1338.80
08/06/87	36.93	1336.27
09/02/87	38.08	1335.12
10/07/87	35.69	1337.51
11/05/87	34.75	1338.45
12/03/87	34.03	1339.17
05/04/88	32.91	1340.29
07/07/88	40.26	1332.94
08/03/88	43.53	1329.67
09/16/88	40.93	1332.27
10/19/88	38.43	1334.77
11/22/88	37.02	1336.18
04/25/89	34.20	1339.00
05/22/89	33.77	1339.43
06/29/89	34.38	1338.82
07/26/89	35.98	1337.22
08/22/89	38.21	1334.99
09/26/89	35.24	1337.96
10/24/89	34.14	1339.06
04/23/90	32.70	1340.50
05/16/90	32.75	1340.45
06/14/90	33.29	1339.91
07/12/90	36.07	1337.13
08/07/90	39.32	1333.88
09/05/90	39.97	1333.23
10/03/90	37.99	1335.21
11/05/90	36.65	1336.55
12/04/90	36.00	1337.20
04/08/91	34.73	1338.47
05/08/91	34.49	1338.71
06/05/91	33.53	1339.67
07/02/91	32.46	1340.74
07/30/91	35.48	1337.72
09/04/91	37.34	1335.86
10/01/91	35.51	1337.69
11/14/91	34.04	1339.16
12/10/91	33.54	1339.66
04/15/92	32.19	1341.01
05/19/92	32.53	1340.67
06/22/92	32.03	1341.17
07/22/92	32.09	1341.11
08/18/92	35.87	1337.33
09/15/92	35.41	1337.79
10/13/92	34.41	1338.79
11/12/92	33.63	1339.57
12/08/92	33.13	1340.07
04/13/93	31.87	1341.33
05/11/93	31.46	1341.74
06/10/93	31.10	1342.10
07/07/93	30.74	1342.46
08/19/93	31.60	1341.60
09/08/93	32.30	1340.90
10/12/93	31.43	1341.77
11/08/93	31.00	1342.20
12/14/93	30.64	1342.56
04/20/94	29.15	1344.05

132-059-17DCD3
Undefined

LS Elev (msl,ft)=1371.1
SI (ft.)=58-63

Date	Depth to Water (ft)	WL Elev (msl, ft)
09/29/82	27.24	1345.86
10/28/82	26.64	1346.46
12/01/82	26.30	1346.80
04/27/83	26.05	1347.05
05/24/83	25.85	1347.25
06/22/83	26.21	1346.89
07/20/83	26.87	1346.23
08/17/83	28.34	1344.76
09/15/83	28.35	1344.75
10/18/83	27.89	1345.21
11/30/83	27.64	1345.46
04/12/84	26.78	1346.32
05/16/84	25.35	1347.75
06/13/84	25.21	1347.89
07/12/84	24.55	1348.55
08/09/84	27.22	1345.88
08/14/84	26.63	1346.47
09/13/84	27.42	1345.68
10/09/84	26.97	1346.13
11/14/84	26.41	1346.69
12/11/84	26.28	1346.82
04/09/85	26.53	1346.57
04/30/85	26.26	1346.84
07/11/85	27.03	1346.07
08/15/85	29.15	1343.95
09/11/85	28.92	1344.18
10/07/85	28.36	1344.74
11/07/85	28.23	1344.87
12/17/85	28.27	1344.83
05/06/86	26.09	1347.01
06/04/86	24.68	1348.42
07/01/86	24.64	1348.46
08/06/86	24.66	1348.44
09/05/86	24.79	1348.31
10/07/86	24.49	1348.61
11/05/86	24.35	1348.75
12/03/86	24.29	1348.81
04/22/87	23.59	1349.51
05/20/87	23.33	1349.77
07/01/87	23.54	1349.56
08/06/87	24.63	1348.47
09/02/87	26.33	1346.77
10/07/87	25.30	1347.80
11/05/87	25.31	1347.79
12/02/87	25.19	1347.91
05/04/88	25.57	1347.53
07/07/88	27.19	1345.91
08/03/88	28.05	1345.05
09/16/88	28.22	1344.88
10/19/88	27.68	1345.42
11/22/88	27.51	1345.59
04/25/89	26.59	1346.51
05/22/89	25.75	1347.35
06/29/89	25.53	1347.57
07/26/89	25.28	1347.82
08/22/89	25.37	1347.73
09/26/89	24.42	1348.68
10/24/89	24.08	1349.02
04/23/90	24.35	1348.75
05/16/90	24.18	1348.92
06/14/90	24.20	1348.90
07/12/90	24.69	1348.41
08/07/90	25.75	1347.35
09/05/90	26.54	1346.56
10/03/90	26.45	1346.65
11/05/90	26.48	1346.62
12/04/90	26.60	1346.50
04/08/91	27.08	1346.02
05/08/91	26.88	1346.22
06/05/91	25.63	1347.47
07/02/91	23.96	1349.14
07/30/91	24.00	1349.10
09/04/91	24.65	1348.45
09/12/91	24.55	1348.55
10/01/91	24.42	1348.68
11/14/91	24.24	1348.86
12/10/91	24.19	1348.91
04/15/92	23.48	1349.62
05/19/92	23.32	1349.78
06/22/92	22.98	1350.12
07/22/92	23.10	1350.00
08/18/92	23.90	1349.20
09/15/92	24.12	1348.98
10/13/92	24.18	1348.92
11/12/92	24.12	1348.98
12/08/92	24.03	1349.07
04/13/93	23.65	1349.45
05/11/93	22.98	1350.12
06/10/93	22.37	1350.73
07/07/93	21.49	1351.61
08/19/93	20.70	1352.40
09/08/93	21.32	1351.78
10/12/93	21.66	1351.44
11/08/93	21.83	1351.27
12/14/93	21.86	1351.24
04/20/94	20.46	1352.64

132-059-27CDC1 LS Elev (msl,ft)=1332.42

Spiritwood Aquifer SI (ft.)=209-214

Date	Depth to Water (ft)	WL Elev (msl, ft)
08/03/83	38.15	1296.42
08/25/83	40.58	1293.99
09/28/83	26.60	1307.97
10/18/83	23.67	1310.90
11/30/83	17.27	1317.30
12/01/83	17.08	1317.49
01/16/84	14.14	1320.43
04/12/84	11.22	1323.35
05/16/84	10.42	1324.15
06/13/84	16.20	1318.37
07/12/84	15.92	1318.65
08/09/84	43.51	1291.06
08/14/84	48.03	1286.54
09/12/84	41.04	1293.53
10/09/84	26.67	1307.90
11/14/84	19.47	1315.10
12/12/84	16.87	1317.70
04/09/85	12.08	1322.49
04/28/85	11.70	1322.87
04/30/85	11.68	1322.89
06/05/85	16.73	1317.84
07/11/85	30.59	1303.98
08/15/85	44.02	1290.55
09/11/85	30.20	1304.37
10/08/85	22.58	1311.99
11/07/85	18.69	1315.88
12/17/85	15.81	1318.76
04/02/86	12.28	1322.29
05/06/86	11.07	1323.50
06/04/86	12.25	1322.32
07/01/86	16.01	1318.56
08/06/86	18.84	1315.73
09/10/86	17.67	1316.90
10/07/86	13.90	1320.67
11/05/86	11.98	1322.59
12/03/86	10.87	1323.70
04/22/87	8.19	1326.38
05/21/87	13.07	1321.50
07/01/87	24.40	1310.17
08/06/87	28.90	1305.67
09/02/87	30.52	1304.05
10/07/87	18.95	1315.62
11/05/87	15.29	1319.28
12/03/87	13.18	1321.39
05/04/88	9.91	1324.66
07/07/88	39.74	1294.83
08/03/88	45.57	1289.00
09/16/88	31.20	1303.37
10/17/88	22.28	1312.29
11/22/88	18.15	1316.42
04/25/89	11.65	1322.92
05/22/89	12.74	1321.83
06/29/89	16.55	1318.02
07/26/89	25.01	1309.56
08/22/89	32.94	1301.63
09/26/89	20.09	1314.48
10/24/89	16.36	1318.21
11/28/89	13.88	1320.69
04/23/90	10.00	1324.57
05/16/90	12.63	1321.94
06/13/90	13.57	1321.00
07/11/90	28.22	1306.35
08/07/90	36.92	1297.65
09/05/90	34.92	1299.65
10/02/90	24.41	1310.16
11/05/90	18.98	1315.59
12/04/90	16.60	1317.97
04/08/91	11.93	1322.64
05/08/91	11.18	1323.39
06/05/91	10.90	1323.67
07/02/91	10.87	1323.70
07/30/91	25.07	1309.50
09/04/91	29.40	1305.17
09/12/91	25.66	1308.91
10/01/91	20.13	1314.44
11/14/91	14.90	1319.67
12/10/91	13.34	1321.23
04/15/92	9.82	1324.75
05/19/92	12.35	1322.22
06/22/92	11.06	1323.51
07/22/92	11.42	1323.15
08/18/92	29.43	1305.14
09/15/92	22.25	1312.32
10/13/92	16.83	1317.74
11/12/92	13.82	1320.75
12/08/92	12.25	1322.32
04/13/93	9.03	1325.54
05/11/93	8.67	1325.90
06/10/93	9.12	1325.45
07/07/93	8.95	1325.62
08/19/93	16.94	1317.63
09/08/93	17.24	1317.33
10/12/93	11.94	1322.63
11/08/93	9.96	1324.61
12/14/93	9.44	1325.13
04/20/94	6.27	1328.30

132-059-27CDC2 LS Elev (msl,ft)=1332.87

Till SI (ft.)=105-110

Date	Depth to Water (ft)	WL Elev (msl, ft)	Date	Depth to Water (ft)	WL Elev (msl, ft)
08/25/83	24.43	1309.94	10/17/88	24.69	1309.68
09/28/83	24.61	1309.76	11/22/88	24.74	1309.63
10/18/83	26.18	1308.19			
11/30/83	24.80	1309.57	04/25/89	24.45	1309.92
12/01/83	24.83	1309.54	05/22/89	24.28	1310.09
12/06/83	24.80	1309.57	06/29/89	24.29	1310.08
			07/26/89	24.38	1309.99
01/16/84	24.86	1309.51	08/22/89	24.53	1309.84
04/12/84	24.13	1310.24	09/26/89	24.73	1309.64
05/16/84	23.96	1310.41	10/24/89	24.79	1309.58
06/13/84	23.83	1310.54	11/28/89	24.88	1309.49
07/12/84	23.75	1310.62			
08/09/84	24.28	1310.09	04/23/90	25.13	1309.24
08/14/84	23.71	1310.66	05/16/90	25.09	1309.28
09/05/84	23.83	1310.54	06/13/90	25.12	1309.25
09/12/84	23.83	1310.54	07/11/90	25.07	1309.30
10/09/84	24.10	1310.27	08/07/90	25.22	1309.15
11/14/84	24.17	1310.20	09/05/90	25.24	1309.13
12/12/84	24.30	1310.07	10/02/90	25.33	1309.04
			11/05/90	25.47	1308.90
04/09/85	24.56	1309.81	12/04/90	25.58	1308.79
04/28/85	24.57	1309.80			
04/30/85	24.59	1309.78	04/08/91	25.68	1308.69
06/05/85	25.20	1309.17	05/08/91	25.56	1308.81
07/11/85	24.73	1309.64	06/05/91	25.04	1309.33
08/15/85	24.83	1309.54	07/02/91	24.36	1310.01
09/11/85	25.09	1309.28	07/30/91	23.65	1310.72
10/08/85	25.04	1309.33	09/04/91	23.59	1310.78
11/07/85	25.20	1309.17	10/01/91	23.63	1310.74
12/17/85	25.31	1309.06	11/14/91	23.77	1310.60
			12/10/91	23.86	1310.51
04/02/86	24.97	1309.40			
05/06/86	24.15	1310.22	04/15/92	23.93	1310.44
06/04/86	23.22	1311.15	05/19/92	23.89	1310.48
07/01/86	22.81	1311.56	06/22/92	23.85	1310.52
08/06/86	22.68	1311.69	07/22/92	23.85	1310.52
09/10/86	22.62	1311.75	08/18/92	23.69	1310.68
10/07/86	22.68	1311.69	09/15/92	23.62	1310.75
11/05/86	22.75	1311.62	10/13/92	23.77	1310.60
12/03/86	22.80	1311.57	11/12/92	23.70	1310.67
			12/08/92	23.72	1310.65
04/22/87	22.61	1311.76			
05/21/87	22.49	1311.88	04/13/93	23.72	1310.65
07/01/87	22.70	1311.67	05/11/93	23.69	1310.68
08/06/87	22.95	1311.42	06/10/93	23.54	1310.83
09/02/87	23.19	1311.18	07/07/93	23.45	1310.92
10/07/87	23.49	1310.88	08/19/93	22.34	1312.03
11/05/87	23.61	1310.76	09/08/93	22.16	1312.21
12/03/87	23.68	1310.69	10/12/93	22.23	1312.14
			11/08/93	22.32	1312.05
05/04/88	23.95	1310.42	12/14/93	22.41	1311.96
07/07/88	24.08	1310.29			
08/03/88	24.11	1310.26	04/20/94	22.05	1312.32
09/16/88	24.43	1309.94			

132-059-27CDC3 LS Elev (msl,ft)=1333.1

Spiritwood Aquifer SI (ft.)=150-155

Date	Depth to Water (ft)	WL Elev (msl, ft)	Date	Depth to Water (ft)	WL Elev (msl, ft)
08/29/84	45.27	1289.83	08/22/89	33.45	1301.65
09/12/84	41.55	1293.55	09/26/89	20.59	1314.51
10/09/84	27.17	1307.93	10/24/89	16.86	1318.24
11/14/84	19.94	1315.16			
12/12/84	17.36	1317.74	04/23/90	10.48	1324.62
			05/16/90	13.14	1321.96
04/09/85	12.58	1322.52	06/13/90	14.05	1321.05
04/28/85	12.18	1322.92	07/11/90	28.75	1306.35
04/30/85	12.17	1322.93	08/07/90	37.42	1297.68
06/05/85	17.45	1317.65	09/05/90	35.43	1299.67
07/11/85	31.10	1304.00	10/02/90	24.92	1310.18
08/15/85	44.50	1290.60	11/05/90	19.47	1315.63
09/11/85	30.69	1304.41	12/04/90	17.12	1317.98
10/08/85	23.07	1312.03			
11/07/85	19.05	1316.05	04/08/91	12.42	1322.68
12/17/85	16.30	1318.80	05/08/91	11.66	1323.44
			06/05/91	11.39	1323.71
04/02/86	12.78	1322.32	07/02/91	11.38	1323.72
05/06/86	11.56	1323.54	07/30/91	25.59	1309.51
06/04/86	12.73	1322.37	09/04/91	29.90	1305.20
07/01/86	16.49	1318.61	09/12/91	26.17	1308.93
08/06/86	19.33	1315.77	10/01/91	20.63	1314.47
09/10/86	18.17	1316.93	11/14/91	15.37	1319.73
10/07/86	14.40	1320.70	12/10/91	13.84	1321.26
11/05/86	12.44	1322.66			
12/03/86	11.35	1323.75	04/15/92	10.30	1324.80
			05/19/92	12.86	1322.24
04/22/87	8.69	1326.41	06/22/92	11.56	1323.54
05/21/87	13.56	1321.54	07/22/92	11.77	1323.33
07/01/87	24.93	1310.17	08/18/92	29.95	1305.15
08/06/87	30.42	1304.68	09/15/92	22.76	1312.34
09/02/87	31.14	1303.96	10/13/92	17.33	1317.77
10/07/87	19.49	1315.61	11/12/92	14.32	1320.78
11/05/87	15.81	1319.29	12/08/92	12.75	1322.35
12/03/87	13.64	1321.46			
			04/13/93	9.54	1325.56
05/04/88	10.45	1324.65	05/11/93	9.18	1325.92
07/07/88	40.24	1294.86	06/10/93	9.62	1325.48
08/03/88	46.11	1288.99	07/07/93	9.45	1325.65
09/16/88	31.73	1303.37	08/19/93	17.32	1317.78
10/17/88	22.78	1312.32	09/08/93	17.74	1317.36
11/22/88	18.65	1316.45	10/12/93	12.42	1322.68
			11/08/93	10.44	1324.66
04/25/89	12.14	1322.96	12/14/93	8.96	1326.14
05/22/89	13.23	1321.87			
06/29/89	17.05	1318.05	04/20/94	6.77	1328.33
07/26/89	25.50	1309.60			

132-059-27CDD LS Elev (msl,ft)=1317.28

Undefined Aquifer SI (ft.)=49-54

Date	Depth to Water (ft)	WL Elev (msl, ft)
10/21/82	9.61	1309.84
12/08/82	9.57	1309.88
02/02/83	9.70	1309.75
03/03/83	9.74	1309.71
04/07/83	9.60	1309.85
05/12/83	9.39	1310.06
06/03/83	9.32	1310.13
07/01/83	9.42	1310.03
07/28/83	9.56	1309.89
08/25/83	9.78	1309.67
09/28/83	9.94	1309.51
10/18/83	9.96	1309.49
12/01/83	9.95	1309.50
01/16/84	9.99	1309.46
04/12/84	9.10	1310.35
05/16/84	9.02	1310.43
06/13/84	9.07	1310.38
07/12/84	9.06	1310.39
08/09/84	9.59	1309.86
08/14/84	9.36	1310.09
09/12/84	9.57	1309.88
10/09/84	9.70	1309.75
11/14/84	9.60	1309.85
12/12/84	9.64	1309.81
04/09/85	9.74	1309.71
04/30/85	9.69	1309.76
06/05/85	10.65	1308.80
07/11/85	9.88	1309.57
08/15/85	10.16	1309.29
09/11/85	10.29	1309.16
10/08/85	10.35	1309.10
11/07/85	10.40	1309.05
12/17/85	10.46	1308.99
04/02/86	9.88	1309.57
05/06/86	9.04	1310.41
06/04/86	8.64	1310.81
07/01/86	8.51	1310.94
08/06/86	9.66	1309.79
09/10/86	8.26	1311.19
10/07/86	8.13	1311.32
11/05/86	8.09	1311.36
12/03/86	8.02	1311.43
04/22/87	7.83	1311.62
05/21/87	7.94	1311.51
07/01/87	8.22	1311.23
08/06/87	8.59	1310.86
09/02/87	8.78	1310.67
10/07/87	7.99	1311.46
11/05/87	8.99	1310.46
12/02/87	9.00	1310.45
05/04/88	9.08	1310.37
07/07/88	9.33	1310.12
08/03/88	9.51	1309.94
09/16/88	9.85	1309.60
10/17/88	9.89	1309.56
11/22/88	9.88	1309.57
04/25/89	9.66	1309.79
05/22/89	9.51	1309.94
06/29/89	9.54	1309.91
07/26/89	9.88	1309.57
08/22/89	10.08	1309.37
09/26/89	10.15	1309.30
10/24/89	10.18	1309.27
11/28/89	10.19	1309.26
04/23/90	10.32	1309.13
05/16/90	10.13	1309.32
06/13/90	10.14	1309.31
07/11/90	10.25	1309.20
08/07/90	10.40	1309.05
09/05/90	10.54	1308.91
10/02/90	10.63	1308.82
11/05/90	10.69	1308.76
12/04/90	10.75	1308.70
04/08/91	10.78	1308.67
05/08/91	10.46	1308.99
06/05/91	9.92	1309.53
07/02/91	9.53	1309.92
07/30/91	9.41	1310.04
09/04/91	9.55	1309.90
09/12/91	9.53	1309.92
10/01/91	9.50	1309.95
11/14/91	9.41	1310.04
12/10/91	9.35	1310.10
04/15/92	9.11	1310.34
05/19/92	9.05	1310.40
06/22/92	9.00	1310.45
07/22/92	9.08	1310.37
08/18/92	9.15	1310.30
09/15/92	9.05	1310.40
10/13/92	9.09	1310.36
11/12/92	9.01	1310.44
12/08/92	8.93	1310.52
04/13/93	8.80	1310.65
05/11/93	8.65	1310.80
06/10/93	8.58	1310.87
07/07/93	8.35	1311.10
08/19/93	7.69	1311.76
09/08/93	7.68	1311.77
10/12/93	7.68	1311.77
11/08/93	7.64	1311.81
12/14/93	7.63	1311.82
04/20/94	6.99	1312.46

131-059-05BAA1 LS Elev (msl,ft)=1351.5

Spiritwood Aquifer SI (ft.)=166-171

Date	Depth to Water (ft)	WL Elev (msl, ft)
09/29/82	46.82	1306.68
10/28/82	38.22	1315.28
12/01/82	30.45	1323.05
04/27/83	30.05	1323.45
05/24/83	29.72	1323.78
06/22/83	37.42	1316.08
07/20/83	45.50	1308.00
08/17/83	60.08	1293.42
09/15/83	51.09	1302.41
10/18/83	40.97	1312.53
11/30/83	36.62	1316.88
04/12/84	30.94	1322.56
05/16/84	30.22	1323.28
06/13/84	35.41	1318.09
07/11/84	33.57	1319.93
08/09/84	57.38	1296.12
08/14/84	61.58	1291.92
09/12/84	57.63	1295.87
10/09/84	45.60	1307.90
11/14/84	38.78	1314.72
12/12/84	36.32	1317.18
04/09/85	31.79	1321.71
04/30/85	31.40	1322.10
07/11/85	45.57	1307.93
08/15/85	59.87	1293.63
09/11/85	48.96	1304.54
10/08/85	41.83	1311.67
11/07/85	38.11	1315.39
12/18/85	35.37	1318.13
04/02/86	31.99	1321.51
05/06/86	30.73	1322.77
06/04/86	31.39	1322.11
07/01/86	33.99	1319.51
08/06/86	36.45	1317.05
09/10/86	36.34	1317.16
10/07/86	33.12	1320.38
11/05/86	31.36	1322.14
12/03/86	30.29	1323.21
04/22/87	27.79	1325.71
05/21/87	30.90	1322.60
07/01/87	39.56	1313.94
08/07/87	46.77	1306.73
09/02/87	48.48	1305.02
10/07/87	38.00	1315.50
11/05/87	34.58	1318.92
12/03/87	32.56	1320.94
05/04/88	29.33	1324.17
07/07/88	53.64	1299.86
08/03/88	60.63	1292.87
09/16/88	49.74	1303.76
10/17/88	41.69	1311.81
11/22/88	37.70	1315.80
04/25/89	31.32	1322.18
05/22/89	31.85	1321.65
06/29/89	34.59	1318.91
07/26/89	43.14	1310.36
08/22/89	49.68	1303.82
09/26/89	39.13	1314.37
10/24/89	35.69	1317.81
11/28/89	33.36	1320.14
04/23/90	29.69	1323.81
05/16/90	31.02	1322.48
06/13/90	32.36	1321.14
07/11/90	43.07	1310.43
08/07/90	52.35	1301.15
09/05/90	51.73	1301.77
10/02/90	43.38	1310.12
11/06/90	38.30	1315.20
12/04/90	36.09	1317.41
04/08/91	31.59	1321.91
05/08/91	30.91	1322.59
06/05/91	30.43	1323.07
07/02/91	30.42	1323.08
07/30/91	37.64	1315.86
09/04/91	47.05	1306.45
09/12/91	44.08	1309.42
10/01/91	39.04	1314.46
11/14/91	34.19	1319.31
12/10/91	32.76	1320.74
04/15/92	29.41	1324.09
05/19/92	31.67	1321.83
06/22/92	30.45	1323.05
07/22/92	30.80	1322.70
08/18/92	46.20	1307.30
09/15/92	40.99	1312.51
10/13/92	36.21	1317.29
11/12/92	33.32	1320.18
12/08/92	31.84	1321.66
04/13/93	28.64	1324.86
05/11/93	28.27	1325.23
06/10/93	28.29	1325.21
07/07/93	28.29	1325.21
08/19/93	35.53	1317.97
09/08/93	36.25	1317.25
10/12/93	31.21	1322.29
11/08/93	29.37	1324.13
12/15/93	27.90	1325.60
04/20/94	25.81	1327.69

131-059-05BAA2 LS Elev (msl,ft)=1351.8
Till SI (ft.)=98-103

Date	Depth to Water (ft)	WL Elev (msl, ft)
09/29/82	14.93	1338.87
10/28/82	15.39	1338.41
12/01/82	15.72	1338.08
04/27/83	16.40	1337.40
05/24/83	16.17	1337.63
06/22/83	15.96	1337.84
07/20/83	15.96	1337.84
08/17/83	16.26	1337.54
09/15/83	16.55	1337.25
10/18/83	17.08	1336.72
11/30/83	17.48	1336.32
04/12/84	18.36	1335.44
05/16/84	15.42	1338.38
06/13/84	14.18	1339.62
07/11/84	13.59	1340.21
08/09/84	11.59	1342.21
08/14/84	13.65	1340.15
09/12/84	14.22	1339.58
10/09/84	14.85	1338.95
11/14/84	15.31	1338.49
12/12/84	15.47	1338.33
04/09/85	16.05	1337.75
04/30/85	15.09	1338.71
07/11/85	14.64	1339.16
08/15/85	15.10	1338.70
09/11/85	16.40	1337.40
10/08/85	15.35	1338.45
11/07/85	15.72	1338.08
12/18/85	16.20	1337.60
04/02/86	17.03	1336.77
05/06/86	14.70	1339.10
06/04/86	13.12	1340.68
07/01/86	12.61	1341.19
08/06/86	12.33	1341.47
09/10/86	12.24	1341.56
10/07/86	12.07	1341.73
11/05/86	12.03	1341.77
12/03/86	11.93	1341.87
04/22/87	11.52	1342.28
05/21/87	11.93	1341.87
07/01/87	10.78	1343.02
08/06/87	11.31	1342.49
09/02/87	11.85	1341.95
10/07/87	12.73	1341.07
11/05/87	12.85	1340.95
12/03/87	13.12	1340.68
05/04/88	15.07	1338.73
07/07/88	15.15	1338.65
08/03/88	15.08	1338.72

Date	Depth to Water (ft)	WL Elev (msl, ft)
09/16/88	15.15	1338.65
10/17/88	15.25	1338.55
11/22/88	15.32	1338.48
04/25/89	15.50	1338.30
05/22/89	13.81	1339.99
06/29/89	13.53	1340.27
07/26/89	13.96	1339.84
08/22/89	14.33	1339.47
09/26/89	14.66	1339.14
10/24/89	14.88	1338.92
11/28/89	15.00	1338.80
04/23/90	16.98	1336.82
05/16/90	17.06	1336.74
06/13/90	16.89	1336.91
07/11/90	16.56	1337.24
08/07/90	16.49	1337.31
09/05/90	16.47	1337.33
10/02/90	16.91	1336.89
11/06/90	17.43	1336.37
12/04/90	17.80	1336.00
04/08/91	19.75	1334.05
05/08/91	19.78	1334.02
06/05/91	19.36	1334.44
07/02/91	17.73	1336.07
07/30/91	15.86	1337.94
09/04/91	15.04	1338.76
09/12/91	15.05	1338.75
10/01/91	15.08	1338.72
11/14/91	15.22	1338.58
12/10/91	15.27	1338.53
04/15/92	15.32	1338.48
05/19/92	14.71	1339.09
06/22/92	14.15	1339.65
07/22/92	13.99	1339.81
08/18/92	13.97	1339.83
09/15/92	14.04	1339.76
10/13/92	14.39	1339.41
11/12/92	14.45	1339.35
12/08/92	14.59	1339.21
04/13/93	15.24	1338.56
05/11/93	13.98	1339.82
06/10/93	13.33	1340.47
07/07/93	12.74	1341.06
08/03/93	12.12	1341.68
08/19/93	11.83	1341.97
09/08/93	11.84	1341.96
10/12/93	12.17	1341.63
11/08/93	12.36	1341.44
12/15/93	12.49	1341.31

131-059-05BAA3 LS Elev (msl,ft)=1351.5

Till SI (ft.)=52-57

Date	Depth to Water (ft)	WL Elev (msl, ft)
09/29/82	14.00	1339.50
10/28/82	14.43	1339.07
12/01/82	14.64	1338.86
04/27/83	14.98	1338.52
05/24/83	14.59	1338.91
06/22/83	14.54	1338.96
07/20/83	14.67	1338.83
08/17/83	15.00	1338.50
09/15/83	15.59	1337.91
10/18/83	16.21	1337.29
11/30/83	16.70	1336.80
04/12/84	16.81	1336.69
05/16/84	13.30	1340.20
06/13/84	12.15	1341.35
07/11/84	11.59	1341.91
08/09/84	12.02	1341.48
08/14/84	12.14	1341.36
09/12/84	12.97	1340.53
10/09/84	13.75	1339.75
11/14/84	14.11	1339.39
12/12/84	14.27	1339.23
04/09/85	14.47	1339.03
04/30/85	13.28	1340.22
07/11/85	12.16	1341.34
08/15/85	13.00	1340.50
09/11/85	13.81	1339.69
10/08/85	14.03	1339.47
11/07/85	14.42	1339.08
12/18/85	15.01	1338.49
04/02/86	15.36	1338.14
05/06/86	12.49	1341.01
06/04/86	11.16	1342.34
07/01/86	10.81	1342.69
08/06/86	11.05	1342.45
09/10/86	11.06	1342.44
10/07/86	10.91	1342.59
11/05/86	10.92	1342.58
12/03/86	10.93	1342.57
04/22/87	9.97	1343.53
05/21/87	9.45	1344.05
07/01/87	9.57	1343.93
08/06/87	10.40	1343.10
09/02/87	11.06	1342.44
10/07/87	11.66	1341.84
11/05/87	12.11	1341.39
12/03/87	12.36	1341.14
05/04/88	14.37	1339.13
07/07/88	14.37	1339.13
08/03/88	14.26	1339.24
09/16/88	14.36	1339.14
10/17/88	14.47	1339.03
11/22/88	14.53	1338.97
04/25/89	13.65	1339.85
05/22/89	11.92	1341.58
06/29/89	11.90	1341.60
07/26/89	12.68	1340.82
08/22/89	13.13	1340.37
09/26/89	13.53	1339.97
10/24/89	13.70	1339.80
11/28/89	13.93	1339.57
04/23/90	15.88	1337.62
05/16/90	16.02	1337.48
06/13/90	15.69	1337.81
07/11/90	15.30	1338.20
08/07/90	15.15	1338.35
09/05/90	15.38	1338.12
10/02/90	15.88	1337.62
11/06/90	16.58	1336.92
12/04/90	17.07	1336.43
04/08/91	18.86	1334.64
05/08/91	19.23	1334.27
06/05/91	18.13	1335.37
07/02/91	15.85	1337.65
09/04/91	13.21	1340.29
09/12/91	13.40	1340.10
10/01/91	13.46	1340.04
11/14/91	13.77	1339.73
12/10/91	13.89	1339.61
04/15/92	13.59	1339.91
05/19/92	13.02	1340.48
06/22/92	12.51	1340.99
07/22/92	12.57	1340.93
08/18/92	12.57	1340.93
09/15/92	12.74	1340.76
10/13/92	13.00	1340.50
11/12/92	13.15	1340.35
12/08/92	13.29	1340.21
04/13/93	13.77	1339.73
05/11/93	12.25	1341.25
06/10/93	11.56	1341.94
07/07/93	10.95	1342.55
08/03/93	10.40	1343.10
08/19/93	10.16	1343.34
09/08/93	10.55	1342.95
10/12/93	10.99	1342.51
11/08/93	11.23	1342.27
12/15/93	11.45	1342.05
04/20/94	11.47	1342.03

131-058-20DDD1

Spiritwood Aquifer

LS Elev (msl,ft)=1319.06
SI (ft.)=152-157

Date	Depth to Water (ft)	WL Elev (msl, ft)	Date	Depth to Water (ft)	WL Elev (msl, ft)
04/01/90	16.15	1306.17	04/10/92	16.29	1306.03
04/28/90	16.02	1306.30	05/06/92	16.34	1305.98
06/03/90	19.67	1302.65	06/07/92	17.32	1305.00
06/29/90	22.41	1299.91	07/08/92	16.66	1305.66
08/05/90	34.53	1287.79	08/01/92	22.02	1300.30
09/11/90	22.17	1300.15	09/02/92	21.15	1301.17
10/11/90	17.07	1305.25	10/05/92	17.40	1304.92
11/09/90	17.92	1304.40	11/12/92	16.46	1305.86
12/06/90	17.64	1304.68	12/05/92	16.26	1306.06
04/06/91	17.16	1305.16	04/15/93	15.56	1306.76
05/06/91	17.21	1305.11	05/10/93	15.60	1306.72
06/11/91	16.60	1305.72	06/07/93	15.15	1307.17
07/08/91	20.50	1301.82	07/09/93	15.02	1307.30
08/11/91	26.00	1296.32	08/10/93	21.00	1301.32
09/09/91	24.51	1297.81	09/05/93	17.55	1304.77
10/13/91	17.90	1304.42	10/08/93	14.89	1307.43
11/14/91	17.02	1305.30	11/09/93	14.25	1308.07
12/16/91	16.73	1305.59	12/09/93	13.99	1308.33

131-058-20DDD2

Till

LS Elev (msl,ft)=1319.07
SI (ft.)=98-103

Date	Depth to Water (ft)	WL Elev (msl, ft)	Date	Depth to Water (ft)	WL Elev (msl, ft)
04/01/90	15.27	1305.40	01/02/92	14.06	1306.61
04/28/90	15.21	1305.46	04/10/92	12.39	1308.28
06/03/90	14.95	1305.72	05/06/92	14.08	1306.59
06/29/90	14.89	1305.78	06/07/92	13.82	1306.85
08/05/90	14.90	1305.77	07/08/92	13.42	1307.25
09/11/90	15.12	1305.55	08/01/92	13.14	1307.53
10/11/90	15.27	1305.40	09/02/92	13.29	1307.38
11/09/90	15.42	1305.25	10/05/92	13.42	1307.25
12/06/90	15.54	1305.13	11/12/92	13.69	1306.98
			12/05/92	61.34	1259.33
04/06/91	15.89	1304.78			
05/06/91	15.79	1304.88	04/15/93	14.32	1306.35
06/11/91	15.16	1305.51	05/10/93	13.84	1306.83
07/08/91	14.55	1306.12	06/07/93	11.36	1309.31
08/11/91	14.95	1305.72	07/09/93	12.98	1307.69
09/09/91	14.01	1306.66	08/10/93	12.19	1308.48
10/13/91	14.17	1306.50	09/05/93	12.03	1308.64
11/14/91	14.13	1306.54	10/08/93	12.06	1308.61
12/16/91	14.17	1306.50	11/09/93	12.17	1308.50
			12/09/93	12.02	1308.65

131-058-20DDD3 LS Elev (msl,ft)=1319.05

Undefined SI (ft.)=55-60

Date	Depth to Water (ft)	WL Elev (msl, ft)
04/01/90	15.80	1305.31
04/28/90	15.60	1305.51
06/03/90	15.27	1305.84
06/29/90	15.06	1306.05
08/05/90	15.65	1305.46
09/11/90	15.86	1305.25
10/11/90	16.17	1304.94
11/09/90	16.29	1304.82
12/06/90	16.39	1304.72
04/06/91	17.40	1303.71
05/06/91	16.67	1304.44
06/11/91	15.11	1306.00
07/08/91	16.02	1305.09
08/11/91	14.19	1306.92
09/09/91	14.80	1306.31
10/13/91	15.19	1305.92
11/14/91	14.90	1306.21
12/16/91	14.89	1306.22

Date	Depth to Water (ft)	WL Elev (msl, ft)
01/02/92	14.93	1306.18
04/10/92	14.02	1307.09
05/06/92	13.83	1307.28
06/07/92	13.71	1307.40
07/08/92	12.58	1308.53
08/01/92	12.97	1308.14
09/02/92	13.70	1307.41
10/05/92	14.13	1306.98
11/12/92	14.35	1306.76
12/05/92	14.42	1306.69
04/15/93	13.70	1307.41
05/10/93	13.42	1307.69
06/07/93	12.86	1308.25
07/09/93	12.38	1308.73
08/10/93	11.28	1309.83
09/05/93	11.69	1309.42
10/08/93	12.14	1308.97
11/09/93	12.36	1308.75
12/09/93	13.28	1307.83

131-058-25CCC1 LS Elev (msl,ft)=1312.73

Spiritwood Aquifer SI (ft.)=205-210

Date	Depth to Water (ft)	WL Elev (msl, ft)
04/01/90	8.89	1305.76
04/28/90	10.58	1304.07
06/03/90	10.25	1304.40
06/29/90	10.21	1304.44
08/05/90	39.90	1274.75
09/11/90	17.38	1297.27
10/11/90	12.11	1302.54
11/09/90	11.25	1303.40
12/06/90	10.94	1303.71
04/06/91	11.06	1303.59
05/06/91	11.15	1303.50
06/11/91	10.31	1304.34
07/08/91	23.56	1291.09
08/11/91	33.99	1280.66
09/09/91	21.57	1293.08
10/13/91	12.07	1302.58
11/14/91	11.07	1303.58
12/16/91	10.69	1303.96

Date	Depth to Water (ft)	WL Elev (msl, ft)
04/10/92	9.42	1305.23
05/06/92	9.19	1305.46
06/07/92	12.17	1302.48
07/08/92	12.08	1302.57
08/01/92	28.66	1285.99
09/02/92	17.94	1296.71
10/05/92	10.83	1303.82
11/12/92	9.72	1304.93
12/05/92	9.42	1305.23
04/15/93	8.65	1306.00
05/10/93	8.36	1306.29
06/07/93	7.99	1306.66
07/09/93	7.74	1306.91
08/10/93	22.33	1292.32
09/05/93	12.59	1302.06
10/08/93	8.37	1306.28
11/09/93	7.63	1307.02
12/09/93	7.18	1307.47

131-058-25CCC2 LS Elev (msl,ft)=1312.95

Spiritwood Aquifer SI (ft.)=166-171

Date	Depth to Water (ft)	WL Elev (msl, ft)	Date	Depth to Water (ft)	WL Elev (msl, ft)
04/01/90	9.08	1305.98	04/10/92	9.81	1305.25
04/28/90	10.79	1304.27	05/06/92	9.60	1305.46
06/03/90	10.50	1304.56	06/07/92	12.59	1302.47
06/29/90	10.11	1304.95	07/08/92	12.33	1302.73
08/05/90	40.13	1274.93	08/01/92	29.06	1286.00
09/11/90	17.58	1297.48	09/02/92	18.35	1296.71
10/11/90	12.31	1302.75	10/05/92	11.29	1303.77
11/09/90	11.46	1303.60	11/12/92	9.73	1305.33
12/06/90	11.15	1303.91	12/05/92	9.81	1305.25
04/06/91	11.11	1303.95	04/15/93	9.04	1306.02
05/06/91	10.89	1304.17	05/10/93	8.77	1306.29
06/11/91	10.36	1304.70	06/07/93	8.39	1306.67
07/08/91	9.53	1305.53	07/09/93	8.14	1306.92
08/11/91	34.04	1281.02	08/10/93	22.72	1292.34
09/09/91	21.64	1293.42	09/05/93	12.98	1302.08
10/13/91	12.12	1302.94	10/08/93	8.77	1306.29
11/14/91	11.11	1303.95	11/09/93	8.00	1307.06
12/16/91	10.75	1304.31	12/09/93	7.63	1307.43

131-058-25CCC3 LS Elev (msl,ft)=1312.82

Silt, sandy, clayey SI (ft.)=102-107

Date	Depth to Water (ft)	WL Elev (msl, ft)	Date	Depth to Water (ft)	WL Elev (msl, ft)
04/01/90	8.03	1306.56	04/10/92	7.69	1306.90
04/28/90	7.75	1306.84	05/06/92	7.50	1307.09
06/03/90	8.07	1306.52	06/07/92	8.86	1305.73
06/29/90	7.89	1306.70	07/08/92	7.79	1306.80
08/05/90	17.47	1297.12	08/01/92	12.09	1302.50
09/11/90	11.87	1302.72	09/02/92	11.14	1303.45
10/11/90	9.37	1305.22	10/05/92	8.38	1306.21
11/09/90	8.99	1305.60	11/12/92	7.75	1306.84
12/06/90	8.86	1305.73	12/05/92	6.49	1308.10
04/06/91	8.34	1306.25	04/15/93	6.84	1307.75
05/06/91	7.92	1306.67	05/10/93	6.54	1308.05
06/11/91	7.04	1307.55	06/07/93	6.12	1308.47
07/08/91	9.54	1305.05	07/09/93	5.55	1309.04
08/11/91	13.65	1300.94	08/10/93	9.32	1305.27
09/09/91	12.04	1302.55	09/05/93	8.39	1306.20
10/13/91	8.33	1306.26	10/08/93	6.52	1308.07
11/14/91	7.33	1307.26	11/09/93	6.18	1308.41
12/16/91	7.70	1306.89	12/09/93	6.03	1308.56

131-058-25CCC4 LS Elev (msl,ft)=1312.59

Till/Silt, Sandy, Clayey Contact SI (ft.)=18-23

Date	Depth to Water (ft)	WL Elev (msl, ft)	Date	Depth to Water (ft)	WL Elev (msl, ft)
04/01/90	7.12	1307.49	04/10/92	6.28	1308.33
04/28/90	6.87	1307.74	05/06/92	6.18	1308.43
06/03/90	6.49	1308.12	06/07/92	6.24	1308.37
06/29/90	6.69	1307.92	07/08/92	5.19	1309.42
08/05/90	8.30	1306.31	08/01/92	6.09	1308.52
09/11/90	8.09	1306.52	09/02/92	7.13	1307.48
10/11/90	7.86	1306.75	10/05/92	7.15	1307.46
11/09/90	7.72	1306.89	11/12/92	6.68	1307.93
12/06/90	7.73	1306.88	12/05/92	6.52	1308.09
04/06/91	7.69	1306.92	04/15/93	4.91	1309.70
05/06/91	5.78	1308.83	05/09/93	4.66	1309.95
06/11/91	4.83	1309.78	06/07/93	4.78	1309.83
07/08/91	5.27	1309.34	07/09/93	4.27	1310.34
08/11/91	6.44	1308.17	08/10/93	4.75	1309.86
09/09/91	7.33	1307.28	09/05/93	5.69	1308.92
10/13/91	7.53	1307.08	10/08/93	5.88	1308.73
11/14/91	7.11	1307.50	11/09/93	5.76	1308.85
12/16/91	7.32	1307.29	12/09/93	5.66	1308.95

131-058-25CCC5 LS Elev (msl,ft)=1312.59

Carlisle Formation SI (ft.)=235.5-240.5

Date	Depth to Water (ft)	WL Elev (msl, ft)	Date	Depth to Water (ft)	WL Elev (msl, ft)
10/05/92	93.35	1221.61	07/09/93	55.21	1259.75
11/12/92	60.44	1254.52	08/10/93	49.13	1265.83
12/05/92	60.29	1254.67	09/05/93	42.25	1272.71
			10/08/93	40.46	1274.50
04/15/93	24.95	1290.01	11/09/93	36.25	1278.71
05/09/93	69.67	1245.29	12/09/93	33.09	1281.87
06/07/93	63.07	1251.89			

APPENDIX 3

WATER CHEMISTRY ANALYSES FROM PIEZOMETER NESTS

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)																					
131-058-20DDD1	152-157	10/20/89	30	1.5	0.15	66	20	110	9.2	436	0	130	19	0.2	1	0.39	602	250	0	48	3	918	10	
131-058-20DDD2	98-103	12/03/92	12	0.02	0.06	30	22	300	7.7	432	32	440	18	0.5	4.4	0.47	1080	170	0	79	10	1550	6.8	8.95
131-058-20DDD3	55-60	10/20/89	26	0.49	0.47	100	30	78	10	456	0	190	6	0.2	1	0.21	667	370	0	31	1.8	966	10	
131-058-20DDD3	55-60	07/21/93	29	1.4	0.57	110	31	70	9.3	448	0	170	6.1	0.2	0.6	0.22	649	400	35	27	1.5	898	8.9	
131-058-25CCC1	205-210	10/24/89	31	0.86	0.51	140	43	98	13	522	0	310	18	0.3	0.3	0.45	912	530	99	28	1.9	1284	10	
131-058-25CCC1	205-210	12/02/92	25	1.4	0.57	150	43	88	11	539	0	310	8.7	0.2	6.8	0.35	911	550	110	25	1.6	1212	7	7.02
131-058-25CCC2	166-171	10/24/89	30	0.19	0.35	69	30	130	11	444	0	180	33	0.5	0.3	0.57	704	300	0	48	3.3	1083	10	
131-058-25CCC2	166-171	12/02/92	24	0.31	0.4	68	30	130	8.7	466	0	180	31	0.4	9.8	0.45	713	290	0	48	3.3	1085	7	7.94
131-058-25CCC3	102-107	10/25/89	27	0.03	0.56	130	37	63	13	517	0	220	8.4	0.1	1	0.38	755	480	53	22	1.2	1080	11	
131-058-25CCC4	18-23	10/20/89	25	1.4	0.75	270	110	42	12	364	0	920	43	0.2	1	0.13	1600	1100	830	7	0.6	1860	11	
131-059-05BAA1	166-171	09/22/82	27	0.28	0.19	40	19	220	13	509	0	180	33	0.5	7.6	0.42	792	180	0	71	7.1	1170	10	
131-059-05BAA1	166-171	05/01/85	31	0.54	0.18	42	19	220	9.4	504	0	190	31	0.6	0.9	0.53	793	180	0	71	7.1			
131-059-05BAA1	166-171	06/04/85	29	0.79	0.23	42	19	210	9.3	508	0	190	36	0.6	2.3	0.6	790	180	0	70	6.8			
131-059-05BAA1	166-171	07/02/85	25	0.66	0.18	39	19	210	11	507	0	210	31	0.5	7	1.3	805	180	0	71	6.8			
131-059-05BAA1	166-171	09/05/85	26	0.47	0.17	41	19	210	11	509	0	190	29	0.5	1	1.7	781	180	0	70	6.8			
131-059-05BAA1	166-171	10/11/85	29	0.69	0.17	42	19	220	12	519	0	190	31	0.5	1	1.2	803	180	0	71	7.1			
131-059-05BAA1	166-171	11/14/85	38	0.66	0.16	42	18	220	10	505	0	190	31	0.6	1	0.83	801	180	0	71	7.1			
131-059-05BAA1	166-171	03/13/86	30	0.6	0.17	42	19	210	9.5	521	0	190	31	0.6	1	1.3	792	180	0	70	6.8			
131-059-05BAA1	166-171	04/22/86	31	0.63	0.17	43	19	210	9.1	509	0	190	33	0.5	1	1.5	790	190	0	70	6.6			
131-059-05BAA1	166-171	06/19/86	31	0.61	0.15	42	19	220	9.3	508	0	190	30	0.6	1	1.7	795	180	0	71	7.1			
131-059-05BAA1	166-171	07/17/86	31	0.72	0.16	41	19	210	11	506	0	200	31	0.4	7.8	1.5	803	180	0	70	6.8			
131-059-05BAA1	166-171	08/13/86	31	0.74	0.15	42	19	220	11	507	0	190	29	0.5	0.8	1.5	796	180	0	71	7.1			
131-059-05BAA1	166-171	09/17/86	32	0.71	0.17	41	19	210	9.9	504	0	190	31	0.6	1	0.55	784	180	0	70	6.8			
131-059-05BAA1	166-171	10/15/86	32	0.7	0.15	40	19	210	12	506	0	190	31	0.6	0.2	1.2	786	180	0	70	6.8			
131-059-05BAA1	166-171	04/02/87	15	0.03	0.14	41	19	210	9.9	508	0	200	34	0.6	5.7	0.64	786	180	0	70	6.8	1102	7.5	7.73
131-059-05BAA1	166-171	05/13/87	36	0.64	0.15	42	19	210	9.8	508	0	180	38	0.4	7.3	0.49	794	180	0	70	6.8		8.5	7.61
131-059-05BAA1	166-171	06/10/87	31	0.66	0.14	41	19	220	9.4	503	0	190	32	0.6	6.5	0.66	799	180	0	71	7.1		9.5	7.7
131-059-05BAA1	166-171	09/12/91	29	0.25	0.14	39	19	220	11	526	0	190	33	0.6	8.3	1.1	810	180	0	72	7.1	1292	8	
131-059-05BAA2	98-103	05/08/85	27	0.24	0.36	51	16	300	8.9	567	0	350	15	0.5	1	0.52	1050	190	0	76	9.5			
131-059-05BAA2	98-103	06/04/85	27	0.38	0.25	50	15	280	8.9	551	0	350	18	0.4	4.1	0.57	1030	190	0	75	8.8			
131-059-05BAA2	98-103	07/02/85	22	0.26	0.25	51	15	280	12	565	0	360	11	0.4	2	1.3	1030	190	0	75	8.8			
131-059-05BAA2	98-103	09/05/85	23	0.18	0.22	49	15	280	11	561	0	340	8.6	0.3	1	1.1	1010	180	0	75	9.1			
131-059-05BAA2	98-103	10/11/85	25	0.16	0.2	51	15	280	12	571	0	340	10	0.4	1	1.3	1020	190	0	75	8.8			
131-059-05BAA2	98-103	11/14/85	33	0.18	0.22	49	14	290	9.8	573	0	340	9.9	0.4	1	1.3	1030	180	0	77	9.4			
131-059-05BAA2	98-103	03/13/86	25	0.1	0.22	51	15	290	9.5	578	0	340	12	0.4	1	1.2	1030	190	0	76	9.1			
131-059-05BAA2	98-103	04/22/86	28	0.25	0.24	51	14	290	8.6	568	0	330	13	0.4	3.7	1.4	1020	180	0	76	9.4			
131-059-05BAA2	98-103	05/20/86	32	0.58	0.21	42	19	220	9.1	506	0	190	33	1	5	1.5	802	180	0	71	7.1			
131-059-05BAA2	98-103	05/20/86	26	0.11	0.24	50	16	290	9.2	563	0	320	12	0.4	1	1.4	1000	190	0	76	9.1			
131-059-05BAA2	98-103	06/19/86	25	0.08	0.17	51	15	290	9.8	564	0	320	9.2	0.4	1	1.6	1000	190	0	76	9.1			
131-059-05BAA2	98-103	07/17/86	27	0.71	0.2	50	14	280	11	554	0	330	9.9	0.3	4.8	1.1	1000	180	0	76	9.1			
131-059-05BAA2	98-103	08/13/86	27	0.34	0.2	49	15	290	11	556	0	330	9.6	0.3	4.4	1.4	1010	180	0	76	9.4			
131-059-05BAA2	98-103	09/17/86	29	0.07	0.21	49	14	280	9.5	556	0	320	11	0.3	1	1.4	989	180	0	76	9.1			
131-059-05BAA2	98-103	10/15/86	29	0.11	0.2	48	15	280	11	557	0	300	10	0.4	1	0.87	970	180	0	76	9.1			
131-059-05BAA2	98-103	04/02/87	0	0.03	0.17	50	15	290	11	574	0	330	13	0.5	0.4	0.62	994	190	0	76	9.1	1448	7.4	7.68
131-059-05BAA2	98-103	05/13/87	29	0.19	0.19	49	14	280	9.4	561	0	320	13	0.4	1	0.73	993	180	0	76	9.1		9	7.39
131-059-05BAA2	98-103	06/10/87	25	0.05	0.13	49	15	290	9.7	557	0	330	10	0.4	4.3	0.59	1010	180	0	76	9.4		9.8	7.7
131-059-05BAA2	98-103	08/03/93	25	0.01	0.18	51	16	290	11	601	0	340	14	0.7	1.9	1	1050	190	0	75	9.1	1372	10	
131-059-05BAA3	52-57	05/08/85	31	0.06	0.23	57	19	79	9.5	397	0	63	3.3	0.3		0.12	459	220	0	43	2.3			
131-059-05BAA3	52-57	06/04/85	31	0.08	0.2	56	18	77	9.2	401	0	60	11	0.3	0.2	0.13	461	210	0	43	2.3			
131-059-05BAA3	52-57	07/02/85	28	0.06	0.22	56	18	80	11	401	0	68	3	0.3	1	0.31	464	210	0	43	2.4			
131-059-05BAA3	52-57	09/05/85	27	0.02	0.2	59	19	82	11	415	0	64	2.9	0.3	1	0.38	471	230	0	43	2.4			
131-059-05BAA3	52-57	10/11/85	31	0.1	0.21	60	20	82	11	430	0	65	3.2	0.3	1	0.34	486	230	0	42	2.4			
131-059-05BAA3	52-57	11/14/85	40	0.04	0.21	59	20	83	11	429	0	64	3.2	0.3	1	0.28	493	230	0	43	2.4			
131-059-05BAA3	52-57	03/13/86	31	0.01	0.23	62	20	80	10	445	0	55	4.3	0.3	1	0.25	483	240	0	41	2.2			
131-059-05BAA3	52-57	04/22/86	32	0.15	0.26	61	20	85	9.3	445	0	60	5.1	0.3	1	0.4	494	230	0	43	2.4			
131-059-05BAA3	52-57	05/20/86	33	0.04	0.3	61	20	83	9.9	550	0	55	7.1	0.3	0.2	0.63	541	230	0	42	2.4			
131-059-05BAA3	52-57	06/19/86	32	0.18	0.22	63	20	83	9.8	447	0	52	3.8	0.3	1	0.47	486	240	0	42	2.3			
131-059-05BAA3	52-57	07/17/86	31	0.18	0.22	61	21	82	11	447	0	53	4.9	0.3	1	0.38	486	240	0	41	2.3			
131-059-05BAA3	52-57	08/13/86	32	0.3	0.22	64	21	85	11	450	0	53	3.5	0.2	0.3	0.42	493	250	0	42	2.3			
131-059-05BAA3	52-57	09/17/86	34	0.02	0.25	64	21	81	10	451	0	52	6.4	0.3	1	0.43	492	250	0	40	2.2			

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 $CaCO_3$	as NCH	% Na	SAR	Spec Cond (µmho)	Temp (°C)	pH
			(milligrams per liter)																					
131-059-05BAA3	52-57	10/15/86	34	0.08	0.23	61	21	80	11	452	0	56	5.4	0.3	1	0.38	493	240	0	41	2.2			
131-059-05BAA3	52-57	04/02/87	18	0.03	0.28	65	22	79	11	462	0	46	5.6	0.3	1	0.28	476	250	0	39	2.2	713	6.2	7.57
131-059-05BAA3	52-57	05/13/87	35	0.07	0.25	66	22	77	10	459	0	45	5	0.3	1	0.25	488	260	0	38	2.1		8.7	7.52
131-059-05BAA3	52-57	06/10/87	33	0.1	0.23	65	22	80	9.9	454	0	51	5	0.3	3.5	0.27	494	250	0	40	2.2		9.4	7.65
131-059-05BAA3	52-57	08/03/93	27	0.01	0.17	67	22	70	11	450	0	39	2.9	0.5	4.6	0.26	466	260	0	36	1.9	681	9.5	
132-059-17DCD1	188-193	09/22/82	29	0.06	0.14	36	15	270	12	513	0	200	71	0.7	8.5	0.83	896	150	0	78	9.6	1300	11	
132-059-17DCD1	188-193	05/01/85	29	0.37	0.14	35	15	270	9	505	0	200	80	0.7	1	0.58	890	150		79	9.6			
132-059-17DCD1	188-193	06/04/85	30	0.5	0.13	34	15	260	8.8	504	0	220	75	0.8	7.2	1.3	901	150	0	78	9.2			
132-059-17DCD1	188-193	07/02/85	26	0.49	0.13	34	15	270	11	505	0	210	73	0.7	6.5	2.3	898	150	0	79	9.6			
132-059-17DCD1	188-193	08/06/85	28	0.51	0.13	34	15	270	11	510	0	210	70	0.7	1	2	893	150	0	79	9.6			
132-059-17DCD1	188-193	09/04/85	28	0.46	0.12	34	15	260	11	511	0	220	70	0.7	1	2.3	895	150	0	78	9.2			
132-059-17DCD1	188-193	10/10/85	23	0.58	0.14	34	15	270	11	507		220	70	0.7	1	1.7	900	150	0	79	9.6			
132-059-17DCD1	188-193	11/13/85	35	0.54	0.13	35	15	270	9.6	508	0	220	72	0.7	1	1.7	911	150	0	78	9.6			
132-059-17DCD1	188-193	03/12/86	28	0.51	0.13	34	15	270	9	513	0	210	77	0.7	0.8	1.4	900	150	0	79	9.6			
132-059-17DCD1	188-193	04/23/86	30	0.44	0.14	35	14	270	8.7	505	0	210	78	0.7	0	1.9	898	150	0	79	9.6			
132-059-17DCD1	188-193	05/20/86	30	0.5	0.14	35	15	270	9	504	0	210	79	0.7	1	2.6	901	150	0	79	9.6			
132-059-17DCD1	188-193	06/19/86	30	0.52	0.11	34	15	270	11	505	0	210	74	0.7	0.1	2.3	897	150	0	79	9.6			
132-059-17DCD1	188-193	07/17/86	31	0.49	0.13	34	15	270	11	502	0	210	78	0.7	0.5	2	900	150	0	79	9.6			
132-059-17DCD1	188-193	08/13/86	32	0.51	0.11	35	15	270	11	507	0	210	74	0.7	6.2	2.8	907	150	0	78	9.6			
132-059-17DCD1	188-193	09/16/86	31	0.36	0.11	33	15	260	11	508	0	210	73	0.6	5.8	2.2	892	140	0	78	9.5			
132-059-17DCD1	188-193	10/15/86	31	0.54	0.12	34	15	270	11	505	0	210	75	0.7	1	1.7	899	150	0	79	9.6			
132-059-17DCD1	188-193	04/01/87	12	0.48	0.13	34	15	270	10	506	0	200	83	0.8	1	1.4	877	150	0	79	9.6	1378	7	6.92
132-059-17DCD1	188-193	05/13/87	28	0.53	0.12	35	15	270	9.5	499	0	210	83	0.7	5	1	904	150	0	78	9.6		9.1	7.71
132-059-17DCD1	188-193	06/10/87	29	0.58	0.12	35	14	270	9.1	498	0	210	79	0.7	5.6	1.2	899	150	0	79	9.6		9.4	7.77
132-059-17DCD1	188-193	09/12/91	27	0.21	0.16	35	14	270	12	517	0	210	81	0.7	8.2	1.5	915	150	0	79	9.6	1470	9	
132-059-17DCD2	114-119	05/01/85	26	0.99	0.34	130	34	100	12	544	0	210	6.1	0.2	1	0.21	789	460	19	31	2			
132-059-17DCD2	114-119	06/04/85	28	1.1	0.32	120	32	100	11	535	0	230	5.5	0.1	3.4	0.46	796	430	0	33	2.1			
132-059-17DCD2	114-119	07/02/85	24	1	0.35	120	33	100	13	512	0	230	6	0.1	3.1	0.65	783	440	16	33	2.1			
132-059-17DCD2	114-119	09/04/85	26	0.97	0.34	120	33	100	13	542	0	220	6.1	0.2	1	0.76	788	440	0	33	2.1			
132-059-17DCD2	114-119	10/10/85	21	1.2	0.35	120	33	100	13	493		230	6.1	0.1	1	0.57	769	440	31	33	2.1			
132-059-17DCD2	114-119	11/13/85	33	1	0.31	130	34	100	12	547	0	230	5.5	0.1	1	0.57	816	470	16	31	2.1			
132-059-17DCD2	114-119	03/12/86	27	1.2	0.35	130	33	100	12	548	0	230	6.8	0.1	1	0.51	812	460	11	31	2			
132-059-17DCD2	114-119	04/23/86	29	0.63	0.35	130	33	100	11	541	0	230	8.9	0.1	1	0.61	812	460	17	31	2			
132-059-17DCD2	114-119	05/20/86	28	1.2	0.38	130	33	100	11	541	0	220	4.7	0.1	1	0.62	797	460	17	31	2			
132-059-17DCD2	114-119	06/19/86	29	0.83	0.32	130	33	100	13	540	0	230	5.9	0.1	1	0.69	810	460	18	31	2			
132-059-17DCD2	114-119	07/17/86	28	1.1	0.33	130	34	100	13	547	0	230	9	0.2	1	0.77	816	460	16	31	2			
132-059-17DCD2	114-119	08/13/86	30	1.1	0.32	130	33	100	14	542	0	220	6.4	0.1	0	0.84	803	460	16	31	2			
132-059-17DCD2	114-119	09/16/86	29	0.88	0.32	120	33	100	13	540	0	220	7.5	0.1	1	0.7	792	440	0	33	2.1			
132-059-17DCD2	114-119	10/15/86	29	1.2	0.33	120	32	100	13	542	0	220	7.9	0.1	1	0.58	792	430	0	33	2.1			
132-059-17DCD2	114-119	04/01/87	9.5	1.1	0.33	120	33	100	13	544	0	210	7.4	0.2	1	0.43	764	440	0	33	2.1	1152	7	7.4
132-059-17DCD2	114-119	05/13/87	27	1.2	0.33	130	33	100	12	476	0	230	13	0.1	4.3	0.41	785	460	70	31	2		9	7.07
132-059-17DCD2	114-119	06/10/87	28	1.2	0.32	130	32	100	12	535	0	220	7.9	0.1	3.1	0.41	799	460	18	32	2		10.1	7.26
132-059-17DCD2	114-119	08/03/93	28	1.4	0.39	120	33	110	13	531	0	230	8	0.3	4.4	0.5	811	440	0	35	2.3	1078	9.2	
132-059-17DCD3	58-63	09/22/82	28	0.1	0.47	130	41	48	12	436	0	210	7.6	0.2	1	0.27	694	490	140	17	0.9	975	10	
132-059-17DCD3	58-63	05/02/85	28	1.6	0.34	130	39	28	9.8	482	0	140	4.5	0.2	1	0.09	620	480	90	11	0.6			
132-059-17DCD3	58-63	06/04/85	28	1.7	0.31	130	37	28	9.3	482	0	150	4.2	0.2	1	0.2	627	480	82	11	0.6			
132-059-17DCD3	58-63	07/02/85	24	1.4	0.34	130	38	29	10	478	0	150	5.1	0.2	2.3	0.33	626	480	90	11	0.6			
132-059-17DCD3	58-63	09/04/85	26	1.4	0.33	130	38	28	10	483	0	150	3.6	0.2	1	0.37	627	480	85	11	0.6			
132-059-17DCD3	58-63	10/10/85	21	1.7	0.34	130	38	29	10	479		150	4.1	0.2	0	0.3	621	480	89	11	0.6			
132-059-17DCD3	58-63	11/13/85	32	1.4	0.31	130	39	29	9.8	482	0	150	4	0.2	1	0.28	634	490	90	11	0.6			
132-059-17DCD3	58-63	03/12/86	28	1.7	0.34	130	38	27	9.6	484	0	150	4	0.2	3	0.2	630	480	85	11	0.5			
132-059-17DCD3	58-63	04/23/86	29	1.3	0.36	130	39	27	9.2	481	0	150	7.3	0.2	1	0.26	632	490	91	11	0.5			
132-059-17DCD3	58-63	05/10/86	29	1.6	0.38	130	37	38	9.4	481	0	150	4.5	0.2	1	0.3	638	480	83	14	0.8			
132-059-17DCD3	58-63	06/19/86	29	1.4	0.31	130	39	29	11	480	0	150	6.9	0.2	1	0.39	634	490	92	11	0.6			
132-059-17DCD3	58-63	07/17/86	29	1.1	0.33	130	37	27	9.6	477	0	140	9.3	0.2	1	0.34	620	480	86	11	0.5			
132-059-17DCD3	58-63	07/17/86	29	1.6	0.33	130	38	28	9.8	487	0	150	8.5	0.2	1	0.39	637	480	82	11	0.6			
132-059-17DCD3	58-63	08/13/86	30	1.5	0.32	130	38	29	10	481	0	150	6.7	0.2	1	0.42	637	480	87	11	0.6			
132-059-17DCD3	58-63	09/16/86	30	1.3	0.31	130	38	28	10	477	0	150	8.7	0.1	1	0.4	633	480	90	11	0.6			
132-059-17DCD3	58-63	10/15/86	30	1.6	0.33	130	38	30	10	480	0	150	7.6	0.2	1	0.28	635	480	88	12	0.6			
132-059-17DCD3	58-63	04/01/87	14	1.6	0.33	130	38	29	10	481	0	150	9.6	0.2	1	0.21	621	480	87	11	0.6	942	7.1	7.29

			(milligrams per liter)																					
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
132-059-17DCD3	58-63	05/13/87	27	1.8	0.33	130	39	28	10	418	0	150	11	0.2	3.6	0.22	607	490	140	11	0.5		9.6	6.96
132-059-17DCD3	58-63	06/10/87	29	1.7	0.33	130	37	29	9.6	474	0	150	8.4	0.2	2.9	0.21	631	480	88	11	0.6		10.2	7.06
132-059-17DCD3	58-63	09/12/91	27	0.56	0.29	130	39	28	9.8	472	0	150	4.9	0.1	1	0.26	624	490	100	11	0.5	987	9	
132-059-27CDC1	209-214	03/08/83	31	0.32	0.21	45	14	370	10	484	0	380	150	1.3	1	0.74	1240	170	0	81	12	2300	11	
132-059-27CDC1	209-214	08/29/84	30	0.05	0.23	45	14	370	12	503	0	410	150	1.5	1	1.9	1280	170	0	81	12	1940	9	
132-059-27CDC1	209-214	05/01/85	28	0.32	0.25	45	14	380	9.3	486	0	380	150	1.5	1	0.69	1250	170	0	82	13			
132-059-27CDC1	209-214	06/04/85	29	0.34	0.24	44	14	370	9.3	485	0	390	150	1.6	7.9	1.4	1260	170	0	82	12			
132-059-27CDC1	209-214	07/02/85	26	0.43	0.24	48	15	380	12	477	0	370	150	1.4	5.3	2.4	1250	180	0	81	12			
132-059-27CDC1	209-214	08/06/85	29	0.4	0.24	46	14	380	11	487	0	400	150	1.4	1	2.1	1280	170	0	82	13			
132-059-27CDC1	209-214	09/04/85	27	0.44	0.22	48	15	390	12	484	0	390	150	1.4	1	2.3	1280	180	0	81	13			
132-059-27CDC1	209-214	11/13/85	34	0.47	0.23	45	14	380	10	491	0	400	150	1.3	1	1.6	1280	170	0	82	13			
132-059-27CDC1	209-214	03/12/86	28	0.45	0.25	44	14	380	9	493	0	380	140	1.5	1	1.5	1240	170	0	82	13			
132-059-27CDC1	209-214	04/22/86	30	0.38	0.28	45	13	380	8.9	490	0	380	150	1.5	5.7	1.9	1260	170	0	82	13			
132-059-27CDC1	209-214	05/20/86	28	0.37	0.3	45	14	380	9.1	487	0	380	150	1.4	1	2.5	1250	170	0	82	13			
132-059-27CDC1	209-214	07/17/86	30	0.54	0.23	44	14	370	11	495	0	400	140	1.7	1	2.4	1260	170	0	82	12			
132-059-27CDC1	209-214	08/13/86	31	0.47	0.23	44	14	380	11	489	0	390	140	1.4	0.5	2.8	1260	170	0	82	13			
132-059-27CDC1	209-214	09/16/86	31	0.47	0.22	43	14	370	12	484	0	380	140	1.3	4.8	2.6	1240	170	0	82	12			
132-059-27CDC1	209-214	10/15/86	31	0.56	0.22	43	13	370	12	486	0	390	140	1.5	1	1.5	1240	160	0	82	13			
132-059-27CDC1	209-214	05/13/87	26	0.48	0.23	44	14	380	10	483	0	390	140	1.4	5.3	1.1	1250	170	0	82	13		9.5	7.5
132-059-27CDC1	209-214	06/10/87	28	0.51	0.22	45	13	380	9.3	481	0	380	140	1.4	4.9	1.3	1240	170	0	82	13		9.7	7.72
132-059-27CDC1	209-214	09/12/91	28	0.31	0.21	44	14	380	11	500	0	390	150	1.3	9.1	1.5	1280	170	0	82	13	1985	10	
132-059-27CDC2	105-110	05/01/85	29	0.08	0.25	41	11	290	10	554	0	250	55	0.4	1	0.55	961	150	0	80	10			
132-059-27CDC2	105-110	06/04/85	31	0.22	0.24	38	12	290	10	559	0	270	53	0.4	4.9	1.1	986	140	0	80	11			
132-059-27CDC2	105-110	07/02/85	27	0.13	0.2	39	12	310	13	557	0	250	56	0.3	4.5	2.1	988	150	0	80	11			
132-059-27CDC2	105-110	08/06/85	31	0.15	0.23	37	12	290	12	548	0	270	61	0.4	1	1.7	986	140	0	80	11			
132-059-27CDC2	105-110	09/04/85	28	0.18	0.18	40	13	290	13	558	0	260	52	0.4	1	1.9	975	150	0	79	10			
132-059-27CDC2	105-110	10/10/85	25	0.26	0.26	39	12	290	13	563		260	52	0.4	1	1.5	970	150	0	79	10			
132-059-27CDC2	105-110	11/13/85	35	0.27	0.21	42	12	300	11	592	0	260	53	0.3	1	1.3	1010	160	0	79	10			
132-059-27CDC2	105-110	03/12/86	31	0.17	0.21	40	13	290	11	586	0	260	52	0.4	1	1.4	989	150	0	79	10			
132-059-27CDC2	105-110	04/22/86	32	0.31	0.3	42	13	300	9.9	592	0	250	55	0.3	4	1.5	1000	160	0	79	10			
132-059-27CDC2	105-110	05/20/86	34	0.26	0.31	42	13	300	10	580	0	260	52	0.4	1	2.1	1000	160	0	79	10			
132-059-27CDC2	105-110	06/19/86	36	0.26	0.26	42	13	300	13	579	0	260	51	0.3	0.2	1.7	1000	160	0	79	10			
132-059-27CDC2	105-110	07/17/86	34	0.24	0.27	40	13	300	12	590	0	260	54	0.4	1	2.1	1010	150	0	79	11			
132-059-27CDC2	105-110	08/13/86	36	0.29	0.27	43	13	300	12	592	0	250	51	0.4	4.4	2.1	1000	160	0	79	10			
132-059-27CDC2	105-110	09/16/86	36	0.25	0.27	42	13	290	13	592	0	260	52	0.3	0.5	2.1	1000	160	0	78	10			
132-059-27CDC2	105-110	10/15/86	35	0.26	0.27	41	14	300	13	596	0	250	53	0.3	1	1.5	1000	160	0	79	10			
132-059-27CDC2	105-110	04/01/87	37	0.29	0.26	40	14	300	12	600	0	250	53	0.3	0.7	1.2	1000	160	0	79	10	1474	7.8	7.91
132-059-27CDC2	105-110	05/13/87	30	0.26	0.27	44	14	300	11	598	0	260	53	0.3	5.2	1.2	1010	170	0	78	10		9.9	7.64
132-059-27CDC2	105-110	06/10/87	33	0.29	0.27	44	13	300	11	596	0	260	52	0.3	4.7	1.2	1010	160	0	79	10		9.7	7.84
132-059-27CDC2	105-110	08/03/93	28	0.2	0.26	47	14	290	12	617	0	250	55	0.7	6.2	1.2	1010	180	0	77	9.4	1429	9.8	
132-059-27CDC3	150-155	08/29/84	31	0.18	0.32	61	20	210	12	504	0	210	59	0.5	1	1.3	854	230	0	65	6	1290	9	
132-059-27CDC3	150-155	05/01/85	28	0.95	0.46	61	20	210	9.5	498	0	190	58	0.5	1	0.51	825	230	3	65	6			
132-059-27CDC3	150-155	06/04/85	30	0.88	0.36	59	20	200	9.1	503	0	200	57	0.5	3.8	1	830	230	0	64	5.7			
132-059-27CDC3	150-155	07/02/85	26	0.86	0.37	60	20	210	11	493	0	190	56	0.5	4.5	1.7	824	230	0	65	6			
132-059-27CDC3	150-155	08/06/85	28	0.89	0.36	61	21	210	11	498	0	200	65	0.5	1	1.5	845	240	0	64	5.9			
132-059-27CDC3	150-155	09/04/85	27	0.79	0.32	60	20	200	11	479	0	200	56	0.5	1	1.7	814	230	0	64	5.7			
132-059-27CDC3	150-155	10/10/85	23	1.1	0.34	61	20	210	110	494	0	200	56	0.4	1	1.4	828	240	0	65	5.9			
132-059-27CDC3	150-155	11/13/85	36	0.84	0.31	61	19	210	9.8	504	0	210	56	0.4	1	1.2	854	230	0	65	6			
132-059-27CDC3	150-155	03/12/86	30	0.98	0.33	61	20	210	9.1	506	0	200	55	0.5	1	1.3	838	230	0	65	6			
132-059-27CDC3	150-155	04/22/86	31	0.33	0.35	62	20	210	9	501	0	200	58	0.4	0.4	1.2	840	240	0	65	5.9			
132-059-27CDC3	150-155	05/20/86	30	1	0.39	62	20	210	9.2	498	0	190	54	0.4	1	1.9	825	240	0	65	5.9			
132-059-27CDC3	150-155	06/19/86	31	0.9	0.31	61	20	210	11	497	0	190	54	0.4	0.2	1.3	825	230	0	65	6			
132-059-27CDC3	150-155	06/19/86	30	0.49	0.22	45	14	380	12	486	0	400	140	1.4	0.3	2.5	1260	170	0	82	13			
132-059-27CDC3	150-155	07/17/86	30	0.99	0.32	60	21	200	11	505	0	200	57	0.6	1	1.9	833	240	0	64	5.6			
132-059-27CDC3	150-155	08/13/86	32	0.87	0.35	61	20	210	11	499	0	190	55	0.5	3.6	0.57	834	230	0	65	6			
132-059-27CDC3	150-155	09/16/86	32	0.84	0.3	60	20	200	11	498	0	200	55	0.4	0.8	1.8	827	230	0	64	5.7			
132-059-27CDC3	150-155	10/00/86	31	0.98	0.34	58	20	200	11	496	0	190	55	0.4	1	1.2	813	230	0	64	5.7			
132-059-27CDC3	150-155	04/01/87	35	0.9	0.3	59	20	210	11	500	0	190	58	0.5	0.4	0.97	832	230	0	65	6	1258	7.6	7.75
132-059-27CDC3	150-155	05/13/87	28	0.98	0.3	60	20	210	10	493	0	200	60	0.4	3.2	1.2	837	230	0	65	6		9.2	7.43
132-059-27CDC3	150-155	06/10/87	30	0.98	0.31	61	20	210	9.5	492	0	200	56	0.4	4.1	0.96	835	230	0	65	6		10.6	7.38

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)																					
132-059-27CDC3	150-155	09/12/91	28	0.32	0.27	59	20	210	11	512	0	210	59	0.5	4	1.1	855	230	0	65	6	1363	9	
132-059-27CDD	49-54	10/29/82	27	0.57	0.43	120	52	45	5.9	369	0	220	10	0.2	1	0.1	664	510	210	16	0.9	960	7	
132-059-27CDD	49-54	05/01/85	26	0.44	0.42	96	50	47	6	372	0	220	9.5	0.3	1	0.04	640	450	140	18	1			
132-059-27CDD	49-54	06/04/85	28	0.5	0.38	91	48	45	5.7	376	0	220	8.4	0.3	1	0.12	633	420	120	18	1			
132-059-27CDD	49-54	07/02/85	25	0.45	0.4	89	49	45	6.8	368	0	200	8.7	0.3	1	0.17	607	420	120	18	1			
132-059-27CDD	49-54	08/06/85	27	0.59	0.4	93	49	46	6.6	372	0	220	7.7	0.3	1	0.12	634	430	130	18	1			
132-059-27CDD	49-54	09/04/85	26	0.45	0.37	91	47	45	6.6	370	0	200	8	0.3	1	0.19	608	420	120	19	1			
132-059-27CDD	49-54	10/10/85	21	0.57	0.38	92	47	47	6.6	370	0	200	8.2	0.3	1	0.18	606	420	120	19	1			
132-059-27CDD	49-54	11/13/85	33	0.47	0.36	89	45	46	6.1	370	0	200	7.9	0.3	1	0.16	611	410	100	18	1			
132-059-27CDD	49-54	03/12/86	28	0.43	0.4	89	46	45	5.6	371	0	180	9.1	0.3	1.9	0.16	589	410	110	19	1			
132-059-27CDD	49-54	04/22/86	28	0.44	0.39	86	44	43	5.4	372	0	170	11	0.2	1	0.17	573	400	91	19	0.9			
132-059-27CDD	49-54	05/20/86	28	0.47	0.41	84	43	46	5.6	369	0	170	8.8	0.3	1	0.21	570	390	84	20	1			
132-059-27CDD	49-54	06/19/86	29	0.43	0.31	82	42	45	6.6	368	0	160	8	0.2	1	0.22	556	380	76	20	1			
132-059-27CDD	49-54	07/17/86	29	0.45	0.34	82	43	47	6.3	370	0	160	12	0.3	1	0.24	564	380	79	21	1			
132-059-27CDD	49-54	08/13/86	30	0.37	0.32	82	42	46	6.5	370	0	170	8.4	0.3	1	0.29	569	380	74	21	1			
132-059-27CDD	49-54	09/16/86	30	0.4	0.31	79	42	45	6.5	368	0	160	10	0.2	1	0.19	556	370	68	21	1			
132-059-27CDD	49-54	10/15/86	29	0.49	0.32	77	41	43	6.4	366	0	150	10	0.3	1	0.17	539	360	61	20	1			
132-059-27CDD	49-54	04/01/87	34	0.33	0.33	80	41	45	6	368	0	140	11	0.3	1	0.14	540	370	67	21	1	827	6.6	7.76
132-059-27CDD	49-54	05/13/87	28	0.44	0.33	79	41	44	5.8	354	0	150	13	0.2	2	0.13	538	370	76	20	1		9.1	7.4
132-059-27CDD	49-54	06/10/87	29	0.47	0.33	80	40	44	5.5	360	0	150	9.9	0.3	0.8	0.13	537	360	69	20	1		9.3	7.63
132-059-27CDD	49-54	09/12/91	28	0.33	0.28	72	38	42	5.2	355	0	140	8.6	0.2	1	0.14	511	340	50	21	1	843	8	
133-060-02CDD1	255-260	09/08/83	32	1.1	0.17	83	32	200	12	452	0	250	110	0.3	1	0.51	945	340	0	55	4.7	1875	8	
133-060-02CDD2	195-200	08/29/84	31	0.02	0.13	48	15	230	15	465	0	270	32	0.4	1	1.3	873	180	0	71	7.5	1220	8	
133-060-02CDD2	195-200	05/02/85	29	0.94	0.13	49	15	240	12	448	0	280	29	0.4	0.7	0.55	878	180	0	72	7.8			
133-060-02CDD2	195-200	06/05/85	29	1.1	0.14	48	15	230	12	447	0	290	28	0.4	0.3	0.58	875	180	0	72	7.5			
133-060-02CDD2	195-200	07/02/85	27	1.1	0.14	49	15	230	14	448	0	290	25	0.4	5	1.4	879	180	0	71	7.5			
133-060-02CDD2	195-200	09/04/85	26	0.85	0.13	49	15	230	14	456	0	280	26	0.4	1	1.7	869	180	0	71	7.5			
133-060-02CDD2	195-200	10/10/85	29	1.1	0.14	48	15	220	14	465	0	280	25	0.4	1	1.4	864	180	0	71	7.1			
133-060-02CDD2	195-200	11/14/85	38	0.87	0.12	49	15	230	13	453	0	280	25	0.4	1	1.3	877	180	0	71	7.5			
133-060-02CDD2	195-200	03/13/86	30	1.1	0.15	50	15	230	12	465	0	290	26	0.5	0.5	1.2	885	190	0	71	7.2			
133-060-02CDD2	195-200	04/23/86	31	1	0.16	50	15	240	12	453	0	300	22	0.5	5.4	1.9	902	190	0	72	7.6			
133-060-02CDD2	195-200	05/21/86	31	0.88	0.16	52	15	260	12	453	0	290	27	0.4	1.9	1.6	915	190	0	73	8.2			
133-060-02CDD2	195-200	06/20/86	31	0.85	0.13	49	15	240	14	455	0	290	24	0.4	0.7	1.6	891	180	0	72	7.8			
133-060-02CDD2	195-200	07/18/86	31	1.2	0.13	49	14	230	14	450	0	290	24	0.3	5.6	1.5	883	180	0	72	7.5			
133-060-02CDD2	195-200	08/14/86	31	1.3	0.13	50	15	230	13	458	0	300	24	0.4	5.4	2	898	190	0	71	7.2			
133-060-02CDD2	195-200	09/17/86	32	1	0.12	49	15	230	15	453	0	300	25	0.4	0.9	1.7	893	180	0	71	7.5			
133-060-02CDD2	195-200	10/16/86	32	1.1	0.13	49	15	220	15	451	0	290	24	0.4	1	1.3	871	180	0	70	7.1			
133-060-02CDD2	195-200	04/02/87	15	0.16	0.13	50	15	230	13	451	0	300	27	0.5	0.2	0.67	874	190	0	71	7.2	1180	7.1	7.72
133-060-02CDD2	195-200	05/14/87	33	0.9	0.14	50	15	230	13	449	0	310	29	0.5	6.9	1	910	190	0	71	7.2		8.6	7.47
133-060-02CDD2	195-200	06/11/87	30	1.1	0.13	49	15	240	12	445	0	290	23	0.5	5.4	0.58	886	180	0	72	7.8		9.1	7.63
133-060-02CDD2	195-200	09/11/91	29	0.39	0.12	46	14	230	14	462	0	300	24	0.4	5.5	1.3	893	170	0	72	7.7	1420	8	
133-060-02CDD3	117-122	05/02/85	37	0.02	0.02	43	16	200	19	232	0	380	8.8	0.3	1	0.28	819	170	0	69	6.7			
133-060-02CDD3	117-122	06/05/85	42	0.03	0.1	59	19	190	17	302	0	410	16	0.3	0.3	0.31	903	230	0	63	5.5			
133-060-02CDD3	117-122	07/02/85	32	0.02	0.12	60	21	200	20	312	0	410	12	0.4	2	0.78	912	240	0	62	5.6			
133-060-02CDD3	117-122	09/04/85	34	0.03	0.16	75	24	190	19	373	0	400	7.2	0.4	1	0.96	936	290	0	57	4.9			
133-060-02CDD3	117-122	10/10/85	39	0.07	0.18	76	24	190	19	388	0	390	6.9	0.4	1	0.74	938	290	0	57	4.8			
133-060-02CDD3	117-122	11/14/85	50	0.02	0.2	79	24	200	18	398	0	410	7.3	0.4	1	0.65	987	300	0	58	5			
133-060-02CDD3	117-122	03/13/86	38	0.02	0.32	87	26	190	16	422	0	410	9.5	0.4	1	0.64	987	320	0	55	4.6			
133-060-02CDD3	117-122	04/23/86	41	0.04	0.32	86	25	190	15	417	0	390	11	0.4	1	0.85	966	320	0	55	4.6			
133-060-02CDD3	117-122	05/21/86	39	0.08	0.42	91	26	200	15	420	0	390	11	0.4	0.2	1	981	330	0	55	4.8			
133-060-02CDD3	117-122	06/20/86	39	0.02	0.34	91	26	200	17	423	0	400	9.7	0.4	0.2	0.85	993	330	0	55	4.8			
133-060-02CDD3	117-122	07/18/86	38	0.09	0.37	89	25	190	17	422	0	400	8.8	0.3	4.2	0.83	982	330	0	54	4.5			
133-060-02CDD3	117-122	08/14/86	38	0.09	0.36	93	26	200	16	427	0	400	9.4	0.4	4.4	0.76	998	340	0	55	4.7			
133-060-02CDD3	117-122	09/17/86	39	0.04	0.39	89	26	190	18	428	0	400	10	0.3	0.4	1.1	985	330	0	54	4.5			
133-060-02CDD3	117-122	10/16/86	40	0.08	0.4	90	25	190	18	427	0	380	8.7	0.4	1	0.65	964	330	0	54	4.5			
133-060-02CDD3	117-122	04/02/87	30	0.07	0.41	94	26	190	16	433	0	390	12	0.5	3.1	0.52	976	340	0	53	4.5	1303	7.2	7.57
133-060-02CDD3	117-122	05/14/87	41	0.05	0.42	95	26	190	15	433	0	400	14	0.5	4.5	0.66	1000	340	0	53	4.5		7.9	7.59
133-060-02CDD3	117-122	06/11/87	38	0.03	0.44	93	26	190	14	428	0	390	9.7	0.5	4.4	0.49	978	340	0	54	4.5		8	7.56
133-060-02CDD3	117-122	08/03/93	34	0.07	0.39	86	24	170	16	419	0	360	9.3	0.7	4.8	0.69	912	310	0	53	4.2	1236	8.8	
133-060-02CDD4	26-31	08/29/84	25	0.02	0.18	64	20	65	9.1	371	0	58	2.7	0.3	1	0.48	429	240	0	36	1.8	630	11	

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)																					
133-060-02CDD4	26-31	05/02/85	26	0.15	0.3	92	28	70	9.3	395	0	160	5.9	0.2	0.1	0.16	587	340	21	30	1.7			
133-060-02CDD4	26-31	06/05/85	24	0.15	0.29	89	28	68	8.7	390	0	170	12	0.2	0.2	0.17	593	340	18	30	1.6			
133-060-02CDD4	26-31	07/02/85	21	0.2	0.34	98	30	69	10	378	0	200	6.9	0.2	1.7	0.42	624	370	58	28	1.6			
133-060-02CDD4	26-31	09/04/85	22	0.22	0.32	100	31	70	11	379	0	210	5.1	0.2	1	0.45	638	380	67	28	1.6			
133-060-02CDD4	26-31	10/10/85	26	0.36	0.33	99	31	65	10	384	0	210	4.9	0.2	1	0.4	637	380	60	27	1.4			
133-060-02CDD4	26-31	11/14/85	33	0.28	0.32	93	29	63	9.7	375	0	190	4.7	0.2	1	0.33	610	350	44	27	1.5			
133-060-02CDD4	26-31	03/13/86	25	0.09	0.29	88	28	63	8.9	380	0	170	6	0.2	1	0.32	578	330	23	28	1.5			
133-060-02CDD4	26-31	04/23/86	26	0.12	0.33	88	28	60	8.7	359	0	170	6.2	0.2	1	0.4	566	330	41	27	1.4			
133-060-02CDD4	26-31	05/21/86	26	0.02	0.39	91	28	63	8.5	359	0	180	7	0.2	1	0.58	583	340	48	28	1.5			
133-060-02CDD4	26-31	06/20/86	26	0.03	0.28	86	28	62	9.8	361	0	160	6	0.2	0.1	0.39	557	330	34	28	1.5			
133-060-02CDD4	26-31	07/18/86	25	0.81	0.35	87	28	61	10	360	0	160	5.5	0.1	1.5	0.36	557	330	37	28	1.5			
133-060-02CDD4	26-31	08/14/86	26	0.2	0.28	86	27	61	9.3	330	0	160	6.1	0.2	1.1	0.37	541	330	55	28	1.5			
133-060-02CDD4	26-31	09/17/86	27	0.14	0.29	83	27	61	9.9	365	0	150	6.9	0.2	0.3	0.52	546	320	19	29	1.5			
133-060-02CDD4	26-31	10/16/86	27	0.19	0.3	82	27	60	10	363	0	140	5	0.2	1	0.33	532	320	18	28	1.5			
133-060-02CDD4	26-31	04/02/87	4.6	0.02	0.18	82	26	57	9.3	371	0	130	9.2	0.3	1	0.25	503	310	8	28	1.4	710	6.4	7.46
133-060-02CDD4	26-31	05/14/87	30	0.03	0.24	84	26	58	9	365	0	140	11	0.2	1.5	0.03	540	320	18	28	1.4		6.7	7.42
133-060-02CDD4	26-31	06/11/87	27	0.17	0.33	83	26	57	8.4	361	0	140	6.5	0.2	2.8	0.22	530	310	18	28	1.4		7.5	7.49
133-060-02CDD4	26-31	09/11/91	26	0.13	0.33	81	27	58	8.8	344	0	160	6.5	0.2	3.5	0.31	541	310	31	28	1.4	883	7	
133-060-36DDD1	212-215	09/24/75	21	0.19	0.48	61	21	100	9	463	0	78	12	0.5	1	4.2	536	240	0	46	2.8	850	8	7.6
133-060-36DDD1	212-215	08/29/84	32	0.04	0.23	60	20	110	12	463	0	84	13	0.4	1	0.63	561	230	0	49	3.2	870	9	
133-060-36DDD1	212-215	04/02/87	17	1.8	0.19	70	24	110	10	465	0	120	22	0.5	0.4	0.44	605	270	0	46	2.9	881	7.8	7.54
133-060-36DDD1	212-215	09/12/91	29	0.5	0.19	57	21	100	11	455	0	81	14	0.4	3.9	0.55	543	230	0	47	2.9	916	9	
133-060-36DDD2	236-241	08/29/84	31	0.28	0.18	69	24	110	12	475	0	110	18	0.4	1	0.64	611	270	0	46	2.9	985	9	
133-060-36DDD2	236-241	05/02/85	30	2	0.18	69	24	110	9.7	456	0	110	17	0.4	1.9	0.25	599	270	0	46	2.9			
133-060-36DDD2	236-241	06/05/85	30	2.3	0.18	67	23	110	9.5	464	0	110	24	0.4	0.4	0.26	606	260	0	47	3			
133-060-36DDD2	236-241	07/02/85	26	2.2	0.19	68	24	110	11	460	0	110	18	0.4	4.3	0.64	602	270	0	46	2.9			
133-060-36DDD2	236-241	09/04/85	27	2.1	0.18	70	24	110	11	463	0	100	17	0.4	0.8	0.75	591	270	0	45	2.9			
133-060-36DDD2	236-241	10/10/85	29	2.4	0.19	68	23	110	11	472	0	110	16	0.4	1	0.6	605	260	0	46	2.9			
133-060-36DDD2	236-241	11/14/85	38	1.7	0.19	69	24	110	10	471	0	110	17	0.4	1	0.52	614	270	0	46	2.9			
133-060-36DDD2	236-241	03/12/86	28	2.6	0.18	70	24	110	9.6	470	0	110	17	0.4	1.5	0.44	606	270	0	46	2.9			
133-060-36DDD2	236-241	04/22/86	31	2.2	0.21	70	24	110	9.4	465	0	110	22	0.4	1	0.7	610	270	0	46	2.9			
133-060-36DDD2	236-241	05/21/86	32	2.2	0.25	71	24	110	9.3	464	0	110	22	0.2	1	1	612	280	0	45	2.9			
133-060-36DDD2	236-241	06/20/86	31	2.2	0.17	70	24	110	11	465	0	110	19	0.4	0.4	0.83	608	270	0	45	2.9			
133-060-36DDD2	236-241	07/18/86	31	2.4	0.18	69	24	110	11	461	0	120	18	0.3	1	0.71	615	270	0	46	2.9			
133-060-36DDD2	236-241	08/14/86	31	2.4	0.17	70	24	110	11	465	0	110	19	0.4	4.9	0.68	613	270	0	45	2.9			
133-060-36DDD2	236-241	09/17/86	32	2.1	0.17	69	24	110	12	464	0	120	20	0.3	1	0.89	620	270	0	46	2.9			
133-060-36DDD2	236-241	10/16/86	32	2.3	0.18	68	24	110	12	462	0	110	19	0.4	1	0.63	608	270	0	46	2.9			
133-060-36DDD2	236-241	00/00/87	35	2	0.18	70	24	110	9.9	463	0	120	24	0.4	4.9	0.33	629	270	0	46	2.9		8.4	7.56
133-060-36DDD2	236-241	04/02/87	14	0.79	0.45	100	27	230	13	430	0	490	23	1.1	2.2	0.66	1110	360	8	57	5.3	1599	7.6	7.72
133-060-36DDD2	236-241	06/11/87	31	2.3	0.17	69	24	110	9.7	458	0	120	19	0.5	5.2	0.38	617	270	0	46	2.9		9.7	7.53
133-060-36DDD2	236-241	08/03/93	28	0.04	0.03	62	21	93	9.3	410	0	100	18	0.7	5.4	0.5	540	240	0	44	2.6	783	9.5	
133-060-36DDD3	120-125	05/02/85	30	0.02	0.1	100	27	230	13	426	0	480	20	0.4	1	0.53	1110	360	12	57	5.3			
133-060-36DDD3	120-125	06/05/85	29	1	0.47	99	26	230	13	427	0	480	25	0.4	3.4	0.57	1120	350	4	57	5.3			
133-060-36DDD3	120-125	07/02/85	25	0.79	0.5	100	26	230	15	428	0	520	18	0.4	1	1.3	1150	360	6	57	5.3			
133-060-36DDD3	120-125	09/04/85	26	0.76	0.49	110	27	230	15	428	0	480	18	0.4	1	1.8	1120	390	35	55	5.1			
133-060-36DDD3	120-125	10/10/85	29	0.71	0.48	100	27	230	15	439	0	480	18	0.4	1	1.3	1120	360	1	57	5.3			
133-060-36DDD3	120-125	11/14/85	38	0.68	0.49	100	26	230	14	435	0	490	18	0.4	1	1.3	1130	360	0	57	5.3			
133-060-36DDD3	120-125	03/12/86	29	0.83	0.52	100	27	230	13	440	0	500	20	0.4	1	1.1	1140	360	0	57	5.3			
133-060-36DDD3	120-125	04/22/86	30	0.51	0.51	100	26	230	12	431	0	480	21	0.4	2.4	1.1	1120	360	4	57	5.3			
133-060-36DDD3	120-125	05/21/86	31	0.38	0.59	100	26	240	12	427	0	480	22	0.4	2.4	1.4	1130	360	7	58	5.5			
133-060-36DDD3	120-125	06/20/86	31	1.2	0.46	100	26	230	15	427	0	470	20	0.4	3.9	1.5	1110	360	7	57	5.3			
133-060-36DDD3	120-125	07/18/86	31	1.1	0.47	100	27	220	15	425	0	490	18	0.2	1.3	1.5	1110	360	12	56	5			
133-060-36DDD3	120-125	08/14/86	31	0.97	0.46	100	27	240	15	427	0	490	18	0.3	2.3	1.4	1140	360	11	58	5.5			
133-060-36DDD3	120-125	09/17/86	31	0.93	0.47	100	27	230	15	428	0	490	19	0.3	0.5	1.8	1130	360	10	57	5.3			
133-060-36DDD3	120-125	10/16/86	32	1.1	0.47	100	26	220	15	426	0	490	19	0.3	1	1.2	1120	360	8	56	5			
133-060-36DDD3	120-125	04/02/87	11	0.03	0.39	170	91	150	15	620	0	610	7.8	0.2	0	0.24	1360	800	290	41	2.3	1775	6.8	7.25
133-060-36DDD3	120-125	05/14/87	34	1.1	0.46	100	26	220	13	426	0	460	26	0.4	5.1	0.82	1100	360	8	56	5		8.8	7.56
133-060-36DDD3	120-125	06/11/87	30	1.7	0.55	110	28	230	13	419	0	460	18	0.4	5.9	0.64	1100	390	46	55	5.1		9.1	7.6
133-060-36DDD3	120-125	08/03/93	29	0.07	0.43	93	25	210	14	449	0	430	20	0.7	6.6	1	1050	340	0	56	5	1350	9	
133-060-36DDD5	40-45	05/02/85	34	0.53	0.71	170	89	160	15	563	0	640	5	0.2	0.1	0.18	1390	790	330	30	2.5			

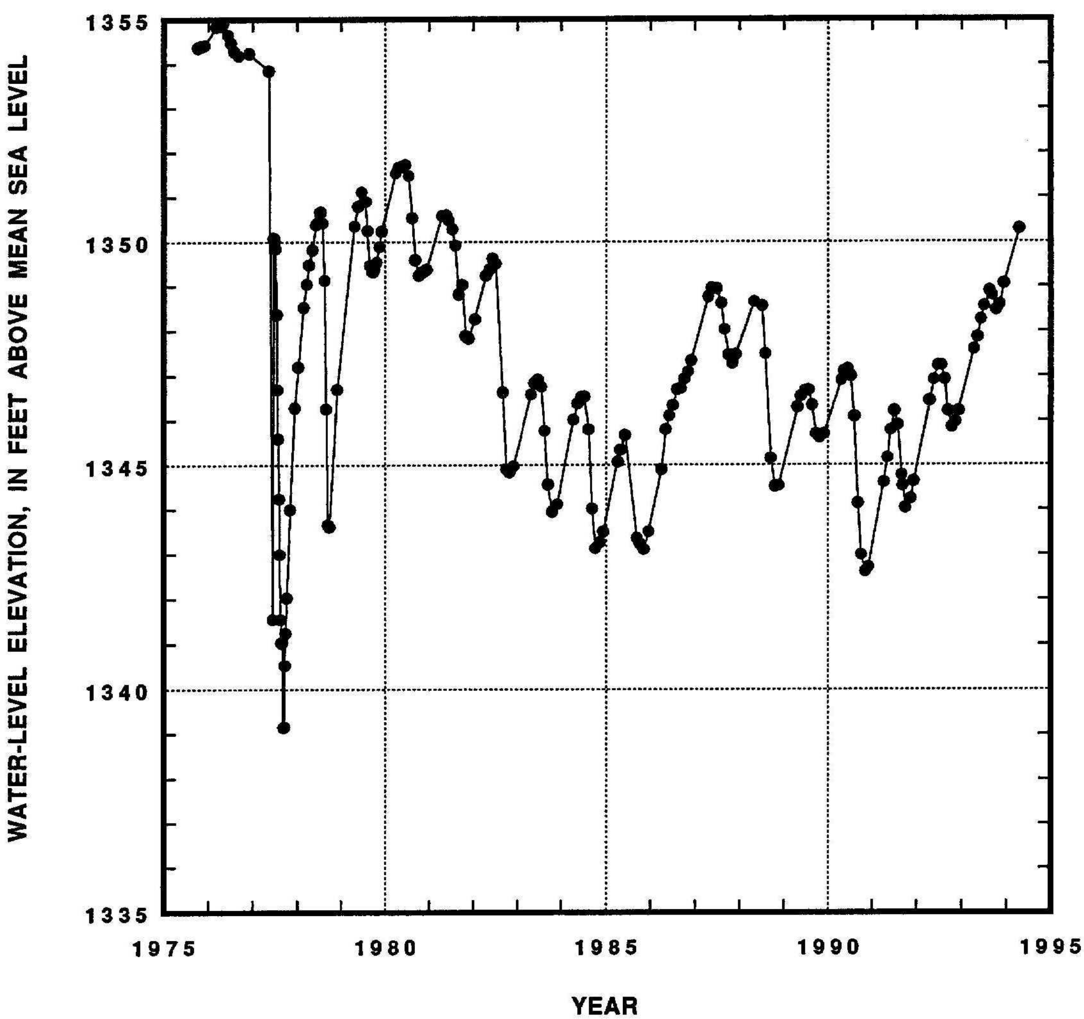
Location	Screened Interval (ft)	Date Sampled	SiO_2 (milligrams per liter)	Fe	Mn	Ca	Mg	Na	K	HCO_3	CO_3	SO_4	Cl	F	NO_3	B	TDS	Hardness as $CaCO_3$	NCH	% Na	SAR	Spec Cond (µmho)	Temp (∞C)	pH
133-060-36DDD5	40-45	06/05/85	31	0.08	0.55	170	90	160	17	598	0	660	10	0.1	3.5	0.18	1440	790	300	30	2.5			
133-060-36DDD5	40-45	07/02/85	29	0.02	0.5	170	96	150	18	556	0	700	1.8	0.1	3.6	0.47	1440	820	360	28	2.3			
133-060-36DDD5	40-45	09/04/85	28	0.04	0.42	180	96	160	17	626	0	660	2.3	0.2	1	0.56	1450	840	330	29	2.4			
133-060-36DDD5	40-45	10/10/85	32	0.11	0.4	180	96	160	17	624	0	650	1.3	0.2	1	0.44	1450	840	330	29	2.4			
133-060-36DDD5	40-45	11/14/85	41	0.06	0.42	180	94	150	16	625	0	670	1.7	0.2	1	0.37	1460	840	320	28	2.3			
133-060-36DDD5	40-45	03/12/86	31	0.07	0.48	180	95	160	15	630	0	680	3.3	0.2	0.2	0.33	1480	840	320	29	2.4			
133-060-36DDD5	40-45	04/22/86	31	0.05	0.45	170	93	150	15	633	0	650	5.3	0.2	1	0.45	1430	810	290	28	2.3			
133-060-36DDD5	40-45	05/21/86	32	0.03	0.51	180	93	160	15	632	0	650	5.4	0.2	1	0.76	1450	830	310	29	2.4			
133-060-36DDD5	40-45	06/20/86	31	0.04	0.37	180	94	150	17	634	0	620	4.5	0.2	1	0.47	1410	840	320	28	2.3			
133-060-36DDD5	40-45	07/18/86	30	0.02	0.39	180	93	150	17	621	0	630	3.4	0.1	0.5	0.42	1410	830	320	28	2.3			
133-060-36DDD5	40-45	08/14/86	29	0.05	0.36	180	93	160	16	629	0	630	2.4	0.2	0.5	0.49	1420	830	320	29	2.4			
133-060-36DDD5	40-45	09/18/86	31	0.03	0.4	180	93	150	16	624	0	620	3.4	0.1	0.7	0.57	1400	830	320	28	2.3			
133-060-36DDD5	40-45	10/16/86	31	0.02	0.37	170	92	150	17	627	0	630	3.9	0.2	0.2	0.39	1400	800	290	28	2.3			
133-060-36DDD5	40-45	05/14/87	34	0.04	0.39	180	92	150	15	618	0	560	7.4	0.2	5.5	0.33	1350	830	320	28	2.3		7.8	7.2
133-060-36DDD5	40-45	06/11/87	33	0.05	0.41	180	90	170	15	626	0	670	5.3	0.2	5.1	0.31	1480	820	310	31	2.6		10.2	7
133-060-36DDD5	40-45	08/03/93	23	0.06	0.49	150	78	120	14	534	0	530	5	0.3	1.3	0.31	1190	700	260	27	2	1508	8.9	
134-061-13DAD1	257-262	09/28/83	32	0.01	0.7	68	18	100	9.8	425	0	81	21	0.3	1	0.36	541	240	0	46	2.8	950	8	
134-061-13DAD1	257-262	08/30/84	30	0.03	0.76	69	19	100	10	459	0	84	18	0.4	1	0.45	559	250	0	45	2.8	825	8	
134-061-13DAD1	257-262	05/02/85	28	0.11	0.71	69	18	100	8.6	446	0	75	18	0.4	0.2	0.18	538	250	0	46	2.8			
134-061-13DAD1	257-262	06/05/85	28	0.14	0.7	68	13	100	8.4	453	0	76	23	0.3	0.2	0.19	546	240	0	46	2.8			
134-061-13DAD1	257-262	07/02/85	24	0.01	0.03	68	18	100	10	469	0	82	17	0.3	2.3	0.49	553	240	0	46	2.8			
134-061-13DAD1	257-262	09/04/85	25	0.1	0.71	70	19	100	9.9	454	0	79	17	0.3	0.3	0.57	546	250	0	45	2.8			
134-061-13DAD1	257-262	10/11/85	28	0.18	0.7	69	19	100	10	459	0	79	17	0.4	1	0.44	551	250	0	45	2.8			
134-061-13DAD1	257-262	11/14/85	36	0.16	0.73	68	18	100	9.4	452	0	79	17	0.4	1	0.39	553	240	0	46	2.8			
134-061-13DAD1	257-262	03/13/86	29	0.09	0.77	68	18	100	8.5	457	0	79	18	0.4	1	0.35	548	240	0	46	2.8			
134-061-13DAD1	257-262	04/23/86	29	0.1	0.84	70	18	100	8.3	452	0	80	15	0.3	2.2	0.5	547	250	0	46	2.8			
134-061-13DAD1	257-262	05/21/86	29	0.1	0.84	70	18	100	8.4	453	0	76	14	0.3	1	0.48	541	250	0	46	2.8			
134-061-13DAD1	257-262	06/20/86	30	0.13	0.69	68	19	100	9.6	453	0	79	18	0.3	1	0.55	549	250	0	46	2.8			
134-061-13DAD1	257-262	07/18/86	27	0.12	0.71	68	18	100	9.9	449	0	76	18	0.3	0.6	0.49	540	240	0	46	2.8			
134-061-13DAD1	257-262	08/14/86	29	0.11	0.7	65	18	100	10	454	0	74	18	0.3	1.6	0.67	541	240	0	47	2.8			
134-061-13DAD1	257-262	09/17/86	30	0.12	0.69	66	18	100	10	453	0	77	18	0.3	0.7	0.65	544	240	0	46	2.8			
134-061-13DAD1	257-262	10/16/86	30	0.11	0.71	67	18	99	10	451	0	71	17	0.3	1	0.38	537	240	0	46	2.8			
134-061-13DAD1	257-262	04/02/87	31	0.03	0.73	69	19	100	9	453	0	78	22	0.5	1	0.29	554	250	0	45	2.8	808	7.1	8.09
134-061-13DAD1	257-262	06/11/87	30	0.13	0.72	69	19	100	8.6	448	0	72	18	0.4	6.3	0.33	545	250	0	45	2.8		10.1	7.49
134-061-13DAD1	257-262	09/11/91	28	0.08	0.67	65	19	100	9.1	455	0	80	18	0.4	3.2	0.41	548	240	0	46	2.8	903	8	
134-061-13DAD2	132-137	08/30/84	30	0.02	0.89	83	23	76	9.5	459	0	88	11	0.4	1	0.42	549	300	0	35	1.9	815	9	
134-061-13DAD2	132-137	05/02/85	28	1.5	1.2	96	24	79	8.3	454	0	82	12	0.4	0.2	0.15	557	340	0	33	1.9			
134-061-13DAD2	132-137	06/05/85	28	0.32	0.83	82	23	76	7.8	457	0	80	17	0.3	1	0.16	541	300	0	35	1.9			
134-061-13DAD2	132-137	07/02/85	25	0.31	0.88	82	23	76	9.5	456	0	88	10	0.3	1.2	0.41	542	300	0	35	1.9			
134-061-13DAD2	132-137	09/04/85	26	0.29	0.84	85	23	77	9.3	463	0	82	9.9	0.3		0.48	542	310	0	34	1.9			
134-061-13DAD2	132-137	10/11/85	35	0.35	0.85	81	23	78	8.9	454	0	81	11	0.4	0.1	0.3	544	380	10	35	1.7			
134-061-13DAD2	132-137	11/14/85	36	0.38	0.86	83	23	78	8.6	457	0	83	10	0.4	1	0.34	550	300	0	35	2			
134-061-13DAD2	132-137	03/13/86	29	0.15	0.9	83	23	77	7.9	463	0	83	12	0.4	1	0.21	546	300	0	35	1.9			
134-061-13DAD2	132-137	04/23/86	30	0.35	0.97	85	23	77	7.8	459	0	81	9	0.2	1.9	0.39	543	310	0	35	1.9			
134-061-13DAD2	132-137	05/21/86	30	0.3	1.1	81	22	75	7.4	459	0	82	12	0.4	1	0.57	538	290	0	35	1.9			
134-061-13DAD2	132-137	06/20/86	30	0.35	0.82	82	23	78	8.9	460	0	76	12	0.3	1	0.42	540	300	0	35	2			
134-061-13DAD2	132-137	07/18/86	30	0.37	0.84	83	22	77	9.1	457	0	73	11	0.3	0.8	0.46	533	300	0	35	1.9			
134-061-13DAD2	132-137	08/14/86	29	0.35	0.83	80	23	77	9.6	460	0	81	12	0.3	1.4	0.57	542	290	0	35	2			
134-061-13DAD2	132-137	09/17/86	31	0.31	0.83	80	23	77	9.5	460	0	79	12	0.3	0.4	0.58	541	290	0	35	2			
134-061-13DAD2	132-137	10/16/86	30	0.33	0.84	82	23	76	9.3	457	0	80	11	0.3	1	0.37	539	300	0	35	1.9			
134-061-13DAD2	132-137	04/02/87	32	0.12	0.84	83	23	75	8.5	455	0	74	16	0.4	1	0.24	538	300	0	34	1.9	795	7.1	7.88
134-061-13DAD2	132-137	06/11/87	30	0.33	0.85	83	23	78	7.9	453	0	77	12	0.4	6.9	0.31	543	300	0	35	2		12.1	7.55
134-061-13DAD2	132-137	09/11/91	28	0.23	0.81	79	23	78	8.2	465	0	85	12	0.4	2.9	0.35	547	290	0	36	2	889	9	
134-061-13DAD3	68-73	08/30/84	31	0.04	0.35	63	19	39	9.8	344	0	36	1.9	0.4	1	0.32	371	240	0	26	1.1	580	11	
134-061-13DAD3	68-73	05/02/85	29	0.36	0.57	67	21	39	10	351	0	47	4.5	0.4	0.2	0.11	392	250	0	24	1.1			
134-061-13DAD3	68-73	06/05/85	29	0.33	0.48	65	20	39	9.5	361	0	31	10	0.4	0.2	0.12	383	240	0	25	1.1			
134-061-13DAD3	68-73	07/03/85	26	0.34	0.49	65	20	38	10	354	0	39	1.8	0.4	1.6	0.32	377	240	0	24	1.1			
134-061-13DAD3	68-73	09/04/85	25	0.29	0.45	67	20	37	10	360	0	32	1.3	0.4	0.4	0.37	371	250	0	23	1			
134-061-13DAD3	68-73	10/11/85	36	0.41	0.46	65	20	39	10	352	0	35	2.6	0.4	0.1	0.3	382	240	0	25	1.1			
134-061-13DAD3	68-73	11/14/85	38	0.37	0.45	66	19	38	9.9	355	0	36	1.6	0.4	1	0.26	386	240	0	24	1.1			

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 $CaCO_3$	as NCH	% Na	SAR	Spec Cond (µmho)	Temp (°C)	pH
			(milligrams per liter)																					
134-061-13DAD3	68-73	03/13/86	30	0.33	0.48	65	19	37	9	363	0	35	3.4	0.4	1	0.28	380	240	0	24	1			
134-061-13DAD3	68-73	04/23/86	30	0.47	0.52	66	19	39	8.6	355	0	40	9.2	0.4	2.3	0.33	391	240	0	25	1.1			
134-061-13DAD3	68-73	05/21/86	31	0.31	0.54	66	19	38	8.4	357	0	38	5	0.4	0.1	0.54	383	240	0	25	1.1			
134-061-13DAD3	68-73	06/20/86	31	0.4	0.41	64	20	39	9.4	357	0	34	3.8	0.4	1.3	0.31	380	240	0	25	1.1			
134-061-13DAD3	68-73	07/18/86	31	0.42	0.42	65	19	37	9.6	354	0	30	2.9	0.3	2.8	0.32	373	240	0	24	1			
134-061-13DAD3	68-73	08/14/86	30	0.39	0.41	63	19	37	10	356	0	33	3	0.4	2.6	0.43	374	240	0	25	1			
134-061-13DAD3	68-73	09/17/86	32	0.34	0.4	63	19	38	9.8	358	0	33	4	0.4	0.4	0.41	377	240	0	25	1.1			
134-061-13DAD3	68-73	10/16/86	32	0.37	0.4	62	19	36	9.8	355	0	33	2.9	0.4	1	0.26	372	230	0	24	1			
134-061-13DAD3	68-73	04/02/87	18	0.34	0.43	65	20	35	9.2	359	0	30	6.8	0.5	1	0.18	363	240	0	23	1	575	7.1	7.8
134-061-13DAD3	68-73	05/14/87	36	0.38	0.4	67	19	36	9	358	0	36	7.7	0.4	2.9	0.07	391	250	0	23	1		8.8	7.51
134-061-13DAD3	68-73	06/11/87	32	0.41	0.4	65	19	37	8.5	351	0	32	4.4	0.4	6.7	0.21	379	240	0	24	1		10.3	7.6
134-061-13DAD3	68-73	09/11/91	30	0.06	0.37	62	20	37	8.6	360	0	32	3.6	0.5	4.9	0.26	376	240	0	25	1	625	8	

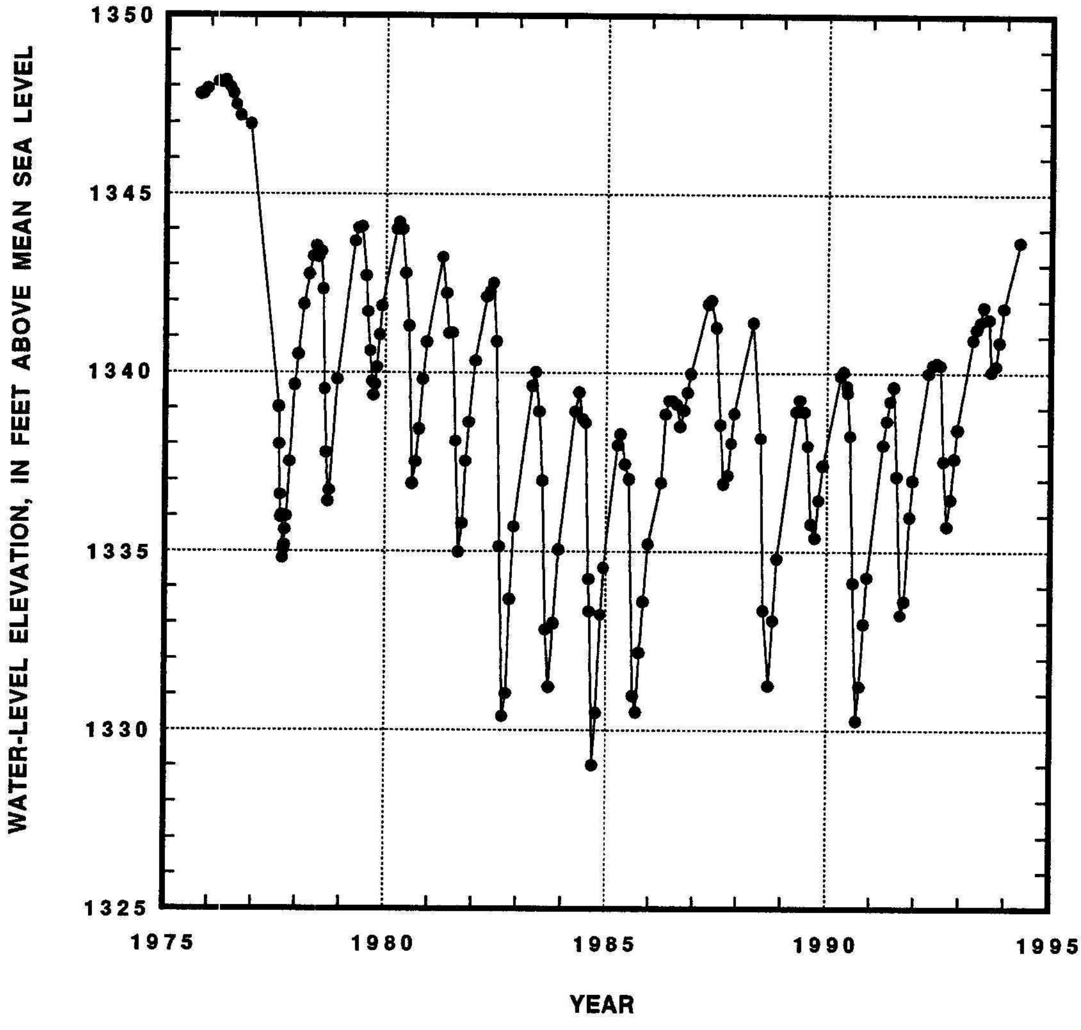
APPENDIX 4

HYDROGRAPHS SHOWING WATER LEVELS IN SELECTED OBSERVATION WELLS IN THE SPIRITWOOD AQUIFER STUDY AREA

HYDROGRAPH
133-059-15CCC
Screened Interval = 188-191 Ft. Below Land Surface
Spiritwood Aquifer



HYDROGRAPH
133-059-32BBB
Screened Interval = 198-201 Ft. Below Land Surface
Spiritwood Aquifer

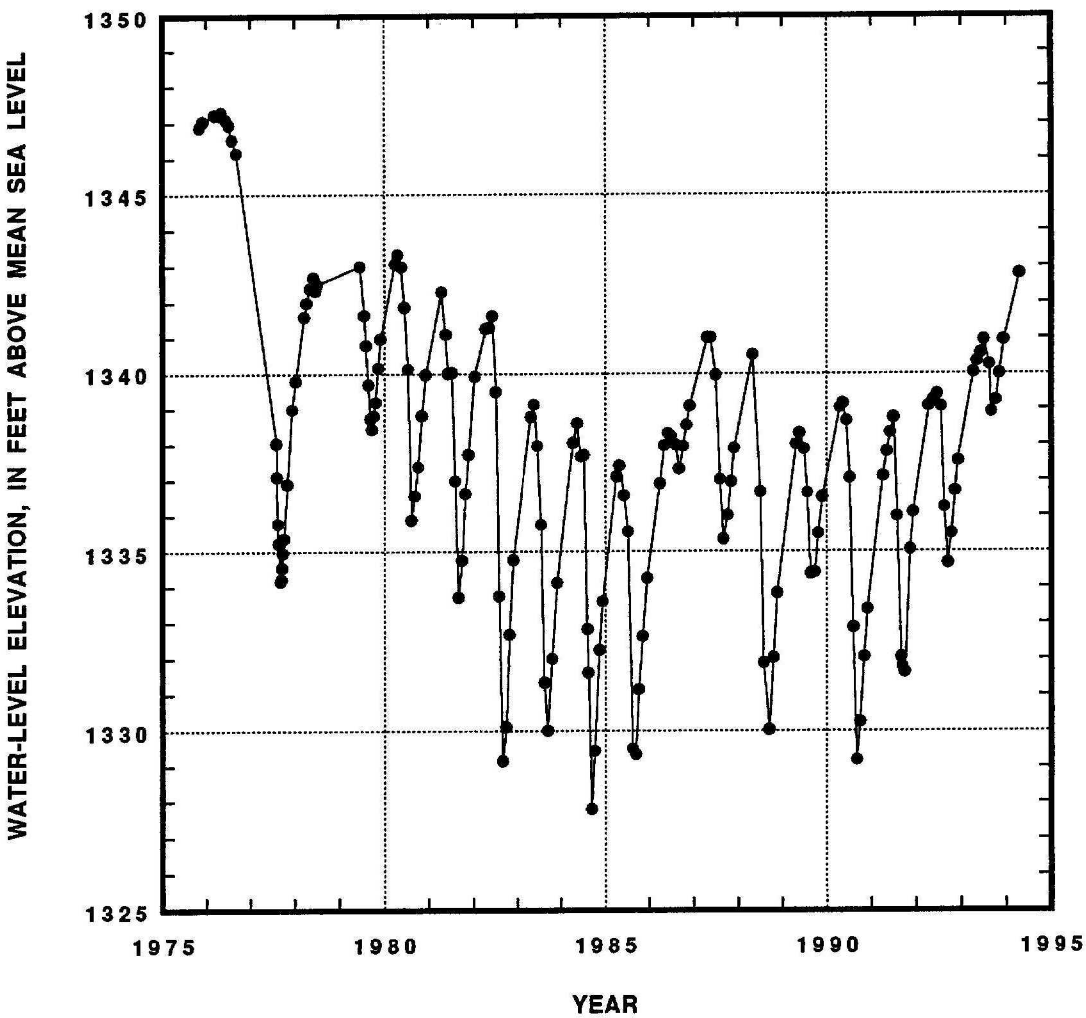


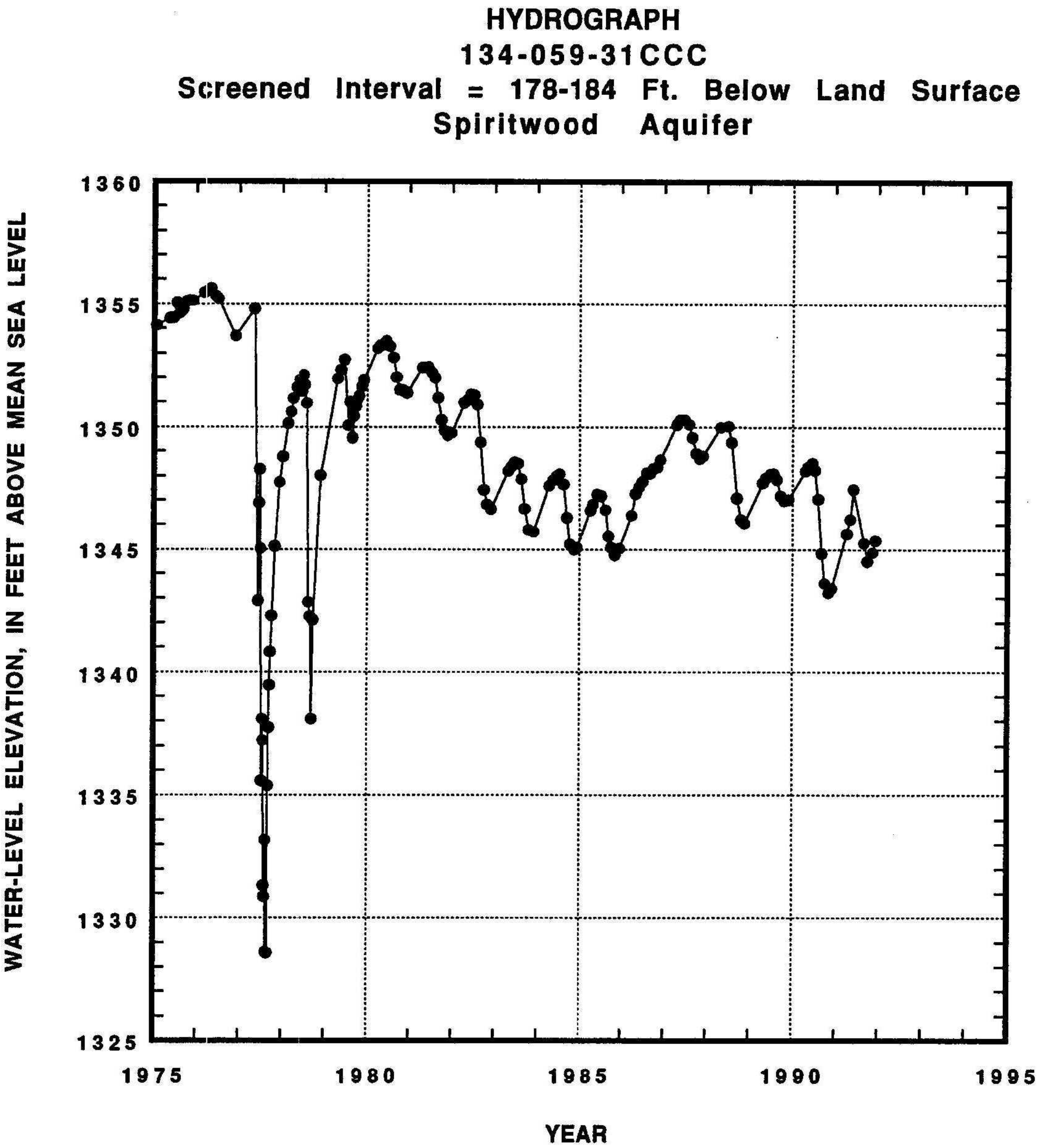
HYDROGRAPH

133-060-36DDD1

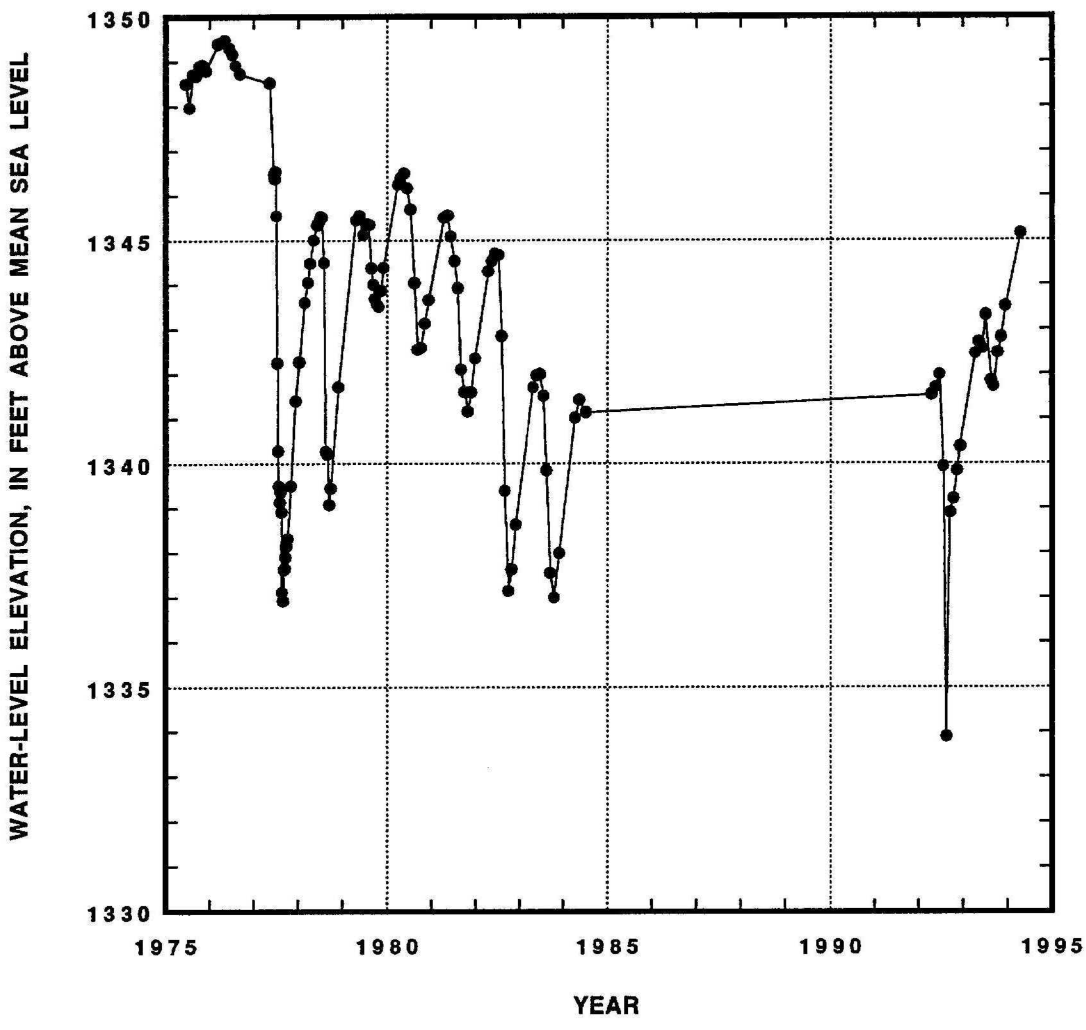
Screened Interval = 212-215 Ft. Below Land Surface

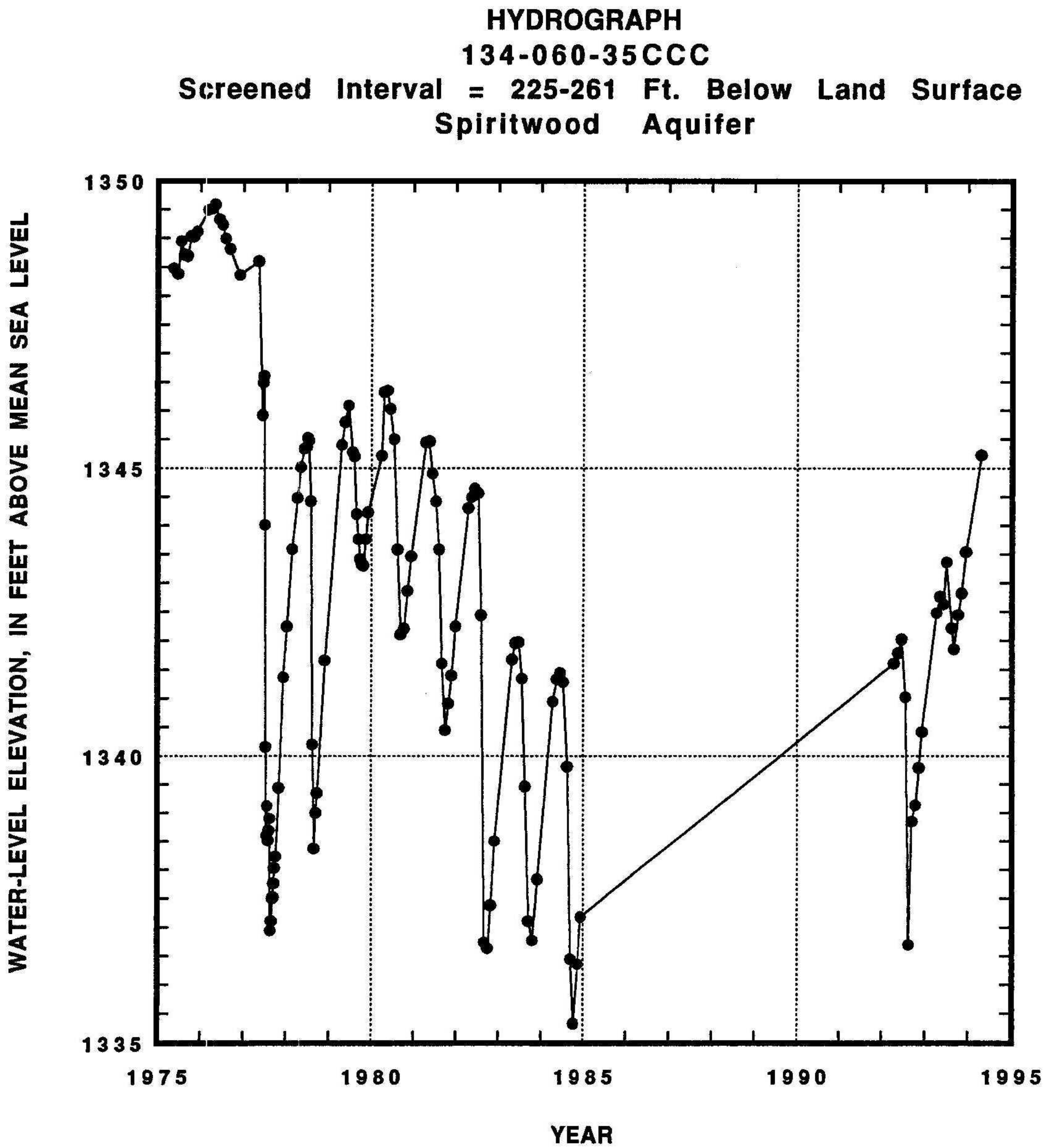
Spiritwood Aquifer




HYDROGRAPH
134-059-31CCC
Screened Interval = 178-184 Ft. Below Land Surface
Spiritwood Aquifer
WATER-LEVEL ELEVATION, IN FEET ABOVE MEAN SEA LEVEL
1360
1355
1350
1345
1340
1335
1330
1325
1975
1980
1985
1990
1995
YEAR

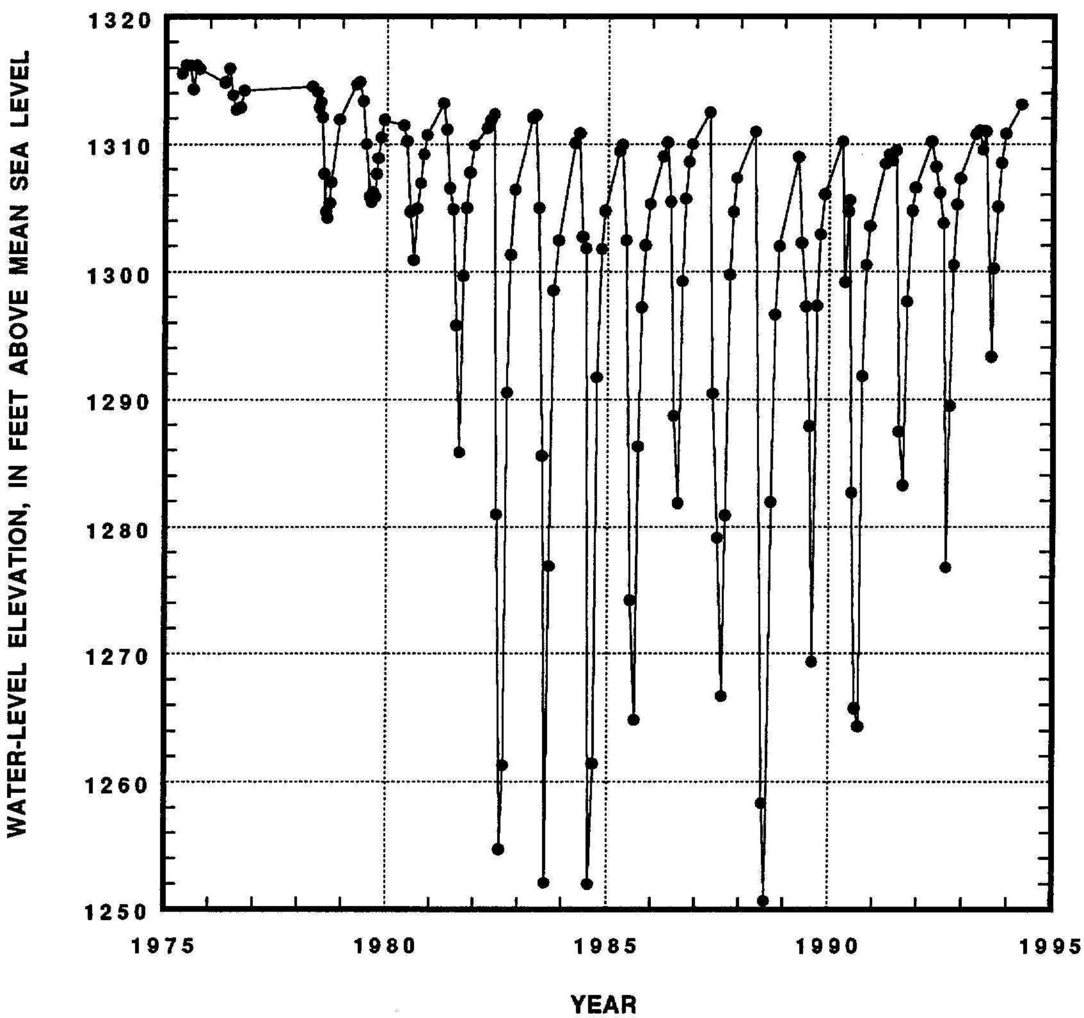
HYDROGRAPH
134-060-32DDD
Screened Interval = 218-224 Ft. Below Land Surface
Spiritwood Aquifer



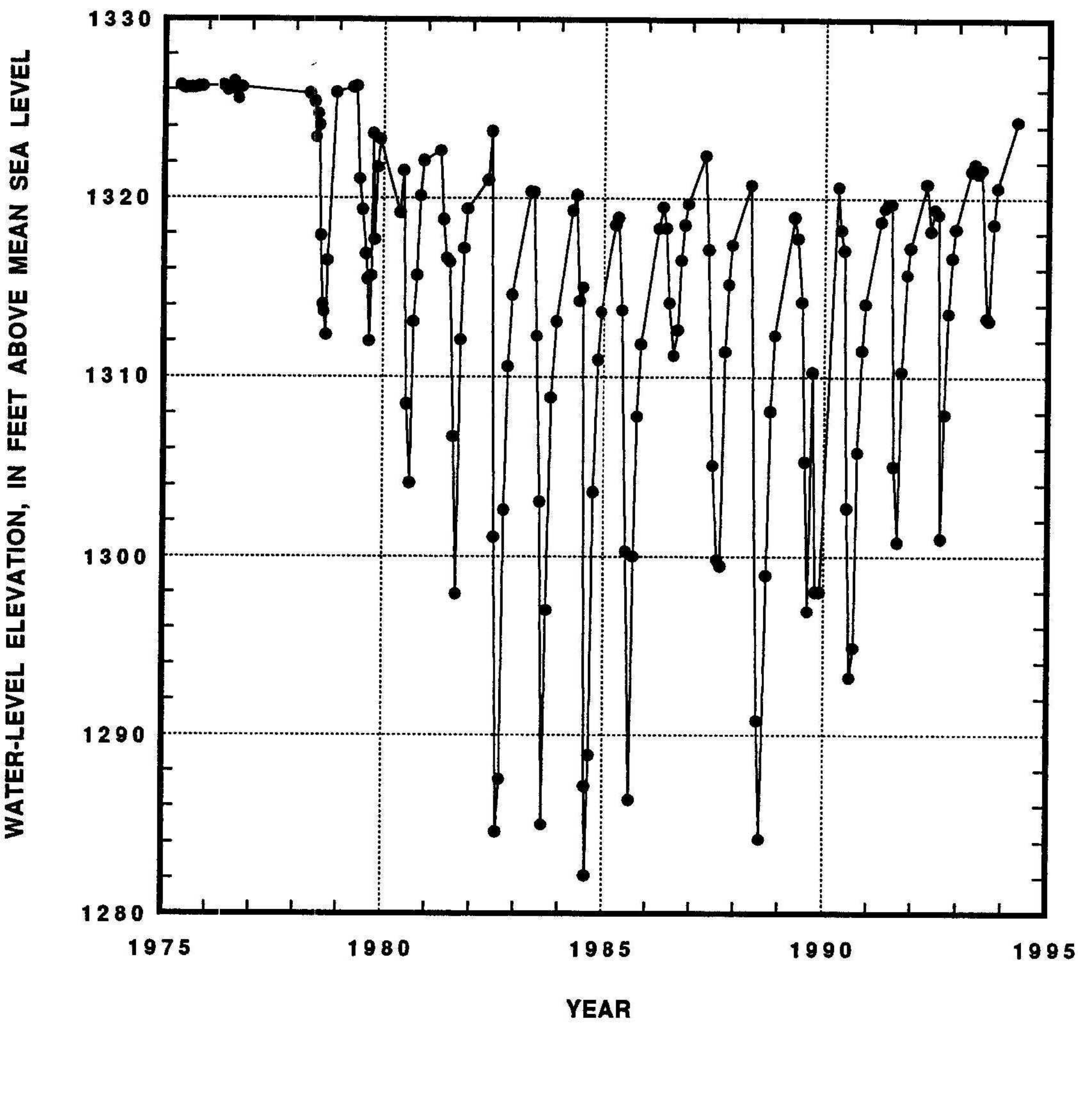


HYDROGRAPH
134-060-35CCC
Screened Interval = 225-261 Ft. Below Land Surface
Spiritwood Aquifer
WATER-LEVEL ELEVATION, IN FEET ABOVE MEAN SEA LEVEL
1350
1345
1340
1335
1975
1980
1985
1990
1995
YEAR

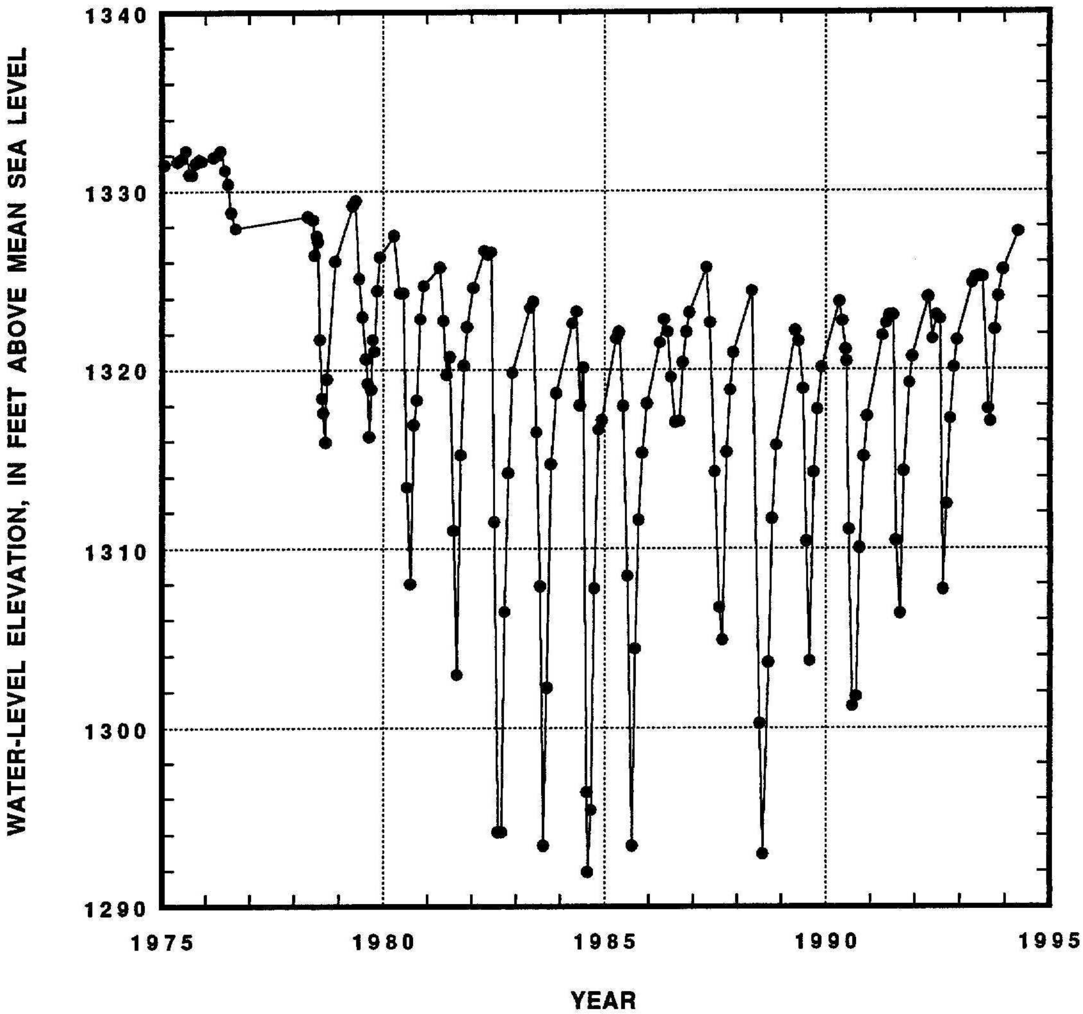
HYDROGRAPH
131-059-02AAA
Screened Interval = 158-161 Ft. Below Land Surface
Spiritwood Aquifer



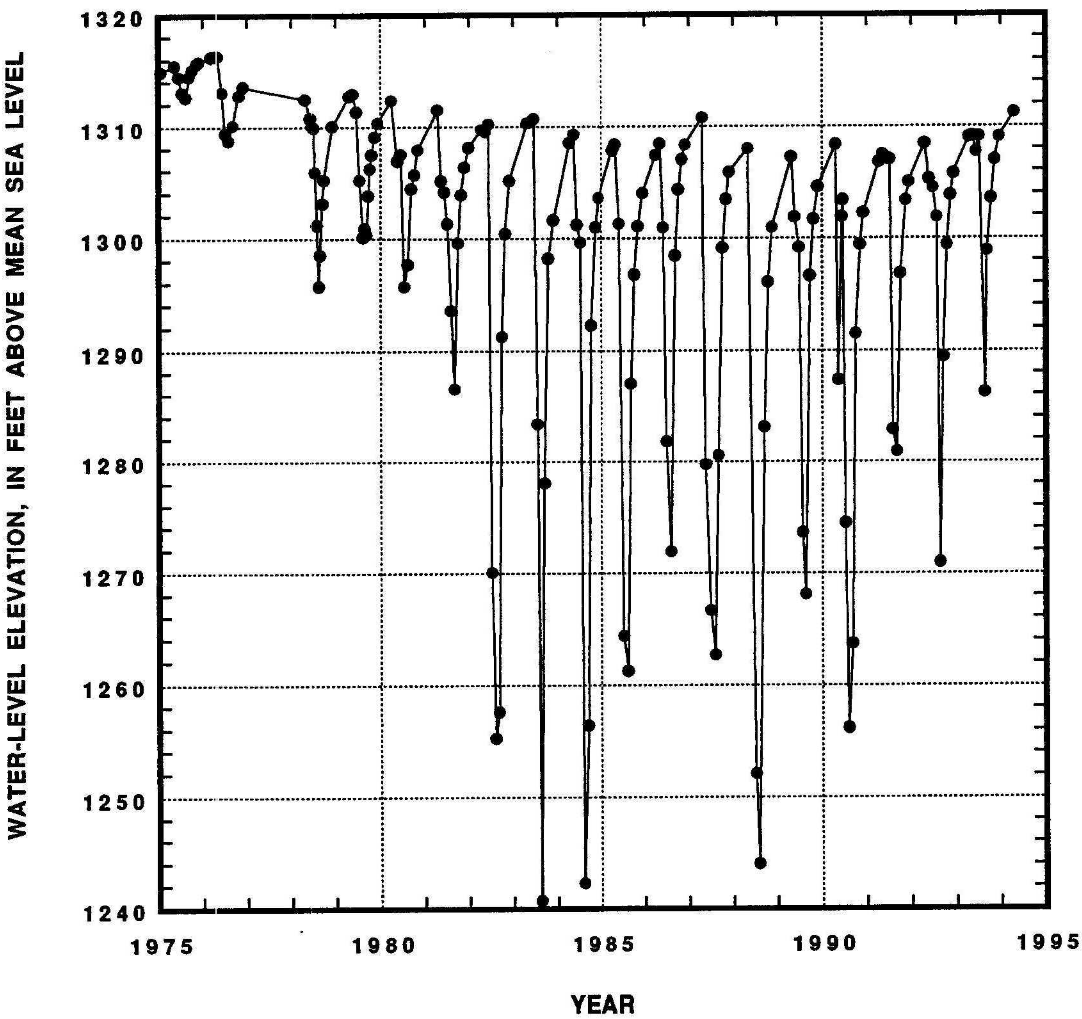
HYDROGRAPH
131-059-03BBB
Screened Interval = 178-184 Ft. Below Land Surface
Spiritwood Aquifer



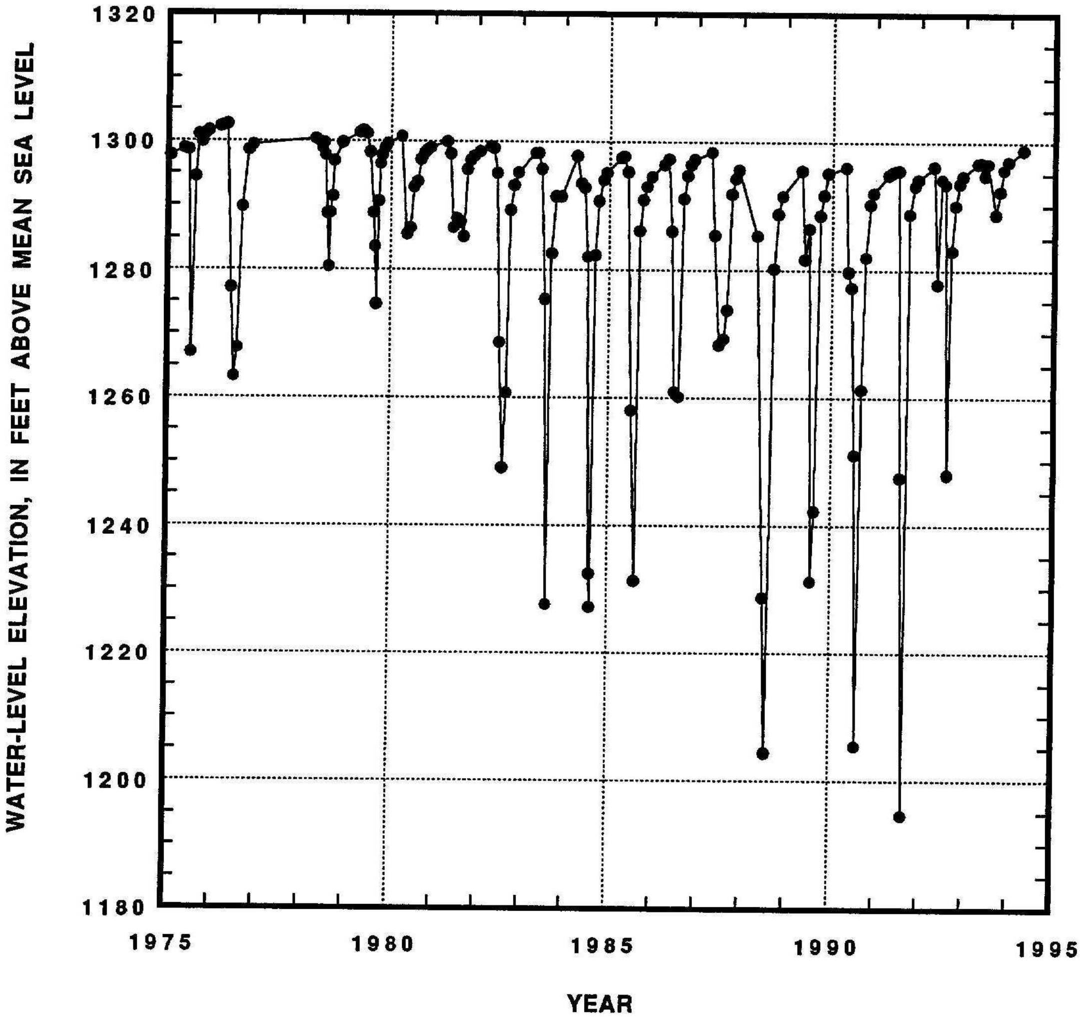
HYDROGRAPH
131-059-05BBB
Screened Interval = 158-161 Ft. Below Land Surface
Spiritwood Aquifer



HYDROGRAPH
131-059-15AAA1
Screened Interval = 188-194 Ft. Below Land Surface
Spiritwood Aquifer



HYDROGRAPH
131-059-20AAA1
Screened Interval = 168-174 Ft. Below Land Surface
Spiritwood Aquifer



HYDROGRAPH
131-058-27AAB
Screened Interval = 1208-211 Ft. Below Land Surface
Spiritwood Aquifer