# THE GEOLOGIC AND HYDROGEOLOGIC CONDITIONS IN THE AREA ADJACENT TO THE DEVILS LAKE WASTEWATER IMPOUNDMENTS

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# ILLUSTRATIONS

# ABSTRACT

The Devils Lake wastewater impoundments are located in a natural depression on the southwest side of the city of Devils Lake. The impoundments are situated within Pleistocene deposits, consisting of lacustrine clay, sand and gravel, and till, which overlie the Pierre Formation. The top of the Pierre Formation is very irregular in this area because it has been incised by outwash channels and portions have experienced glacial thrusting. One of these major buried outwash channels is the Spiritwood Aquifer.

There was some general concern in this area that wastewater from the impoundments could be leaking into the Spiritwood Aquifer. There was not sufficient subsurface information available in the Devils Lake area to determine the proximity of the wastewater impoundments to the Spiritwood Aquifer. Therefore, 38 monitoring wells were installed within a three mile radius of the wastewater impoundments. From this drilling program, it was determined that the impoundments are situated approximately 1 mile distance from the edge of the Spiritwood Aquifer.

The natural or background quality of groundwater within both the Pleistocene sediments and the Cretaceous rocks is highly variable and may be highly mineralized. Therefore, it was very difficult to determine whether this groundwater was being degraded by wastewater from the impoundments. Bacterial analysis of the groundwater did not conclusively indicate any wastewater contamination of the surrounding groundwater.

Previously unknown deposits of buried sand and gravel were discovered in the area around the wastewater impoundments. We could not determine if any connection exists between the Spiritwood Aquifer and these deposits. A gravity or shallow seismic may be able to determine if any connection exists between these sand and gravel bodies and the Spiritwood Aquifer.

# ACKNOWLEDGEMENTS

The authors wish to thank Mr. Bill Davis, Mr. Les Riggins, and the Devils Lake Equipment Company for graciously allowing us access to their land during this study.

# INTRODUCTION

## Study Location

The Devils Lake municipal wastewater impoundments are situated within a natural depression on the southwest edge of the city (Fig. 1). The impoundments are bounded on the north by a large natural wetland covering approximately 500 acres, on the east by a business district, on the south by rangeland, and on the west by Creel Bay. The impoundments are approximately 2.5 miles north and 1/2 mile east of the shores of Devils Lake.

## Project Inception

This study of the geology and hydrogeology of the area adjacent to the Devils Lake wastewater impoundments was initiated as a result of a meeting held in the city of Devils Lake on April 13, 1988. Personnel of the North Dakota State Water Commission, North Dakota Health and Consolidated Laboratories Department, and the North Dakota Geological Survey, along with Representative Gordon Berg from Devils Lake and Ramsey County Commissioner Lloyd Stromme, met to discuss local concerns conveyed by Representative Berg that wastewater contained in the lagoons might be leaking and contaminating local groundwater supplies. A decision was made to proceed with a study to evaluate if leakage had occurred and, if so, to determine whether remedial measures are necessary.

A regional study of the hydrology in the Devils Lake Basin has been underway by the North Dakota State Water Commission and the United States Geological Survey since 1986. This regional study is nearing completion (Sether and Wiche, 1989, Wiche, 1992, and Pusc, 1992). Water Commission representatives agreed to extend the groundwater portion of their study and to cooperate with the North Dakota Geological Survey in a detailed study of the area surrounding the Devils Lake wastewater impoundments.

## Purpose

The purpose of this study is to evaluate the local geology and hydrogeology, and to analyze the interactive groundwater flow conditions with respect to the Devils Lake wastewater impoundments. Specifically, the limits of the Spiritwood Aquifer, within the vicinity of the wastewater impoundments, had to be determined. In addition, an inventory of the domestic wells was needed to determine the local source of water supply. Monitoring wells were installed between the impoundments and the Spiritwood Aquifer in this area to determine the direction of groundwater flow and the chemistry of the groundwater. These wells were used to determine if any leachate plumes were emanating from the impoundments and contaminating the Spiritwood Aquifer or any other groundwater resources.

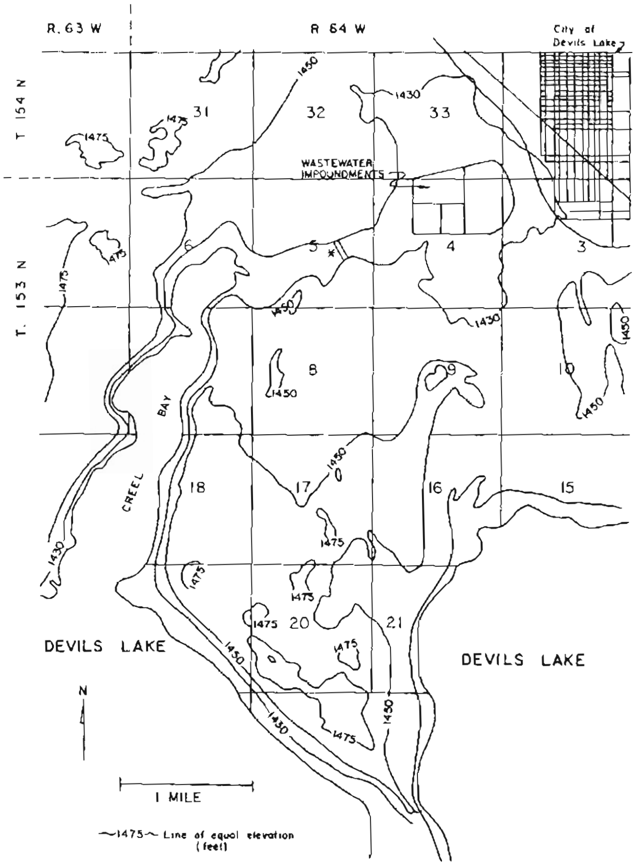

**Figure 1.** Topographic map of the Devils Lake area. (* denotes location of Creel Bay embankment).

## PREVIOUS STUDIES

### Geologic and Hydrogeologic Studies of the Devils Lake Basin

The entire Devils Lake Basin and surrounding areas have been mapped and extensive test-hole drilling completed during a series of county groundwater studies conducted jointly by the North Dakota State Water Commission, North Dakota Geological Survey, and United States Geological Survey with the support of the various counties involved. As a result of these studies, the near-surface geology of Ramsey County (Hobbs and Bluemle, 1987), Benson and Pierce Counties (Carlson and Freers, 1975) and Nelson and Walsh Counties (Bluemle, 1973) have been mapped giving a good understanding of the regional geology of the area. Compilations of test-hole data and studies of the hydrology of the same counties have also been published (Hutchinson, 1977; Hutchinson and Klausing, 1980; Randich, 1972, 1977; Downey, 1971, 1973, Pusc, 1992).

Other studies of the geology and geohydrology of the Devils Lake Basin area include those by Paulson and Akin (1964), Naplin (1974), Bluemle (1984), Callender (1968), Hutchinson (1976), and Aronow (1963).

### Wastewater Impoundment Studies

Wastewater impoundments first came into use in North Dakota in the late 1940's (Towne, et al., 1957). As early as 1954, scientists have been warning that these impoundments must be placed a safe distance from wells and municipalities (Van Huevelen and Svore, 1954). Van Huevelen and Svore (1954) suggest that good management practices require that wastewater impoundments be placed at least 1/2 mile, and preferably 1 mile, from a town or city, and at least 1/4 mile from a farm well to prevent contaminating a drinking water supply. A more recent study of wastewater impoundments in North Dakota determined that a large percentage of the sites were located in areas that were poorly suited geologically (Kehew and others, 1980). Kehew and others (1980) determined that one third to one half of all municipal impoundments were located in areas that had a moderate to high potential for groundwater pollution. Given this conclusion, the authors expressed surprise that more incidents of groundwater pollution had not been reported from these sites. Although there had been numerous claims of groundwater contamination and damage to the land surrounding the wastewater facilities, no documented cases of groundwater pollution from these impoundments in North Dakota had been reported prior to 1980 (Kehew and others, 1980).

Kehew and others (1983) studied the groundwater quality around six municipal impoundments in North Dakota. They determined that total dissolved solids (TDS), chloride, sodium, calcium, magnesium, bicarbonate, and coliform bacteria were the best indicators of groundwater pollution by wastewater seeping from municipal impoundments. At one of their study sites, the impact to shallow groundwater extended at least 700 feet downgradient of the impoundments. Kehew and others (1983) report was the first documentation of groundwater pollution from improperly located municipal wastewater impoundments in North Dakota.

## DEVILS LAKE WASTEWATER IMPOUNDMENTS

### Construction

The Devils Lake wastewater impoundments occupy an area of approximately 275 acres on the southwest edge of the city of Devils Lake (Fig. 1). The facility has operated since 1956, at which time the main cell was constructed (Towne et al., 1957). By 1978, the system had been expanded to three cells (Olson, personal communication). The dikes for the impoundments were constructed from the half foot or so of material that was removed from the base of the cells. The base of the cells is at 1,425.5 feet elevation and the top of the dikes is at 1,432 feet (Olson, personal communication). The cells were not lined, but it is believed that a soil stabilizer was added to the base of cell 1. It is generally assumed that a sludge layer will accumulate at the base of the impoundment over time. This sludge layer will help to reduce subsurface infiltration of the wastewater (Kehew and others, 1983). Cell 1 covers an area of 120 acres and cells 2 and 3 are each approximately 60 acres in size (Fig. 1). The *lemna* pond occupies approximately 45 acres.

Elevations in the flat area surrounding the wastewater impoundments range from 1,423 feet to 1,430 feet above sea level. This area is a lake plain that, under natural conditions, would be flooded if Devils Lake rose above 1,424 feet. However, the Creel Bay embankment protects the impoundment area from flooding by the lake (Fig. 1) (U.S. Army Corps of Engineers, 1983).

### Methods of Operation

For many years, wastewater from the impoundments was periodically released into the wetland north of Highway 19 and eventually into Creel Bay on Devils Lake. Due to recent design changes at the site, wastewater now enters the three cells, is directed into the wetland north of the highway (previously called Davis Flats), then south into the *lemna* ponds. Ultimately, the treated water is discharged into Creel Bay.

## FIELD METHODS

### Drilling Program

The hydrologic investigation of the area surrounding the Devils Lake wastewater impoundments began by test drilling at 14 locations and installing 38 monitoring wells, an average of three wells per site (Fig. 2). The monitoring wells were screened at depths ranging from 10 to 220 feet. Ten of the shallow holes (10 to 28 feet) were installed using the Geological Survey's Mobil B-50 hollow-stem auger. Sediment core from these 10 holes was obtained using shelby tubes and a dry auger system. The deeper holes were drilled with the Water Commission's Failing 1250 forward mud rotary drilling rig. These rotary holes were drilled with fresh water.

Samples of the drill cuttings were continuously collected and visually analyzed (Appendix I). Resistivity and spontaneous potential logs were run in the deepest hole at each of the Water Commission nest sites. Copies of the geophysical logs are available for inspection in the office of the State Water Commission.

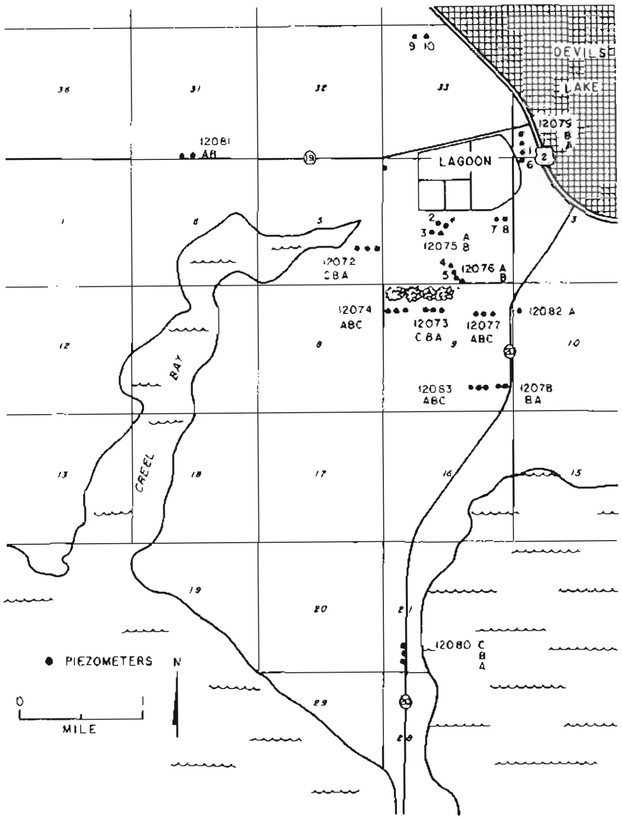

**Figure 2.** Location of observation wells near the Devils Lake wastewater impoundments.

### Monitoring Well Construction

Nests of monitoring were constructed for this study to enable a determination of the vertical hydraulic gradients in the area. Construction of the monitoring well nests involved the drilling of an initial deep test hole. The information from this deep hole was then used to determine the number of, and the depths for, monitoring wells to be installed at each nest site (Appendix II). The initial deep test hole also served as a hole for the deep monitoring well. First, the desired length of casing and screen were inserted into the test hole. The casing consist of either 1 1/4 or 2-inch schedule 40 PVC pipe. Slotted PVC pipe (.010) in lengths of two to ten feet was used as the well screen. Silica sand was then placed around the screen using a tremie pipe. After sand packing, the tremie pipe was lifted so that the bottom of the pipe was above the top of the sand pack. Neat cement grout was then injected down the tremie pipe and upward in the annular space. This process continued until the grout overflowed around the casing in the annular space. After the grout settled, additional grout was used to fill the annulus to landsurface. The grout was allowed to "set" and then the monitoring wells were slugged with a small amount of fresh water and pumped with air for development. Wells screened in glacial till and/or lake clay were not, however, slugged with fresh water. Instead, these wells were bailed immediately after well construction. Subsequent monitoring wells were completed at each site by moving the drilling rig ahead 15 to 20 feet and drilling the next hole. The shallow Survey wells were packed with sand along the screen interval and a bentonite plug was set above the screen. Cuttings were placed above the bentonite plug and a one-foot cement cap was placed at the surface. As many as five monitoring wells were installed at various depths at the same site using these techniques.

### Water Sampling Program

General Chemistry--Water samples were obtained for general chemical analysis from the monitoring wells in October, 1988. Two to three casing volumes were removed from each well prior to sampling. Water removal was done with either a bailer or by airlift to introduce formation water into the well. Airlift evacuation was used in wells that were rotary drilled and were screened in sand and gravel to insure that any introduced water was removed from the sediments adjacent to the screen. After evacuating at least three casing volumes of water, a variable-capacity point-source bailer (pvc) was lowered to just above the bottom of the well screen. Bailing continued until enough water was secured for the sample.

The water-sampling procedure involved the collection of 500 milliliters (ml) of raw water, 500 ml of filtered water, and 500 ml of filtered and acidified (nitric acid) water. Select wells were also sampled for trace metals and nutrients. Field measurements of specific conductance and water temperature were also made. Water temperature was, however, measured at land surface and does not represent an in situ temperature. The pH was measured in the lab. The water samples were analyzed for general chemistry by the North Dakota State Water Commission Laboratory.

Bacteria Samples--Water samples were collected on September 13, 1988 and February 7, 1992 for bacterial analysis. Selected wells were vacated two to three times and were then sampled with a teflon bailer. In 1988, one teflon bailer was used throughout the sampling project. After the sampling of each well, the teflon bailer was rinsed with deionized water. To eliminate the potential for cross-well contamination, disposable bailers were dedicated, one to each well, when groundwater was sampled in 1992. In both cases, the samples were collected in specially treated bottles and delivered to the State Health Department Microbiologic Laboratory in Bismarck within 4 hours of sampling.

### Water Levels

Depths to water measurements were recorded on a bi-monthly or monthly basis in a number of monitoring wells throughout the study area (Appendix III). Inclement weather, poor road conditions, and freezing up of monitoring wells prevented readings during most of the winter months. Water levels were measured with steel tapes and electronic well sounders.

### Field Permeability Tests

Rising head and falling head permeability (slug) tests were performed on many of the shallow monitoring wells in this study. A few of the shallow wells were not tested because the well screen interval included two or more geologic units.

## GEOLOGY

### Regional Topography

The Devils Lake Basin, in northeastern North Dakota, is a 3,800-square-mile closed drainage basin contained entirely within the drainage of the Red River of the North. About 3,310 square miles of the total area drains to Devils Lake and the remaining 490 square miles drains to Stump Lake. All of the topographic relief and surficial features are of glacial origin. Numerous shallow depressions and kettle lakes occur throughout the Devils Lake Basin. Elevations in the basin range from as high as about 2,000 feet above sea level near St. John on the east side of the Turtle Mountains to less than 1,400 feet at Stump Lake.

Devils Lake is the largest natural body of water in North Dakota. Its total area is approximately 90 square miles (when the level of the lake is at about 1,429 feet above sea level). In 1940, when the lake reached its lowest recorded level of 1,400 feet above sea level, it covered only 10 square miles.

## Preglacial History of the Area

Data collected from the Devils Lake Basin demonstrates that the preglacial drainage in the Devils Lake Basin area, and in fact in all of eastern North Dakota, was mainly northward and northeastward (Hobbs and Bluemle, 1986). The main river system that flowed through the immediate Devils Lake area was probably a tributary to the combined ancestral Cannonball/Knife River. This ancestral river flowed northward past Minnewaukan to Cando and on into Canada through Towner County, entering Canada about 20 miles east of the Turtle Mountains. A smaller, tributary valley that joined this major river just south of Churchs Ferry flowed to the northwest along what is now the southern edge of the modern Devils Lake.

The landscape through which the abovementioned rivers flowed was gently rolling, developed on the Cretaceous Pierre Formation. The Pierre Formation in this area is a soft to moderately hard, dark gray, clayey shale. This shale was formed in a large sea that flooded the midcontinent some 75 to 80 million years ago (Hobbs and Bluemle, 1986). Throughout much of the Devils Lake Basin, especially in the northern parts of the area, the upper 50 to 200 feet of the Pierre Formation (immediately beneath the glacial deposits) is sufficiently fractured to serve as an aquifer (Hutchinson and Klausing, 1980).

## Glacial History of the Area

During the Pleistocene Epoch (approximately the last 2.5 million years), eastern North Dakota was glaciated as often as a dozen times; direct evidence for at least a half dozen separate glacial advances can be documented from testhole data collected in Towner and Ramsey Counties (Bluemle, 1984; Hobbs and Bluemle, 1987).

Each time glaciers advanced southward through the area, they blocked and diverted all the north-trending rivers. Large lakes were dammed in front of the glaciers during each advance and also when the glaciers melted back. Eventually, after an unknown number of glaciations, the north-trending river valleys through the Devils Lake Basin area were filled in with layers of gravel, sand, and glacial sediment and permanently blocked. The thick sequences of gravel and sand in the now-buried valleys constitute the Spiritwood Aquifer system in this area (Fig. 3).

In addition to forming lakes, the water dammed by the glaciers eventually overflowed and meltwater diversion trenches were eroded southeastward along the edge of the glaciers. These diversion trenches represent the routes of rivers that carried the runoff southeastward along the ice margin. Many such trenches were eroded in the area during Pleistocene time because, each time the glaciers advanced, they overrode the earlier diversion trenches, filling them with till and glaciofluvial materials, causing new ones to form. Some of the older diversion trenches are now buried beneath as much as 500 feet of glacial sediment, the combined deposits of several glaciations. One especially deep and narrow diversion trench, the Starkweather trench, is now

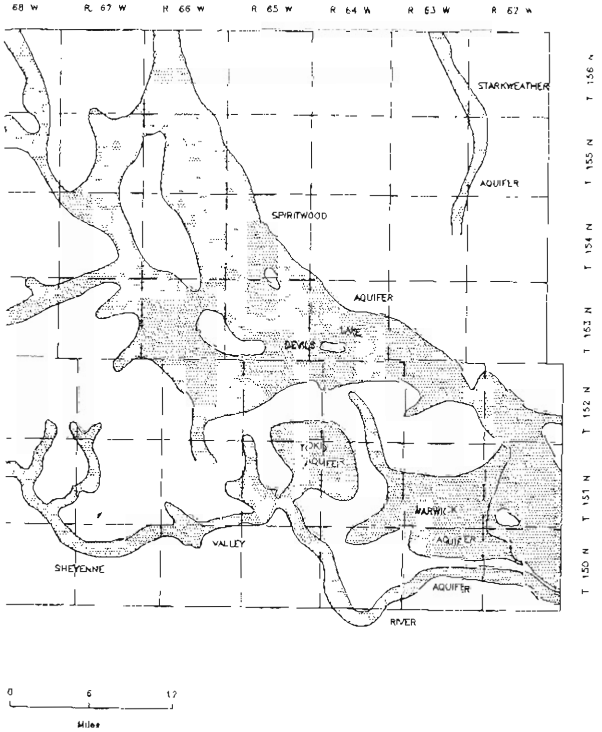

**Figure 3.** Major aquifers in the Devils Lake area. (From Pusc, 1992).

completely buried by glacial sediment (Fig. 3). The Starkweather trench was eroded by a river that flowed southeastward from near Cando, and then southward past Crary for several more miles.

A further important result of the glaciation and the accompanying disruption of the existing drainage systems was that large amounts of water collected in some places. This included runoff from parts of the state that weren't covered by ice as well as water from the melting glacial ice. In places, meltwater flooded areas ahead of the glacier. The Devils Lake area was one of these places. The water saturated both the preglacial and glacial sediments in the Devils Lake Basin area, filling the aquifers to their capacity. The excess water was ponded in glacial Lakes Cando and Minnewaukan (Hobbs and Bluemle, 1986).

The ground ahead of the advancing glacier was permanently frozen (permafrost) to a depth of several hundred feet during the advancing phase of the latest glaciation (this wasn't true when the glacier was receding). Because the sediments beneath the permafrost layer were saturated with water, high excess pore-water pressures built up in these sediments. When the water in the ground was subjected to great pressure, as a combined result of the weight of the glacier overriding the area and the downward migration of the "freezing front" at the base of the permafrost layer, the excess pore-water pressures tended to support the weight of the overlying materials so that they essentially "floated" on the pressurized water that filled the pore spaces in the fine grained sediments.

As a result of the great pressures that developed in the groundwater-saturated sediments, both in the Spiritwood Aquifer and in sediments adjacent to the aquifer, friction was greatly reduced and large blocks of the overlying frozen sediment and rock were easily transported by the advancing glacier. This caused large-scale thrusting in the Devils Lake area.

The glacier moved large, intact blocks of shale and glacial sediment as well as jumbled masses of mixed materials. It pushed and thrust these blocks of material from the area that is now flooded by Devils Lake and deposited them just south of the lake, in the Fort Totten-Sully's Hill area. Sully's Hill consists largely of a massive block of Pierre Formation shale that was quarried--thrust--from what is now the main bay area of Devils Lake. As soon as the thrusting episode took place, the pressurized groundwater was able to escape from the place from which the ice-thrust materials had been quarried and the quarried area became the depression that is now the location of Devils Lake. The escape of the groundwater dissipated the high pore-water pressures thereby terminating the thrusting process. However, large volumes of water that flowed from beneath the ground as the thrusting was occurring apparently brought great volumes of gravel and sand to the surface. Some of this gravel and sand may have ended up in features such as Devils Heart Butte, near Tokio.

The exact time of the thrusting events that formed the Devils Lake-Sully's Hill complex are not known, but because the features were not overridden by later glaciers it is likely that the thrusting occurred during latest Wisconsinan time, perhaps as recently as 12,000 to 13,000 years ago.

## Local Geology

The top of the Cretaceous Pierre Formation occurs at elevations ranging from 1,207 to 1,437 feet above sea level (at depths of 3 to 248 feet below the surface) in a 30-square-mile area around the Devils Lake wastewater impoundments (Fig. 4, 5, and 6). The considerable range in elevation of the top of the Pierre Formation is the result of incising by the Spiritwood Aquifer channel and tributary glaciofluvial channels. The top of the Pierre Formation was found at an elevation of 1,207 feet (at a depth of 230 feet) at the base of the Spiritwood Aquifer three miles south of the wastewater impoundments (Fig. 6).

In the immediate area of the Devils Lake wastewater impoundments the Pierre Formation shale is thoroughly weathered and fractured at its contact with the overlying glacial deposits. Consequently, it is more like a soil than typical shale rock for 1 to 3 feet below its contact with the glacial deposits. The shale becomes more competent with increasing depth, but it is quite fractured to depths of several tens of feet and typically has a high water content.

The Pierre Formation is overlain by Pleistocene deposits in the Devils Lake Basin. These sediments were deposited during the last 1.6 million years when most of North Dakota was periodically covered by glaciers. The Pleistocene deposits are from 3 to 250 feet thick in the study area (Fig. 7). Till is the major sedimentological component above the Pierre Formation around the wastewater impoundments (Fig. 4 and 5). The till, which generally ranges from 25 to 30 feet thick, appears to be highly fractured and contains numerous discontinuous lenses of sand. These lenses range from an inch to five feet in thickness. In addition, at least one large (>10 feet) block of Pierre Formation shale was found incorporated within the till (test hole # 12076; Fig. 5). This block of shale is evidence that glacial thrusting has occurred in this area.

The till in the area is generally overlain by lacustrine sediments in the area surrounding the wastewater impoundments. The cells themselves are situated within lacustrine deposits (Fig. 4 and 5). The lacustrine sediments consist of yellowish brown to gray, laminated clay. This clay is interbedded with both silt and sand. A sandy facies of this deposit was observed in a solid waste trench a half mile southwest of the lagoons. This sand appears to be a thin deltaic deposit, suggesting that a river or stream entered the lake in this area. A thick, silty sand unit, which contains interbedded clay, is also present in the subsurface below the lacustrine clay a half mile south of the wastewater impoundments (Fig. 5). This unit was probably deposited by a fluvial system that fed the lake in this area. The lake deposits range in thickness from 2 to 20 feet and are approximately 15 to 20 feet thick in the area of the wastewater impoundments. Sand and gravel deposits were not encountered at the surface in any of the holes drilled in the study area.

In addition to the till and lacustrine deposits, sand and gravel deposits are present at or near the base of Pleistocene deposits in some areas around the wastewater impoundments (Fig. 8). These sediments were deposited by rivers fed by melting glacial ice. Sand and gravel was encountered at the base of the Pleistocene deposits in three drill sites within a half mile of the wastewater impoundments. The buried sand and gravel deposit in closest proximity to the impoundments occurs in the SW 1/4 of section 34 (mw #12079). This deposit is 19 feet thick and occurs 60 feet below the surface (Appendix I). An 18-foot thick deposit of sand and gravel was also encountered at the base of the Pleistocene, 18 feet below the surface, in mw #12072 (Fig. 5). The thickest of the three deposits is located 1/2 mile south of the impoundments in a 110-foot-deep buried channel (mw #12076 and 12077) (Fig. 4 and 5). The base of the channel contains 38 feet of sand and gravel and is overlain by 41 feet of till (Appendix I). The lithology at this site indicates that the glacier flowed into the channel while it was still an active river system. Although we drilled numerous holes in this area, we could not determine what, if any, relationship exists between these scattered buried sand and gravel deposits and the Spiritwood Aquifer channel.

The center of a large buried channel is located 3 1/2 miles south of the impoundments. This channel is 250 feet deep and contains 170 feet of sand and gravel (mw #12080)(Fig. 4). The sand and gravel deposits in this channel are part of the Spiritwood Aquifer. The channel-fill deposits become finer upward, grading into lake clay, indicating that the fluvial system lost competency over time and that the channel was flooded by a lake during the latter part of its existence. The apparent relief on the till/lake clay contact indicates that, by the time the glacier overrode this area, the channel was already filled with deposits (Fig. 4). The Spiritwood Aquifer trends north-south in the area west and north of the impoundments, but turns and trends towards the east in the area south of the impoundments (Fig. 3). The Spiritwood Aquifer is present approximately 1.5 miles south and west of the wastewater impoundments.

## HYDROGEOLOGY OF THE AREA

### General Hydrogeology of the Region

Devils Lake occupies the low points of a large, inland basin. As the lake has no outlet at its present level, evaporation is the only way water leaves the system. Based on work by Hutchinson (1980) and Pusc (1992), groundwater in the area flows toward Devils Lake, from all directions, to replace a small portion of the water

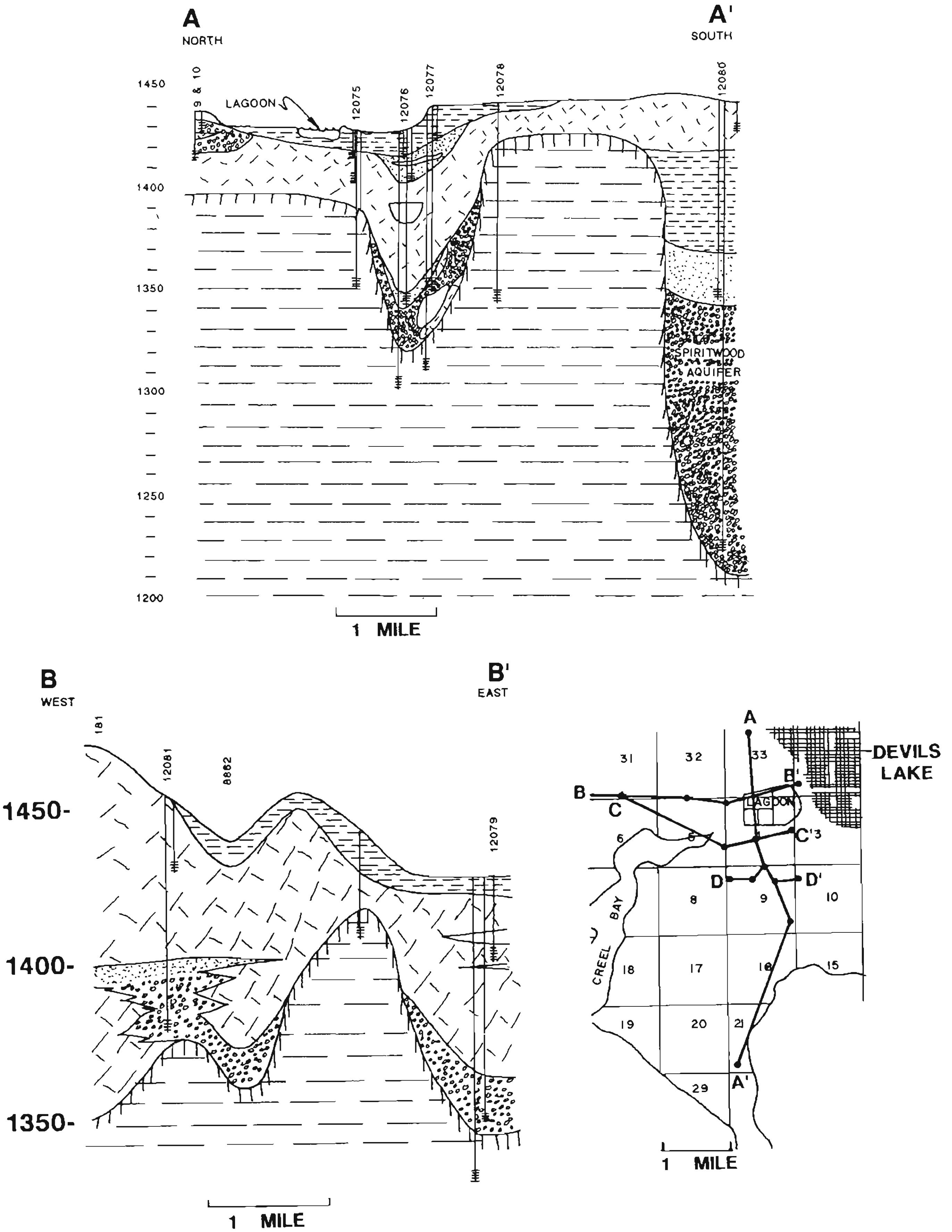

Figure 4. Geologic cross-sections A and B.

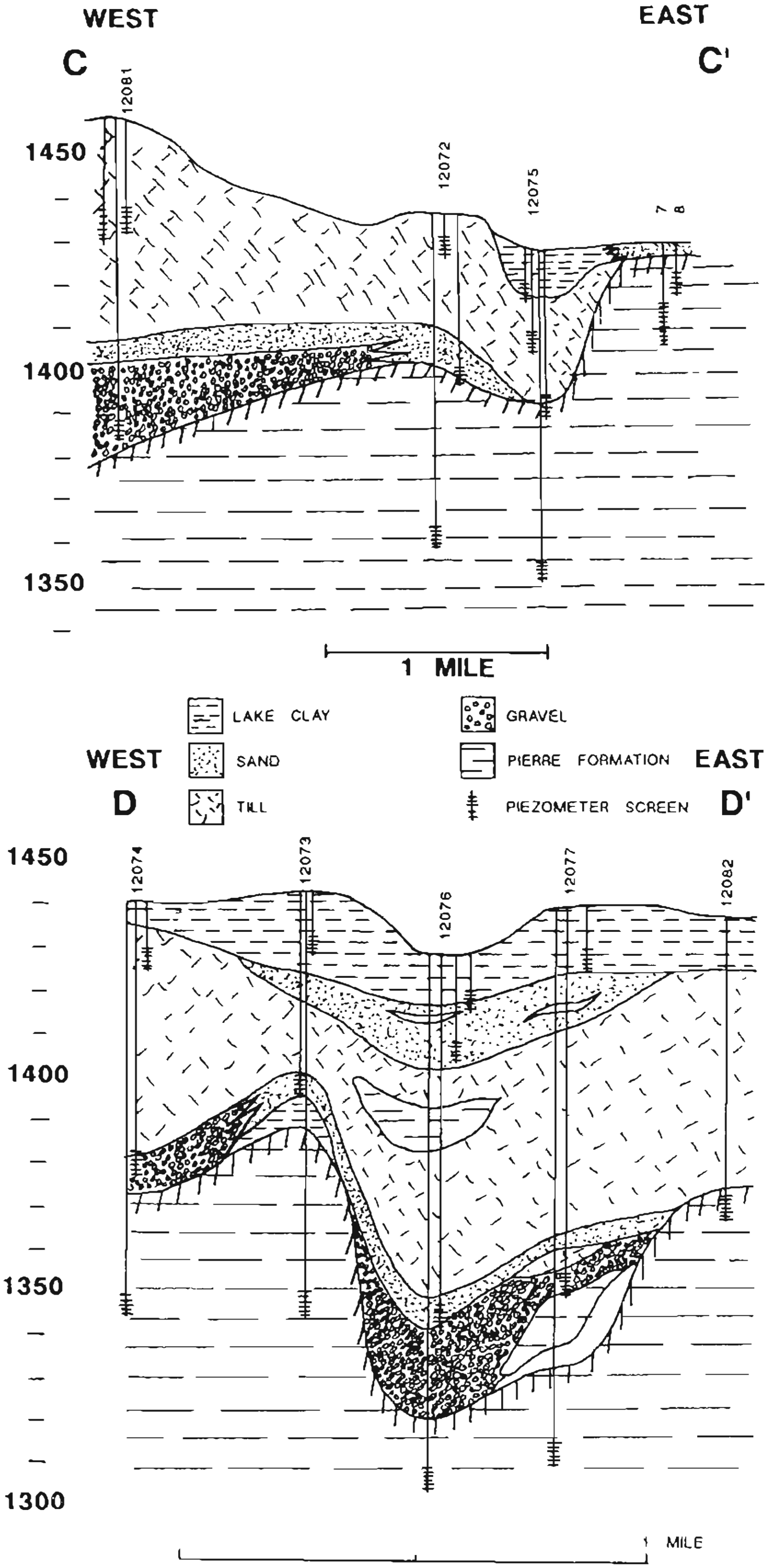

Figure 5. Geologic cross-sections C and D.

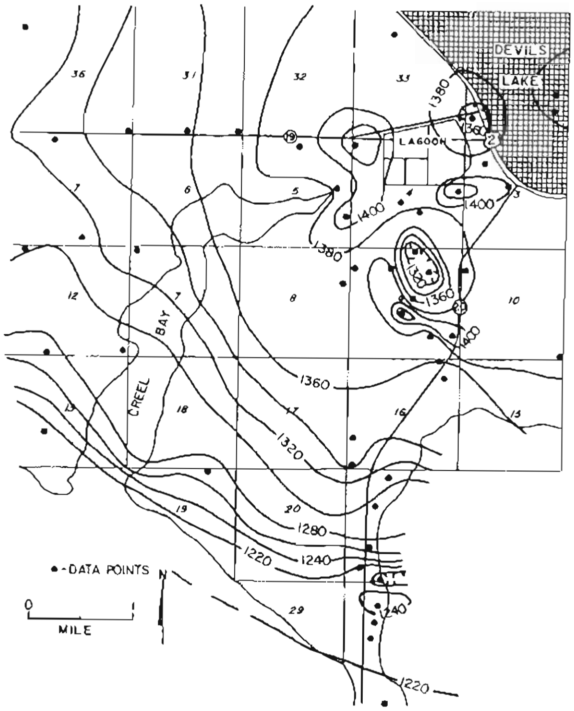

Figure 6. Contour map on the top of the Pierre Formation.

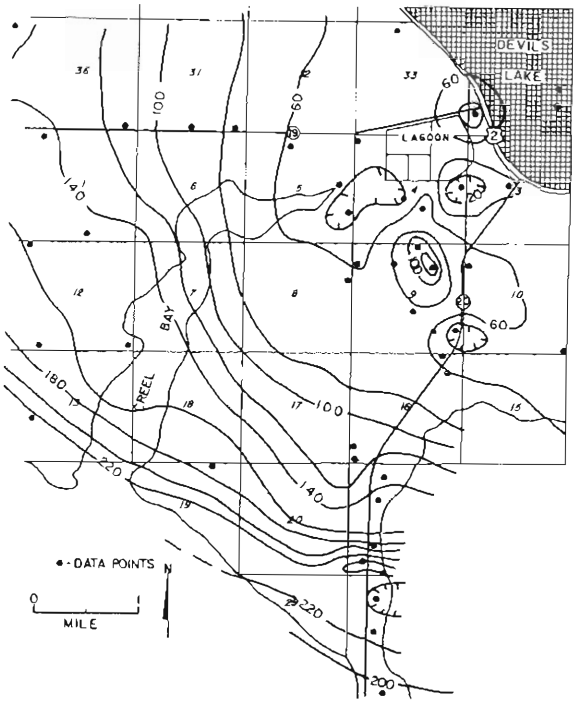

Figure 7. Isopach of the Pleistocene deposits near the Devils Lake impoundments.

being removed from the lake by evaporation. Thus, Devils Lake can be classified as a regional groundwater discharge area.

## The Shallow Hydrogeologic System Adjacent to the Wastewater Impoundments

As noted earlier, the Devils Lake wastewater impoundments are located in the natural depression of Creel Bay. The majority of the site is covered by 15 to 20 feet of lake sediments, mainly clay. Beneath the lake clays lies a 25- to 30-foot-thick sequence of glacial till with low permeability. In most of the area around the wastewater impoundments, shale of the Pierre Formation underlies the till. An exception is in the SW/4 Sec. 34, T. 154 N., R. 54 W., where a 20-foot-thick layer of gravel occurs directly beneath the glacial till at a depth of 63 to 83 feet (1326 to 1346 fasl). This buried sand and gravel unit may be related to a channel deposit found in the north-central portion of section 9 at an elevation of 1319 feet. Although numerous holes were drilled in the area between these two sites, no hydrologic connection was discovered.

Water-level measurements obtained from the shallow monitoring wells indicate that groundwater flow in the shallow water table is generally inward, from all directions, toward the depression in which the wastewater impoundments are located (Fig. 9 and 10). Water-level gradients range between 10 ft/mile and 13 ft/mile. The average linear velocity of groundwater flow in the shallow water table is 0.6 ft/year. This rate of flow was calculated using Darcy's Law, a hydraulic conductivity of $3.0 \times 10^{-6}$ ft/s and a porosity of 0.3. Throughout the summer of 1988, water levels in the shallow water table declined as much as five feet in response to removal of water from the area by evapotranspiration (Fig. 11). This significant water-level fluctuation is a result of minimal recharge combined with the low hydraulic conductivity and low specific yield of the sediments in the area.

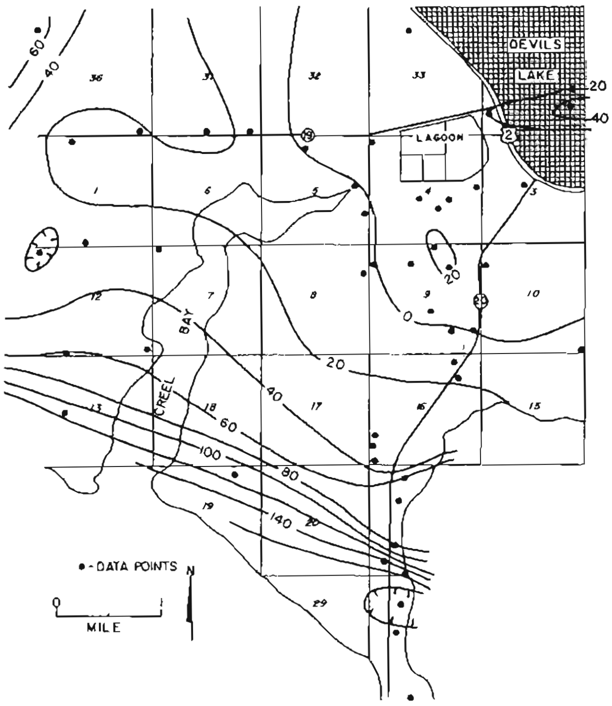

Figure 8. Isopach of the Pleistocene sand and gravel deposits.

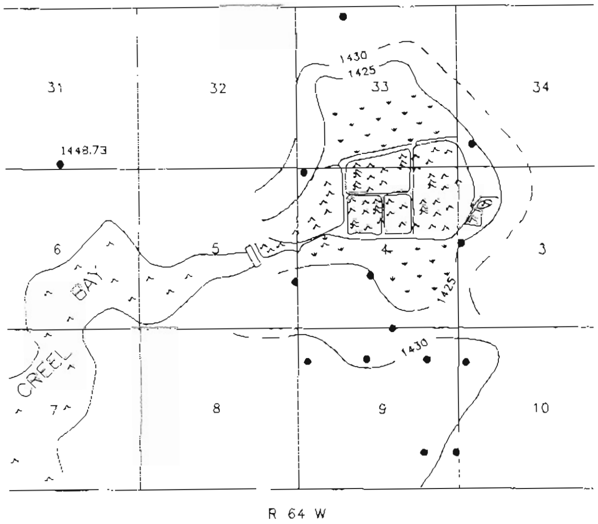

Figure 9. Contour map of the water table on May 12, 1989.

## Pierre Formation

Transmissivity of the Pierre Formation shale, as reported by Hutchinson (1980), ranges from 10 to 121 ft²/day. According to Hutchinson (1980), most wells completed in the shale yield a maximum of 10 gallons of water per minute. Available data indicate that most domestic wells in the vicinity of the wastewater impoundments obtain groundwater from fractured zones within the shale (Fig. 12).

Water levels measured in wells screened in the upper fractured zone of the Pierre Formation shale also indicate that, locally, groundwater flow in these sediments is toward the large depression in which the wastewater impoundments are located (Fig. 13). Water-level gradients range from 5 to 13 ft/mile. Water levels in these wells declined throughout the summer of 1988, mainly in response to evapotranspiration, although a small portion of the drawdown may also be due to removal of groundwater by domestic wells in the area. The available data indicate, however, that pumping in the area is presently not sufficient to overcome the effects of evapotranspiration. Groundwater movement in the area is therefore controlled mainly by precipitation, land-surface configuration and evapotranspiration.

Water-level measurements from nested monitoring wells in the area indicate that, near the depression in which the wastewater impoundments are located, water-level elevations generally increase with depth, indicating upward groundwater flow (Fig. 11) (Appendix IV).

On higher ground, some distance away from the depression in which the wastewater impoundments are located, water-level elevations decrease with depth, indicating downward groundwater flow (Appendix IV). It appears that in areas of higher ground, groundwater flows very slowly downward from the surface, through the lake clays and glacial till, and into either the Pierre Formation shale or sand and gravel units. Movement is then directed toward the Creel Bay depression due to the effects of evapo-

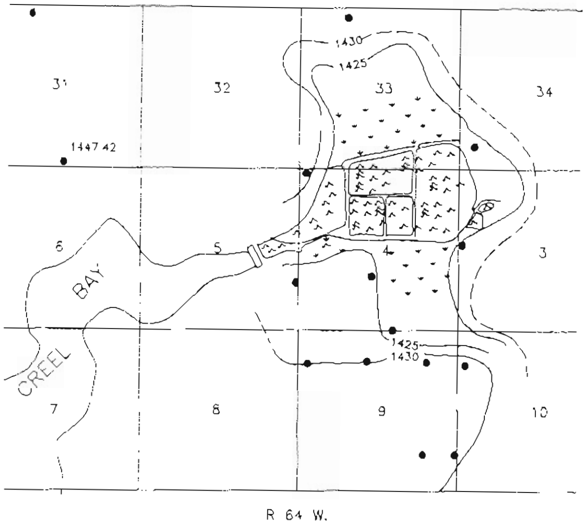

**Figure 10.** Contour map of the water table on August 3, 1988.

transpiration.

### Spiritwood Aquifer

Recent test drilling did not detect the Spiritwood Aquifer beneath the wastewater impoundments. In fact, the aquifer is located about 1.5 miles south and 1 mile west of the impoundments (Fig. 12).

In general, water levels in the Spiritwood Aquifer near Devils Lake are higher than, and sloping towards, Devils Lake (Pusc, 1992). This suggests that groundwater from the Spiritwood Aquifer is moving very slowly towards the lake to replace a small portion of the water being removed by evaporation. Water levels in the main channel of the Spiritwood Aquifer near Camp Grafton and Lakewood, however, dropped slightly below the level of Devils Lake during the summers of 1988 and 1989. It appears that, in this area, the pumping of over one hundred domestic wells, coupled with pumping wells at the Town and Country Golf Club, causes water levels to seasonally decline about two to three feet. The water levels recover during the late fall and winter, and eventually rise back above the level of Devils Lake (Fig. 12). Thus, in this area, a potential exists for the very slow movement of water from Devils Lake into the Spiritwood Aquifer during spring and summer pumping. The potential reverts back to natural conditions after the summer pumping cycle is completed and the Spiritwood Aquifer once again becomes a possible source of water for Devils Lake.

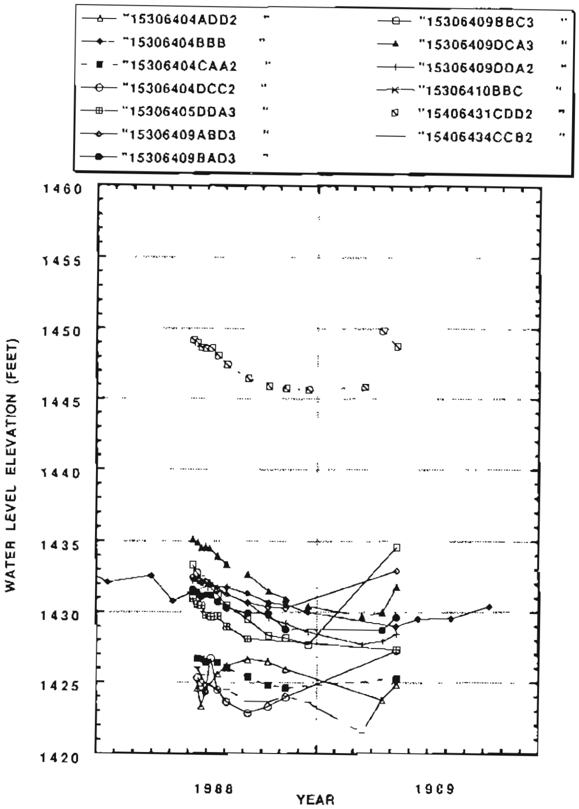

**Figure 11.** Profile of potentiometric heads from selected piezometers near the wastewater impoundments.

As already noted, it appears that most domestic wells in the area surrounding the Devils Lake wastewater impoundments derive water from fractured and sandy zones in the Pierre Formation shale (North Dakota Board of Water Well Contractors, 1972-1989). The question then is: are the impoundments leaking and, if so, is the water movement downward through the low hydraulic conductivity lake clays and till and into the shale? Present water-level information indicates that groundwater movement in the area is generally very slowly upward, replacing a portion of the water removed from the area by evapotranspiration. Under these conditions, any leakage from the impoundments would be cycled locally by the effects of the depressed topography and evapotranspiration.

### Hydraulic Conductivity of Sediments

Permeability tests in the form of falling head tests (slug tests) were performed on selected monitoring wells. The falling head tests were analyzed using the methods described by Hvorslev (1951). A comparison of the test results with those in the literature demonstrates that many of the hydraulic conductivities that were determined in our tests fall outside of the normal range for those sediments. The only exception to this is in monitoring well 4 in which the hydraulic conductivity determined for a layer of silt falls in the middle of the expected range (Table 1). The hydraulic conductivity determined for the screened interval in monitoring well 9 is on the low end of a clean sand. This well contains a 5-foot screen which is adjacent to 3 feet of till overlain by 2 feet of sand and gravel. The Hvorslev tests were run with both a 5-foot screen and a 2-foot screen in the formula (the result of the former is used in the table and the latter resulted in an increased value of hydraulic conductivity of 8.7 x $10^{-4}$ cm/s) (Table 1).

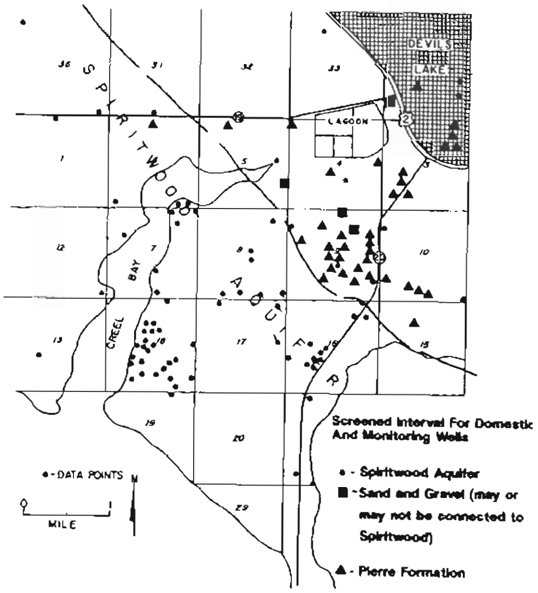

**Figure 12.** The location of the Spiritwood aquifer as determined by monitoring and domestic wells.

The values determined for shale were two magnitudes higher than the highest values generally encountered for this lithology (Table 1). The Pierre Formation shale in wells 7 and 8 was highly fractured, as was noted on the lithologic descriptions of the cores obtained from these holes. This fracturing accounts for the elevated hydraulic conductivity values determined in these wells. This high degree of fracturing extends in some areas to a depth of 200 feet and is the reason the Pierre Formation, generally regarded as an aquitard, is actually an aquifer in parts of Ramsey County (Hutchinson and Klausing, 1980).

As has been discussed, there is a logical explanation why the hydraulic conductivities in wells 7, 8, and 9 plotted on the edge or outside of the normal range of hydraulic conductivities for these lithologies. However, we know of no logical explanation to explain why the hydraulic conductivity determined for lacustrine clay in monitoring well 5 was determined to be 3 orders of magnitude higher than the highest levels

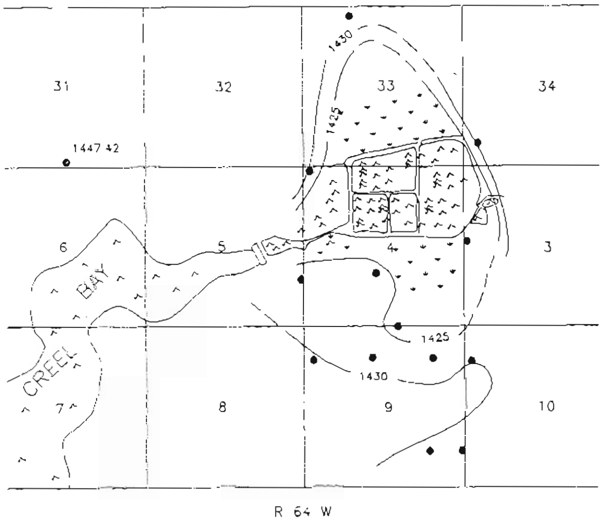

**Figure 13.** Potentiometric map of wells screened on the top of the Pierre Formation.

generally encountered (Table 1). Shelby tube cores of this interval were examined and noted to be very clean clay ie., devoid of coarser grained lenses which could have increased the hydraulic conductivity readings. There was no evidence of fracturing in this unit. The extremely high hydraulic conductivity value for this well is especially surprising because it had been anticipated that the hydraulic conductivity of the lacustrine clays at this site would plot on the low end of the clay range ie., $10^{-9}$ etc., given the outward appearance of the clay cores.

## WASTEWATER CHEMISTRY

The results of 8 analyses of wastewater from the Devils Lake impoundments demonstrate that the wastewater contains elevated concentrations of total dissolved solids (TDS) (1878 to 3090 mg/l), chloride (264 to 360 mg/l), and sulfate (755 to 1700 mg/l) (Table 2). The highest concentrations were found in the drainage between the impoundments and Creel Bay on Devils Lake (5350 mg/l TDS, 580 mg/l of chloride, and 2700 mg/l of sulfate).

**Table 1.** Hydraulic Conductivities of Sediments in the Vicinity of the Devils Lake Wastewater Impoundments.

| Well# | Lithology | K (from tests) | K (literature*) |
|---|---|---|---|
| 5 | Lake Clay | $2.6 \times 10^{-3}$ cm/s | $10^{-11}$ to $10^{-6}$ |
| 9 | Sand & gravel/till | $8.7 \times 10^{-4}$ cm/s | $10^{-4}$ to $10^{2}$ |
| 4 | Silt | $9.2 \times 10^{-5}$ cm/s | $10^{-7}$ to $10^{-3}$ |
| 8 | Pierre Fm. Shale | $3.9 \times 10^{-5}$ cm/s | $10^{-11}$ to $10^{-7}$ |
| 7 | Pierre Fm. Shale | $4.3 \times 10^{-5}$ cm/s | $10^{-11}$ to $10^{-7}$ |

* values in this column obtained from Freeze and Cherry (1979)

**Table 2.** Chemistry of Wastewater at Devils Lake.

| Location | Cells+ | N cell | Drainage | Se Cell | S Cell |
|---|---|---|---|---|---|
| Date | 1987 | 10/13/88 | 10/13/88 | 10/13/88 | 10/13/88 |
| TDS | 1878 | 2080 | 5350 | 3090 | 2670 |
| Fe |  | 0.03 | 0.07 | 0.05 | 0.05 |
| Mn |  | 0.59 | 0.26 | 0.2 | .04 |
| Ca | 88 | 120 | 150 | 140 | 110 |
| Mg | 87 | 100 | 350 | 170 | 150 |
| Na | 420 | 420 | 1100 | 530 | 570 |
| K | 31 | 28 | 82 | 25 | 38 |
| $HCO_3$ | 423 | 626 | 894 | 294 | 595 |
| $CO_3$ | 36 | 0 | 27 | 0 | 34 |
| $SO_4$ | 755 | 720 | 2700 | 1700 | 1100 |
| Cl | 264 | 300 | 580 | 250 | 360 |
| F |  | 1.2 | 0.6 | 0.2 | 1.1 |
| $NO_3$ | 0.179* | 2.1 | 1 | 1 | 2.3 |
| Hardness | 711.71 | 1816 | 1050 |  | 892 |
| NCH |  | 200 | 1000 | 810 | 350 |
| %Na | 53.6 | 55 | 55 | 52 | 57 |
| SAR | 7.82 | 68 | 11 | 73 | 83 |
| S.C. | 2643 | 3000 | 6730 | 3840 | 3690 |
| Temp. C |  | 7 | 7 | 7 | 7 |
| pH | 8.8 | 8.1 | 8.5 | 8.07 | 8.7 |

\+ The average value of 5 samples from D.L. impoundments, taken from Olson-Kaufman Inc./Ulteig report.

* reported as N, all other values are reported as $NO_3$.

S.C. Specific conductance reported in umhos/cm.

Hardness is reported as $CaCO_3$.

## GROUNDWATER CHEMISTRY

The discontinuity of the geologic units and the high degree of relief on the top of the Pierre Formation makes it difficult to determine the groundwater flow paths between the wells. Therefore, it is difficult to compare the groundwater chemistry from well to well. As a result, isoconcentration maps were not constructed. Instead, major ion chemical concentrations were plotted adjacent to the well screens and were studied to determine whether or not a pattern was evident (Appendices V and VI). The following parameters displayed a pattern and will be discussed further: TDS, Cl, NO3-, SO4-, and bacteria. Fluoride should be a good indicator of wastewater because the city of Devils Lake has been fluoridating the city water supply since 1964. Fluoride levels in the city water range from 1.1-1.7 mg/l--5 to 10 times the natural background levels of 0.2 mg/l (Chuck Abel, personal communication). However, fluoride was not found at elevated levels in the monitoring wells adjacent to the wastewater impoundments (table 2 and Appendix V).

### Pleistocene Units

Previous work has shown that the quality of groundwater is extremely variable within the near-surface Pleistocene sediments. This is a reflection of the influence of surface activities as well as the natural differences of the quality of the recharge waters and groundwater leakage from adjacent bedrock units.

Total Dissolved Solids--The total dissolved solids concentrations of groundwater within the Pleistocene units in the study area around the wastewater impoundments ranged from 1210 to 14,400 mg/l with a mean of 3446 mg/l. The TDS concentration of groundwater within the Spiritwood Aquifer (1840 and 1260 mg/l in mw 12080A and B) and within the buried channel deposits (1670 mg/l in 12076B, 1830 mg/l in 12077B, and 1590 mg/l in 12079B) are comparable to concentrations found in these units throughout Ramsey County (Appendix VI). This corresponds closely with a range of 671 to 5270 and a mean of 1514 mg/l TDS for groundwater in the Spiritwood Aquifer and in buried sand and gravel deposits in Ramsey County (Hutchinson, 1977 and Pusc, 1992).

High concentrations of TDS were found in two shallow wells adjacent to the wastewater impoundments, mw 3 (9260 mg/l) and mw 6 (14,400 mg/l) (Appendix VI). These elevated concentrations may indicate an impact from wastewater but may also be the result of natural variation in the highly mineralized groundwater within till and lacustrine clay. In fact, data obtained from shallow water-table wells that are located miles from the wastewater impoundments demonstrates that the TDS of shallow groundwater can vary from 5,000 to as much as 26,000 mg/l (Pusc, 1992).

Chloride--The chloride concentration of groundwater within the Pleistocene sediments was found to range from 23 to 1700 mg/l in the study area. Chloride concentrations in groundwater within the Spiritwood Aquifer and the buried channel deposits ranged from 23 to 230 mg/l, the latter concentration coming from mw 12080A screened at the base of the Spiritwood Aquifer (Appendix VI). The relatively high concentrations of chloride ion in the Spiritwood Aquifer is apparently the result of highly mineralized groundwater flowing into the aquifer from the underlying Pierre Formation. This would account for the increase in the chloride ion concentration with depth in the aquifer from 45 mg/l within the confining units above the aquifer, 150 mg/l chloride in the middle of the aquifer, and 230 mg/l of chloride near its base (as seen in the 12080 nest). As a result of this natural variation in the chloride ion content, it is extremely difficult to determine whether or not the city of Devils Lake wastewater impoundments are impacting the Spiritwood Aquifer or any of the other buried channel aquifers at the site.

The highest concentrations of the chloride ion were found in wells screened adjacent to the wastewater impoundments. Monitoring well 6 contained concentrations of 1700 mg/l and mw 2 contained levels of 810 mg/l (Appendix VI).

Nitrate--The concentration of nitrates in the groundwater within the Pleistocene sediments ranged from 0.1 to 26 mg/l (Appendix V and VI). This compares favorably with the range of 0.1 to 170 mg/l for nitrates in groundwater within the Spiritwood Aquifer and other buried channel deposits in Ramsey County (Hutchinson, 1977). Hutchinson (1977) found only two buried channel groundwater samples in Ramsey County which contained concentrations exceeding 18 mg/l of nitrate. In general, there was an increase in the concentration of nitrate in the groundwater adjacent to the wastewater impoundments. However, the highest concentration of nitrate encountered (26 mg/l) occurred in mw 12081B and does not appear to have any relationship to either the wastewater impoundments or to the discharge area of these impoundments (Appendix VI).

Sulfate--The concentration of sulfate in groundwater within the Pleistocene sediments surrounding the wastewater impoundments ranged from 410 to 7800 mg/l (Appendix V and VI). Within the Spiritwood Aquifer and the buried channel deposits, these concentrations ranged from 410 to 3100 mg/l. The highest concentrations of sulfate occurred in groundwater adjacent to the eastern edge of the wastewater impoundments (7800 mg/l in mw 8).

### Pierre Formation

Previous work has shown that groundwater quality varies considerably within the Pierre Formation (Pusc, 1992 and Hutchinson, 1977).

Total Dissolved Solids (TDS)--The total dissolved solids concentrations of groundwater within the Pierre Formation were found to range from 375 to 9800 mg/l with a mean of 2479 mg/l in Ramsey County (Hutchinson, 1977 and Pusc, 1992). The concentrations of TDS in groundwater within the Pierre Formation around the Devils Lake wastewater impoundments were found to range from 1220 to 9260 mg/l (Appendix V). Most of the concentrations were below 3300 mg/l. The exceptions to this were the high levels within wells 7 (5250) and 8 (9260). With the exception of wells 7 and 8, the TDS of the groundwater within the Pierre Formation generally increased with depth (Appendix VI). There were no other discernable water quality patterns.

Chloride--Hutchinson (1977) and Pusc (1992) found that the chloride ion content of groundwater within the Pierre Formation ranges from 1.3 to 2700 mg/l in Ramsey County. The concentrations of chloride in the Pierre Formation in the 30-square-mile area around the Devils Lake wastewater impoundments vary from 26 to 1400 mg/l, well within the chloride range found for groundwater in this unit throughout the county (Appendix V). In general, the chloride ion was found to increase in concentration in groundwater with depth in the Pierre Formation. The notable exception to this trend were the two shallow Pierre wells (no. 7 and 8) located close to the southeast end of the wastewater impoundments (Appendix VI). The chloride concentration in these wells ranged from 1400 in well 7 to 1100 mg/l in well 8.

The Pierre Formation shale in this area is extremely fractured, as was evident in the cores from these two holes. The fractures enable groundwater to move more quickly through this unit than would normally be expected. The Pierre Formation was present at this site at a higher elevation than was anticipated, which may be the result of glacial thrusting, and if so, there may be Pleistocene sediments below the depths that were drilled.

Nitrate--The concentration of nitrates in the groundwater within the Pierre Formation averaged 1 mg/l (reported as $NO_3^-$) within the study area. Notable exceptions to this were monitoring wells 12078A, 12075B, 7, and 8 (Appendix V). Well no. 12078A is screened at a depth of 98 feet, 80 feet into the Pierre Formation. Septic systems in this area may account for the increased $NO_3^-$ levels in this well (Appendix VI). Well no. 12075B is screened at the Pleistocene/bedrock contact at a depth of 39 feet. This well is close to the impoundments and the elevated $NO_3^-$ level may be attributable to the wastewater facility. The monitoring wells screened in the Pleistocene units at this site also contain high $NO_3^-$ concentrations. None of the nitrate concentrations reported exceeded the maximum permissible concentration limit of 45 mg/l.

Sulfate--Sulfate concentrations within groundwater in the Pierre Formation ranged from 460 to 4900 mg/l with a mean of 1215 mg/l (Appendix V). This compares to a range of 1 to 6400 mg/l, with a mean of 780 mg/l, of sulfate in groundwater within the Pierre Formation in Ramsey County (Hutchinson, 1977 and Pusc, 1992). There was no discernable relationship between depth and $SO_4^-$ concentrations within groundwater in the Pierre Formation (Appendix

VI). Sulfate concentrations varied widely from well to well at the same stratigraphic horizon ie., mw #12072A contained 1900 mg/l of sulfate compared to 460 mg/l in mw #12075A. The highest concentrations detected within Pierre Formation groundwater occurred in mw 8 (4900 mg/l) (Appendix VI). This high concentration seems to indicate the presence of leachate at this horizon. However, sulfate concentrations in the wastewater impoundments were found at much lower concentrations ie., 755 mg/l (Table 2). During our study, we found that sulfate concentrations, both in the cells and in surface water adjacent to the cells, ranged from 720 to 2700 mg/l. These concentrations are still lower than those found in monitoring well no. 8. The increased concentrations in the groundwater may be a result of the increased concentrations of salts due to evaporation.

## Bacteria

Groundwater samples were collected for bacteriological analysis from selected monitoring wells on September 13, 1988. The samples were analyzed for coliform bacteria by the Microbiology Lab of the State Health Department using the fermentation tube method. An indication of the presence of municipal wastewater contamination is the presence of fecal coliforms. A number of the wells tested in 1988 contained detectable levels of total coliforms. These include well numbers 1, 4, 5, 7, 8, 9, and 12073B (Table 3). The lab did not test for the presence of fecal bacteria in 1988. Therefore, selected wells were resampled during 1992. Four piezometers (mw 1, 6, 12079A, and 12079B) were plugged during the four-year interim and could not be resampled and wells 12075A, 12075B, 4, and 5 were frozen and could not be sampled.

Only one well, 12072C, tested positive for coliforms in February, 1992 (Table 3). Although coliforms were detected in the groundwater in this well, no fecal coliforms were found. Well no. 12072C is screened in sandy till at a depth of 5 to 10 feet. This well is near the canal which carries discharged water from the impoundments into Devils Lake through Creel Bay.

The presence of coliforms in the water samples from the monitoring wells does not in itself demonstrate wastewater contamination because bacteria can be introduced into the well or subsurface during the drilling or sampling phase of the study. Dedicated disposable bailers were used in 1992 to eliminate the chance of cross-contamination during sampling. Four (mw #1, 7, 8, 12072C), or half, of the monitoring wells which detected total coliforms were located near either the wastewater impoundments or, as in the case of mw # 12072C, adjacent to the wastewater discharge path (Fig. 2). The presence of coliforms in these wells may be the result of wastewater contamination. However, it is much more difficult to attribute the presence of total coliforms in the other four wells to wastewater impact given their distance from the wastewater impoundments ie., mw 9 is one mile north, mw 4, 5, and 12073B approximately 1/2 mile south of the impoundments (Fig. 2).

The study by Kehew and others (1983) also detected fecal bacteria in monitoring wells several hundred feet downgradient of the wastewater impoundments at McVille. Their results are extremely significant given the theories that fecal bacteria will not survive long in a groundwater system (Kern, personal communication). The authors questioned the validity of their sampling techniques and were concerned that cross-contamination might have adversely contributed to their findings. For this reason, they suggested that future studies attempt to verify their results.

## CONCLUSIONS

1. The increased concentrations of several chemical constituents in groundwater quality in a small area immediately adjacent to the Devils Lake wastewater impoundments may be attributed to the movement of wastewater out of the impoundments over the 34-year period of existence. The chemical concentrations of the groundwater found adjacent to the wastewater impoundments generally exceeded those concentrations found within the wastewater impoundments themselves. This increase may be the result of concentrations of the salts by evapotranspiration of the wastewater outside of the cells. The information gathered to date does not indicate any large scale impact of the wastewater lagoons on the Spiritwood Aquifer.

The relatively high concentrations of salts

**Table 3.** Bacteriological analysis of groundwater and wastewater samples at the Devils Lake Impoundments.

| Well No. | Location | 9/13/88 | 2/7/92 |
|---|---|---|---|
| 1 | 154-64-34CCB | 2.2 | |
| 6 | 154-64-34CCB | <2.2 | |
| 12079A | 154-64-34CCB | <2.2 | |
| 12079B | 154-64-34CCB | <2.2 | |
| 7 | 153-64-04ADD | 2.2 | nd |
| 8 | 153-64-04ADD | 5.1 | nd |
| 2 | 153-64-04CAA | <2.2 | nd |
| 3 | 153-64-04CAA | <2.2 | nd |
| 12075A | 153-64-04CAA | <2.2 | |
| 12075B | 153-64-04CAA | <2.2 | |
| 4 | 153-64-04DCC | 5.1 | |
| 5 | 153-64-04DCC | 16.0 | |
| | 153-64-04BBB | | nd |
| 12077B | 153-64-09ABD | <2.2 | |
| 12073A | 153-64-09BAD | <2.2 | |
| 12073B | 153-64-09BAD | 2.2 | |
| 12074A | 153-64-09BBC | <2.2 | |
| 9 | 154-64-33BBA | 2.2 | |
| 10 | 154-64-33BBA | <2.2 | |
| 12072B | 153-64-05DDA | | nd |
| 12072C | 153-64-05DDA | | nfd |
| Wastewater | 153-64-04A | >16.0 | |

Values given are most probable numbers (MPN) derived from the fermentation tube method (APHA, 1975).
nd = no coliform detected.
nfd = no fecal coliforms detected.

within groundwater in this area may also be the result of natural processes. The impoundments are located within a basin in which the groundwater flow direction was inward during the time of the study. During dry times, the hydraulic heads of the units may reverse and the highly mineralized pore water may be recharged into the shallow groundwater system. This natural phenomenon would occur when heavy snowmelt or large thunderstorms pond water in the basin following an extended period of drought when the hydraulic heads in the underlying units are lowered. This natural phenomenon would be exaggerated with the presence of the wastewater impoundments at an elevated constant or near-constant water level or positive head. The dikes around the impoundment cells were recently raised and this has increased the pond levels and therefore the hydraulic heads in these impoundments. This may increase the amount of wastewater which infiltrates into the subsurface. There does not appear to be much of a driving force for movement of the wastewater far beyond the impoundments due to the flow of groundwater into the basin within which the cells are located.

We do not have a sufficient number of shallow holes in the area around the wastewater impoundments to determine whether a groundwater mound exists beneath the site. The presence of a groundwater mound would indicate that wastewater from the impoundments is leaking into the underlying groundwater.

2.Geologic information obtained during the drilling program indicates that the Devils Lake impoundments are situated within lacustrine clays. However, it appears that a portion of the southeast corner of the impoundments may lie directly on the Pierre Formation. The lacustrine clays should be very low in hydraulic conductivity (despite the field conductivity test results) and therefore should restrict or reduce wastewater movement from the impoundments to the groundwater system.

3. Our drilling program discovered heretofore unknown buried deposits of sand and gravel both east (well no. 12079A) and south (well no. 12076A) of the wastewater impoundments. These sand and gravel units lie on top of the Pierre Formation and may represent one or more tributary channels. These channels may intersect the Spiritwood Aquifer east, west, or south of the wastewater impoundments. A number of additional holes would need to be drilled in this area to determine the relationship between these sand and gravel units and the Spiritwood Aquifer.

4. The natural variation of the groundwater quality within both the Pleistocene and the Cretaceous Pierre Formation throughout Ramsey County made detection of wastewater leachate very difficult in these units. The chloride ion is usually one of the best indicators of leachate movement because its background concentrations in North Dakota groundwater is generally <30 mg/l. However, this is not true in the study area due to the wide range of chloride concentrations in the Pierre Formation and leakage from these shales into the Pleistocene channels. Another factor in this area is the increased chloride levels in surface water in the Devils Lake Basin.

5. The hydraulic conductivities of the sediments determined by field tests generally fell within the expected range. The field hydraulic conductivities for the Pierre Formation were higher than those generally seen in shale due to the presence of fractures.

## RECOMMENDATIONS

Additional studies of the area around the impoundments would be useful to further define the extent of the Spiritwood Aquifer and to determine what, if any, relationship exists between the Spiritwood Aquifer and other buried channels in this area. A shallow seismic survey or gravity study across the area would be useful in answering this question and may result in more detailed information than would a number of additional drill holes. Profiles should be run oriented both north-south and east-west for a three mile stretch south of the impoundments.

Ideally, a report should be written only after at least two rounds of water analyses have been obtained in an area. Additional analyses enable verification of the initial chemical results. Unfortunately, funding was not available during this study to enable us to obtain a second round of general chemical analysis. Any future studies of this area should sample the remaining wells and compare the results to this study.

Due to the highly variable nature of the groundwater chemistry in the Devils Lake Basin, this study was not able to determine, unequivocally, the impact the wastewater impoundments were having on the surrounding area. Therefore, it is recommended that any person in this area, who is concerned about the quality of their drinking water, should have a representative sample of their water chemically analyzed.

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# APPENDICIES

# APPENDIX 1
# Lithologic Logs of Drill Holes

## 153-064-04ADD1
## NDGS #7

| | | | |
|---|---|---|---|
| Date Completed: | 05/24/88 | Well Type: | 2 inch PVC |
| Depth Drilled (ft): | 25 | Principal Aquifer: | Pierre Formation |
| Screened Interval (ft): | 14.5-24.5 | L.S. Elevation (ft) | 1428.86 |

Lithologic Log

| Unit | Description | Depth (ft) |
|---|---|---|
| TOPSOIL | | 0-1 |
| SAND | medium to light brown, shaly quartz | 1-3 |
| SHALE | Pierre, light brown to gray, iron stained | 3-8 |
| SHALE | dark gray, Pierre shale | 8-25 |

## 153-064-04ADD2
## NDGS #8

| | | | |
|---|---|---|---|
| Date Completed: | 05/24/88 | Well Type: | 2 inch PVC |
| Depth Drilled (ft): | 8 | Principal Aquifer: | Pierre Formation |
| Screened Interval (ft): | 8-13 | L.S. Elevation (ft) | 1428.82 |

Lithologic Log

| Unit | Description | Depth (ft) |
|---|---|---|
| TOPSOIL | | 0-1 |
| SAND | medium to light brown, shale and quartz grains | 1-3 |
| SHALE | light brown to gray, very few stains, along with fractures and gypsum | 3-8 |

## 153-064-04CAA1
## NDGS #2

| | | | |
|---|---|---|---|
| Date Completed: | 05/24/88 | Well Type: | 2 inch PVC |
| Depth Drilled (ft): | 25 | Principal Aquifer: | Sand |
| Screened Interval (ft): | 19.5-24.5 | L.S. Elevation (ft) | 1428.56 |

Lithologic Log

| Unit | Description | Depth (ft) |
|---|---|---|
| TOPSOIL | | 0-1 |
| CLAY | yellowish brown to gray, gypsum crystals, laminated | 1-10 |
| TILL | yellowish brown, gray, pebbles, sandy mottled | 10-11 |
| TILL | gray brown, not sandy | 11-13 |

| | | |
|---|---|---|
| TILL | gray, reduced, very sandy, silt from 15 to 15.5 feet and sand from 16 to 16.3 feet | 13-16.3 |
| TILL | gray clayey | 16.3-20 |
| SAND | gray, fine | 20-21 |
| SILT | gray | 21-23 |
| TILL | gray with pebbles | 23-23.2 |
| SILT | gray with pebbles | 23.2-25 |

## 153-064-04CAA2
## NDGS #3

| | | | |
|---|---|---|---|
| Date Completed: | 05/24/88 | Well Type: | 2 inch PVC |
| Depth Drilled (ft): | 13 | Principal Aquifer: | Till |
| Screened Interval (ft): | 8-13 | L.S. Elevation (ft) | 1428.54 |

Lithologic Log

| Unit | Description | Depth (ft) |
|---|---|---|
| TOPSOIL | | 0-1 |
| CLAY | | 1-10 |
| TILL | | 10-13 |

## 153-064-04CAA3
## NDSWC 12075A

| | | | |
|---|---|---|---|
| Date Completed: | 5/24/88 | Well Type: | 2 inch PVC |
| Depth Drilled (ft): | 80 | Principal Aquifer: | Pierre Formation |
| Screened Interval (ft): | 73-78 | L.S. Elevation (ft) | 1428.61 |

Lithologic Log

| Unit | Description | Depth (ft) |
|---|---|---|
| TOPSOIL | | 0-1 |
| CLAY | yellowish brown, greasy, iron stained, oxidized, lake clays | 1-9 |
| CLAY | yellowish brown, silty with pebbles, interbedded with very fine sand and silt, till | 9-12 |
| CLAY | as above, olive gray till, interbedded with sand and gravel | 12-32 |
| CLAY | olive gray to black, greasy, lake clays mixed with bedrock shale | 32-35 |
| SHALE | black brittle, chatters when drilled | 35-80 |

## 153-064-04CAA4
## NDSWC 12075B

| | | | |
|---|---|---|---|
| Date Completed: | 5/24/88 | Well Type: | 2 inch PVC |
| Depth Drilled (ft): | 40 | Principal Aquifer: | Pierre Formation |
| Screened Interval (ft): | 34-39 | L.S. Elevation (ft) | 1428.68 |

Lithologic Log

| Unit | Description | Depth (ft) |
|---|---|---|
| TOPSOIL | | 0-1 |
| CLAY | yellowish brown, oxidized lake clays | 1-12 |
| CLAY | yellowish brown, silty, sandy with pebbles, till | 12-16 |
| CLAY | olive gray, silty, sandy with pebbles, till | 16-21 |
| SAND | fine to coarse, mostly shale | 21-27 |
| CLAY | olive gray till as above | 27-32 |
| SHALE | black, brittle, chatters when drilled | 32-40 |

## 153-064-04DCC1
## NDGS #4

| | | | |
|---|---|---|---|
| Date Completed: | 05/24/88 | Well Type: | 2 inch PVC |
| Depth Drilled (ft): | 25 | Principal Aquifer: | Silt |
| Screened Interval (ft): | 19-24 | L.S. Elevation (ft) | 1428.01 |

Lithologic Log

| Unit | Description | Depth (ft) |
|---|---|---|
| TOPSOIL | | 0-1 |
| CLAY | light brown to gray, laminated | 1-13 |
| SILT | gray reduced | 13-14 |
| TILL | gray with pebbles | 14-15 |
| SAND | gray, medium to fine grained, quartz, subangular to subrounded, coarse shale pebbles | 15-15.5 |
| SILT | gray, sandy, fining downward to 16 feet, then coarser | 15.6-25 |

## 153-064-04DCC2
## NDGS #5

| | | | |
|---|---|---|---|
| Date Completed: | 05/24/88 | Well Type: | 2 inch PVC |
| Depth Drilled (ft): | 13 | Principal Aquifer: | Lake Clay |
| Screened Interval (ft): | 8-13 | L.S. Elevation (ft) | 1428.05 |

Lithologic Log

| Unit | Description | Depth (ft) |
|---|---|---|
| TOPSOIL | | 0-1 |
| CLAY | light brown to gray, laminated, few stains, lake clays | 1-12 |

## 153-064-04DCC3
## NDSWC 12076A

| | | | |
|---|---|---|---|
| Date Completed: | 5/24/88 | Well Type: | 2 inch PVC |
| Depth Drilled (ft): | 130 | Principal Aquifer: | Pierre Formation |
| Screened Interval (ft): | 120-125 | L.S. Elevation (ft) | 1428.03 |

Lithologic Log

| Unit | Description | Depth (ft) |
|---|---|---|
| TOPSOIL | | 0-1 |
| CLAY | yellowish brown, oxidized, sticky, plastic, lake clays | 1-12 |
| CLAY | as above, olive gray | 12-17 |
| SAND | and gravel, mostly shale, well rounded to subrounded, very fine to coarse sand, mostly fine to medium, 10 % gravel | 17-28 |
| CLAY | olive gray, silty, sandy with pebbles, till | 28-36 |
| SHALE | black brittle, angular, drill choppy | 36-45 |
| CLAY | olive gray, gravel and rocks, till | 45-69 |
| GRAVEL | interbedded with till | 69-81 |
| SAND | well rounded to subrounded, very fine to coarse sand | 81-87 |
| GRAVEL | sandy, coarse sand to pea gravel, mostly shale, well rounded to subrounded, caving and taking water | 87-107 |
| SHALE | black, brittle, Pierre shale | 107-108 |
| CLAY | black, mostly shale, drills smooth and slow tight | 108-120 |
| SHALE | black, brittle, drills choppy as if fractured (Pierre shale) | 120-125 |
| CLAY | black, mostly, drills smooth and slow | 125-130 |

## 153-064-04DCC4
## NDSWC 12076B

| | | | |
|---|---|---|---|
| Date Completed: | 5/24/88 | Well Type: | 2 inch PVC |
| Depth Drilled (ft): | 95 | Principal Aquifer: | Sand |

| | | | |
|---|---|---|---|
| Screened Interval (ft): | 80-85 | L.S. Elevation (ft) | 1428.08 |

Lithologic Log

| Unit | Description | Depth (ft) |
|---|---|---|
| TOPSOIL | | 0-1 |
| CLAY | yellowish brown, oxidized and iron stained, lake clays | 1-8 |
| GRAVEL | oxidized, mostly shale | 8-11 |
| CLAY | olive gray, silty | 11-16 |
| SAND | and gravel, 80 shale | 16-28 |
| CLAY | olive gray, sticky, greasy | 28-42 |
| CLAY | olive gray till | 42-82 |
| SAND | and gravel, mostly shale, well rounded to subrounded | 82-95 |

### 153-064-05DDA1
### NDSWC 12072A

| | | | |
|---|---|---|---|
| Date Completed: | 5/23/88 | Well Type: | 2 inch PVC |
| Depth Drilled (ft): | 80 | Principal Aquifer: | Pierre Formation |
| Screened Interval (ft): | 73.2-78.2 | L.S. Elevation (ft) | 1437.17 |

Lithologic Log

| Unit | Description | Depth (ft) |
|---|---|---|
| TOPSOIL | | 0-1 |
| CLAY | yellowish brown, iron stained, oxidized, silty, sandy with pebbles, some lignites, till | 1-11 |
| GRAVEL | mostly shale | 11-12 |
| CLAY | oxidized till as above | 12-16 |
| CLAY | yellowish brown, very fine sand | 18-20 |
| CLAY | olive gray, very sandy (very fine) | 20-23 |

### 153-064-05DDA2
### NDSWC 12072B

| | | | |
|---|---|---|---|
| Date Completed: | 5/23/88 | Well Type: | 2 inch PVC |
| Depth Drilled (ft): | 40 | Principal Aquifer: | Pierre Formation |
| Screened Interval (ft): | 35-40 | L.S. Elevation (ft) | 1437.18 |

Lithologic Log

| Unit | Description | Depth (ft) |
|---|---|---|
| TOPSOIL | | 0-1 |
| CLAY | yellowish brown, silty sandy with pebbles, iron stained, oxidized, till | 1-18 |
| SAND | very fine, clayey, yellowish brown, oxidized, | 18-20 |
| SAND | very fine, olive gray, clayey, silty, bedrock sand? | 20-24 |
| CLAY | olive gray, silty sandy with pebbles, till | 24-26 |
| CLAY | gray to black, lots of shale, very fine sand and silt, Bedrock | 26-36 |
| SHALE | gray to black with bedrock clays, Bedrock, Pierre shale | 36-40 |

### 153-064-05DDA3
### NDSWC 12072C

| | | | |
|---|---|---|---|
| Date Completed: | 5/23/88 | Well Type: | 2 inch PVC |
| Depth Drilled (ft): | 10 | Principal Aquifer: | Till |
| Screened Interval (ft): | 5-10 | L.S. Elevation (ft) | 1437.28 |

Lithologic Log

| Unit | Description | Depth (ft) |
|---|---|---|
| TOPSOIL | | 0-1 |
| CLAY | yellowish brown, iron stained, silty, sandy with pebbles, till | 1-10 |

### 153-064-09ABD1
### NDSWC 12077A

| | | | |
|---|---|---|---|
| Date Completed: | 5/24/88 | Well Type: | 1 1/4 inch ABS |
| Depth Drilled (ft): | 134 | Principal Aquifer: | Pierre Formation |
| Screened Interval (ft): | 125-130 | L.S. Elevation (ft) | 1443.41 |

Lithologic Log

| Unit | Description | Depth (ft) |
|---|---|---|
| TOPSOIL | | 0-1 |
| CLAY | yellowish brown, oxidized, silty, very sandy with shale pebbles, till | 1-16 |
| SAND | fine to coarse, mostly shale | 16-22 |
| CLAY | silty, olive gray | 22-24 |
| SAND | very fine to fine, silty | 24-34 |

|  |  |  |
|---|---|---|
| CLAY | silty, sandy with pebbles, some rocks, till | 34-78 |
| GRAVEL | 90 % shale, sandy, well rounded to subrounded | 78-82 |
| CLAY | olive gray, silty, very sandy till | 82-84 |
| GRAVEL | sandy, 80 % shale, well rounded to subrounded | 84-91 |
| SHALE | gray to black, fractured, angular cuttings, brittle, drills choppy, interbedded with gray, silty clays | 91-103 |
| CLAY | olive gray, rocky till as above | 103-110 |
| CLAY | silty, olive gray, drills smooth | 110-121 |
| SHALE | black, brittle, angular cuttings, drills slightly choppy, some bentonite clay mixed in | 121-134 |

## 153-064-09ABD2
## NDSWC 12077B

|  |  |  |  |
|---|---|---|---|
| Date Completed: | 5/26/88 | Well Type: | 2 inch PVC |
| Depth Drilled (ft): | 100 | Principal Aquifer: | Gravel |
| Screened Interval (ft): | 85-90 | L.S. Elevation (ft) | 1443.43 |

Lithologic Log

| Unit | Description | Depth (ft) |
|---|---|---|
| TOPSOIL |  | 0-1 |
| CLAY | yellowish brown, silty, sandy with pebbles, oxidized till | 1-4 |
| CLAY | yellowish brown, silty, plastic | 4-9 |
| SAND | very fine to fine, 80 % shale | 9-11 |
| CLAY | yellowish brown, silty, lake clays | 11-16 |
| CLAY | as above, more sandy | 16-20 |
| CLAY | olive gray, sandy | 20-24 |
| CLAY | as above, interbedded with very fine sand | 24-31 |
| CLAY | olive gray till | 31-71 |
| GRAVEL | sandy, 80 % shale | 71-72 |
| CLAY | olive gray till | 72-74 |
| GRAVEL | sandy, 80 % shale, 10 % carbonates, 10 % igneous, well rounded to subrounded, taking water, rocky | 74-98 |

| | | |
|---|---|---|
| CLAY | till as above, rocky | 98-100 |

## 153-064-09ABD3
## NDSWC 12077C

| | | | |
|---|---|---|---|
| Date Completed: | 5/26/88 | Well Type: | 2 inch PVC |
| Depth Drilled (ft): | 15 | Principal Aquifer: | Lake Clay |
| Screened Interval (ft): | 10-15 | L.S. Elevation (ft) | 1443.39 |

### Lithologic Log

| Unit | Description | Depth (ft) |
|---|---|---|
| TOPSOIL | | 0-1 |
| CLAY | yellowish brown, very sandy with pebbles, oxidized till | 1-7 |
| SAND | oxidized | 7-11 |
| CLAY | silty, yellowish brown, oxidized | 11-12 |
| CLAY | olive gray, silty, sandy with pebbles, till | 12-15 |

## 153-064-09BAD1
## NDSWC 12073A

| | | | |
|---|---|---|---|
| Date Completed: | 5/24/88 | Well Type: | 2 inch PVC |
| Depth Drilled (ft): | 100 | Principal Aquifer: | Pierre Formation |
| Screened Interval (ft): | 93-98 | L.S. Elevation (ft) | 1443.41 |

### Lithologic Log

| Unit | Description | Depth (ft) |
|---|---|---|
| TOPSOIL | | 0-1 |
| CLAY | light gray, very sandy | 1-3 |
| CLAY | yellowish brown, oxidized, very fine sand in clay, lake clays | 3-14 |
| CLAY | olive gray, very fine sand, lake clays, more sandy at 17 feet | 14-17 |
| SAND | very fine, some clay, olive gray | 17-25 |
| CLAY | silty, sandy, olive gray, pebbles to rocks, till | 25-42 |
| SAND | fine to coarse, mostly shale, well rounded to subrounded | 42-47 |
| CLAY | olive gray, silty | 47-54 |
| SHALE | gray to black, brittle, drills choppy, shales are angular occasional chunk of whitish gray sandstone/siltstone | 54-100 |

**153-064-09BAD2**
**NDSWC 12073B**

| | | | |
|---|---|---|---|
| Date Completed: | 5/24/88 | Well Type: | 2 inch PVC |
| Depth Drilled (ft): | 50 | Principal Aquifer: | Gravel |
| Screened Interval (ft): | 43-48 | L.S. Elevation (ft) | 1443.43 |

Lithologic Log

| Unit | Description | Depth (ft) |
|---|---|---|
| TOPSOIL | | 0-1 |
| CLAY | Whitish gray, silty | 1-3 |
| CLAY | silty, very fine sand, yellowish brown, iron stained, Lake Clays | 3-16 |
| CLAY | olive gray, silty, sandy, Lake Clays | 16-28 |
| CLAY | olive gray, silty, sandy with pebbles, till, abundant gravel | 28-42 |
| GRAVEL | sandy, well rounded to subrounded, 60 % shale, drills choppy and fast | 42-50 |

**153-064-09BAD3**
**NDSWC 12073C**

| | | | |
|---|---|---|---|
| Date Completed: | 5/24/88 | Well Type: | 2 inch PVC |
| Depth Drilled (ft): | 15 | Principal Aquifer: | Lake Clay |
| Screened Interval (ft): | 10-15 | L.S. Elevation (ft) | 1443.39 |

Lithologic Log

| Unit | Description | Depth (ft) |
|---|---|---|
| TOPSOIL | | 0-1 |
| CLAY | yellowish brown, silty, sandy with pebbles, till | 1-3 |
| CLAY | very fine sand, silty, yellowish brown, oxidized lake clays | 3-15 |

**153-064-09BBC1**
**NDSWC 12074A**

| | | | |
|---|---|---|---|
| Date Completed: | 5/24/88 | Well Type: | 2 inch PVC |
| Depth Drilled (ft): | 100 | Principal Aquifer: | Pierre Formation |
| Screened Interval (ft): | 92-97 | L.S. Elevation (ft) | 1439.69 |

Lithologic Log

| Unit | Description | Depth (ft) |
|---|---|---|
| TOPSOIL | | 0-1 |
| CLAY | yellowish brown, silty, with very fine sand, oxidized lake | 1-4 |

| | | |
|---|---|---|
| | clays | |
| CLAY | yellowish brown, iron stained, silty sandy with pebbles, oxidized | 4-19 |
| CLAY | olive gray, silty, sandy with pebbles, poorly sorted, rocky, till | 19-55 |
| CLAY | olive gray very sandy | 55-58 |
| SHALE | gray to black, gravels, 50 % angular shale and 50 % well rounded to subrounded gravel, mostly shale gravels, some bentonite chunks | 58-67 |
| SHALE | black, brittle, angular, drills choppy, Pierre shale | 67-100 |

### 153-064-09BBC2
### NDSWC 12074B

| | | | |
|---|---|---|---|
| Date Completed: | 5/24/88 | Well Type: | 2 inch PVC |
| Depth Drilled (ft): | 67 | Principal Aquifer: | Sand |
| Screened Interval (ft): | 58-63 | L.S. Elevation (ft) | 1439.72 |

Lithologic Log

| Unit | Description | Depth (ft) |
|---|---|---|
| TOPSOIL | | 0-1 |
| CLAY | yellowish brown, oxidized, iron stained, silty, Lake Clays | 1-3 |
| CLAY | yellowish brown, silty, sandy with pebbles, oxidized till | 3-20 |
| CLAY | olive gray, silty, sandy with pebbles, 80 % shale | 20-57 |
| SAND | very fine to fine, some gravel, 80 % shale, well rounded to subrounded | 57-67 |

### 153-064-09BBC3
### NDSWC 12074C

| | | | |
|---|---|---|---|
| Date Completed: | 5/24/88 | Well Type: | 2 inch PVC |
| Depth Drilled (ft): | 15 | Principal Aquifer: | Till |
| Screened Interval (ft): | 10-15 | L.S. Elevation (ft) | 1439.72 |

Lithologic Log

| Unit | Description | Depth (ft) |
|---|---|---|
| TOPSOIL | | 0-1 |
| CLAY | yellowish brown, oxidized | 1-4 |
| CLAY | yellowish brown, silty, sandy with pebbles, till | 4-15 |

### 153-064-09DCA1
### NDSWC 12083A

| | | | |
|---|---|---|---|
| Date Completed: | 6/2/88 | Well Type: | 2 inch PVC |
| Depth Drilled (ft): | 100 | Principal Aquifer: | Pierre Formation |
| Screened Interval (ft): | 85-95 | L.S. Elevation (ft) | 1443.67 |

Lithologic Log

| Unit | Description | Depth (ft) |
|---|---|---|
| TOPSOIL | | 0-1 |
| CLAY | whitish gray, greasy | 1-5 |
| CLAY | yellowish brown, silty, very sandy with pebbles, oxidized till | 5-14 |
| CLAY | olive gray, silty, sandy with pebbles, shale gravel from 21 to 23 feet and 29 to 31 feet, (till) | 14-36 |
| SHALE | black, brittle, interbedded with 1/2 foot stringers of shale gravel, some black clay, shale drills as if fractured | 36-46 |
| SHALE | as above, no sand and gravel | 46-67 |
| GRAVEL | mostly shale, poor return | 67-69 |
| SHALE | black brittle, fractured | 69-100 |

### 153-064-09DCA2
### NDSWC 12083B

| | | | |
|---|---|---|---|
| Date Completed: | 6/2/88 | Well Type: | 2 inch PVC |
| Depth Drilled (ft): | 50 | Principal Aquifer: | Pierre Formation |
| Screened Interval (ft): | 38-48 | L.S. Elevation (ft) | 1443.64 |

Lithologic Log

| Unit | Description | Depth (ft) |
|---|---|---|
| TOPSOIL | | 0-1 |
| CLAY | yellowish brown, silty, oxidized | 1-7 |
| CLAY | yellowish brown, silty, sandy with pebbles, oxidized till | 7-24 |
| CLAY | till as above, interbedded with sand and gravel | 24-36 |
| SHALE | black, brittle, drills as if fractured | 36-50 |

### 153-064-09DCA3
### NDSWC 12083C

| | | | |
|---|---|---|---|
| Date Completed: | 6/2/88 | Well Type: | 2 inch PVC |
| Depth Drilled (ft): | 20 | Principal Aquifer: | Till |

| | | | |
|---|---|---|---|
| Screened Interval (ft): | 10-20 | L.S. Elevation (ft) | 1443.62 |

Lithologic Log

| Unit | Description | Depth (ft) |
|---|---|---|
| TOPSOIL | | 0-1 |
| CLAY | yellowish brown, greasy, plastic, cohesive, Lake Clays | 1-6 |
| CLAY | yellowish brown, silty, sandy with pebbles, rocky, oxidized till | 6-20 |

### 153-064-09DDA1
### NDSWC 12078A

| | | | |
|---|---|---|---|
| Date Completed: | 5/26/88 | Well Type: | 2 inch PVC |
| Depth Drilled (ft): | 100 | Principal Aquifer: | Pierre Formation |
| Screened Interval (ft): | 93-98 | L.S. Elevation (ft): | 1438.97 |

Lithologic Log

| Unit | Description | Depth (ft) |
|---|---|---|
| TOPSOIL | | 0-1 |
| CLAY | yellowish brown, oxidized lake clays | 1-6 |
| CLAY | yellowish brown, oxidized till | 6-10 |
| SAND | oxidized, 80 % shale | 10-13 |
| CLAY | oxidized till | 13-14 |
| GRAVEL | shale, oxidized, sandy | 14-16 |
| CLAY | oxidized till as above | 16-19 |
| CLAY | olive gray, silty sandy with pebbles, till | 19-21 |
| SHALE | black, brittle, drills as if fractured, minor interbeds of black, sandy clay and bentonite, Pierre shale, bedrock | 21-100 |

### 153-064-09DDA2
### NDSWC 12078B

| | | | |
|---|---|---|---|
| Date Completed: | 5/26/88 | Well Type: | 2 inch PVC |
| Depth Drilled (ft): | 27 | Principal Aquifer: | Pierre Formation |
| Screened Interval (ft): | 18-23 | L.S. Elevation (ft) | 1438.98 |

Lithologic Log

| Unit | Description | Depth (ft) |
|---|---|---|
| TOPSOIL | | 0-1 |

| | | |
|---|---|---|
| CLAY | yellowish brown, silty, Lake Clays | 1-6 |
| CLAY | yellowish brown, silty, sandy with pebbles, oxidized till | 6-10 |
| SAND | and gravel, oxidized | 10-12 |
| CLAY | poor return | 12-17 |
| SHALE | black, brittle, interbedded with black silty clays, Pierre shale, bedrock | 17-27 |

### 153-064-10BBC2
### NDSWC 12082A

| | | | |
|---|---|---|---|
| Date Completed: | 6/2/88 | Well Type: | 2 inch PVC |
| Depth Drilled (ft): | 70 | Principal Aquifer: | Pierre Formation |
| Screened Interval (ft): | 64-69 | L.S. Elevation (ft) | 1438.55 |

Lithologic Log

| Unit | Description | Depth (ft) |
|---|---|---|
| TOPSOIL | | 0-1 |
| CLAY | yellowish brown, plastic, cohesive, Lake Clays | 1-10 |
| CLAY | as above, olive gray | 10-12 |
| CLAY | olive gray, silty, sandy with pebbles, till | 12-62 |
| SHALE | black, brittle, drills choppy, some greasy black clays, Pierre shale, bedrock | 62-70 |

### 153-064-21CCC1
### NDSWC 12080A

| | | | |
|---|---|---|---|
| Date Completed: | 6/1/88 | Well Type: | 1 1/4 inch ABS |
| Depth Drilled (ft): | 250 | Principal Aquifer: | Spiritwood Aquifer |
| Screened Interval (ft): | 218-223 | L.S. Elevation (ft) | 1442.65 |

Lithologic Log

| Unit | Description | Depth (ft) |
|---|---|---|
| TOPSOIL | | 0-1 |
| CLAY | yellowish brown, very sandy, with pebbles, rocky, oxidized till | 1-16 |
| CLAY | olive gray, silty, very sandy with pebbles, rocky, till | 16-24 |
| CLAY | olive gray, plastic, sticky, drills smooth | 24-76 |
| SAND | very fine to fine, well rounded, good sorting, 80 % shale | 76-80 |

| | | |
|---|---|---|
| SAND | medium to coarse, 80 % shale, 20 % lignites, well rounded to subrounded | 80-101 |
| GRAVEL | well rounded to subrounded, 60 % shale, 20 % igneous, 10 % carbonates and 10 % lignites, some wood fragments, drills choppy, very coarse sand to pea size gravel, some rocks | 101-236 |
| SHALE | black, brittle, drills slow, Pierre Shale, bedrock | 236-250 |

## 153-064-21CCC2
## NDSWC 12080B

| | | | |
|---|---|---|---|
| Date Completed: | 6/1/88 | Well Type: | 1 1/4 inch ABS |
| Depth Drilled (ft): | 100 | Principal Aquifer: | Spiritwood Aquifer |
| Screened Interval (ft): | 93-98 | L.S. Elevation (ft) | 1442.3 |

Lithologic Log

| Unit | Description | Depth (ft) |
|---|---|---|
| TOPSOIL | | 0-1 |
| CLAY | yellowish brown, rocky, very sandy, till | 1-4 |
| GRAVEL | oxidized | 4-6 |
| CLAY | yellowish brown, till as above, oxidized | 6-14 |
| CLAY | olive gray, silty, sandy with pebbles, till | 14-26 |
| CLAY | olive gray, sticky, plastic, Lake Clays | 26-73 |
| SAND | very fine to medium, well rounded to subrounded, 2 % angular lignites, drills fast and clean | 73-100 |

## 153-064-21CCC3
## NDSWC 12080C

| | | | |
|---|---|---|---|
| Date Completed: | 6/1/88 | Well Type: | 2 inch PVC |
| Depth Drilled (ft): | 20 | Principal Aquifer: | Till |
| Screened Interval (ft): | 8.5-18.5 | L.S. Elevation (ft) | 1442.29 |

Lithologic Log

| Unit | Description | Depth (ft) |
|---|---|---|
| TOPSOIL | | 0-1 |
| CLAY | yellowish brown, silty sandy with pebbles, oxidized till | 1-14 |
| CLAY | olive gray, silty, sandy with pebbles, till | 13-20 |

### 154-064-31CDD1
### NDSWC 12081A

| | | | |
|---|---|---|---|
| Date Completed: | 6/2/88 | Well Type: | 2 inch PVC |
| Depth Drilled (ft): | 90 | Principal Aquifer: | Spiritwood Aquifer |
| Screened Interval (ft): | 69-74 | L.S. Elevation (ft) | 1456.31 |

Lithologic Log

| Unit | Description | Depth (ft) |
|---|---|---|
| TOPSOIL | | 0-1 |
| CLAY | yellowish brown, silty, very sandy, pebbled, rocky, oxidized till | 1-16 |
| CLAY | olive gray, silty, sandy with pebbles, till | 16-51 |
| SAND | poor return, probably fine and silty, drills fast | 51-57 |
| GRAVEL | sandy, drills choppy, medium sand to pea gravel, well rounded to subrounded, caving and taking water, 70 % shale, 10 % igneous and 20 % carbonates, some shale pebbles have angular edges, mixed 2 mud | 57-77 |
| CLAY | black, angular, few shale pebbles in clay matrix, drills slow, very sticky, | 77-90 |

### 154-064-31CDD2
### NDSWC 12081B

| | | | |
|---|---|---|---|
| Date Completed: | 6/1/88 | Well Type: | 2 inch PVC |
| Depth Drilled (ft): | 28 | Principal Aquifer: | Till |
| Screened Interval (ft): | 14.5-24.5 | L.S. Elevation (ft) | 1456.1 |

Lithologic Log

| Unit | Description | Depth (ft) |
|---|---|---|
| TOPSOIL | | 0-1 |
| CLAY | yellowish brown, silty, sandy with pebbles, oxidized till | 1-16 |
| CLAY | olive gray, silty, very sandy with pebbles, till | 16-28 |

### 154-064-33BBA1
### NDGS 9

| | | | |
|---|---|---|---|
| Date Completed: | 05/25/88 | Well Type: | 2 inch PVC |
| Depth Drilled (ft): | 23 | Principal Aquifer: | Sand |
| Screened Interval (ft): | 18-23 | L.S. Elevation (ft) | 1436.87 |

Lithologic Log

| Unit | Description | Depth (ft) |
|---|---|---|
| TOPSOIL | | 0-0.5 |

| | | |
|---|---|---|
| CLAY | red, bentonitic, gray laminated, iron staining, silt zones, moist lacustrine | 0.5-3 |
| SAND & GRAVEL | reddish stained, medium to coarse grained, 1/2 inch pebbles, some clay zones | 3-10 |
| TILL | gray, contains 3 to 6 inch thick sand and silt zones | 10-13 |
| SAND & GRAVEL | gray, medium to coarse sand to 1 and 1/2 inch pebbles, 40 to 60 % shale | 13-29 |
| TILL | gray, sandy at top, becomes coarser with depth | 20-23 |

**154-064-33BBA2**
**NDGS10**

| | | | |
|---|---|---|---|
| Date Completed: | 05/25/88 | Well Type: | 2 inch PVC |
| Depth Drilled (ft): | 10 | Principal Aquifer: | Sand |
| Screened Interval (ft): | 5-10 | L.S. Elevation (ft) | 1436.91 |

Lithologic Log

| Unit | Description | Depth (ft) |
|---|---|---|
| see log for 33 BBA 1 | | 0-0 |

**154-064-34CCB1**
**NDGS1**

| | | | |
|---|---|---|---|
| Date Completed: | 05/23/88 | Well Type: | 2 inch PVC |
| Depth Drilled (ft): | 28 | Principal Aquifer: | Till |
| Screened Interval (ft): | 18-28 | L.S. Elevation (ft) | 1427.92 |

Lithologic Log

| Unit | Description | Depth (ft) |
|---|---|---|
| TOPSOIL | | 0-1 |
| TILL | gray/brown, clay with pebbles, iron stained | 1-10 |
| TILL | gray clay with pebbles | 10-17 |
| SILT | gray, saturated | 17-17.5 |
| SAND | gray, fine, well sorted | 17.5-18 |
| SAND | gray, medium to coarse, some pebbles | 0-0 |
| TILL | gray, shale pebbles | 21-28 |

## 154-064-34CCB2
## NDGS6

|  |  |  |  |
|---|---|---|---|
| Date Completed: | 05/24/88 | Well Type: | 2 inch PVC |
| Depth Drilled (ft): | 17 | Principal Aquifer: | Till |
| Screened Interval (ft): | 8-13 | L.S. Elevation (ft) | 1427.77 |

Lithologic Log

| Unit | Description | Depth (ft) |
|---|---|---|
| TOPSOIL |  | 0-1 |
| CLAY | gray/brown, iron stained | 1-6 |
| TILL | gray/brown, iron stained | 6-10 |
| TILL | gray, clay with pebbles | 10-17 |

## 154-064-34CCB3
## NDSWC 12079A

|  |  |  |  |
|---|---|---|---|
| Date Completed: | 5/27/88 | Well Type: | 2 inch PVC |
| Depth Drilled (ft): | 100 | Principal Aquifer: | Pierre Formation |
| Screened Interval (ft): | 93-98 | L.S. Elevation (ft) | 1427.86 |

Lithologic Log

| Unit | Description | Depth (ft) |
|---|---|---|
| TOPSOIL |  | 0-1 |
| CLAY | yellowish brown, silty, sandy with shale pebbles, oxidized till | 1-11 |
| CLAY | olive gray, silty sandy with pebbles, unoxidized till | 11-21 |
| TILL | layered wtih 1/2 to 1 foot stringers of shale gravel | 21-25 |
| CLAY | olive gray till as above | 25-28 |
| GRAVEL | shale, poor return | 28-29 |
| CLAY | till as above | 29-54 |
| TILL | interbedded with 1/2 foot stringers of sand and gravel | 54-63 |
| GRAVEL | sandy, 80 % shale, 10 % limestone and 10 % igneous, well rounded to subrounded, drills fast, taking water | 63-82 |
| SHALE | black, brittle, layered with silty, black, greasy clay, also some bentonite, bedrock, Pierre Shale | 82-100 |

## 154-064-34CCB4
## NDSWC 12079B

| | | | |
|---|---|---|---|
| Date Completed: | 5/27/88 | Well Type: | 2 inch PVC |
| Depth Drilled (ft): | 80 | Principal aquifer: | Gravel |
| Screened Interval (ft): | 74-79 | L.S. Elevation (ft) | 1427.93 |

Lithologic Log

| Unit | Description | Depth (ft) |
|---|---|---|
| TOPSOIL | | 0-1 |
| CLAY | yellowish brown, iron stained, silty, sandy with pebbles, oxidized till | 1-11 |
| CLAY | olive gray, silty, sandy with pebbles, till, not as layered with sand and gravel as 34CCB3 | 11-72 |
| GRAVEL | sandy, 80 % shale, medium sand to pea gravel, interbedded with till, well rounded to subrounded, gravel not taking water | 72-80<br>0-0 |

# APPENDIX II
# Monitoring Well Completion Data

| Location | SWC Well No | Aq Code | L S Elev (feet) | Total Depth (feet) | Top Screen (feet) | Bottom Screen (feet) |
|---|---|---|---|---|---|---|
| 15306404ADDI | NDGS #7 | PRS | 1428.86 | 25 | 14.5 | 24.5 |
| 15306404ADD2 | NDGS #8 | PRS | 1428.82 | 8 | 8 | 13 |
| 15306404CAA1 | NDGS #2 | SND | 1428.56 | 25 | 19.5 | 24.5 |
| 15306404CAA2 | NDGS #3 | TIL | 1428.54 | 13 | 8 | 13 |
| 15306404CAA3 | 12075A | PRS | 1428.61 | 80 | 73 | 78 |
| 15306404CAA4 | 12075B | PRS | 1428.68 | 40 | 34 | 39 |
| 15306404DCC1 | NDGS #4 | SLT | 1428.01 | 25 | 19 | 24 |
| 15306404DCC2 | NDGS #5 | LCS | 1428.05 | 13 | 8 | 13 |
| 15306404DCC3 | 12076A | PRS | 1428.03 | 130 | 120 | 125 |
| 15306404DCC4 | 12076B | SND | 1428.08 | 95 | 80 | 85 |
| 15306405DDA1 | 12072A | PRS | 1437.17 | 80 | 73.2 | 78.2 |
| 15306404DDA2 | 12072B | PRS | 1437.18 | 40 | 35 | 40 |
| 15306405DDA3 | 12072C | TIL | 1437.28 | 10 | 5 | 10 |
| 15306409ABD1 | 12077A | PRS | 1443.41 | 134 | 125 | 130 |
| 15306409ABD2 | 12077B | GRV | 1443.43 | 100 | 85 | 90 |
| 15306409ABD3 | 12077C | LCS | 1443.39 | 15 | 10 | 15 |
| 15306409BAD1 | 12073A | PRS | 1443.41 | 100 | 93 | 98 |
| 15306409BAD2 | 12073B | GRV | 1443.43 | 50 | 43 | 48 |
| 15306409BAD3 | 12073C | LCS | 1443.39 | 15 | 10 | 15 |
| 15306409BBC1 | 12074A | PRS | 1439.69 | 100 | 92 | 97 |
| 15306409BBC2 | 12074B | SND | 1439.72 | 67 | 58 | 63 |
| 15306409BBC3 | 12074C | TIL | 1439.72 | 15 | 10 | 15 |
| 15306409DCA1 | 12083A | PRS | 1443.67 | 100 | 85 | 95 |
| 15306409DCA2 | 12083B | PRS | 1443.64 | 50 | 38 | 48 |
| 15306409DCA3 | 12083C | TIL | 1443.62 | 20 | 10 | 20 |
| 15306409DDA1 | 12078A | PRS | 1438.97 | 100 | 93 | 98 |
| 15306409DDA2 | 12078B | PRS | 1438.98 | 27 | 18 | 23 |
| 15306410BBC2 | 12082A | PRS | 1438.55 | 70 | 64 | 69 |
| 15306421CCC1 | 12080A | SPW | 1442.65 | 250 | 218 | 223 |
| 15306421CCC2 | 12080B | SPW | 1442.3 | 100 | 93 | 98 |
| 15306421CCC3 | 12080C | TIL | 1442.29 | 20 | 8.5 | 18.5 |
| 15406431CDD1 | 12081A | SPW | 1456.31 | 90 | 69 | 74 |
| 15406431CDD2 | 12081B | TIL | 1456.1 | 28 | 14.5 | 24.5 |
| 15406433BBA1 | NDGS #9 | SND | 1436.87 | 23 | 18 | 23 |
| 15406433BBA2 | NDGS #10 | SND | 1436.91 | 10 | 5 | 10 |
| 15406434CCB1 | NDGS #1 | TIL | 1427.92 | 28 | 18 | 28 |
| 15406434CCB2 | NDGS #6 | TIL | 1427.77 | 17 | 8 | 13 |
| 15406434CCB3 | 12079A | PRS | 1427.86 | 100 | 93 | 98 |
| 15406434CCB4 | 12079B | GRV | 1427.93 | 80 | 74 | 79 |

PRS, Pierre Shale
GRV, Gravel
SND, Sand
TIL, Till
LLS, Lake Clays
SPW, Spiritwood Aquifer

| Location | L.S. Elev. | Top of PVC | MP | Comments |
|---|---|---|---|---|
| 154-64-33BBA1 | 1436.87 | 1438.71 | 1.84 | NDGS #9, South |
| -33BBA2 | 1436.91 | 1439.29 | 2.38 | NDGS #10, North |
| 154-64-34CCB1 | 1427.92 | 1429.99 | 2.07 | NDGS #1, East |
| -34CCB2 | 1427.77 | 1430.03 | 2.26 | NDGS #6, West |
| -34CCB3 | 1427.86 | 1433.49 | 5.63 | First well north of NDGS pair |
| -34CCB4 | 1427.93 | 1436.17 | 8.24 | North well |
| 153-64-04ADD1 | 1428.86 | 1430.59 | 1.73 | NDGS #7, West |
| -04ADD2 | 1428.82 | 1431.58 | 2.76 | NDGS #8, East |
| 153-64-10BBC | 1438.62 | 1440.26 | 1.64 | North |
| -10BBC2 | 1438.55 | 1440.41 | 1.86 | South |
| 153-64-09ABD1 | 1440.21 | 1441.70 | 1.49 | West |
| -09ABD2 | 1440.33 | 1442.06 | 1.73 | Middle |
| -09ABD3 | 1440.42 | 1442.65 | 2.23 | East |
| 153-64-09BAD1 | 1443.41 | 1444.90 | 1.49 | East |
| -09BAD2 | 1443.43 | 1445.00 | 1.57 | Middle |
| -09BAD3 | 1443.39 | 1445.61 | 2.22 | West |
| 153-64-04DCC1 | 1428.01 | 1429.63 | 1.62 | NDGS #4, Western |
| -04DCC2 | 1428.05 | 1429.40 | 1.35 | NDGS #5, Eastern |
| -04DCC3 | 1428.03 | 1430.49 | 2.46 | First well SE of pair |
| -04DCC4 | 1428.08 | 1429.97 | 1.89 | South |
| 153-64-04CAA1 | 1428.56 | 1430.21 | 1.65 | NDGS #2, West |
| -04CAA2 | 1428.54 | 1429.01 | 0.47 | NDGS #3, East |
| -04CAA3 | 1428.61 | 1430.57 | 1.96 | First well south of NDGS pair |
| -04CAA4 | 1428.68 | 1430.62 | 1.94 | Southwest well |
| 153-64-05DAA1 | 1437.17 | 1439.44 | 2.27 | East |
| -05DAA2 | 1437.18 | 1439.21 | 2.03 | Middle |
| -05DAA3 | 1437.28 | 1439.42 | 2.14 | West |
| 153-64-09BBC1 | 1439.69 | 1442.68 | 2.99 | West |
| -09BBC2 | 1439.72 | 1441.02 | 1.30 | Middle |
| -09BBC3 | 1439.72 | 1441.90 | 2.18 | East |
| 154-64-31CDD1 | 1456.31 | 1458.44 | 2.13 | West |
| -31CDD2 | 1456.10 | 1457.20 | 1.10 | East |
| 153-64-09DDA1 | 1438.97 | 1440.82 | 1.85 | East |
| -09DDA2 | 1438.98 | 1440.62 | 1.64 | West |
| 153-64-09DCA1 | 1443.67 | 1445.87 | 2.20 | West |

|  |  |  |  |  |
|---|---|---|---|---|
| -09DCA2 | 1443.64 | 1445.35 | 1.71 | Middle |
| -09DCA3 | 1443.62 | 1445.64 | 2.02 | East |
| 153-64-21CCC1 | 1442.65 | 1445.17 | 2.52 | South |
| -21CCC2 | 1442.30 | 1444.12 | 1.82 | Middle |
| -21CCC3 | 1442.29 | 1444.35 | 2.06 | North |

# APPENDIX III
## Monitoring Well Water Levels

153-064-04ADD1 LS Elev (msl,ft)=1428.86
Pierre Shale SI (ft.)=14.5-24.5

| Date | Depth to Water (ft) | WL Elev (msl, ft) | Date | Depth to Water (ft) | WL Elev (msl, ft) |
|---|---|---|---|---|---|
| 06/16/88 | 4.31 | 1424.55 | 10/11/88 | 2.09 | 1426.77 |
| 06/22/88 | 4.61 | 1424.25 | 11/09/88 | 2.25 | 1426.61 |
| 06/29/88 | 4.29 | 1424.57 | | | |
| 07/19/88 | 3.69 | 1425.17 | 04/19/88 | 5.15 | 1423.71 |
| 08/03/88 | 3.10 | 1425.76 | 05/12/89 | 5.17 | 1423.69 |
| 09/07/88 | 2.24 | 1426.62 | | | |

153-064-04ADD2 LS Elev (msl, ft)=1428.82
Pierre Shale SI (ft.)=8-13

| Date | Depth to Water (ft) | WL Elev (msl, ft) | Date | Depth to Water (ft) | WL Elev (msl, ft) |
|---|---|---|---|---|---|
| 06/16/88 | 4.25 | 1424.57 | 10/11/88 | 2.33 | 1426.49 |
| 06/22/88 | 5.51 | 1423.31 | 11/09/88 | 2.87 | 1425.95 |
| 06/29/88 | 4.35 | 1424.47 | | | |
| 07/19/88 | 3.22 | 1425.60 | 04/19/89 | 5.05 | 1423.77 |
| 08/03/88 | 2.62 | 1426.20 | 05/12/89 | 3.98 | 1424.84 |
| 09/07/88 | 2.19 | 1426.63 | | | |

153-064-04CAA1 LS Elev (msl, ft)=1428.56
Sand SI (ft)=19.5-24.5

| Date | Depth to Water (ft) | WL Elev (msl, ft) | Date | Depth to Water (ft) | WL Elev (msl, ft) |
|---|---|---|---|---|---|
| 06/16/88 | 9.73 | 1418.83 | 09/07/88 | 5.39 | 1423.17 |
| 06/22/88 | 10.61 | 1417.95 | 10/11/88 | 6.19 | 1422.37 |
| 06/29/88 | 10.45 | 1418.11 | 11/09/88 | 8.74 | 1419.82 |
| 07/19/88 | 8.80 | 1419.76 | | | |
| 08/03/88 | 7.79 | 1420.77 | 05/12/89 | 5.20 | 1423.36 |

153-064-04CAA2 LS Elev (msl, ft)=1428.54
Till SI (ft.)=8-13

| Date | Depth to Water (ft) | WL Elev (msl, ft) | Date | Depth to Water (ft) | WL Elev (msl, ft) |
|---|---|---|---|---|---|
| 06/16/88 | 1.82 | 1426.72 | 09/07/88 | 3.13 | 1425.41 |
| 06/22/88 | 1.87 | 1426.67 | 10/11/88 | 3.71 | 1424.83 |
| 06/29/88 | 2.12 | 1426.42 | 11/09/88 | 3.93 | 1424.61 |
| 07/19/88 | 2.15 | 1426.39 | | | |
| 08/03/88 | 2.49 | 1426.05 | 05/12/89 | 3.25 | 1425.29 |

153-064-04CAA3
Pierre Shale

LS Elev (msl, ft)=1428.61
SI (ft.)=73-78

| Date | Depth to Water (ft) | WL Elev (msl, ft) | Date | Depth to Water (ft) | WL Elev (msl, ft) |
|---|---|---|---|---|---|
| 06/08/88 | 0.02 | 1428.59 | 09/07/88 | 1.48 | 1427.13 |
| 06/16/88 | 0.06 | 1428.55 | 10/11/88 | 1.91 | 1426.70 |
| 06/22/88 | 0.12 | 1428.49 | 11/09/88 | 2.08 | 1426.53 |
| 07/19/88 | 0.54 | 1428.07 | | | |
| 08/03/88 | 0.82 | 1427.79 | 05/12/89 | 2.01 | 1426.60 |

153-064-04CAA4
Pierre Shale

LS Elev (msl, ft)=1428.68
SI (ft.)=34-39

| Date | Depth to Water (ft) | WL Elev (msl, ft) | Date | Depth to Water (ft) | WL Elev (msl, ft) |
|---|---|---|---|---|---|
| 06/08/88 | -0.50 | 1429.18 | 09/07/88 | 1.90 | 1426.78 |
| 06/16/88 | 0.59 | 1428.09 | 10/11/88 | 2.36 | 1426.32 |
| 06/22/88 | 0.54 | 1428.14 | 11/09/88 | 2.54 | 1426.14 |
| 07/19/88 | 0.93 | 1427.75 | | | |
| 08/03/88 | 1.21 | 1427.47 | 05/12/89 | 2.33 | 1426.35 |

153-064-04DCC1
Silt

LS Elev (msl, ft)=1428.01
SI (ft.)=19-24

| Date | Depth to Water (ft) | WL Elev (msl, ft) | Date | Depth to Water (ft) | WL Elev (msl, ft) |
|---|---|---|---|---|---|
| 06/16/88 | 3.03 | 1424.98 | 10/11/88 | 4.92 | 1423.09 |
| 06/22/88 | 3.57 | 1424.44 | 11/09/88 | 4.31 | 1423.70 |
| 06/29/88 | 3.98 | 1424.03 | | | |
| 07/08/88 | 1.46 | 1426.55 | 05/12/89 | 1.70 | 1426.31 |
| 07/19/88 | 3.73 | 1424.28 | | | |
| 08/03/88 | 4.64 | 1423.37 | 04/17/90 | 2.94 | 1425.07 |
| 09/07/88 | 5.39 | 1422.62 | | | |

153-064-04DCC2
Lake Clay

LS Elev (msl, ft)=1428.05
SI (ft.)=8-13

| Date | Depth to Water (ft) | WL Elev (msl, ft) | Date | Depth to Water (ft) | WL Elev (msl, ft) |
|---|---|---|---|---|---|
| 06/16/88 | 2.70 | 1425.35 | 10/11/88 | 4.75 | 1423.30 |
| 06/22/88 | 3.10 | 1424.95 | 11/09/88 | 4.10 | 1423.95 |
| 06/29/88 | 3.68 | 1424.37 | | | |
| 07/08/88 | 1.31 | 1426.74 | 05/12/89 | 0.81 | 1427.24 |
| 07/19/88 | 3.56 | 1424.49 | | | |
| 08/03/88 | 4.40 | 1423.65 | 04/17/90 | 2.89 | 1425.16 |
| 09/07/88 | 5.20 | 1422.85 | | | |

153-064-04DCC3
Pierre Shale

LS Elev (msl, ft)=1428.03
SI (ft.)=120-125

| Date | Depth to Water (ft) | WL Elev (msl, ft) | Date | Depth to Water (ft) | WL Elev (msl, ft) |
|---|---|---|---|---|---|
| 06/08/88 | 39.24 | 1388.79 | 10/11/88 | 4.27 | 1423.76 |
| 06/16/88 | 46.51 | 1381.52 | 11/09/88 | 3.80 | 1424.23 |
| 06/22/88 | 32.24 | 1395.79 | | | |
| 07/08/88 | 10.72 | 1417.31 | 05/12/89 | 3.70 | 1424.33 |
| 07/19/88 | 5.14 | 1422.89 | | | |
| 08/03/88 | 4.65 | 1423.38 | 04/17/90 | 4.31 | 1423.72 |
| 09/07/88 | 4.76 | 1423.27 | | | |

153-064-04DCC4
Sand

LS Elev (msl, ft)=1428.08
SI (ft.)=80-85

| Date | Depth to Water (ft) | WL Elev (msl, ft) | Date | Depth to Water (ft) | WL Elev (msl, ft) |
|---|---|---|---|---|---|
| 06/08/88 | 2.77 | 1425.31 | 10/11/88 | 4.18 | 1423.90 |
| 06/16/88 | 1.84 | 1426.24 | 11/09/88 | 2.64 | 1425.44 |
| 06/22/88 | 3.45 | 1424.63 | | | |
| 07/08/88 | 3.20 | 1424.88 | 05/12/89 | 3.58 | 1424.50 |
| 07/19/88 | 3.82 | 1424.26 | | | |
| 08/03/88 | 4.52 | 1423.56 | 04/17/90 | 4.17 | 1423.91 |
| 09/07/88 | 4.65 | 1423.43 | | | |

153-064-05DDA1
Pierre Shale

LS Elev (msl, ft)=1437.17
SI (ft.)=73.2-78.2

| Date | Depth to Water (ft) | WL Elev (msl, ft) | Date | Depth to Water (ft) | WL Elev (msl, ft) |
|---|---|---|---|---|---|
| 06/08/88 | 7.69 | 1429.48 | 11/09/88 | 10.38 | 1426.79 |
| 06/15/88 | 7.78 | 1429.39 | 12/16/88 | 10.54 | 1426.63 |
| 06/22/88 | 7.92 | 1429.25 | | | |
| 07/08/88 | 7.91 | 1429.26 | 03/17/89 | 11.29 | 1425.88 |
| 07/19/88 | 8.36 | 1428.81 | 04/19/89 | 10.99 | 1426.18 |
| 08/03/88 | 8.59 | 1428.58 | 05/12/89 | 9.90 | 1427.27 |
| 09/07/88 | 9.46 | 1427.71 | | | |
| 10/12/88 | 10.20 | 1426.97 | 04/17/90 | 11.94 | 1425.23 |

153-064-05DDA2
Pierre Shale

LS Elev (msl, ft)=1437.18
SI (ft.)=35-40

| Date | Depth to Water (ft) | WL Elev (msl, ft) | Date | Depth to Water (ft) | WL Elev (msl, ft) |
|---|---|---|---|---|---|
| 06/08/88 | 6.52 | 1430.66 | 11/09/88 | 10.44 | 1426.74 |

| | | | | | |
|---|---|---|---|---|---|
| 06/15/88 | 6.72 | 1430.46 | 12/16/88 | 10.86 | 1426.32 |
| 06/22/88 | 7.09 | 1430.09 | | | |
| 07/08/88 | 7.53 | 1429.65 | 03/17/89 | 11.41 | 1425.77 |
| 07/19/88 | 7.61 | 1429.57 | 04/19/89 | 10.66 | 1426.52 |
| 08/03/88 | 8.24 | 1428.94 | 05/12/89 | 9.73 | 1427.45 |
| 09/07/88 | 9.06 | 1428.12 | | | |
| 10/12/88 | 10.12 | 1427.06 | 04/17/90 | 11.81 | 1425.37 |

153-064-05DDA3
Till

LS Elev (msl, ft)=1437.28
SI (ft.)=5-10

| Date | Depth to Water (ft) | WL Elev (msl, ft) | Date | Depth to Water (ft) | WL Elev (msl, ft) |
|---|---|---|---|---|---|
| 06/08/88 | 6.35 | 1430.93 | 07/19/88 | 7.56 | 1429.72 |
| 06/15/88 | 6.74 | 1430.54 | 08/03/88 | 8.30 | 1428.98 |
| 06/22/88 | 6.83 | 1430.45 | 09/07/88 | 9.18 | 1428.10 |
| 06/29/88 | 7.52 | 1429.76 | | | |
| 07/08/88 | 7.62 | 1429.66 | 05/12/89 | 9.95 | 1427.33 |

153-064-09ABD1
Pierre Shale

LS Elev (msl, ft)=1443.41
SI (ft.)=125-130

| Date | Depth to Water (ft) | WL Elev (msl, ft) | Date | Depth to Water (ft) | WL Elev (msl, ft) |
|---|---|---|---|---|---|
| 06/08/88 | 15.61 | 1427.80 | 10/11/88 | 16.99 | 1426.42 |
| 06/16/88 | 15.25 | 1428.16 | 11/09/88 | 16.44 | 1426.97 |
| 06/22/88 | 16.28 | 1427.13 | | | |
| 07/08/88 | 16.18 | 1427.23 | 05/12/89 | 16.51 | 1426.90 |
| 07/19/88 | 16.71 | 1426.70 | | | |
| 08/03/88 | 17.61 | 1425.80 | 04/17/90 | 17.14 | 1426.27 |
| 09/07/88 | 16.59 | 1426.82 | | | |

153-064-09ABD2
Gravel

LS Elev (msl, ft)-1443.43
SI (ft.)=85-90

| Date | Depth to Water (ft) | WL Elev (msl, ft) | Date | Depth to Water (ft) | WL Elev (msl, ft) |
|---|---|---|---|---|---|
| 06/08/88 | 15.77 | 1427.66 | 10/11/88 | 17.36 | 1426.07 |
| 06/16/88 | 15.80 | 1427.63 | 11/09/88 | 17.49 | 1425.94 |
| 06/22/88 | 16.37 | 1427.06 | | | |
| 07/08/88 | 16.25 | 1427.18 | 05/12/89 | 16.71 | 1426.72 |
| 07/19/88 | 16.93 | 1426.50 | | | |
| 08/03/88 | 17.69 | 1425.74 | 04/17/90 | 17.23 | 1426.20 |
| 09/07/88 | 17.75 | 1425.68 | | | |

153-064-09ABD3 LS Elev (msl, ft)=1443.39
Lake Clay SI (ft.)=10-15

| Date | Depth to Water (ft) | WL Elev (msl, ft) | Date | Depth to Water (ft) | WL Ele (msl, ft) |
|---|---|---|---|---|---|
| 06/08/88 | 10.91 | 1432.48 | 09/07/88 | 12.72 | 1430.67 |
| 06/16/88 | 11.15 | 1432.24 | 10/11/88 | 13.04 | 1430.35 |
| 06/22/88 | 11.34 | 1432.05 | 11/09/88 | 13.12 | 1430.27 |
| 06/29/88 | 11.24 | 1432.15 | | | |
| 07/08/88 | 11.46 | 1431.93 | 05/12/89 | 10.47 | 1432.92 |
| 07/19/88 | 11.89 | 1431.50 | | | |
| 08/03/88 | 12.13 | 1431.26 | 04/17/90 | 14.04 | 1429.35 |

153-064-09BAD1 LS Elev (msl, ft)=1443.41
Pierre Shale SI (ft.)=93-98

| Date | Depth to Water (ft) | WL Elev (msl, ft) | Date | Depth to Water (ft) | WL Elev (msl, ft) |
|---|---|---|---|---|---|
| 06/08/88 | 12.36 | 1431.05 | 11/09/88 | 14.96 | 1428.45 |
| 06/15/88 | 12.42 | 1430.99 | 12/16/88 | 14.94 | 1428.47 |
| 06/22/88 | 12.68 | 1430.73 | | | |
| 07/08/88 | 13.06 | 1430.35 | 03/17/89 | 15.75 | 1427.66 |
| 07/19/88 | 13.31 | 1430.10 | 04/19/89 | 15.24 | 1428.17 |
| 08/03/88 | 13.95 | 1429.46 | 05/12/89 | 14.43 | 1428.98 |
| 09/07/88 | 14.73 | 1428.68 | | | |
| 10/12/88 | 14.06 | 1429.35 | 04/17/90 | 16.99 | 1426.42 |

153-064-09BAD2 LS Elev (msl, ft)=1443.43
Gravel SI (ft.)=43-48

| Date | Depth to Water (ft) | WL Elev (msl, ft) | Date | Depth to Water (ft) | WL Elev (msl, ft) |
|---|---|---|---|---|---|
| 06/08/88 | 11.81 | 1431.62 | 11/09/88 | 14.62 | 1428.81 |
| 06/15/88 | 12.11 | 1431.32 | 12/16/88 | 15.07 | 1428.36 |
| 06/22/88 | 12.25 | 1431.18 | | | |
| 07/08/88 | 12.28 | 1431.15 | 03/17/89 | 15.20 | 1428.23 |
| 07/19/88 | 12.73 | 1430.70 | 04/19/89 | 14.68 | 1428.75 |
| 08/03/88 | 13.22 | 1430.21 | 05/12/89 | 13.68 | 1429.75 |
| 09/07/88 | 13.86 | 1429.57 | | | |
| 10/12/88 | 14.50 | 1428.93 | 04/17/90 | 16.31 | 1427.12 |

153-064-09BAD3 LS Elev (msl, ft.)=1443.39
Lake Clay SI (ft)=10-15

| Date | Depth to Water (ft) | WL Elev (msl, ft) | Date | Depth to Water (ft) | WL Elev (msl, ft) |
|---|---|---|---|---|---|

| | | | | | |
|---|---|---|---|---|---|
| 06/08/88 | 11.79 | 1431.60 | 09/07/88 | 13.46 | 1429.93 |
| 06/15/88 | 12.03 | 1431.36 | 10/11/88 | 13.51 | 1429.88 |
| 06/22/88 | 12.30 | 1431.09 | 11/09/88 | 14.61 | 1428.78 |
| 06/29/88 | 12.18 | 1431.21 | | | |
| 07/08/88 | 12.21 | 1431.18 | 04/19/89 | 14.68 | 1428.71 |
| 07/19/88 | 12.68 | 1430.71 | 05/12/89 | 13.75 | 1429.64 |
| 08/03/88 | 13.06 | 1430.33 | | | |

153-064-09BBC1
Pierre Shale

LS Elev (msl, ft)=1439.69
SI (ft.)=92-97

| Date | Depth to Water (ft) | WL Elev (msl, ft) | Date | Depth to Water (ft) | WL Elev (msl, ft) |
|---|---|---|---|---|---|
| 06/08/88 | 8.91 | 1430.78 | 11/09/88 | 11.68 | 1428.01 |
| 06/15/88 | 9.16 | 1430.53 | 12/16/88 | 11.69 | 1428.00 |
| 06/22/88 | 9.25 | 1430.44 | | | |
| 07/08/88 | 9.23 | 1430.46 | 04/19/89 | 11.89 | 1427.80 |
| 07/19/88 | 9.84 | 1429.85 | 05/12/89 | 8.08 | 1431.61 |
| 08/03/88 | 10.25 | 1429.44 | | | |
| 09/07/88 | 11.23 | 1428.46 | 04/17/90 | 13.39 | 1426.30 |
| 10/12/88 | 11.58 | 1428.11 | | | |

153-064-09BBC2
Sand

LS Elev (msl, ft)=1439.72
SI (ft.)=58-63

| Date | Depth to Water (ft) | WL Elev (msl, ft) | Date | Depth to Water (ft) | WL Elev (msl, ft) |
|---|---|---|---|---|---|
| 06/08/88 | 6.67 | 1433.05 | 11/09/88 | 9.82 | 1429.90 |
| 06/15/88 | 6.72 | 1433.00 | 12/16/88 | 10.03 | 1429.69 |
| 06/22/88 | 6.97 | 1432.75 | | | |
| 07/08/88 | 6.76 | 1432.96 | 04/19/89 | 10.52 | 1429.20 |
| 07/19/88 | 7.30 | 1432.42 | 05/12/89 | 9.77 | 1429.95 |
| 08/03/88 | 7.77 | 1431.95 | | | |
| 09/07/88 | 8.87 | 1430.85 | 04/17/90 | 12.35 | 1427.37 |
| 10/12/88 | 9.64 | 1430.08 | | | |

153-064-09BBC3
Till

LS Elev (msl, ft)=1439.72
SI (ft.)=10-15

| Date | Depth to Water (ft) | WL Elev (msl, ft) | Date | Depth to Water (ft) | WL Elev (msl, ft) |
|---|---|---|---|---|---|
| 06/08/88 | 6.39 | 1433.33 | 10/12/88 | 11.40 | 1428.32 |
| 06/15/88 | 6.97 | 1432.75 | 11/09/88 | 11.56 | 1428.16 |
| 06/22/88 | 7.37 | 1432.35 | 12/16/88 | 12.04 | 1427.68 |
| 06/29/88 | 7.64 | 1432.08 | | | |
| 07/08/88 | 8.06 | 1431.66 | 05/12/89 | 5.14 | 1434.58 |
| 07/19/88 | 8.52 | 1431.20 | | | |

| | | | | | |
|---|---|---|---|---|---|
| 08/03/88 | 9.22 | 1430.50 | 04/17/90 | 11.14 | 1428.58 |
| 09/07/88 | 10.22 | 1429.50 | | | |

153-064-09DCA1
Pierre Shale

LS Elev (msl, ft)=1443.67
SI (ft.)=85-95

| Date | Depth to Water (ft) | WL Elev (msl, ft) | Date | Depth to Water (ft) | WL Elev (msl, ft) |
|---|---|---|---|---|---|
| 06/08/88 | 19.75 | 1423.92 | 11/09/88 | 20.21 | 1423.46 |
| 06/16/88 | 20.17 | 1423.50 | 12/16/88 | 19.37 | 1424.30 |
| 06/22/88 | 20.56 | 1423.11 | | | |
| 07/06/88 | 20.61 | 1423.06 | 03/17/89 | 18.97 | 1424.70 |
| 07/19/88 | 20.64 | 1423.03 | 04/19/89 | 19.31 | 1424.36 |
| 08/03/88 | 21.71 | 1421.96 | 05/12/89 | 20.29 | 1423.38 |
| 09/07/88 | 21.78 | 1421.89 | | | |
| 10/12/88 | 23.03 | 1420.64 | 04/17/90 | 21.52 | 1422.15 |

153-064-09DCA2
Pierre Shale

LS Elev (msl, ft)=1443.64
SI (ft.)=38-48

| Date | Depth to water (ft) | WL Elev (msl, ft) | Date | Depth to Water (ft) | WL Elev (msl, ft) |
|---|---|---|---|---|---|
| 06/08/88 | 12.54 | 1431.10 | 11/09/88 | 15.39 | 1428.25 |
| 06/16/88 | 12.72 | 1430.92 | 12/16/88 | 15.54 | 1428.10 |
| 06/22/88 | 12.78 | 1430.86 | | | |
| 07/06/88 | 12.87 | 1430.77 | 03/17/89 | 15.93 | 1427.71 |
| 07/19/88 | 13.59 | 1430.05 | 04/19/89 | 15.77 | 1427.87 |
| 08/03/88 | 13.95 | 1429.69 | 05/12/89 | 15.33 | 1428.31 |
| 09/07/88 | 14.67 | 1428.97 | | | |
| 10/12/88 | 15.44 | 1428.20 | 04/17/90 | 18.48 | 1425.16 |

153-064-09DCA3
Till

LS Elev (msl, ft)=1443.62
SI (ft.)=10-20

| Date | Depth to Water (ft) | WL Elev (msl, ft) | Date | Depth to Water (ft) | WL Elev (msl, ft) |
|---|---|---|---|---|---|
| 06/08/88 | 8.51 | 1435.11 | 11/09/88 | 12.68 | 1430.94 |
| 06/16/88 | 8.72 | 1434.90 | 12/16/88 | 13.22 | 1430.40 |
| 06/22/88 | 9.11 | 1434.51 | | | |
| 06/29/88 | 9.04 | 1434.58 | 03/17/89 | 13.92 | 1429.70 |
| 07/06/88 | 9.15 | 1434.47 | 04/19/89 | 13.65 | 1429.97 |
| 07/19/88 | 9.69 | 1433.93 | 05/12/89 | 11.84 | 1431.78 |
| 08/03/88 | 10.24 | 1433.38 | | | |
| 09/07/88 | 10.97 | 1432.65 | 04/17/90 | 15.36 | 1428.26 |
| 10/12/88 | 12.64 | 1431.46 | | | |

153-064-09DDA1 LS Elev (msl, ft)=1438.97
Pierre Shale SI (ft.)=93-98

| Date | Depth to Water (ft) | WL Elev (msl, ft) | Date | Depth to Water (ft) | WL Elev (msl, ft) |
|---|---|---|---|---|---|
| 06/08/88 | 11.85 | 1427.12 | 11/09/88 | 12.48 | 1426.49 |
| 06/16/88 | 11.69 | 1427.28 | 12/16/88 | 12.56 | 1426.41 |
| 06/22/88 | 11.83 | 1427.14 | | | |
| 07/06/88 | 11.55 | 1427.42 | 03/17/89 | 13.82 | 1425.15 |
| 07/19/88 | 11.81 | 1427.16 | 04/19/89 | 14.25 | 1424.72 |
| 08/03/88 | 12.84 | 1426.13 | 05/12/89 | 14.37 | 1424.60 |
| 09/07/88 | 12.55 | 1426.42 | | | |
| 10/12/88 | 12.74 | 1426.23 | 04/17/90 | 16.22 | 1422.75 |

153-064-09DDA2 LS Elev (msl, ft)=1438.98
Pierre Shale SI (ft.)=18-23

| Date | Depth to Water (ft) | WL Elev (msl, ft) | Date | Depth to Water (ft) | WL Elev (msl, ft) |
|---|---|---|---|---|---|
| 06/08/88 | 6.75 | 1432.23 | 11/09/88 | 9.78 | 1429.20 |
| 06/16/88 | 6.83 | 1432.15 | 12/16/88 | 10.39 | 1428.59 |
| 06/22/88 | 6.95 | 1432.03 | | | |
| 06/29/88 | 6.94 | 1432.04 | 03/17/89 | 11.26 | 1427.72 |
| 07/06/88 | 6.88 | 1432.10 | 04/19/89 | 11.04 | 1427.94 |
| 07/19/88 | 7.23 | 1431.75 | 05/12/89 | 10.56 | 1428.42 |
| 08/03/88 | 7.71 | 1431.27 | | | |
| 09/07/88 | 8.35 | 1430.63 | 04/17/90 | 13.13 | 1425.85 |
| 10/12/88 | 9.39 | 1429.59 | | | |

153-064-10BBC2 LS Elev (msl, ft)=1438.55
Pierre Shale SI (ft.)=64-69

| Date | Depth to Water (ft) | WL Elev (msl, ft) | Date | Depth to Water (ft) | WL Elev (msl, ft) |
|---|---|---|---|---|---|
| 06/08/88 | 6.19 | 1432.36 | 08/08/89 | 10.49 | 1428.06 |
| 06/15/88 | 7.53 | 1431.02 | 09/12/89 | 10.37 | 1428.18 |
| 06/22/88 | 7.68 | 1430.87 | 10/12/89 | 10.44 | 1428.11 |
| 07/06/88 | 7.67 | 1430.88 | 12/20/89 | 10.07 | 1428.48 |
| 07/19/88 | 8.07 | 1430.48 | | | |
| 08/03/88 | 8.59 | 1429.96 | 02/07/90 | 10.20 | 1428.35 |
| 09/07/88 | 9.22 | 1429.33 | 04/16/90 | 10.33 | 1428.22 |
| 10/12/88 | 9.78 | 1428.77 | 05/16/90 | 9.78 | 1428.77 |
| 11/09/88 | 9.72 | 1428.83 | 06/13/90 | 9.30 | 1429.25 |
| 12/16/88 | 9.81 | 1428.74 | 07/10/90 | 8.69 | 1429.86 |
| | | | 08/09/90 | 8.79 | 1429.76 |
| 03/17/89 | 9.98 | 1428.57 | 09/07/90 | 9.29 | 1429.26 |
| 04/19/89 | 8.94 | 1429.61 | 10/02/90 | 9.60 | 1428.95 |
| 05/12/89 | 8.40 | 1430.15 | 10/31/90 | 9.61 | 1428.94 |

| | | | | | |
|---|---|---|---|---|---|
| 06/15/89 | 9.50 | 1429.05 | 11/28/90 | 9.57 | 1428.98 |
| 07/13/89 | 9.36 | 1429.19 | | | |

153-064-21CCC1
Spiritwood Aquifer

LS Elev (msl, ft) = 1442.65
SI (ft.) = 218-223

| Date | Depth to Water (ft) | WL Elev (msl, ft) | Date | Depth to Water (ft) | WL Elev (msl, ft) |
|---|---|---|---|---|---|
| 06/08/88 | 15.46 | 1427.19 | 08/08/89 | 19.34 | 1423.31 |
| 06/16/88 | 15.65 | 1427.00 | 09/12/89 | 18.68 | 1423.97 |
| 06/22/88 | 15.83 | 1426.82 | 10/12/89 | 18.53 | 1424.12 |
| 07/06/88 | 16.20 | 1426.45 | 12/20/89 | 18.12 | 1424.53 |
| 07/19/88 | 16.67 | 1425.98 | | | |
| 08/03/88 | 17.49 | 1425.16 | 02/07/90 | 17.87 | 1424.78 |
| 09/07/88 | 18.42 | 1424.23 | 04/17/90 | 18.03 | 1424.62 |
| 10/12/88 | 17.20 | 1425.45 | 05/16/90 | 18.44 | 1424.21 |
| 11/09/88 | 16.83 | 1425.82 | 06/13/90 | 18.80 | 1423.85 |
| 12/15/88 | 16.66 | 1425.99 | 07/10/90 | 19.03 | 1423.62 |
| | | | 08/09/90 | 20.04 | 1422.61 |
| 03/17/89 | 16.17 | 1426.48 | 09/07/90 | 20.34 | 1422.31 |
| 04/19/89 | 16.17 | 1426.48 | 10/02/90 | 20.09 | 1422.56 |
| 05/12/89 | 16.57 | 1426.08 | 10/31/90 | 19.98 | 1422.67 |
| 06/15/89 | 17.11 | 1425.54 | 11/28/90 | 19.63 | 1423.02 |
| 07/12/89 | 18.37 | 1424.28 | | | |

153-064-21CCC2
Spiritwood Aquifer

LS Elev (msl, ft) = 1442.3
SI (ft.) = 93-98

| Date | Depth to Water (ft) | WL Elev (msl, ft) | Date | Depth to Water (ft) | WL Elev (msl, ft) |
|---|---|---|---|---|---|
| 06/08/88 | 15.06 | 1427.24 | 08/08/89 | 18.93 | 1423.37 |
| 06/16/88 | 14.20 | 1428.10 | 09/12/89 | 18.25 | 1424.05 |
| 06/22/88 | 15.43 | 1426.87 | 10/12/89 | 18.11 | 1424.19 |
| 07/06/88 | 15.78 | 1426.52 | 12/20/89 | 17.71 | 1424.59 |
| 07/19/88 | 16.20 | 1426.10 | | | |
| 08/03/88 | 17.08 | 1425.22 | 02/07/90 | 17.47 | 1424.83 |
| 09/07/88 | 17.13 | 1425.17 | 04/17/90 | 17.63 | 1424.67 |
| 10/12/88 | 16.78 | 1425.52 | 05/16/90 | 18.04 | 1424.26 |
| 11/09/88 | 16.42 | 1425.88 | 06/13/90 | 18.37 | 1423.93 |
| 12/15/88 | 16.24 | 1426.06 | 07/10/90 | 18.60 | 1423.70 |
| | | | 08/09/90 | 19.62 | 1422.68 |
| 03/17/89 | 15.77 | 1426.53 | 09/07/90 | 19.93 | 1422.37 |
| 04/19/89 | 15.75 | 1426.55 | 10/02/90 | 19.68 | 1422.62 |
| 05/12/89 | 16.18 | 1426.12 | 10/31/90 | 19.57 | 1422.73 |
| 06/15/89 | 16.68 | 1425.62 | 11/28/90 | 19.24 | 1423.06 |
| 07/12/89 | 17.97 | 1424.33 | | | |

153-064-21CCC3
Till

LS Elev (msl, ft)=1442.29
SI (ft.)=8.5-18.5

| Date | Depth to Water (ft) | WL Elev (msl, ft) | Date | Depth to Water (ft) | WL Elev (msl, ft) |
|---|---|---|---|---|---|
| 06/08/88 | 11.64 | 1430.65 | 07/12/89 | 13.54 | 1428.75 |
| 06/16/88 | 11.58 | 1430.71 | 08/08/89 | 13.54 | 1428.75 |
| 06/22/88 | 11.78 | 1430.51 | 09/12/89 | 13.78 | 1428.51 |
| 06/29/88 | 11.49 | 1430.80 | 10/12/89 | 13.92 | 1428.37 |
| 07/06/88 | 11.47 | 1430.82 | 12/20/89 | 14.26 | 1428.03 |
| 07/19/88 | 11.93 | 1430.36 | | | |
| 08/03/88 | 12.10 | 1430.19 | 02/07/90 | 14.34 | 1427.95 |
| 09/07/88 | 12.11 | 1430.18 | 04/17/90 | 14.56 | 1427.73 |
| 10/12/88 | 12.68 | 1429.61 | 05/16/90 | 14.41 | 1427.88 |
| 11/09/88 | 12.97 | 1429.32 | 06/13/90 | 14.60 | 1427.69 |
| 12/15/88 | 13.27 | 1429.02 | 07/10/90 | 14.44 | 1427.85 |
| | | | 08/09/90 | 14.38 | 1427.91 |
| 03/17/89 | 13.42 | 1428.87 | 09/07/90 | 14.53 | 1427.76 |
| 04/19/89 | 13.53 | 1428.76 | 10/02/90 | 14.48 | 1427.81 |
| 05/12/89 | 13.49 | 1428.80 | 10/31/90 | 14.61 | 1427.68 |
| 06/15/89 | 13.44 | 1428.85 | 11/28/90 | 14.89 | 1427.40 |

154-064-31CDD1
Spiritwood Aquifer

LS Elev (msl, ft)=1456.31
SI (ft.)=69-74

| Date | Depth to Water (ft) | WL Elev (msl, ft) | Date | Depth to Water (ft) | WL Elev (msl, ft) |
|---|---|---|---|---|---|
| 06/08/88 | -0.79 | 1457.10 | 11/09/88 | 0.98 | 1455.33 |
| 06/15/88 | -0.89 | 1457.20 | 12/16/88 | 1.32 | 1454.99 |
| 06/22/88 | -0.96 | 1457.27 | | | |
| 07/08/88 | -1.17 | 1457.48 | 04/19/89 | 2.44 | 1453.87 |
| 07/19/88 | -0.64 | 1456.95 | 05/12/89 | 2.13 | 1454.18 |
| 08/03/88 | -0.39 | 1456.70 | | | |
| 09/07/88 | 0.23 | 1456.08 | 04/17/90 | 4.03 | 1452.28 |
| 10/12/88 | 0.74 | 1455.57 | | | |

154-064-31CDD2
Till

LS Elev (msl, ft)=1456.1
SI (ft.)=14.5-24.5

| Date | Depth to Water (ft) | WL Elev (msl, ft) | Date | Depth to Water (ft) | WL Elev (msl, ft) |
|---|---|---|---|---|---|
| 06/08/88 | 6.93 | 1449.17 | 11/09/88 | 10.36 | 1445.74 |
| 06/15/88 | 7.12 | 1448.98 | 12/16/88 | 10.47 | 1445.63 |
| 06/22/88 | 7.48 | 1448.62 | | | |
| 06/29/88 | 7.53 | 1448.57 | 03/20/89 | 10.25 | 1445.85 |
| 07/08/88 | 7.50 | 1448.60 | 04/19/89 | 6.24 | 1449.86 |
| 07/19/88 | 8.05 | 1448.05 | 05/12/89 | 7.37 | 1448.73 |
| 08/03/88 | 8.68 | 1447.42 | | | |

| | | | | | |
|---|---|---|---|---|---|
| 09/07/88 | 9.64 | 1446.46 | 04/17/90 | 10.51 | 1445.59 |
| 10/12/88 | 10.20 | 1445.90 | | | |

154-064-33BBA1
Sand

LS Elev (msl, ft)=1436.87
SI (ft.)=18-23

| Date | Depth to Water (ft) | WL Elev (msl, ft) | Date | Depth to Water (ft) | WL Elev (msl, ft) |
|---|---|---|---|---|---|
| 07/19/88 | -1.72 | 1438.59 | 11/09/88 | -0.20 | 1437.07 |
| 08/03/88 | -1.14 | 1438.01 | | | |
| 09/07/88 | -0.54 | 1437.41 | 04/19/89 | 0.29 | 1436.58 |
| 10/11/88 | -0.20 | 1437.07 | 05/12/89 | -1.08 | 1437.95 |

154-064-33BBA2
Sand

LS Elev (msl, ft)-1436.91
SI (ft.)=5-10

| Date | Depth to Water (ft) | WL Elev (msl, ft) | Date | Depth to Water (ft) | WL Elev (msl, ft) |
|---|---|---|---|---|---|
| 06/15/88 | 2.99 | 1433.92 | 10/12/88 | 4.59 | 1432.32 |
| 06/22/88 | 3.07 | 1433.84 | 11/09/88 | 4.13 | 1432.78 |
| 06/29/88 | 3.65 | 1433.26 | 12/16/88 | 4.41 | 1432.50 |
| 07/06/88 | 2.03 | 1434.88 | | | |
| 07/19/88 | 3.82 | 1433.09 | 03/17/89 | 5.06 | 1431.85 |
| 08/03/88 | 4.60 | 1432.31 | 04/19/89 | 0.76 | 1436.15 |
| 09/07/88 | 5.00 | 1431.91 | 05/12/89 | 2.05 | 1434.86 |

154-064-34CCB1
Till

LS Elev (msl, ft)=1427.92
SI (ft.)=18-28

| Date | Depth to Water (ft) | WL Elev (msl, ft) | Date | Depth to Water (ft) | WL Elev (msl, ft) |
|---|---|---|---|---|---|
| 06/15/88 | 1.18 | 1426.74 | 11/09/88 | 3.73 | 1424.19 |
| 06/22/88 | 1.34 | 1426.58 | 12/16/88 | 4.16 | 1423.76 |
| 06/29/88 | 1.26 | 1426.66 | | | |
| 07/06/88 | 1.38 | 1426.54 | 03/17/89 | 5.50 | 1422.42 |
| 07/19/88 | 1.58 | 1426.34 | 05/12/89 | 1.33 | 1426.59 |
| 08/03/88 | 1.80 | 1426.12 | | | |
| 09/07/88 | 2.52 | 1425.40 | 04/17/90 | 5.51 | 1422.41 |
| 10/12/88 | 3.56 | 1424.36 | | | |

154-064-34CCB2
Till

LS Elev (msl, ft)=1427.77
SI (ft.)=8-13

| Date | Depth to Water (ft) | WL Elev (msl, ft) |
|---|---|---|
| 06/15/88 | 1.74 | 1426.03 |
| 06/22/88 | 2.23 | 1425.54 |
| 06/29/88 | 2.86 | 1424.91 |
| 07/06/88 | 2.98 | 1424.79 |
| 07/19/88 | 3.26 | 1424.51 |
| 08/03/88 | 3.23 | 1424.54 |
| 09/07/88 | 4.11 | 1423.66 |
| 10/12/88 | 4.10 | 1423.67 |
| 11/09/88 | 3.72 | 1424.05 |
| 12/16/88 | 4.17 | 1423.60 |
| 03/17/89 | 6.29 | 1421.48 |
| 05/12/89 | 2.34 | 1425.43 |
| 04/17/90 | 4.79 | 1422.98 |

154-064-34CCB3
Pierre Shale

LS Elev (msl, ft)=1427.86
SI (ft.)=93-98

| Date | Depth to Water (ft) | WL Elev (msl, ft) |
|---|---|---|
| 07/06/88 | -4.98 | 1432.84 |
| 07/19/88 | -4.43 | 1432.29 |
| 08/03/88 | -3.94 | 1431.80 |
| 09/07/88 | -3.27 | 1431.13 |
| 10/11/88 | -3.11 | 1430.97 |
| 04/19/89 | -1.60 | 1429.46 |

154-064-34CCB4
Gravel

LS Elev (msl, ft)=1427.93
SI (ft.)=74-79

| Date | Depth to Water (ft) | WL Elev (msl, ft) |
|---|---|---|
| 06/15/88 | -4.76 | 1432.69 |
| 06/22/88 | -4.69 | 1432.62 |
| 06/29/88 | -4.88 | 1432.81 |
| 07/19/88 | -4.38 | 1432.31 |
| 08/03/88 | -3.86 | 1431.79 |
| 09/07/88 | -3.23 | 1431.16 |
| 10/12/88 | -3.09 | 1431.02 |
| 04/19/89 | -2.55 | 1430.48 |
| 05/12/89 | -3.98 | 1431.91 |

# APPENDIX IV
# Water Level Profiles

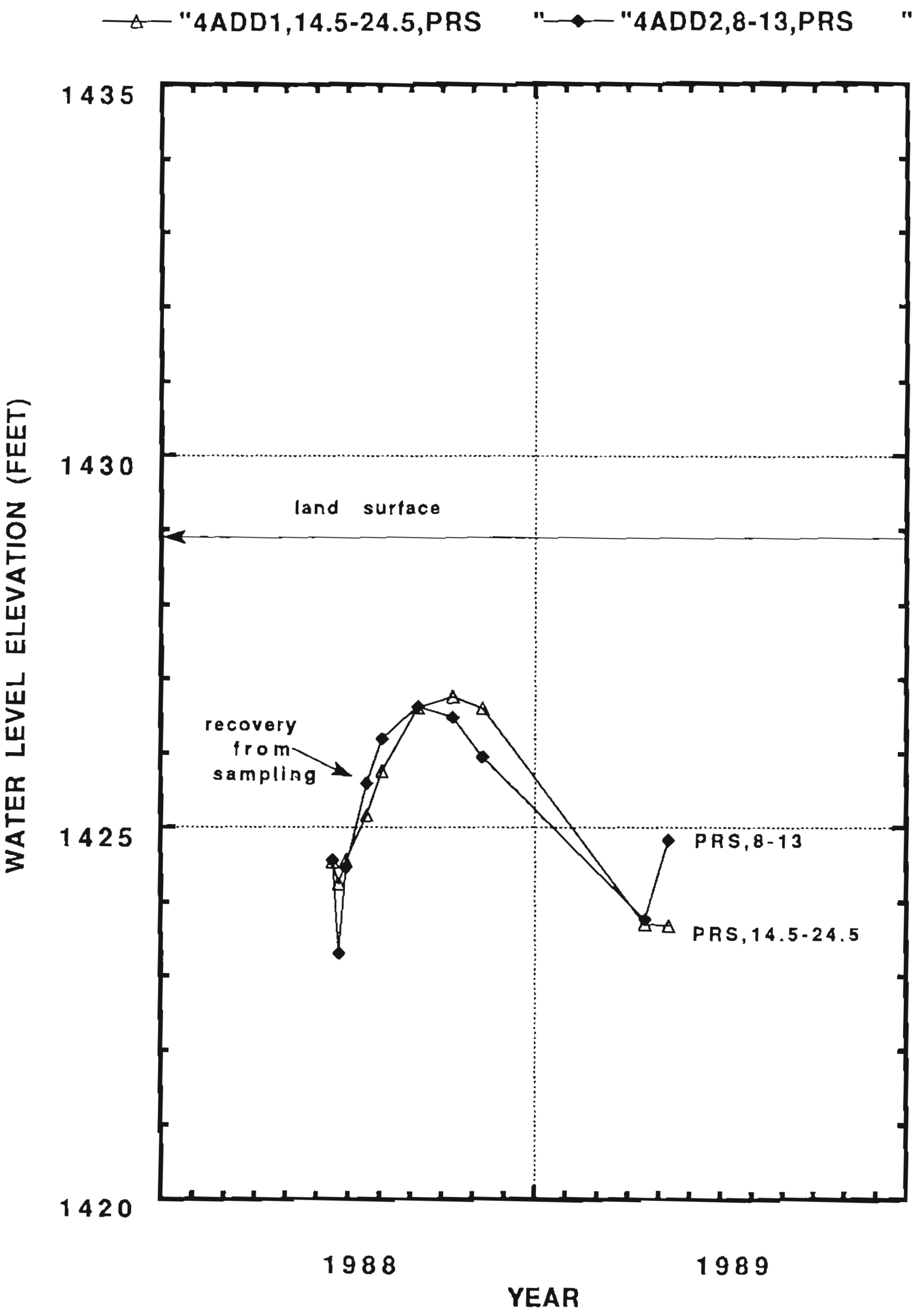

Figure 14. Water levels from wells in section 4, ADD.

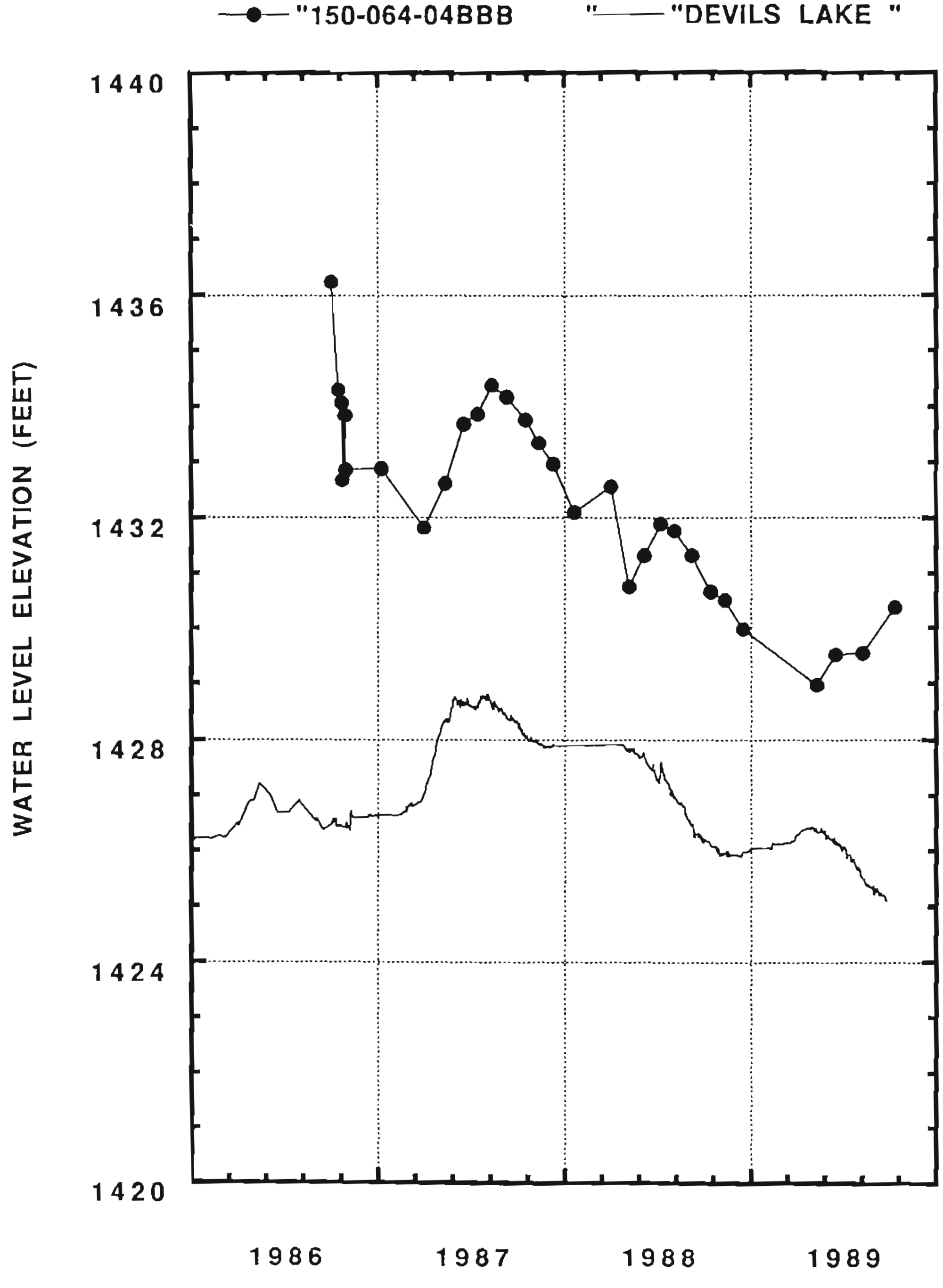

Figure 15. Water levels from wells in section 4, BBB.

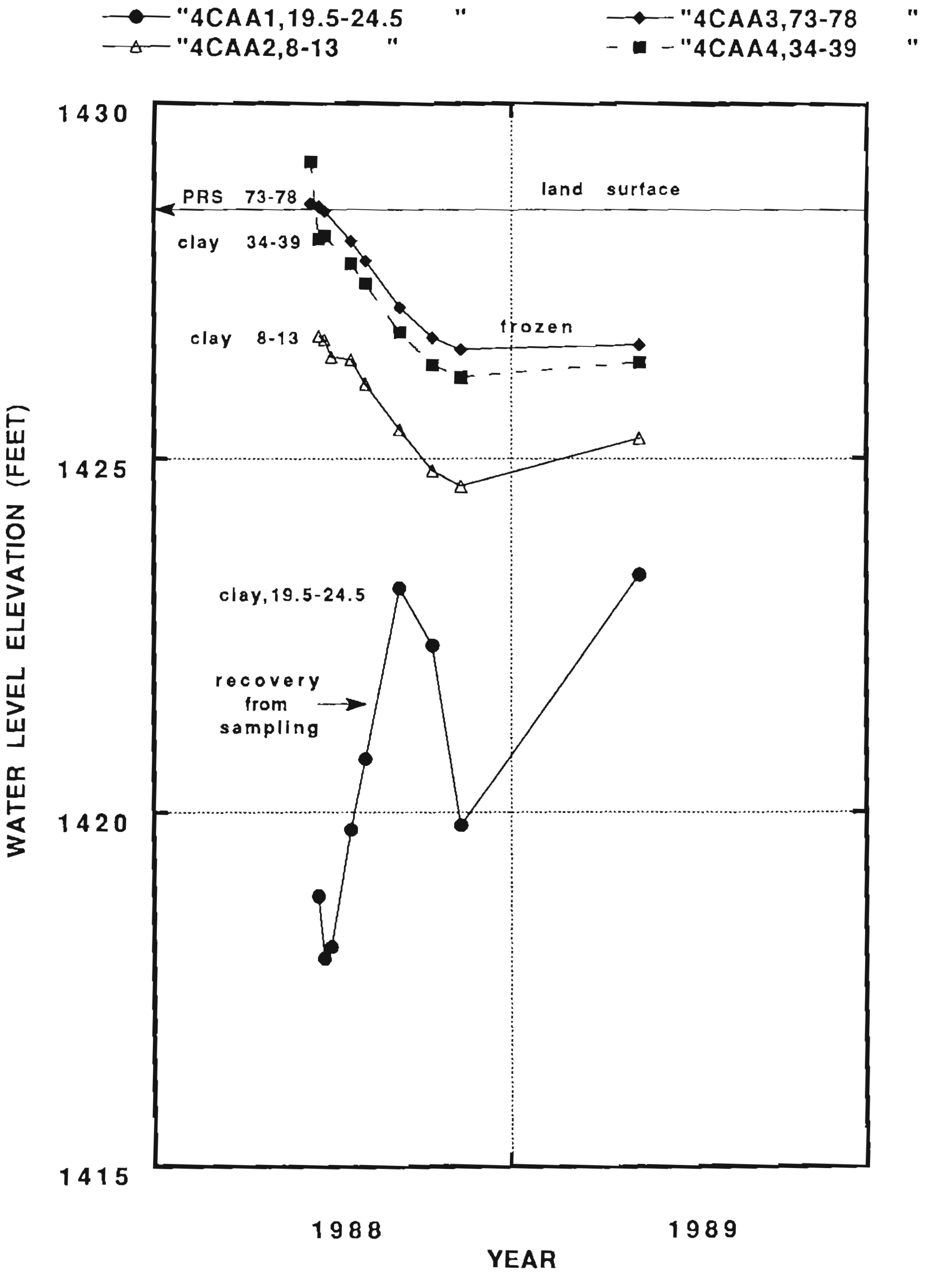

**Figure 16.** Water levels from wells in section 4, CAA.

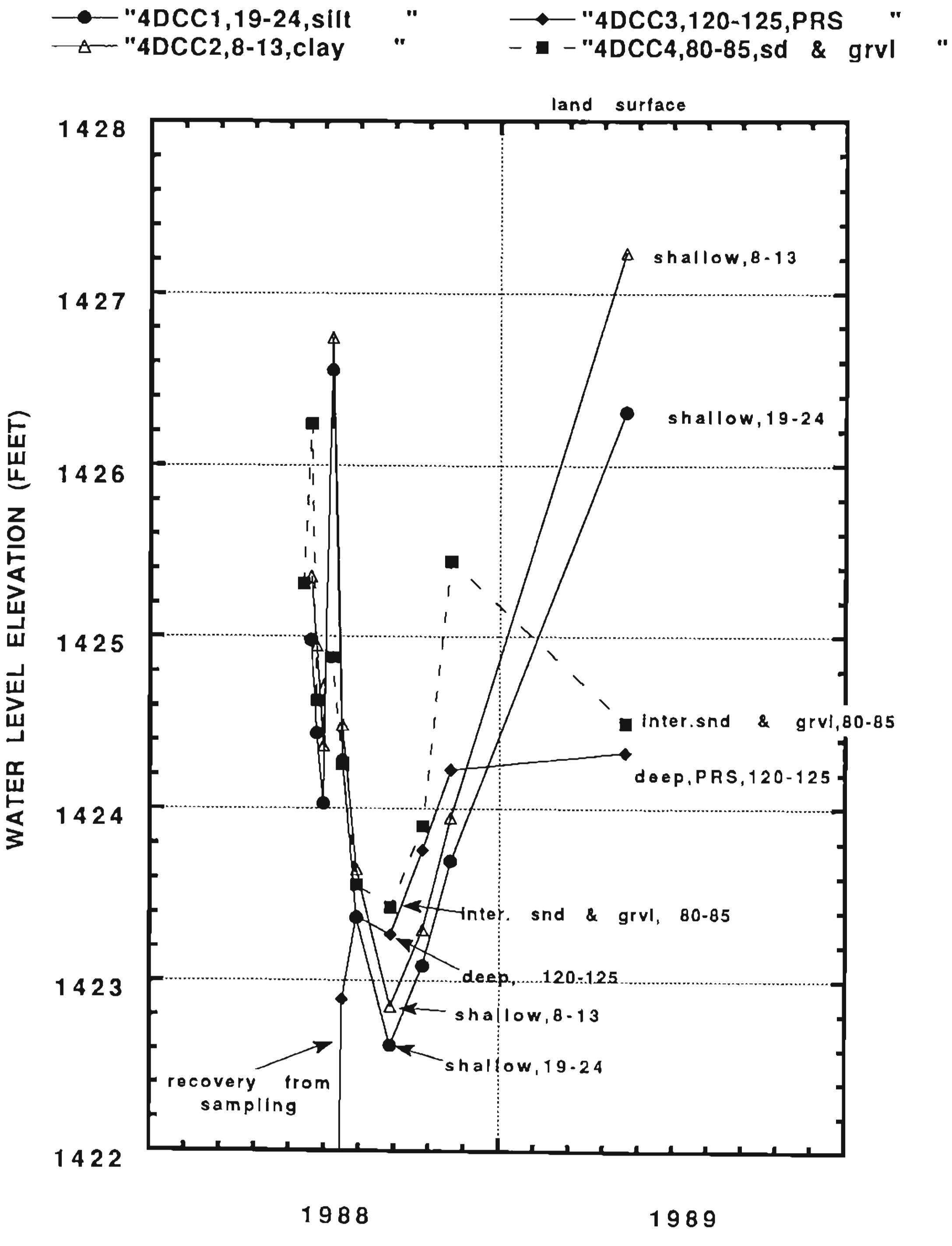

Figure 17. Water levels from wells in section 4, DCC.

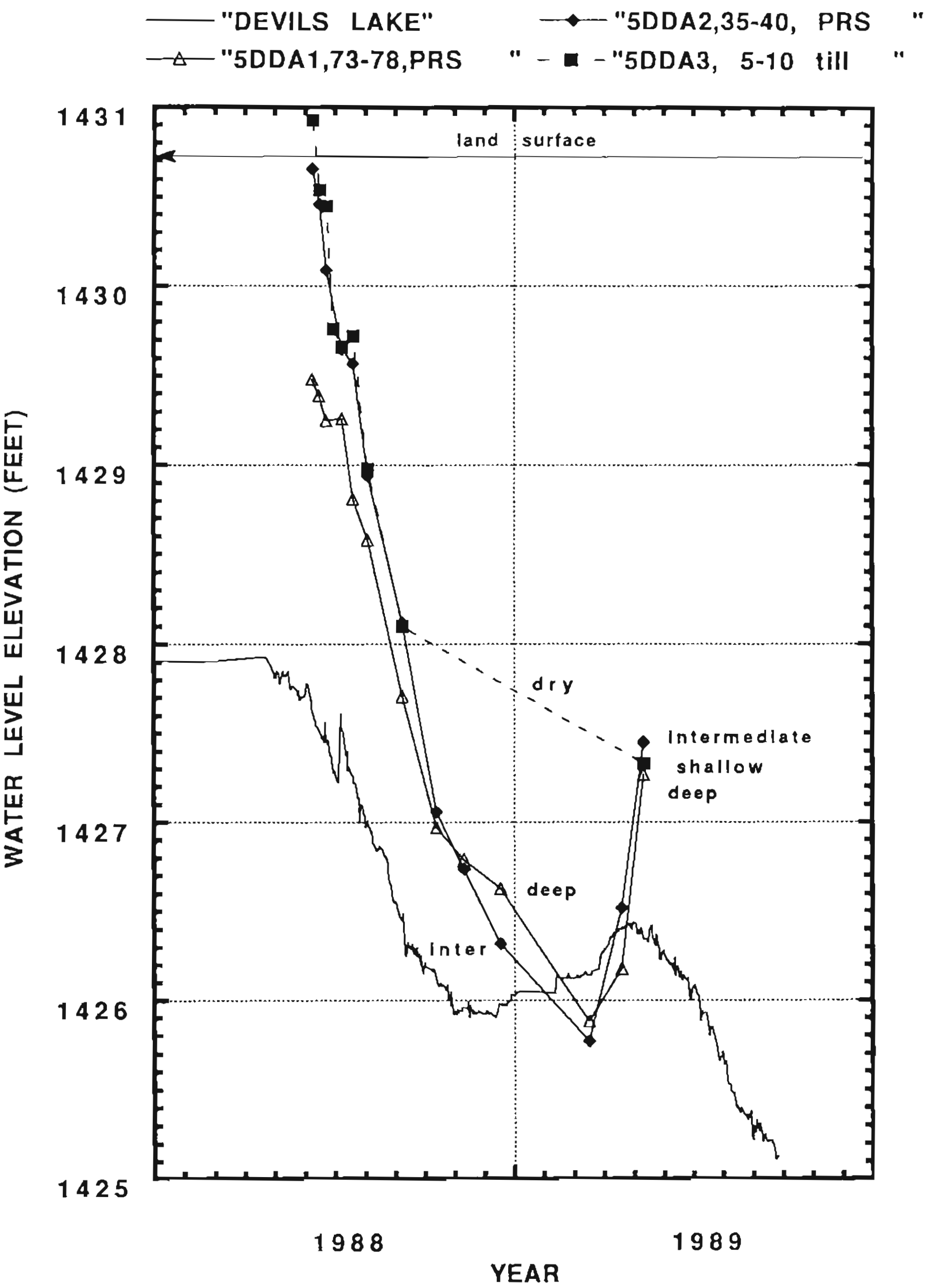

Figure 18. Water levels from wells in section 5, DDA and Devils Lake.

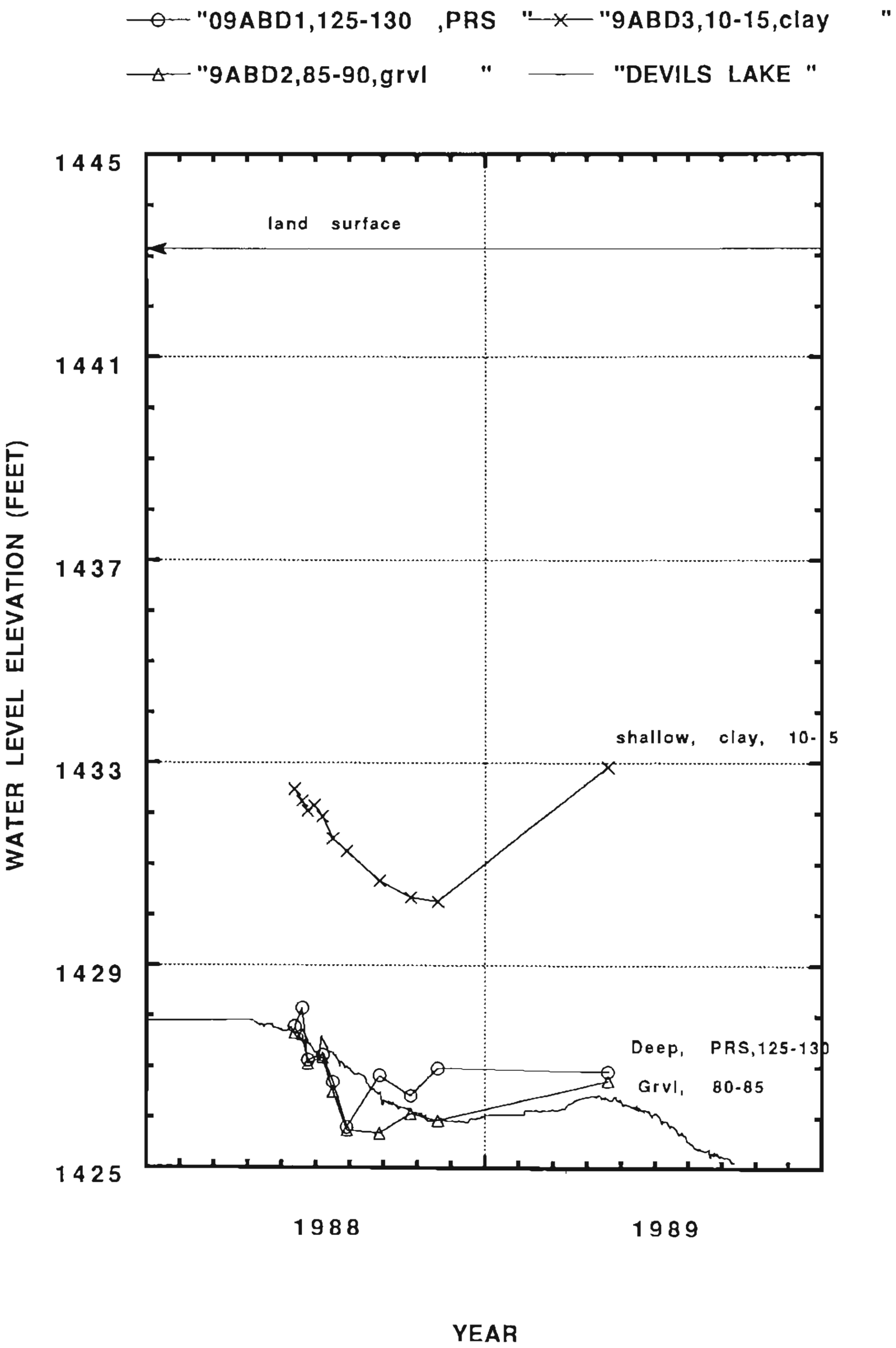

Figure 19. Water Levels from wells in section 9, ABD and Devils Lake.

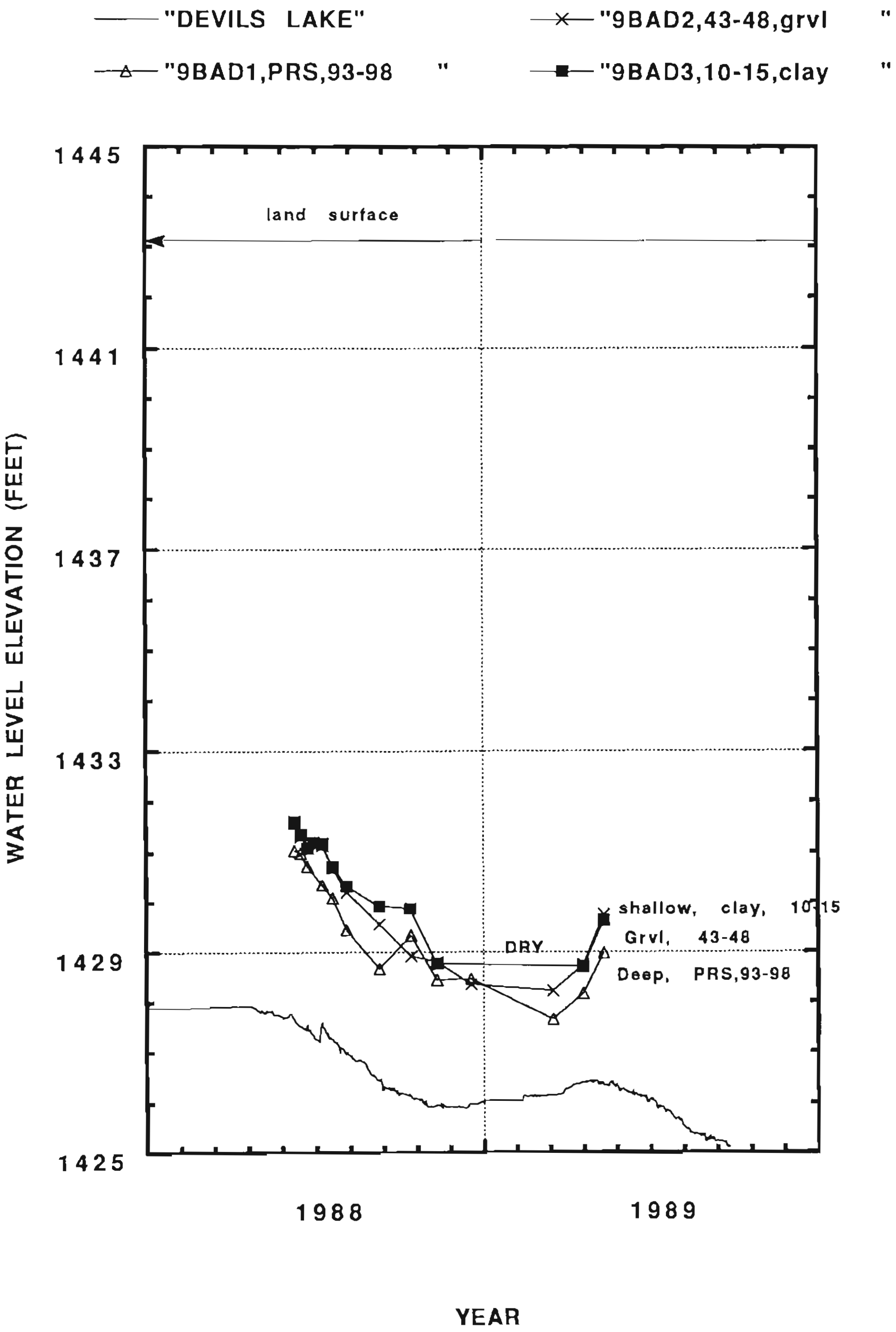

**Figure 20.** Water levels from wells in section 9, BAD and Devils Lake.

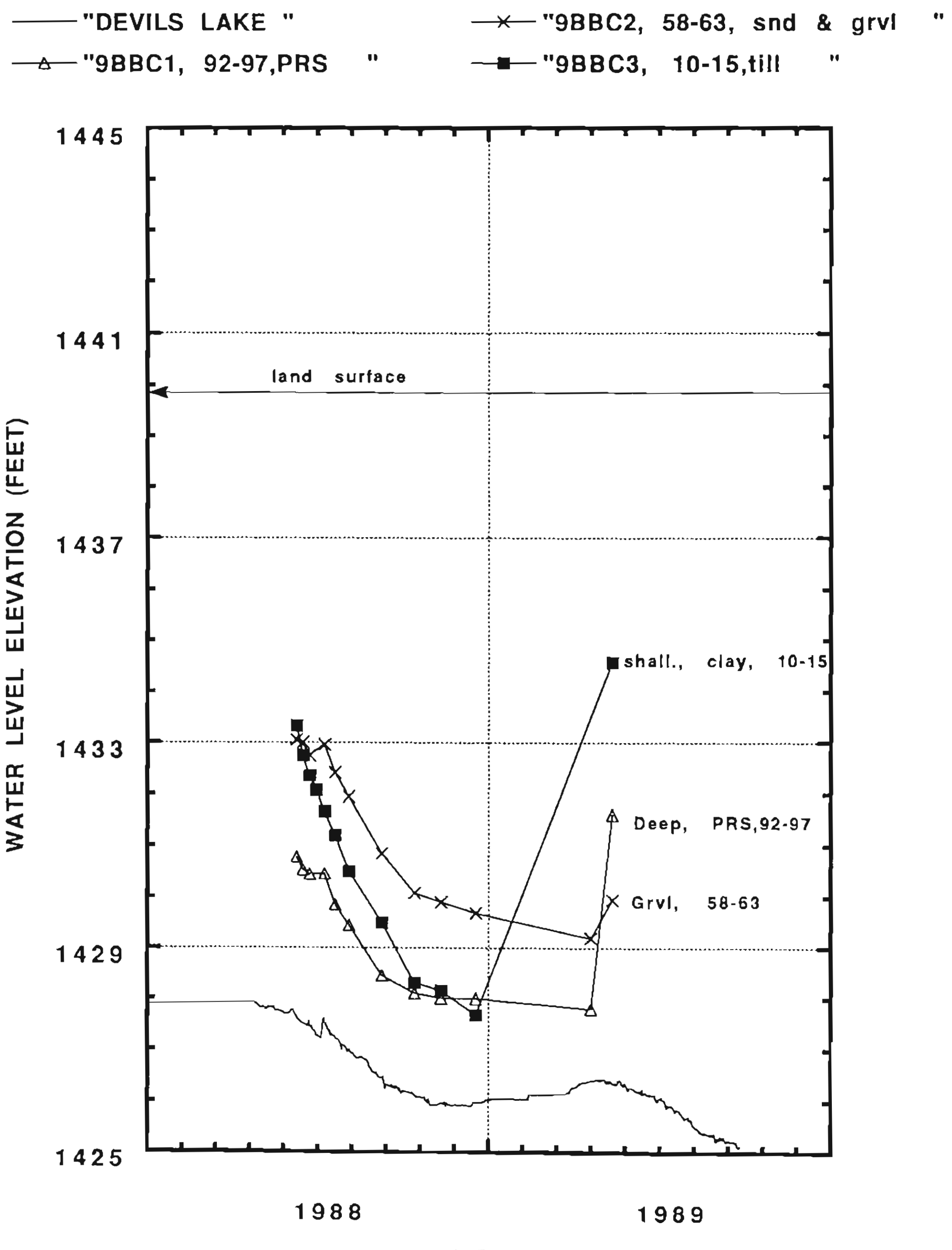

Figure 21. Water levels from wells in section 9, BBC and Devils Lake.

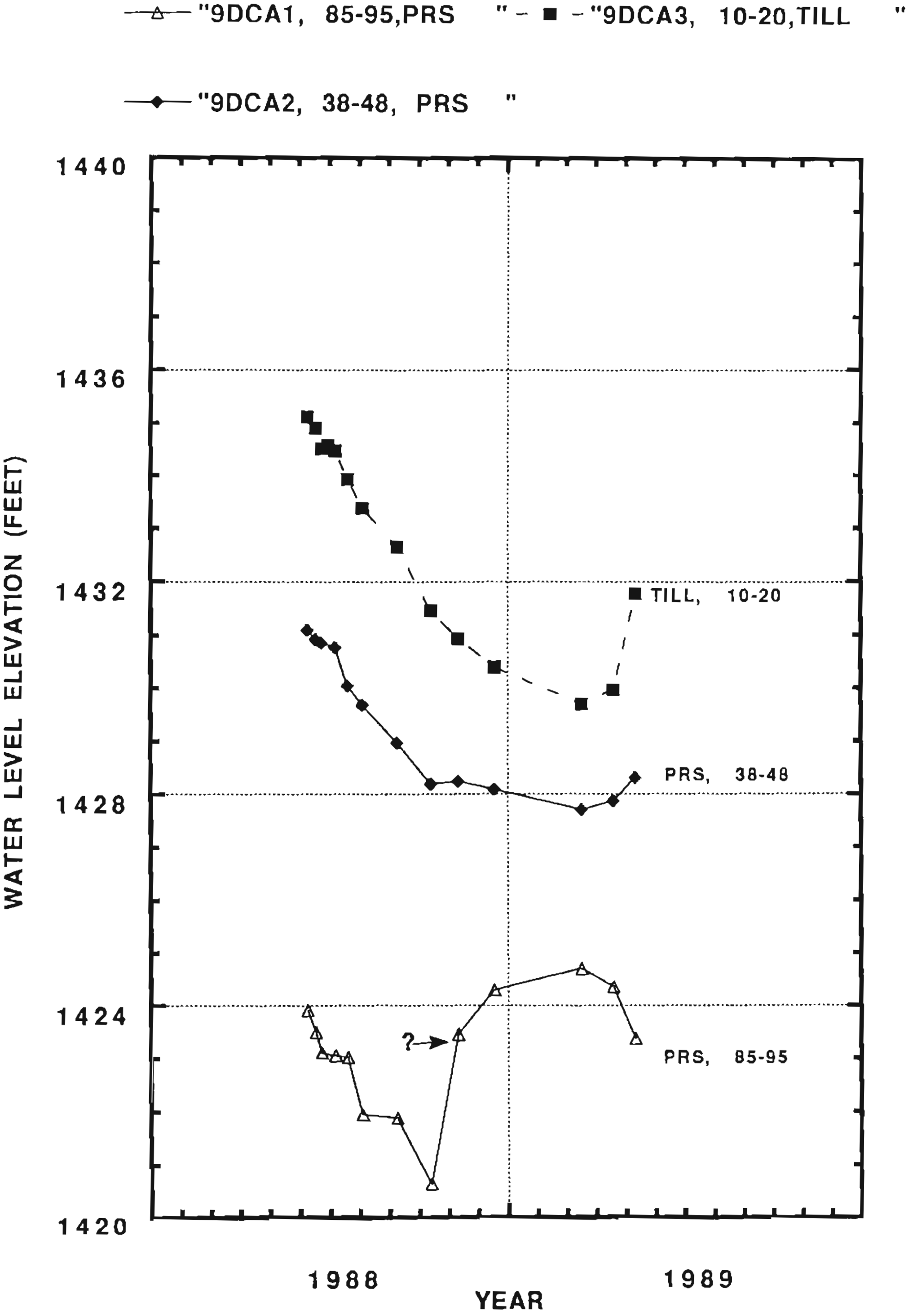

Figure 22. Water levels from wells in section 9, DCA.

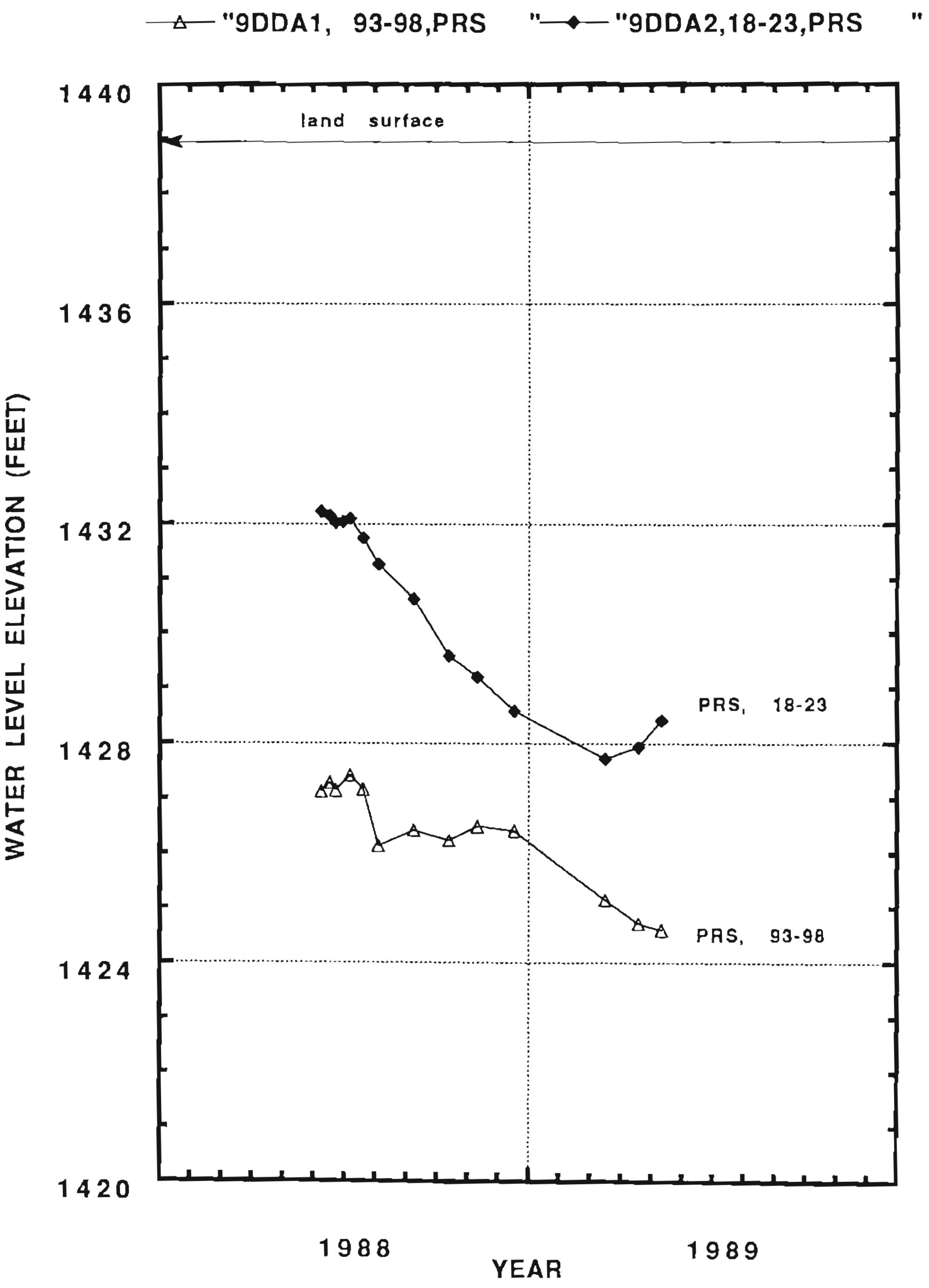

Figure 23. Water levels from wells in section 9, DDA.

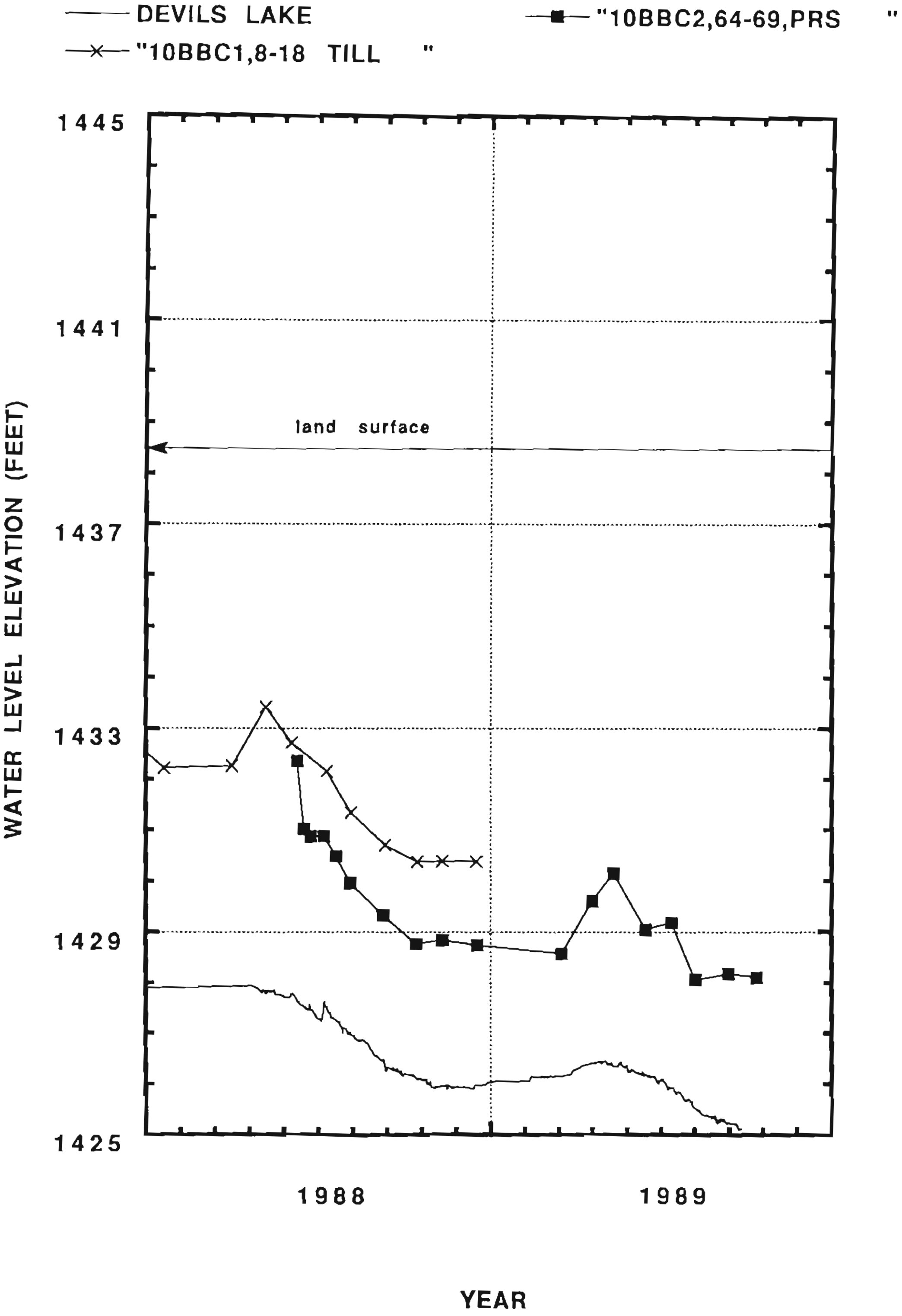

**Figure 24.** Water levels from wells in section 10, BBC and Devils Lake.

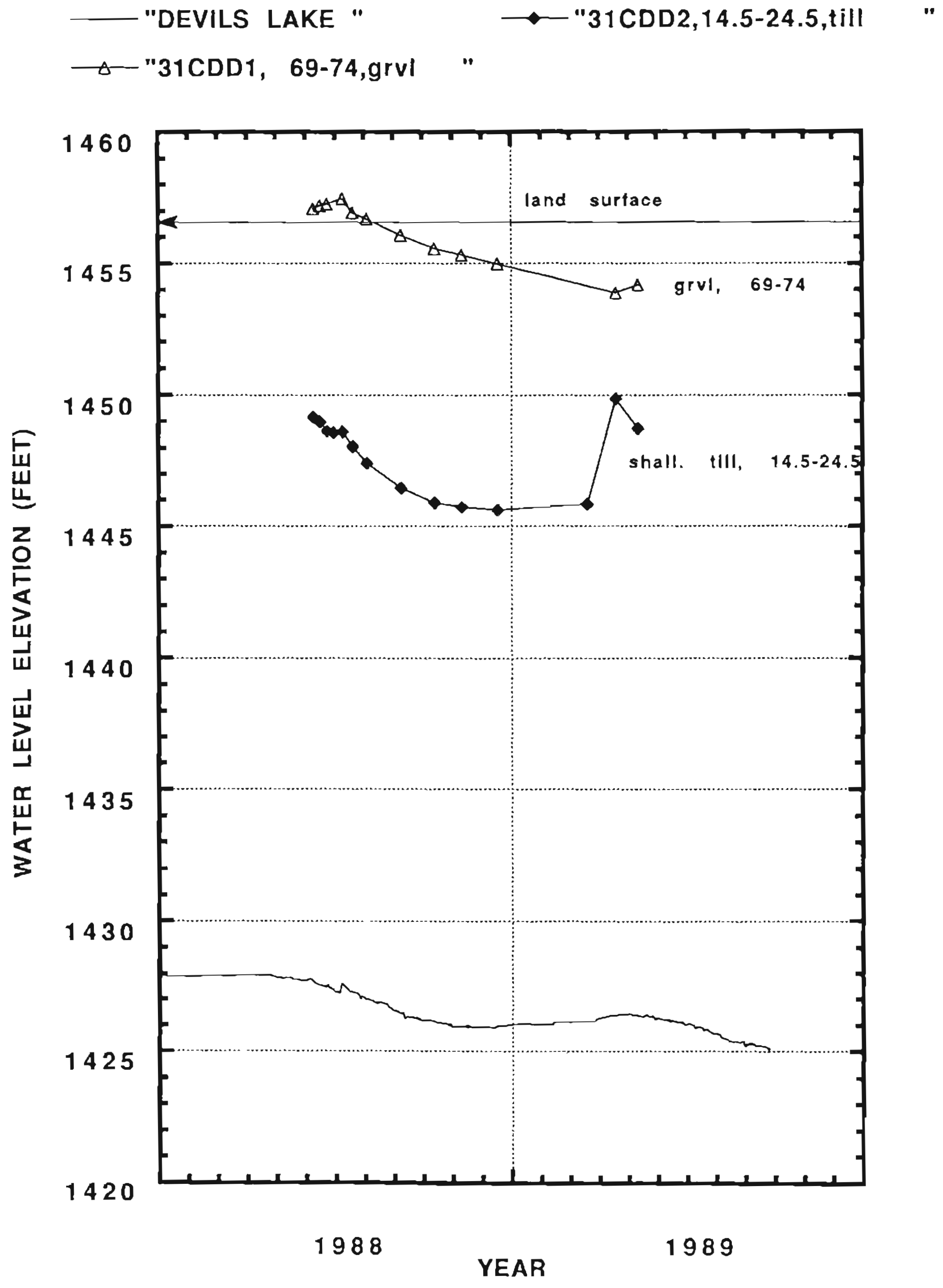

Figure 25. Water levels from wells in section 31, CDD and Devils Lake.

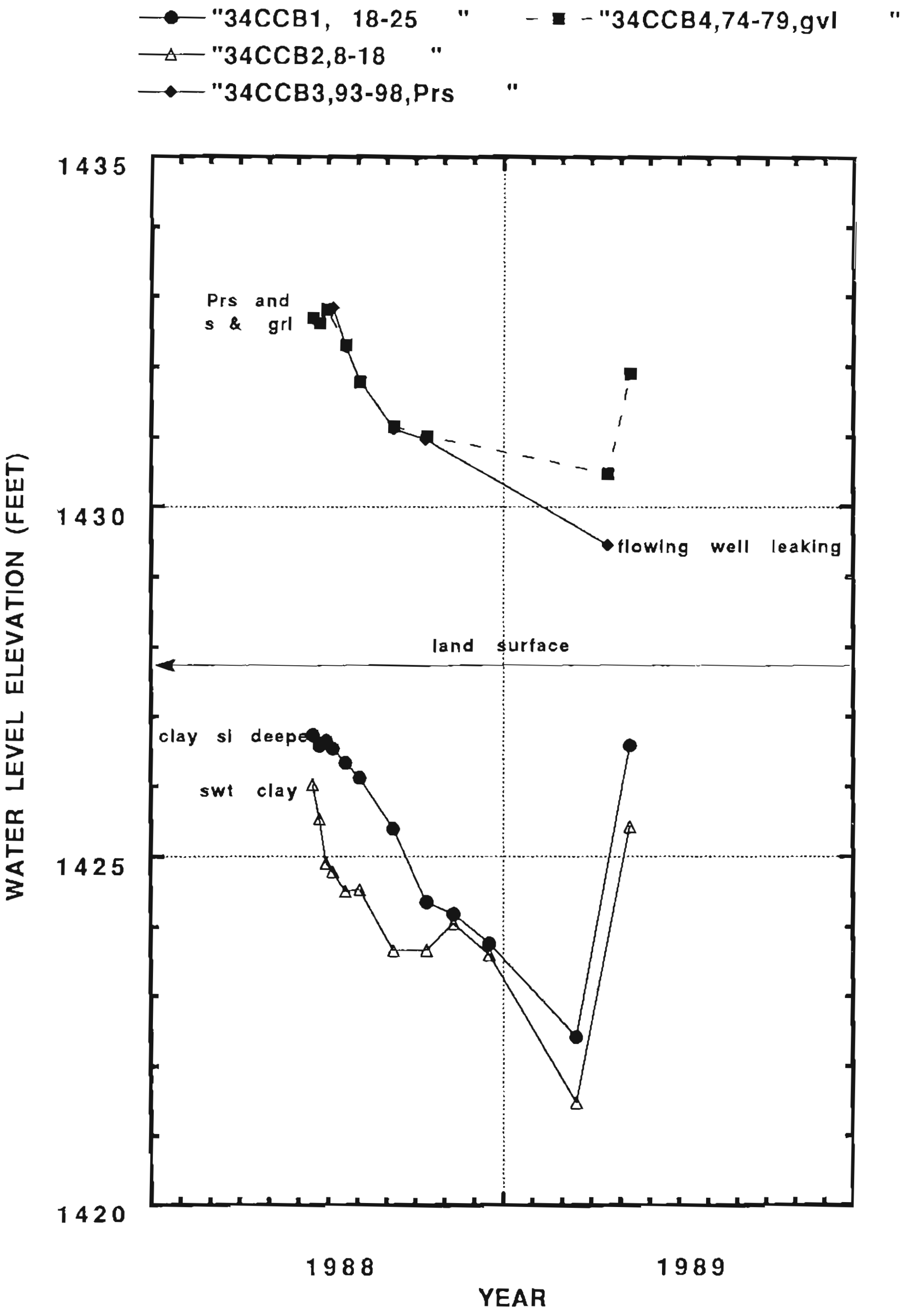

Figure 26. Water levels from wells in section 34, CCB.

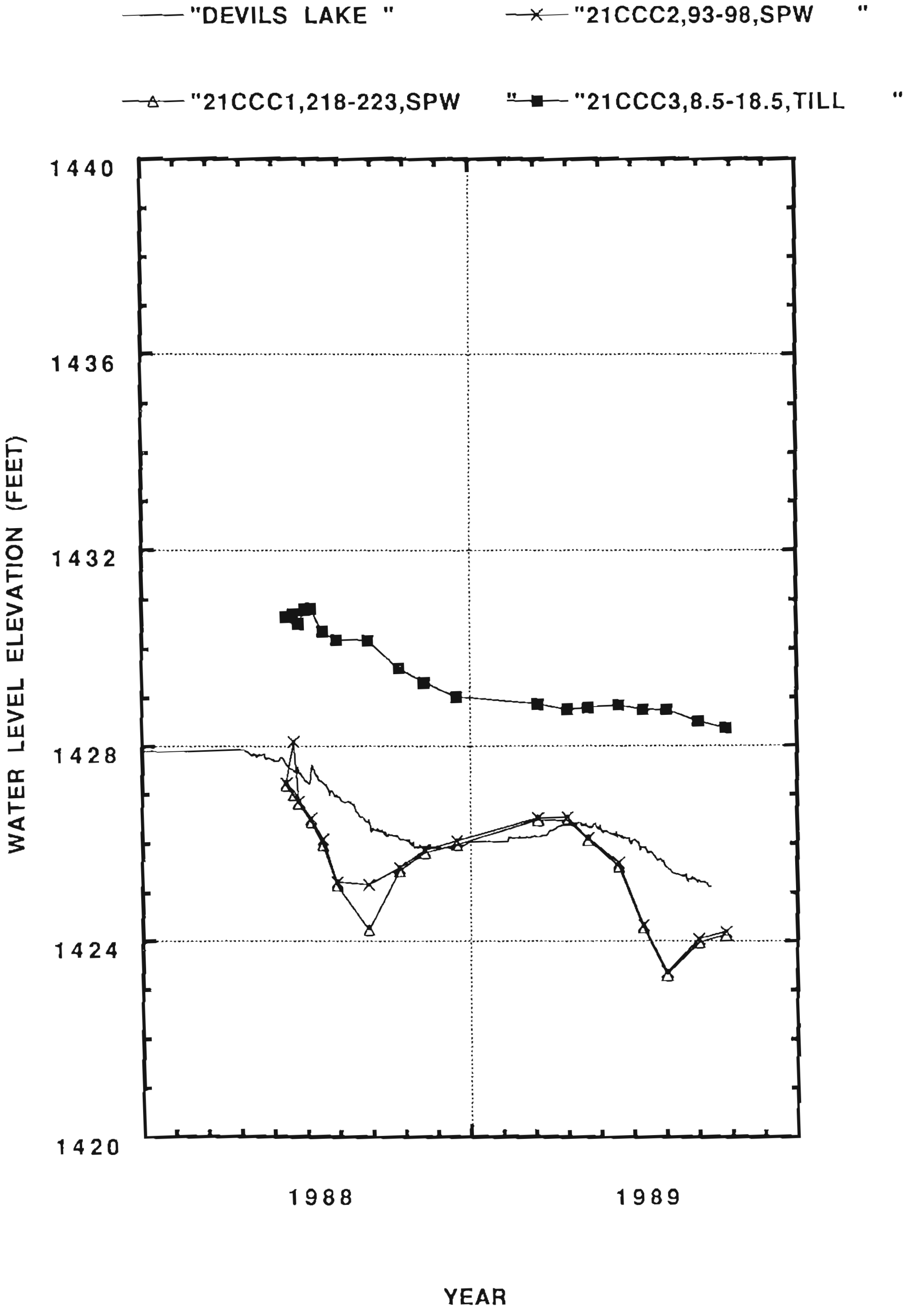

Figure 27. Water levels from wells in section 21, CCC and Devils Lake.

# APPENDIX V
Groundwater Chemistry

|  | Screened |  | (milligrams per liter) |  |  |  |  |  |  |  |  |  |  |  |  |  |  | Hardness as |  | % |  | Spec |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Location | Interval (ft) | Date Sampled | $SiO_2$ | Fe | Mn | Ca | Mg | Na | K | $HCO_3$ | $CO_3$ | $SO_4$ | Cl | F | $NO_3$ | B | TDS | $CaCO_3$ | NCH | Na | SAR | Cond (µmho) | Temp (∞C) |
| 153-064-04ADD1 | 14.5-<br>24.5 | 07/25/88 | 27 | 0.06 | 0.02 | 110 | 55 | 1700 | 27 | 642 | 0 | 1600 | 1400 | 0.3 | 19 | 0.45 | 5250 | 500 | 0 | 87 | 33 | 8240 | 17 |
| 153-064-04ADD2 | 8-13 | 07/25/88 | 31 | 0.09 | 0.08 | 360 | 250 | 2300 | 52 | 514 | 0 | 4900 | 1100 | 0.4 | 9.5 | 2.1 | 9260 | 1900 | 1500 | 72 | 23 | 11400 | 16 |
| 153-064-04CAA1 | 19.5-<br>24.5 | 07/25/88 | 29 | 0.08 | 0.04 | 400 | 280 | 1900 | 34 | 579 | 0 | 4600 | 810 | 0.2 | 4.6 | 0.56 | 8340 | 2200 | 1700 | 65 | 18 | 10370 | 12 |
| 153-064-04CAA2 | 8-13 | 07/25/88 | 32 | 0.09 | 1 | 380 | 130 | 1400 | 29 | 513 | 0 | 3700 | 380 | 0.1 | 17 | 0.95 | 6320 | 1500 | 1100 | 67 | 16 | 7530 | 16 |
| 153-064-04CAA3 | 73-78 | 06/08/88 | 36 | 0.05 | 0.07 | 15 | 7 | 580 | 13 | 802 | 0 | 460 | 200 | 0.5 | 0.5 | 2.3 | 1710 | 67 | 0 | 94 | 31 | 2820 | 10 |
| 153-064-04CAA4 | 34-39 | 06/08/88 | 35 | 1.7 | 0.59 | 90 | 35 | 850 | 24 | 581 | 0 | 1400 | 300 | 0.2 | 12 | 1.6 | 3040 | 370 | 0 | 82 | 19 | 4320 | 9 |
| 153-064-04DCC1 | 19-24 | 07/08/88 | 25 | 0.02 | 0.18 | 150 | 79 | 190 | 10 | 552 | 0 | 560 | 82 | 0.2 | 0.6 | 0.18 | 1370 | 700 | 250 | 37 | 3.1 | 1970 | 13 |
| 153-064-04DCC2 | 8-13 | 07/08/88 | 27 | 0.01 | 0.53 | 130 | 63 | 180 | 9.6 | 540 | 0 | 460 | 70 | 0.2 | 1 | 0.2 | 1210 | 580 | 140 | 40 | 3.3 | 1940 | 10 |
| 153-064-04DCC3 | 120-125 | 06/08/88 | 28 | 0.06 | 0.17 | 60 | 50 | 900 | 40 | 709 | 0 | 790 | 700 | 0.5 | 0.8 | 2.5 | 2920 | 360 | 0 | 83 | 21 | 4670 | 10 |
| 153-064-04DCC4 | 80-85 | 06/08/88 | 32 | 0.65 | 0.46 | 95 | 33 | 410 | 20 | 512 | 0 | 690 | 130 | 0.5 | 5.2 | 1.3 | 1670 | 370 | 0 | 69 | 9.3 | 2730 | 10 |
| 153-064-05DDA1 | 73.2-<br>78.2 | 06/09/88 | 37 | 1.4 | 1.4 | 250 | 95 | 660 | 29 | 355 | 0 | 1900 | 200 | 0.2 | 0.9 | 0.76 | 3350 | 1000 | 720 | 58 | 9 | 4270 | 8 |
| 153-064-05DDA1 | 73.2-<br>78.2 | 07/08/88 | 25 | 0.1 | 1.2 | 240 | 100 | 700 | 23 | 338 | 0 | 1900 | 180 | 0.1 | 1 | 0.66 | 3340 | 1000 | 730 | 59 | 9.6 | 4420 | 9 |
| 153-064-05DDA2 | 35-40 | 06/09/88 | 29 | 2.5 | 2.2 | 500 | 270 | 520 | 32 | 368 | 0 | 3100 | 140 | 0.1 | 1 | 0.34 | 4780 | 2400 | 2100 | 32 | 4.6 | 5070 | 8 |
| 153-064-09ABD1 | 125-130 | 06/08/88 | 34 | 0.07 | 0.19 | 29 | 11 | 690 | 15 | 667 | 0 | 710 | 290 | 0.4 | 0.8 | 2.6 | 2110 | 120 | 0 | 92 | 27 | 3480 | 9 |
| 153-064-09ABD2 | 85-90 | 06/08/88 | 24 | 0.21 | 0.59 | 100 | 28 | 460 | 19 | 475 | 0 | 800 | 160 | 0.1 | 0.6 | 0.86 | 1830 | 360 | 0 | 72 | 11 | 2730 | 10 |
| 153-064-09BAD1 | 93-98 | 06/08/88 | 30 | 0.35 | 0.26 | 21 | 8 | 410 | 9.8 | 382 | 0 | 540 | 110 | 0.5 | 0.4 | 1.1 | 1320 | 86 | 0 | 90 | 19 | 2370 | 9 |
| 153-064-09BAD2 | 43-48 | 06/08/88 | 30 | 1.5 | 1.8 | 370 | 120 | 380 | 25 | 404 | 0 | 1700 | 160 | 0.1 | 0.4 | 0.24 | 2990 | 1400 | 1100 | 36 | 4.4 | 3910 | 9 |
| 153-064-09BBC1 | 92-97 | 06/08/88 | 25 | 0.18 | 0.9 | 140 | 60 | 440 | 17 | 528 | 0 | 1000 | 90 | 0.1 | 0.7 | 0.71 | 2030 | 600 | 160 | 61 | 7.8 | 3150 | 9 |
| 153-064-09BBC2 | 58-63 | 06/08/88 | 28 | 0.05 | 0.97 | 260 | 100 | 360 | 20 | 524 | 0 | 1300 | 140 | 0.1 | 1 | 0.54 | 2470 | 1100 | 630 | 42 | 4.7 | 3070 | 9 |
| 153-064-09BBC3 | 10-15 | 07/08/88 | 22 | 0.11 | 5.1 | 440 | 390 | 810 | 37 | 460 | 0 | 3800 | 170 | 0.4 | 1 | 0.39 | 5900 | 2700 | 2300 | 39 | 6.8 | 6670 | 10 |
| 153-064-09DCA1 | 85-95 | 06/09/88 | 28 | 0.39 | 0.61 | 67 | 27 | 300 | 11 | 387 | 0 | 600 | 26 | 0.2 | 8.8 | 0.73 | 1260 | 280 | 0 | 69 | 7.8 | 1910 | 8 |
| 153-064-09DCA2 | 38-48 | 06/09/88 | 29 | 0.46 | 2.7 | 620 | 160 | 300 | 20 | 374 | 0 | 2100 | 220 | 0.2 | 0.2 | 0.22 | 3640 | 2200 | 1900 | 23 | 2.8 | 4300 | 9 |
| 153-064-09DCA3 | 10-20 | 07/06/88 | 26 | 0.04 | 0.04 | 460 | 290 | 460 | 15 | 553 | 0 | 2700 | 26 | 0.8 | 4.4 | 0.72 | 4260 | 2300 | 1900 | 30 | 4.2 | 5240 | 10 |
| 153-064-09DDA1 | 93-98 | 06/09/88 | 29 | 0.01 | 0.16 | 22 | 9 | 560 | 11 | 656 | 0 | 760 | 33 | 0.3 | 8.2 | 0.96 | 1760 | 92 | 0 | 92 | 25 | 2700 | 9 |
| 153-064-09DDA2 | 18-23 | 07/06/88 | 23 | 0.05 | 6 | 440 | 300 | 870 | 30 | 516 | 0 | 3400 | 210 | 0.4 | 1.1 | 0.49 | 5540 | 2300 | 1900 | 44 | 7.9 | 6910 | 10 |
| 153-064-21CCC1 | 218-223 | 06/09/88 | 28 | 2 | 0.27 | 150 | 57 | 390 | 17 | 534 | 0 | 690 | 230 | 0.2 | 8.7 | 0.83 | 1840 | 610 | 170 | 57 | 6.9 | 2780 | 10 |
| 153-064-21CCC2 | 93-98 | 06/09/88 | 29 | 4.8 | 0.4 | 170 | 55 | 160 | 14 | 519 | 0 | 410 | 150 | 0.2 | 8.6 | 0.42 | 1260 | 650 | 220 | 34 | 2.7 | 1910 | 9 |
| 153-064-21CCC3 | 8.5-<br>18.5 | 07/06/88 | 22 | 0.02 | 0.13 | 140 | 92 | 340 | 12 | 831 | 0 | 730 | 45 | 0.2 | 1 | 0.29 | 1790 | 730 | 47 | 50 | 5.5 | 2560 | 11 |
| 154-064-31CDD1 | 69-74 | 06/09/88 | 28 | 2.1 | 0.54 | 170 | 57 | 130 | 14 | 503 | 0 | 540 | 23 | 0.2 | 7.5 | 0.38 | 1220 | 660 | 250 | 29 | 2.2 | 1680 | 8 |
| 154-064-31CDD2 | 14.5-<br>24.5 | 07/08/88 | 24 | 0.02 | 0.28 | 190 | 96 | 180 | 11 | 478 | 0 | 800 | 32 | 0.3 | 26 | 0.51 | 1600 | 870 | 480 | 31 | 2.6 | 2260 | 8 |
| 154-064-33BBA1 | 18-23 | 07/06/88 | 25 | 1.1 | 1.1 | 200 | 56 | 200 | 11 | 424 | 0 | 680 | 93 | 0.2 | 0.1 | 0.4 | 1480 | 730 | 380 | 37 | 3.2 | 2440 | 9 |
| 154-064-33BBA2 | 5-10 | 07/06/88 | 27 | 0.02 | 1.2 | 160 | 66 | 180 | 9.7 | 395 | 0 | 590 | 84 | 0.3 | 0.6 | 0.36 | 1310 | 670 | 350 | 36 | 3 | 2160 | 10 |
| 154-064-34CCB1 | 18-28 | 07/06/88 | 24 | 0.02 | 0.35 | 140 | 52 | 480 | 19 | 487 | 0 | 900 | 310 | 0.2 | 0.4 | 1.3 | 2170 | 560 | 160 | 64 | 8.8 | 3620 | 11 |
| 154-064-34CCB2 | 8-13 | 07/06/88 | 21 | 0.11 | 0.08 | 450 | 850 | 3200 | 80 | 622 | 0 | 7800 | 1700 | 0.2 | 8.8 | 0.84 | 14400 | 4600 | 4100 | 60 | 21 | 19600 | 10 |
| 154-064-34CCB3 | 93-98 | 06/08/88 | 31 | 0.3 | 0.22 | 30 | 9 | 550 | 14 | 612 | 0 | 490 | 240 | 0.4 | 0.7 | 1.8 | 1670 | 110 | 0 | 90 | 23 | 2940 | 9 |
| 154-064-34CCB4 | 74-79 | 06/08/88 | 31 | 0.31 | 0.24 | 38 | 10 | 500 | 14 | 600 | 0 | 520 | 170 | 0.4 | 6.5 | 0.16 | 1590 | 140 | 0 | 88 | 18 | 2460 | 8 |

# APPENDIX VI
## Groundwater Chemistry Cross-Sections

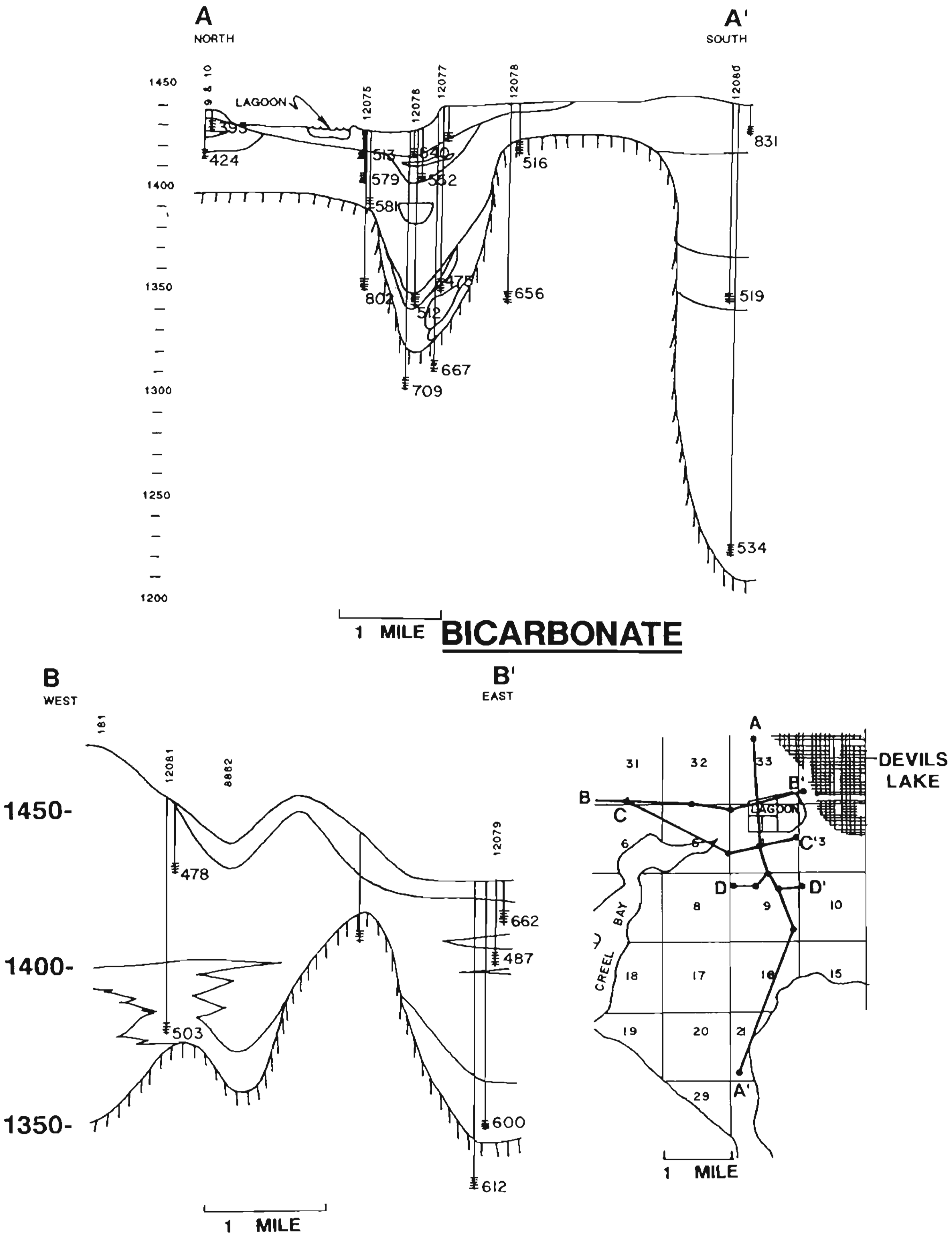

Figure 28. Bicarbonate profiles for groundwater in sections A and B.

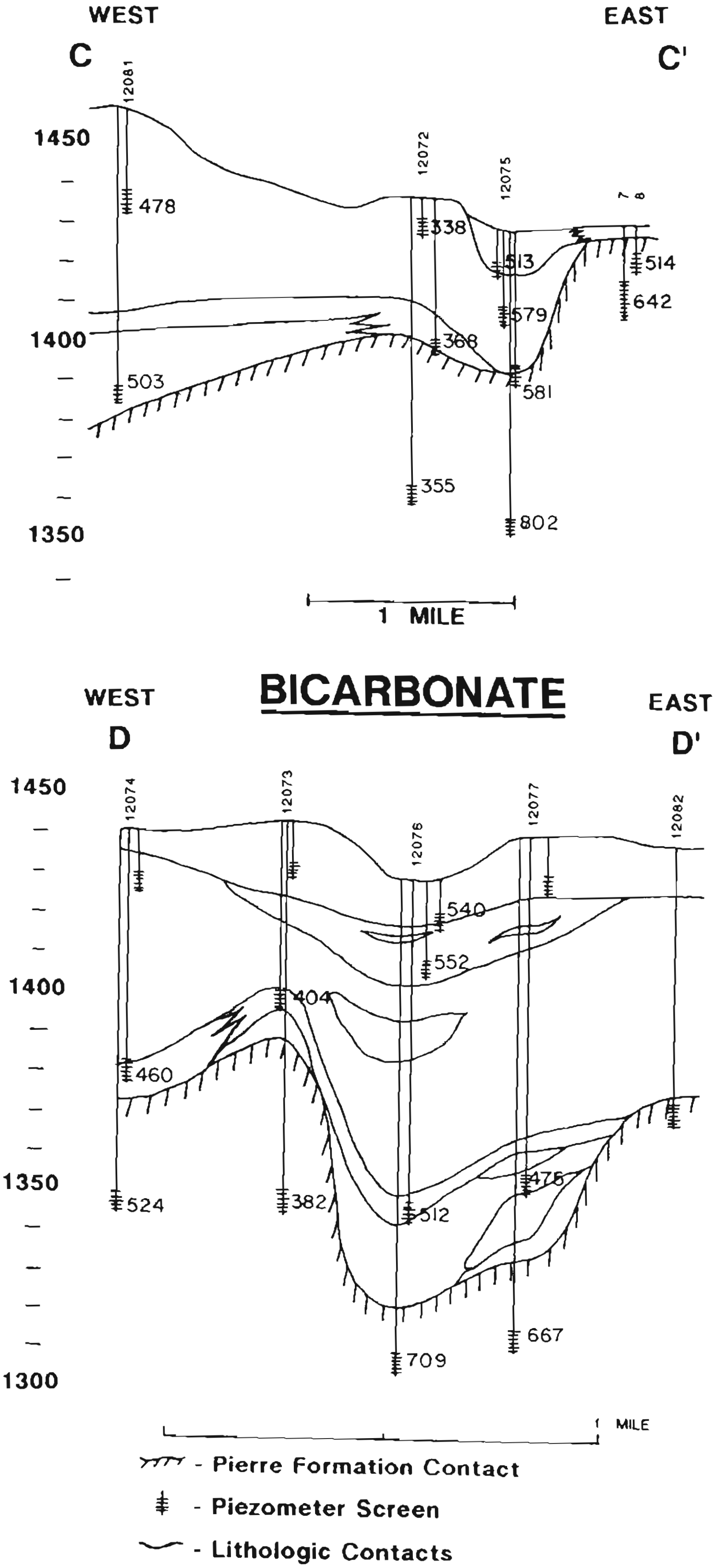

Figure 29. Bicarbonate profiles for groundwater in sections C and D.

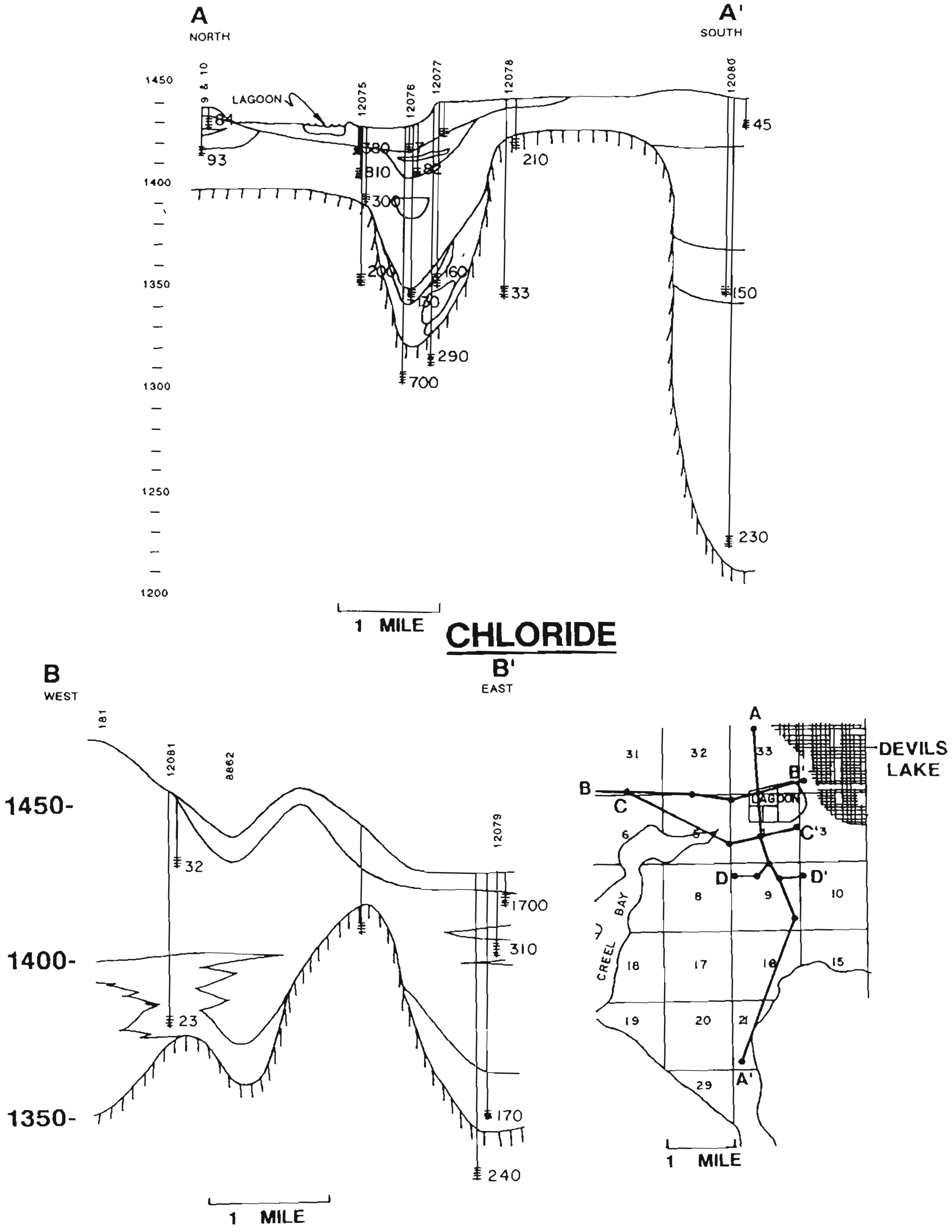

Figure 30. Chloride profiles for groundwater in sections A and B.

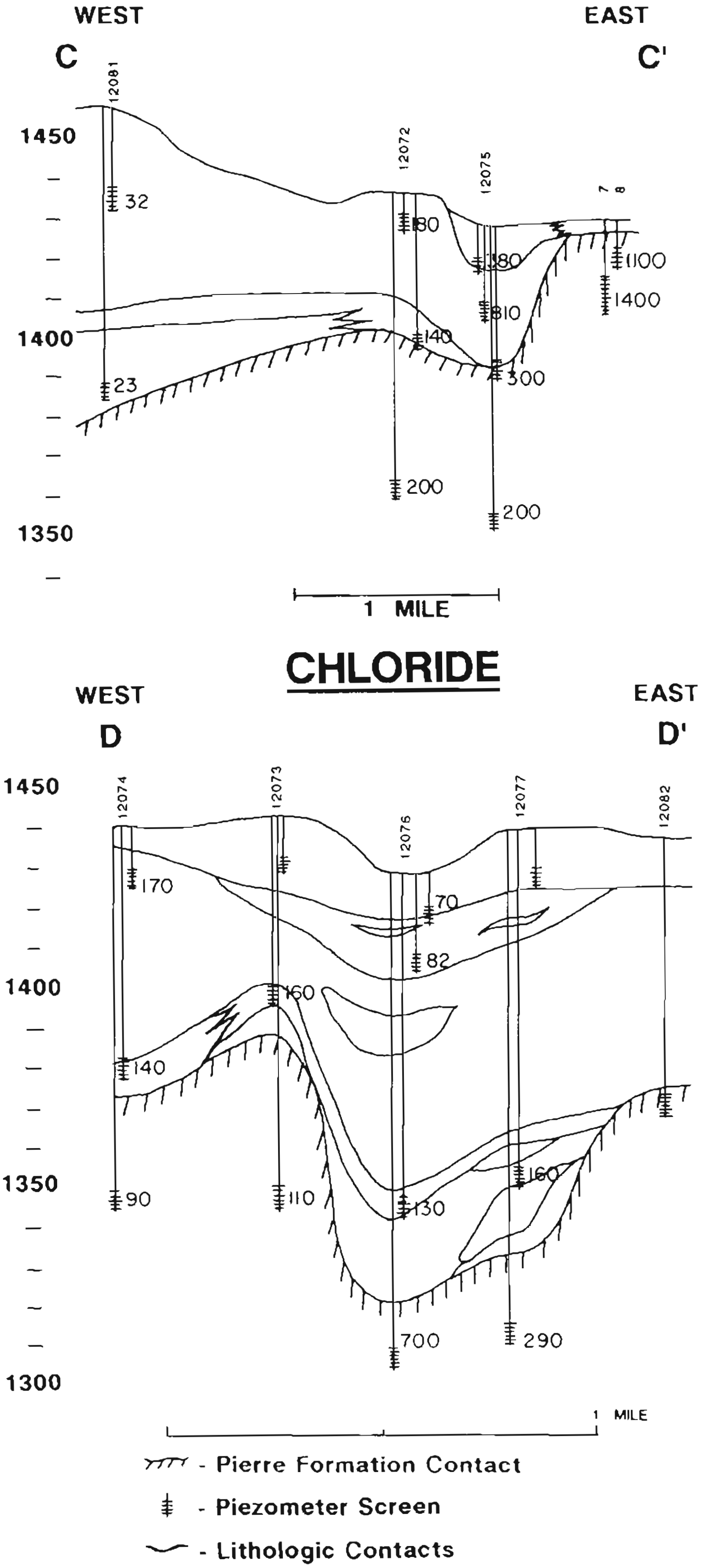

Figure 31. Chloride profiles for groundwater in sections C and D.

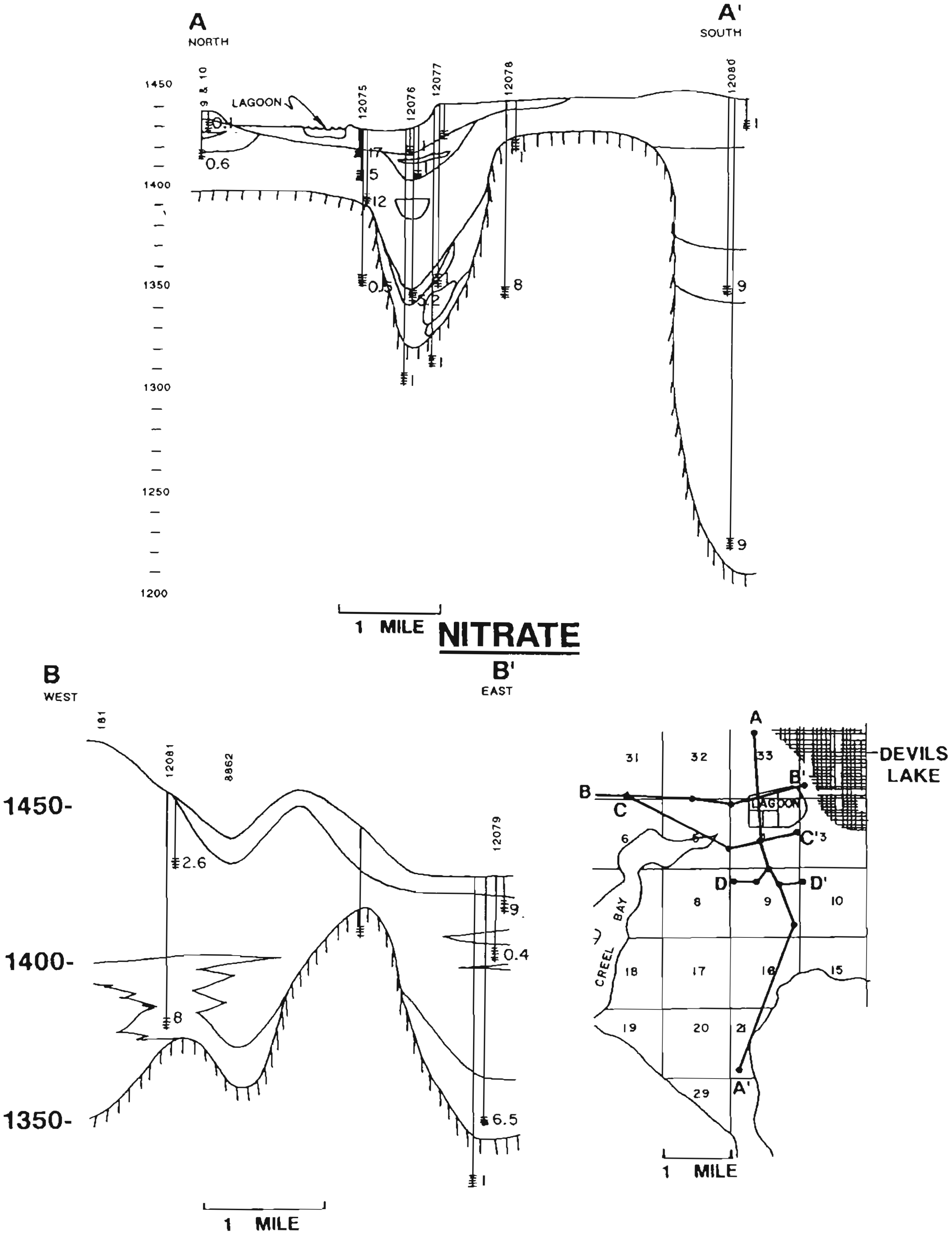

Figure 32. Nitrate profiles for groundwater in sections A and B.

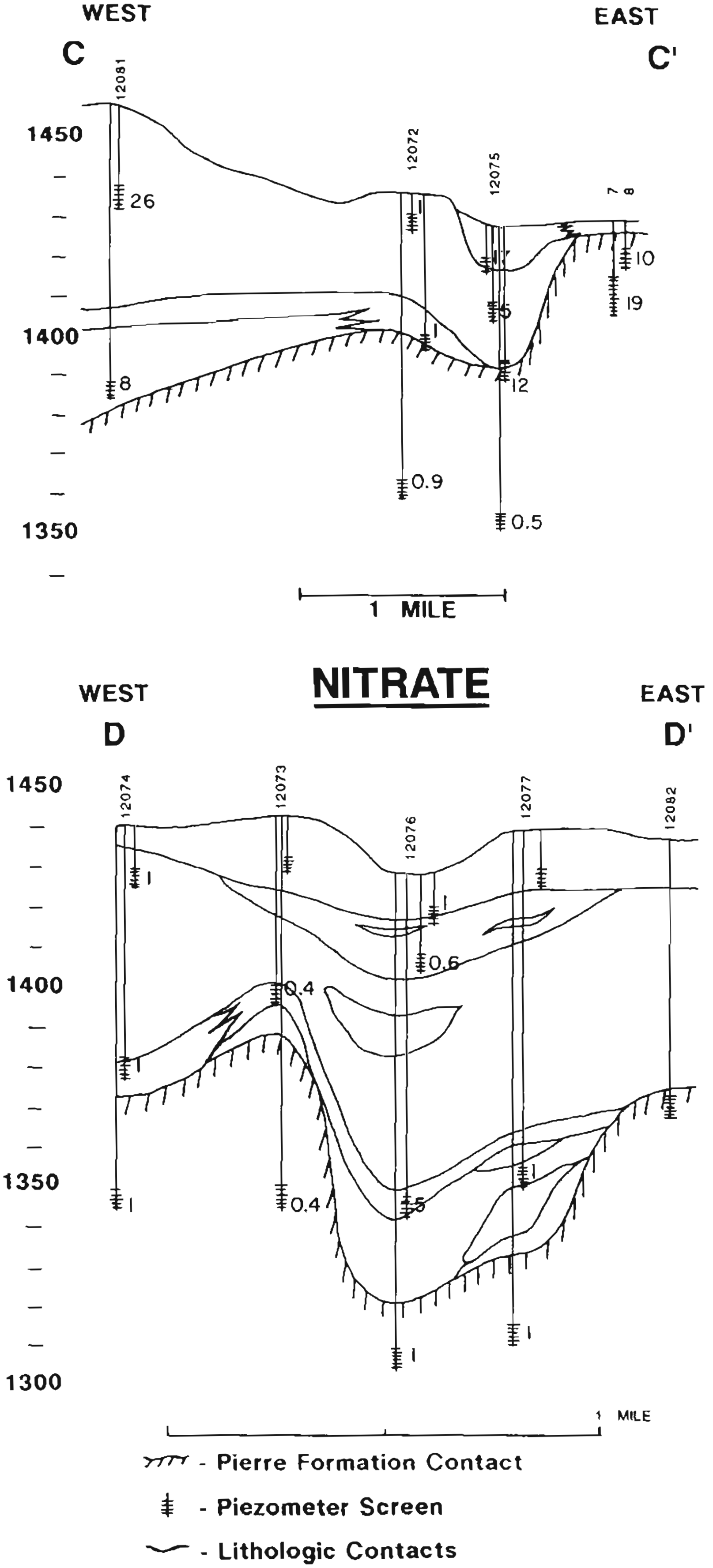

**Figure 33.** Nitrate profiles for groundwater in sections C and D.

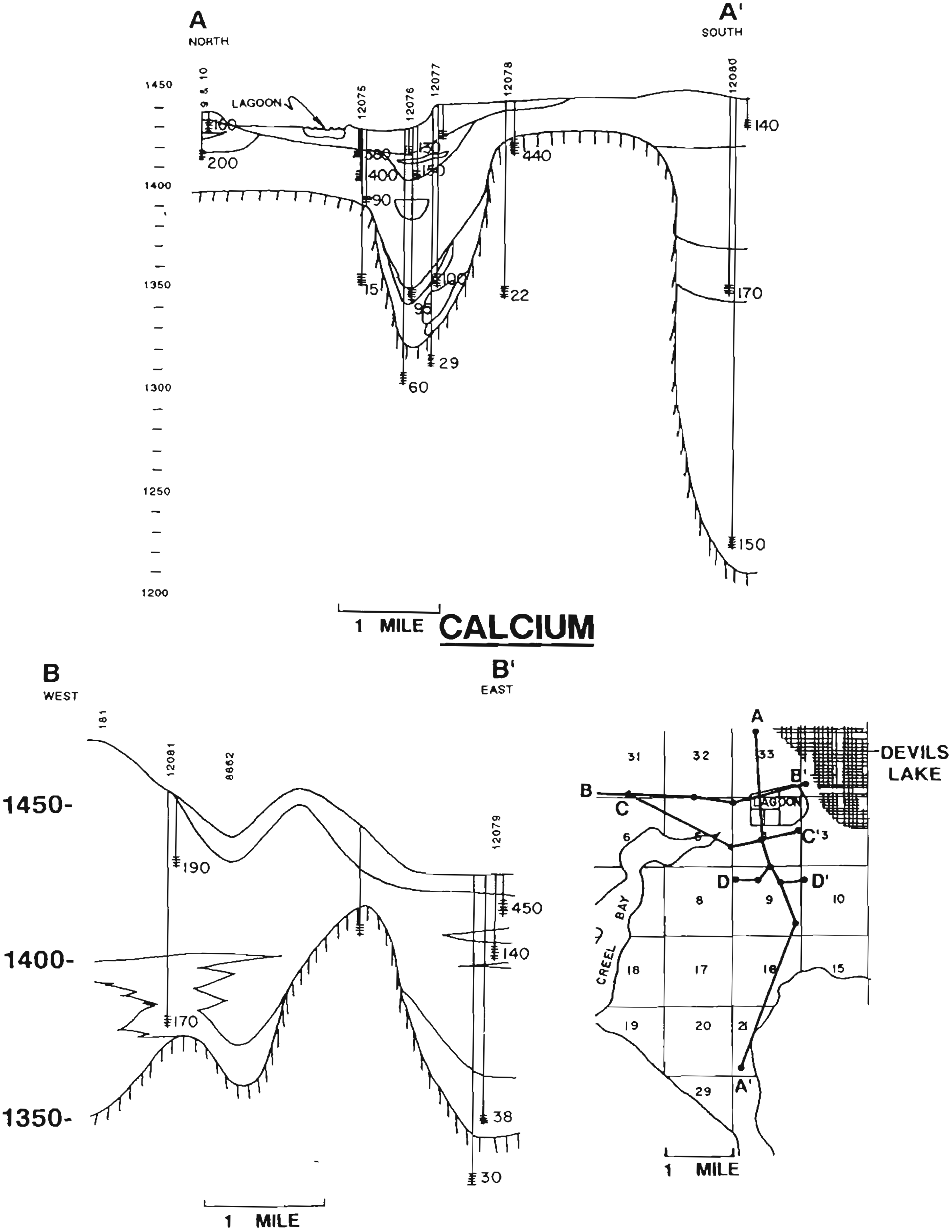

Figure 34. Calcium profiles for groundwater in sections A and B.

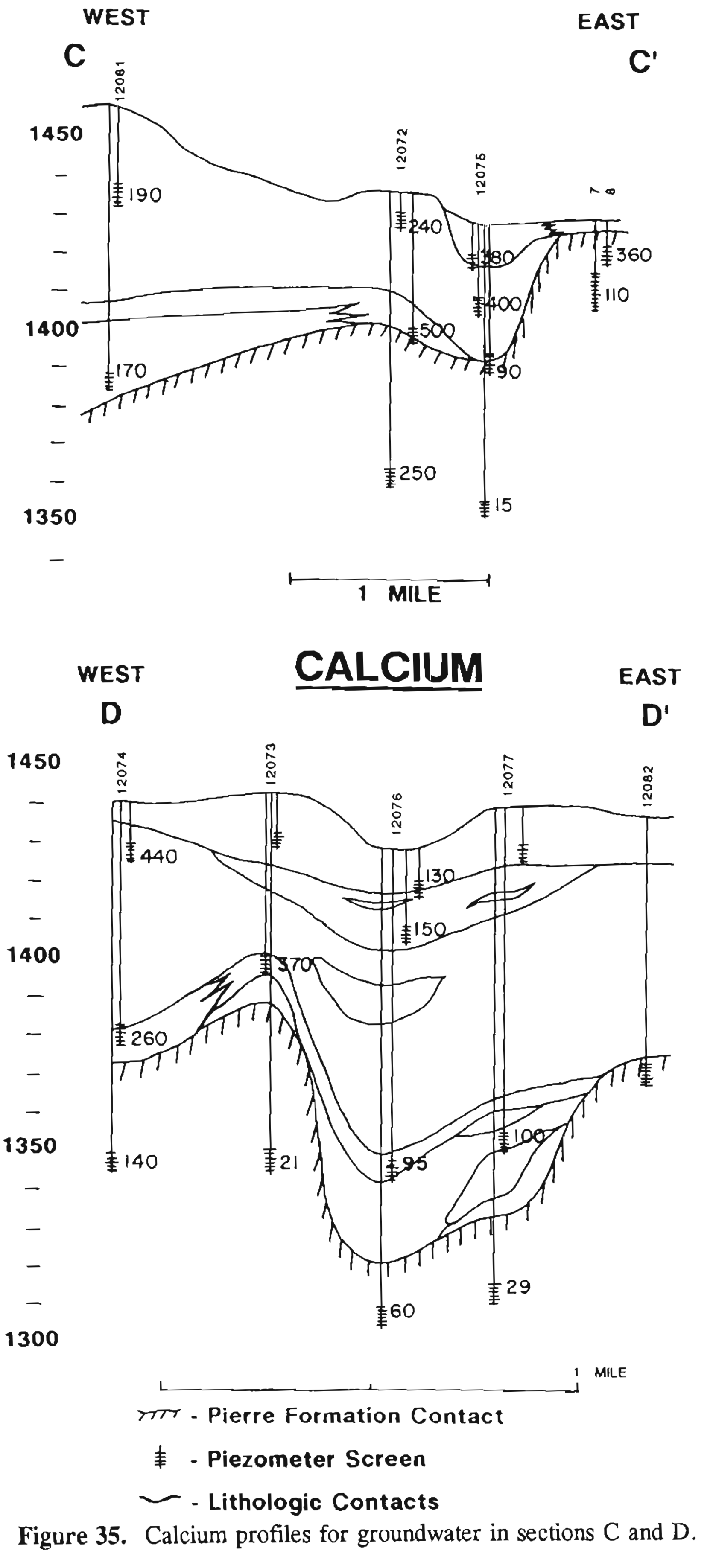

Figure 35. Calcium profiles for groundwater in sections C and D.

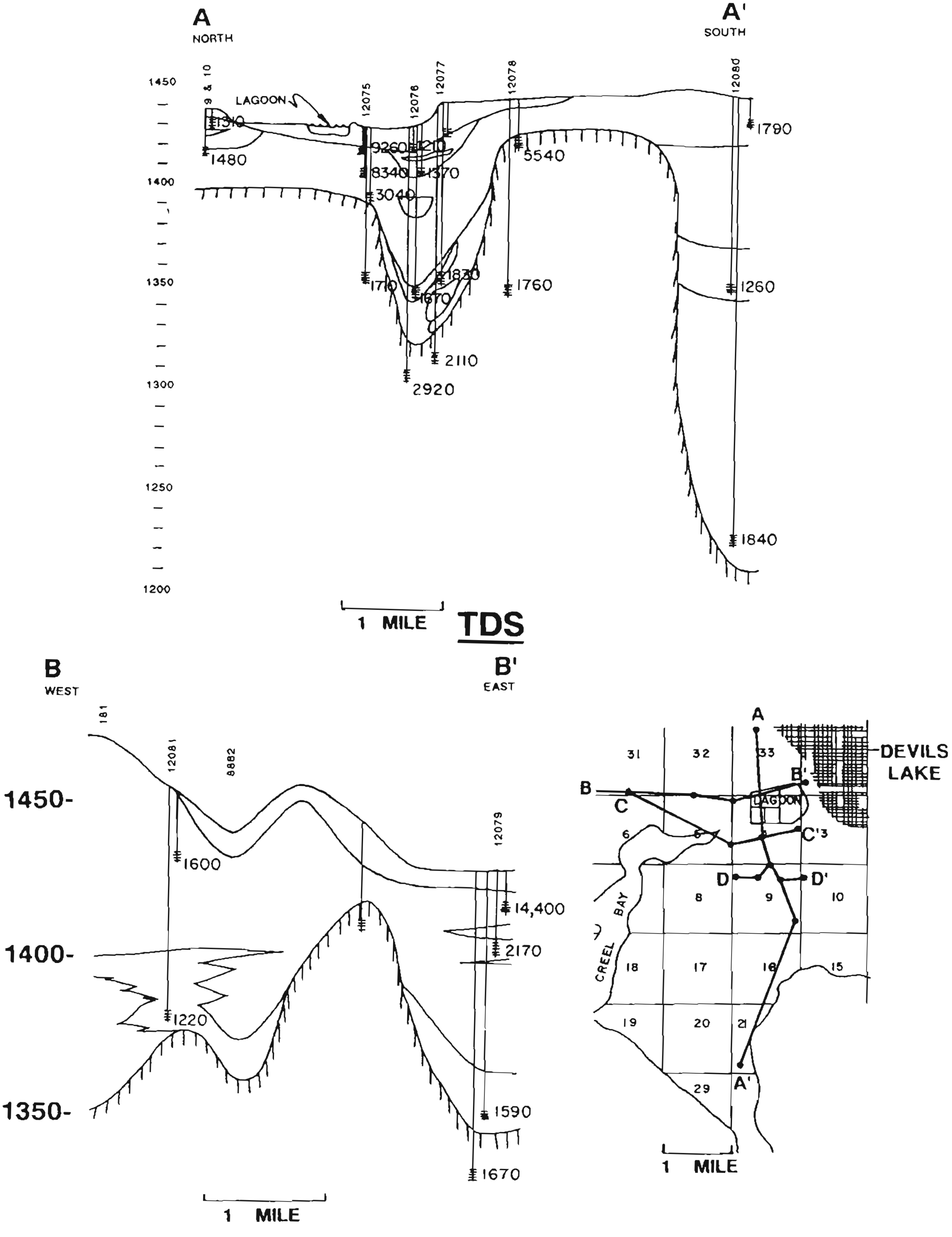

Figure 36. TDS profiles for groundwater in sections A and B.

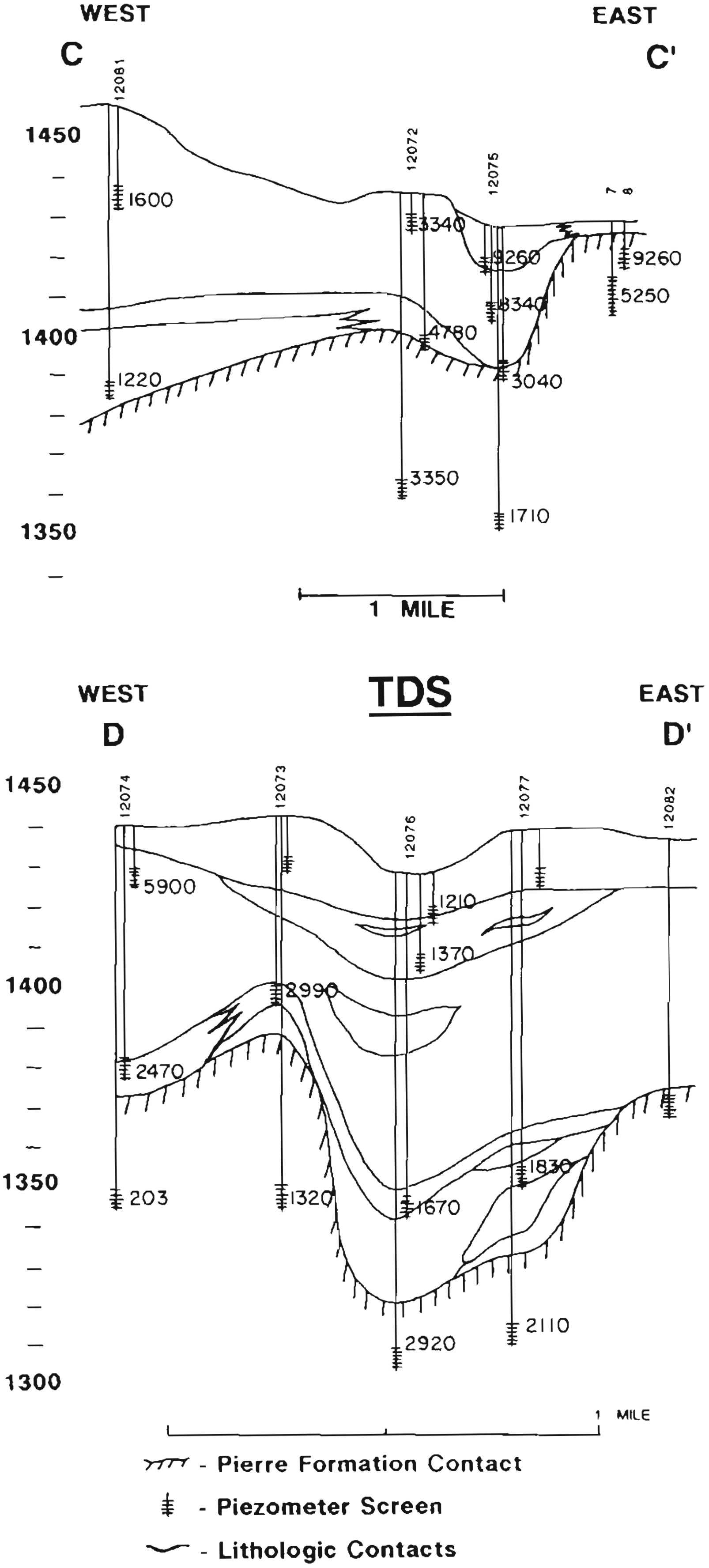

Figure 37. TDS profiles for groundwater in sections C and D.

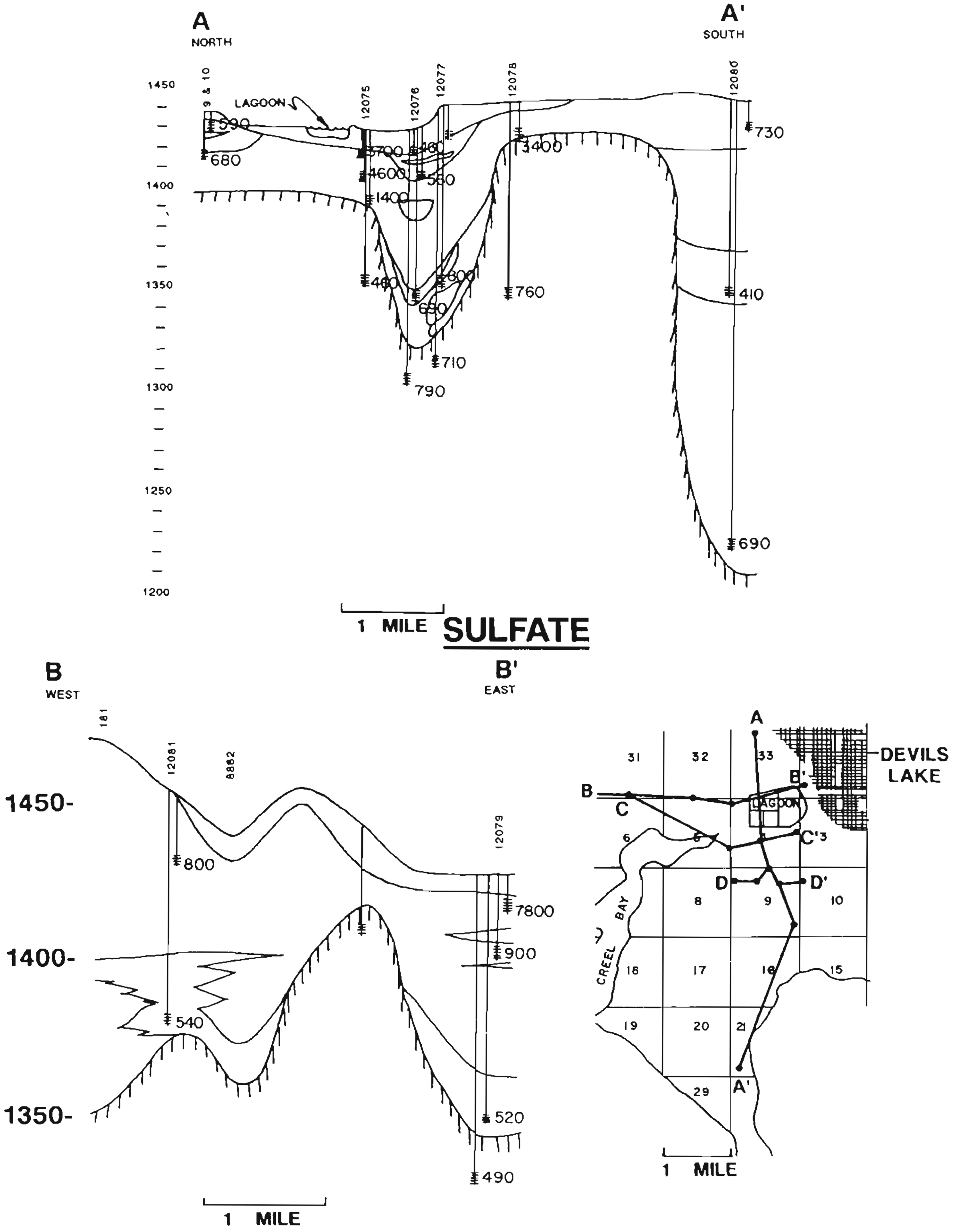

Figure 38. Sulfate profiles for groundwater in sections A and B.

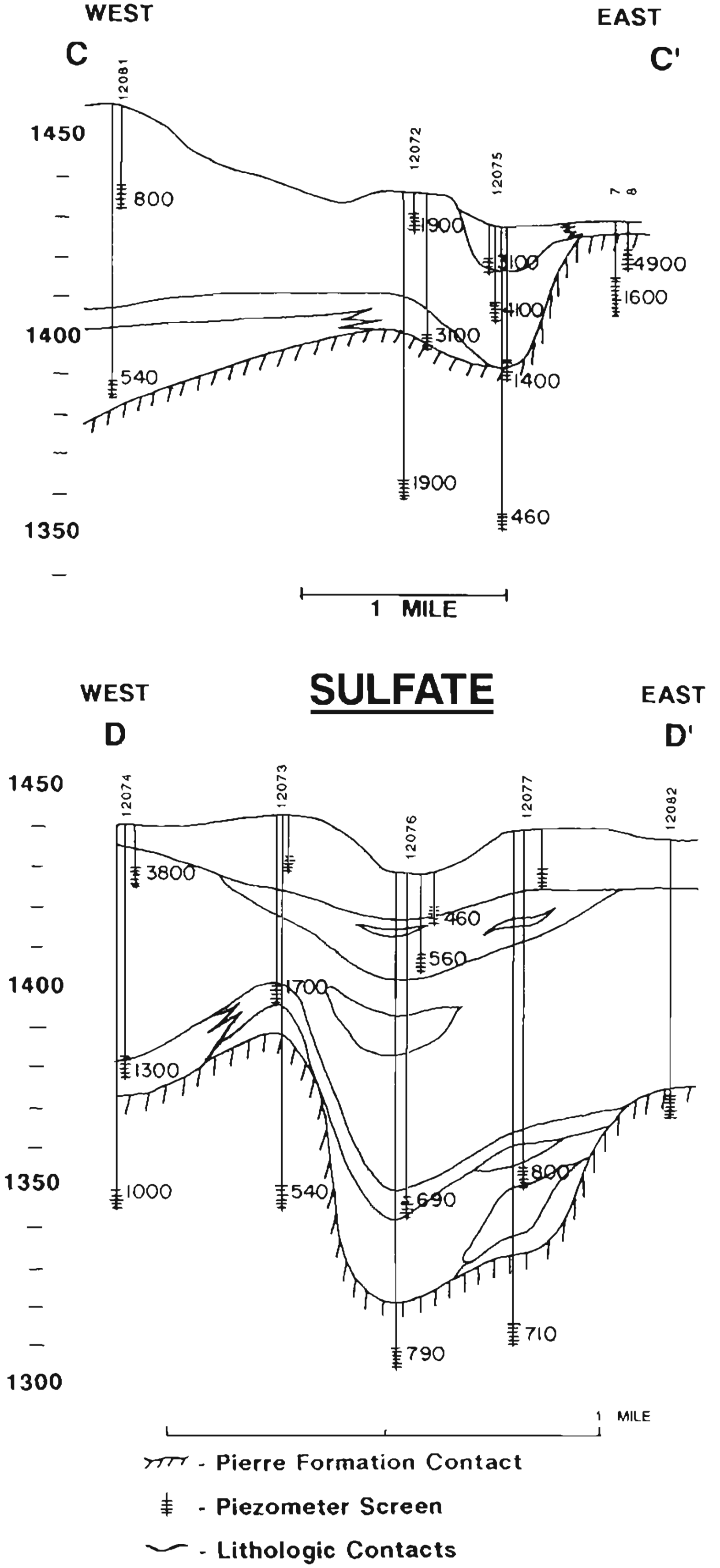

Figure 39. Sulfate profiles for groundwater in sections C and D.