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GROUND WATER MOVEMENT WITHIN TILL IN LINCOLN COUNTY, SOUTH DAKOTA

by

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INTRODUCTION

Purpose and Scope

This report was prepared to provide the results of research on the potential for water movement through till in an area of Lincoln County, South Dakota. The Lincoln County area is one of three areas that have been studied in South Dakota (fig. 1). The data presented in this report from the till study sites in Lincoln County were gathered from August 1984 through August 1986.

The impetus for this type of research was an interest at local, state, and national levels on the feasibility of large-scale irrigation of South Dakota soils which are derived mainly from till. Major concerns when irrigating are potential problems of soil salinization and water logging. Thus, it is essential to understand and quantify the movement and fate of water which percolates below the root zone in order to fully understand and predict the ramifications of long-term irrigation.

Concepts of water movement through till were examined and discussed by the South Dakota Geological Survey in March of 1983 (Barari, 1983). Barari pointed out that there were problems with the traditional conceptual models used to explain water movement through till. Specifically, these models generally attributed dissipation of water in the till to:

1. significant downward movement of water through unweathered till, and/or

2. significant lateral movement of water through weathered and unweathered till.

Barari suggested that these two concepts could not account for enough water movement to balance the water budget. Rather, he suggested, that most water reaching the water table in till is dissipated through upward movement by the process of evaporation.

To test the validity of the above-mentioned theory and to define and characterize ground water movement through till, three areas in eastern South Dakota with different hydrogeologic conditions were chosen for detailed investigation. Study results from two of the three areas were presented by Barari and Hedges (1985). Results from the third area of study, the Lincoln County area, are contained in this report.

The results of this and other ongoing research will have significant impacts beyond the specific problems identified with irrigation. For example, there will be impacts on (1) the selection, design, and monitoring of waste disposal sites, (2) regulation and cleanup of contamination sites, and (3) estimates of recharge to buried glacial aquifers.

The Lincoln County area was chosen for study because of a unique site condition which sets it apart from other areas studied in South Dakota. This study area is underlain by an outwash which is under confined, flowing hydraulic conditions.

Location of Study Area

This study area is located in Lincoln County, South Dakota, and consists of three investigation sites (fig. 2).

METHODS

Drill Hole Identification and Location

The methods of drill hole and/or piezometer designation, such as GT-LN-1A, and locations, such as 099N-50W-24BBBB, are explained in appendix A.

Drilling and Construction of Piezometers

The word "piezometer" as used in this report refers to any drill hole with casing for the intended purpose of measuring water levels or collecting water samples. All drill holes, except one (GT-LN-3F), were drilled using 4-inch diameter solid flight auger. The exception was drilled using an 8-inch outside diameter, hollow stem auger. A total of 38 piezometers were installed.

After the desired bottom-hole depth was reached, the auger was removed from the hole and 2-inch diameter, schedule 80, threaded joint, polyvinyl chloride (PVC) casing was inserted. A well screen was attached to the bottom of the casing prior to insertion in only two instances (piezometers GT-LN-1G and GT-LN-2D, app. A). In these two piezometers, a filter pack was placed around the outside of the well screen. The filter pack was composed of quartz and feldspar with a grain size of very coarse sand to very fine gravel. For the other 36 piezometers, the open-ended bottom of the casing was ground to a sharp edge and covered with a thin flexible cap prior to insertion into the hole. The thin flexible cap was used to keep foreign matter out of the casing during insertion. For those piezometers without a well screen, the casing was pushed approximately 3 inches into bottom-hole sediment. Pushing the casing into the bottom-hole sediment served to:

1. cut the thin flexible cap thereby allowing a hydraulic connection with the sediment, and

2. provide a seal around the end of the casing between the annular space on the outside of the casing and the water-intake area at the bottom of the casing.

The annulus around the outside of the casing was then filled with a bentonite slurry having at least a 60-second per quart Marsh Funnel viscosity. This was accomplished by pumping the slurry from the bottom of the annulus to the top (ground surface). In 32 of the 36 piezometers without well screens, a 1.5-inch diameter thin wall tube sampler (shelby tube) was then inserted inside the casing, and a 12-inch long core sample was taken of the bottom-hole sediment. Completion techniques were the same in the other four piezometers except the bottom core sample was not taken.

Thus, the water-intake area of the 38 piezometers consisted of one of the following:

1. a 5- or 10-foot long well screen (piezometers GT-LN-1G and GT-LN-2D respectively, app. A),

2. the area of the open-ended casing directly in contact with bottom-hole sediment (piezometers GT-LN-1B, GT-LN-1E, GT-LN-2B, and GT-LN-3F, app. A), or

3. the area of the open-ended casing plus the open hole remaining after collection of bottom-hole sediment using a shelby tube (in the remainder of the piezometers, app. A).

Collection and Use of Large Diameter Core Samples

Four core samples, 5-inch diameter by 2.5-feet long, were obtained using a hollow stem auger rig: two from weathered and two from unweathered till. These samples were used for grain-size analyses, determination of mineralogical composition, and determination of hydraulic conductivity in the laboratory.

Determination of Hydraulic Conductivity

Hydraulic conductivities of the till were determined in three ways. Two methods were to use procedures described by Hvorslev (1951) and Luthin and Kirkham (1949) utilizing recovery measurements of ground water in piezometers completed in till. The third method was to use the undisturbed 5-inch diameter by 2.5-feet long core samples of till for laboratory analysis. Two different methods were used for this analysis: (1) high pressure permeability method, U.S. Bureau of Reclamation; and (2) flow pump permeability method, University of Colorado, Boulder, Colorado.

Collection of Water Samples

Water samples for chemical analysis were collected using a clean teflon bailer. No specific amount of water was removed from each well before sampling occurred because of extremely slow recharge to many of the piezometers.

GEOLOGY

Bedrock

Bedrock beneath the study area consists of Precambrian age Sioux Quartzite which is overlain by Cretaceous age sediments. The Cretaceous sediments are, in ascending order from oldest to youngest, the Dakota Formation, Graneros Shale, Greenhorn Limestone, Carlile Shale, and Niobrara Formation.

Sioux Quartzite is a very hard, silica cemented, fine- to medium-grained sandstone (ortho-quartzite) which locally has been extensively fractured. The thickness of the Sioux Quartzite is unknown. The Dakota Formation consists of about 200 to 300 feet of interbedded sand, sandstone, clay, and sandy clay. The Graneros Shale, Greenhorn Limestone, and Carlile Shale are all basically clays or shales with a combined thickness of about 150 to 300 feet. The Niobrara Formation ranges from 0 to 14 feet thick and is composed primarily of calcareous silt and clay. Thicknesses given are for the immediate vicinity of investigation sites 1, 2, and 3. Figure 3 shows the locations of cross sections drawn through the study area. Figures 4 and 5 show the stratigraphic relationships between the various bedrock units near and through the study area. Logs of drill holes used in the figures can be found in appendix B. At one location (098N-50W-32AAAA), data from two drill holes were used in constructing figure 5. The bedrock correlations are based on examination of subsurface samples and electric log interpretations.

Glacial

Pleistocene age sediments consisting of till and outwash cover the entire study area and range in thickness from 68 to 223 feet in the drill holes used to construct figures 4 and 5. The till is composed of a clay and silt matrix containing sand, gravel, pebbles, and boulder-size particles. Outwash is composed of sand and/or gravel and may or may not contain clay layers or lenses.

Outwash

Outwash is present beneath the study area with depths to the top of the outwash ranging from 49 to 120 feet (figs. 4 and 5). The outwash layer ranges in thickness from near 0 to 116 feet and may contain some clay layers or lenses.

The occurrence and lateral continuity of the outwash are not fully defined throughout the study area. However, the existence of buried outwash at sites 1 and 2 has been documented by test drilling and the existence of outwash beneath site 3 is inferred from other test hole and private well data. Lateral continuity of the outwash among the three sites and throughout at least an 8 square mile area in the immediate vicinity of the sites is assumed and will be discussed later in this report.

Outwash underlying sites 1, 2, and 3 is presently correlated with that which occurs northeast of the study area near Harrisburg (fig. 6). Figure 7 further illustrates the inferred lateral continuity of the outwash between Harrisburg and the vicinity of sites 1, 2, and 3. It should be noted that cross section A-A'-A" (fig. 7) has an east-west component, which is A-A' (fig. 4), and a north-south component, which is A'-A". Also, two drill hole logs were used at one location (099N-50W-02AABA) in constructing figure 7.

Till

A mantle of late Wisconsin age till is ubiquitous throughout the study area (Schroeder, 1972). It contains a surficial weathered (oxidized) layer that ranges in thickness from 12 to 36 feet in the test holes shown on figures 4, 5, and 7, and from 18 to 28 feet in the test holes at sites 1, 2, and 3. A description of the weathered till, based on soil trimmings from a core sample, is provided in appendix C.

An unweathered layer of gray till underlies the upper brown, weathered layer. The first (shallowest) occurrence of unweathered till may be directly underlain by any of the following:

1. outwash,

2. an apparent zone of weathering in the till, or

3. the Niobrara Formation.

Thickness of the upper layer of unweathered till ranges from 28 to 96 feet in test holes shown on figures 4 and 5 and is at least 49, 48, and 44 feet thick, respectively, at sites 1, 2, and 3. A description of the unweathered till, based on soil trimmings from a core sample, is provided in appendix C.

Grain size analysis was performed on two samples of weathered till taken at site 1 from depths of 5 to 7.5 feet and 25 to 27.5 feet. These analyses show the textural classification to be that of a clay loam (according to terminology used and accepted by the U.S. Bureau of Reclamation). It is believed that these analyses may be representative of till present in and near sites 1, 2, and 3. Other soil properties that were determined from the same two samples are listed in appendix C.

Core samples of till from this study area were not examined for the presence of fractures. Fractures in till have been reported in other areas of South Dakota (Beadle and Union Counties, fig. 1) where visual examination of cores found weathered till to contain fractures with secondary mineralization (T. Cowman, South Dakota Geological Survey, personal communication, 1986).

Two samples of till from site 1, one weathered and one unweathered, were examined for mineralogical content using the x-ray diffraction method (table 1). Results listed in table 1 show that there is slightly more gypsum, slightly less pyrite, and much more iron oxides present in the weathered till (sample 62Q-1) than in the unweathered till (sample 62Q-2). These differences may be due to the oxidizing conditions present in the weathered till. The sulfide in pyrite may be oxidized to sulfate; evidence of this is a high sulfate content in the ground water from weathered till. This sulfate would then potentially be available for chemical interaction and incorporation into authigenic gypsum. Iron oxides are visible as the brownish coloration in the weathered till. Percentages for minerals listed in table 1 are believed to be representative of the weathered and unweathered till within the study area.

HYDROLOGY

Water Levels

Bedrock

The only bedrock unit for which water level data are available is the Dakota Formation. This is also the only bedrock unit in the study area which is commonly used as a source of ground water, although in some instances, the Niobrara Formation may be utilized. The Graneros Shale, Greenhorn Limestone, and Carlile Shale are not considered aquifers and act as a confining layer between the Dakota Formation and overlying Pleistocene sediments.

The top of the Dakota Formation is at a depth of about 350 to 450 feet in the study area, and is under confined conditions. Data on the potentiometric surface were obtained from many observation wells completed in the Dakota Formation in this area. The potentiometric surface of water in the Dakota Formation ranges from about 100 feet to more than 200 feet below land surface and is everywhere lower than the potentiometric surface of the outwash and the water table in the weathered till, and is below the base of these glacial sediments throughout much of the area (fig. 7).

Outwash

Outwash is under confined conditions at, and in the vicinity of sites 1, 2, and 3, but is under unconfined conditions in the vicinity of Harrisburg (figs. 3 and 7). The potentiometric surface of the outwash shows that water from wells completed in the outwash will flow onto the land surface at sites 1, 2, and 3 (fig. 7). Although the full extent of the area containing flowing wells is not documented,

a quick reconnaissance of local farm wells indicated at least an 8 square mile area with flowing wells (fig. 8).

The hydraulic head in the outwash body that underlies sites 1, 2, and 3 generally decreases from north to south. Hydraulic head in the outwash in the vicinity of the study sites is sufficient to produce flowing well conditions. Water levels in the outwash are about 12 feet higher near Harrisburg than they are in the vicinity of the study sites. Data show that part of the outwash in the northern part of the outwash body is unsaturated at 099N-50W-02AABA and 099N-50W-24BBBB (fig. 7), however, the hydraulic connection of the area containing unsaturated outwash to the area where flowing wells occur is not fully defined.

The spatial relationship of till underlain by outwash that produces flowing wells was the primary reason this area was chosen for study. The significance of this relationship will be addressed later in this report.

Till

Cross sections showing the relationship of weathered and unweathered till to the depth and construction of piezometers used to examine water levels are shown in figures 9, 10, and 11. Logs and piezometer completion data are in appendix A. Water levels accurate to the nearest 0.01 foot were measured on a regular basis in these piezometers from October 22, 1984, through May 19, 1986 (apps. D, E, F). Hydrographs of these piezometers completed in till at sites 1, 2, and 3 are presented in figures 12, 13, and 14, respectively. The water elevations shown on the hydrographs are relative to mean sea level.

When analyzing water level recoveries in materials of low hydraulic conductivity, especially unweathered till, there are two groups of factors that could influence the recovery rate. One group relates to the effects of intake area on water level recovery rates. The other group relates to construction integrity and post-construction activities or changes that may alter the rate of water level response.

EFFECT OF PIEZOMETER INTAKE AREA ON WATER LEVELS

Rate of Recovery

The rate of water level recovery is dependent upon the area of the intake zone (all other conditions being equal). It should be recalled that piezometers used in this study were constructed having three different intake areas:

1. a filter-packed well screen (5 or 10 feet long, 0.018-inch slot size),

2. open-ended casing in direct contact with bottom-hole sediment including a 12-inch long by 1.5-inch diameter shelby tube core hole in the bottom-hole sediment, or

3. open-ended casing in direct contact with bottom-hole sediment (no shelby tube core hole).

Thus, the rate of water level recovery should be highest in item 1 above and lowest in item 3 in unweathered till and the lower portions of weathered till. This relationship is probably not valid for piezometers completed in the upper portion of the weathered till where the dominant water level response is assumed to be due to fracture flow and not intergranular flow. Hydraulically active fractures present in the water-intake area at any depth have the potential to be the dominant control on recovery rates.

In unweathered till, the only comparison of water level recovery rate that can be made between piezometers of similar depth with intake areas of items 2 and 3 above are at site 1 (GT-LN-1E and GT-LN-1D; figs. 9 and 12). At the other two sites, such comparisons between piezometers of similar depth are impossible because of the apparent influence of a more permeable zone at piezometer completion depth. At site 1, piezometer GT-LN-1D (shelby tube core intake) shows a substantially greater rate of recovery than piezometer GT-LN-1E (open-ended casing intake). The faster recovery rate may be due to the larger water-intake area.

Water Elevation

In weathered till at sites 1 and 2, the screened piezometers and shallowest shelby tube core intake piezometers (figs. 9 and 10) exhibit similar water level readings. This similarity in water levels is probably because the piezometers with screens, although deeper, intersect the same horizon as the shallower piezometers. As a result of screen length, those piezometers with a screen do not reflect the hydraulic pressure from a specific horizon. Thus, water levels in them cannot be directly compared to those in other piezometers with a small intake.

CONSTRUCTION INTEGRITY AND POST-CONSTRUCTION ACTIVITY

In addition to the influence of the water-intake area on the water level recovery rates, the following factors must also be evaluated:

1. a break in the casing during installation or at a later date,

2. incomplete grouting procedures,

3. breakdown of grout integrity with time, and

4. effects of piezometer development or other causes for water withdrawal.

In general, a loss of integrity with casing or grouting material, or post-construction activity, would tend to increase the rate of water level recovery. Recovery curves from piezometers completed in the lower weathered till and unweathered till (figs. 12, 13, and 14) do not reflect a breakdown in construction integrity or post-construction activity resulting in an increase in water level recovery. A probable exception to this general conclusion in noted at piezometer GT-LN-2C (fig. 13) which shows a higher recovery rate after water withdrawal.

WEATHERED TILL

Water level fluctuations in piezometers completed in shallow weathered till are similar to fluctuations in open holes. This is partially illustrated by two holes that were drilled to depths of 8 and 6 feet, respectively, at sites 1 and 2 (one at each site) and were left open. Water levels were monitored in both holes (apps. D and E) and were found to fluctuate similarly (correlation coefficients of 0.99 or greater) with levels in shallow piezometers GT-LN-1G and GT-LN-1H (figs. 9 and 12) and GT-LN-2D and GT-LN-2F (figs. 10 and 13). This relationship indicates that those shallow piezometers correctly reflect the water table response in shallow weathered till. Two other piezometers completed in weathered till, GT-LN-3C and GT-LN-3D (figs. 11 and 14), also reflect a direct connection to infiltrating water. Examination of hydrographs for these piezometers (figs. 12, 13, and 14) reveals:

1. a very shallow water table throughout the period of monitoring, and

2. a striking similarity in water level response.

Piezometers GT-LN-1F (figs. 9 and 12) and GT-LN-2A (figs. 10 and 13) are the deepest piezometers in weathered till at their respective sites. Water levels in these piezometers do not show response to precipitation events or seasonal variations. This lack of water level response to precipitation events or seasonal variations is not surprising, even though they are completed in weathered till. Hendry (1983) points out that the presence of vertical conduits (fractures) in weathered till play an important role in the path and velocity of water movement through the till. The degree of response in any given piezometer to precipitation or seasonal variations is dependent upon the number, size, and continuity of fractures which are intersected by the water-intake area of the piezometer and upon the hydraulic conductivity of the till. Those piezometers completed in the lower portion of the weathered till where the hydraulic conductivity is likely to be low may not intersect any fractures, thus, they may not show response to precipitation events or seasonal variation.

UNWEATHERED TILL

Piezometers completed in unweathered till (figs. 9, 10, and 11) exhibit a wide range of water level recovery rates (figs. 12, 13, and 14). The fastest rates of recovery are recorded in the deepest piezometers at all three sites (those with drill hole depths of 67 and 70 feet). At site 1 (piezometers GT-LN-1A and GT-LN-1B) and site 3 (piezometer GT-LN-3A), visual examination of the bottom-hole core showed the presence of more highly permeable (silty) material overlying the buried outwash. The log of the deep drill hole at site 2 (piezometer GT-LN-2E) did not indicate more permeable material at completion depth.

Response curves for piezometers GT-LN-1C, -1D, and -1E at site 1 and response curves for piezometers GT-LN-2B and -2C at site 2 (figs. 12 and 13) are typical response curves for unweathered till. However, response curves for piezometers GT-LN-3B and -3E at site 3 (fig. 14) exhibit fluctuations as they approach water table elevations. These fluctuations do not mirror the shallow water table fluctuations in the weathered till. The condition or conditions causing different behavior at site 3 as compared to the other sites is unknown.

As previously mentioned, the two deepest piezometers at each of sites 1 and 3 (figs. 9 and 11) were apparently completed in a silty zone above the outwash. This material undoubtedly has a higher hydraulic conductivity than the till which explains the rapid water level recovery to an elevation above or near land surface (figs. 12 and 14). Water flows continuously from one deep piezometer (GT-LN-1A) and much of the time from the other deep piezometer at site 1 (GT-LN-1B) but does not quite reach land surface in the two deep ones at site 3 (GT-LN-3A and -3F). Site 3 has a higher land surface elevation than site 1 and water elevations in the deep piezometers at site 3 may reflect the potentiometric surface of the outwash.

VERTICAL GRADIENTS

During the period of water level measurements, a consistent upward or downward vertical gradient was not determined throughout the till because the water levels did not reach equilibrium (apps. D, E, and F). Some of the water level differences may be attributed to water-intake area construction methods as discussed earlier. However, when only those wells that are completed with the open-ended casing plus shelby tube core are considered (figs. 9, 10, and 11), the results shown in table 2 still show an inconsistent vertical gradient. The implication of the vertical gradients at equilibrium with respect to resulting direction of vertical flow of water will be discussed later in this report under the section entitled "Vertical Water Movement in Unweathered Till."

Hydraulic Conductivity of Till

Hydraulic conductivity values were obtained for till at all three investigation sites. The specific piezometers involved and the hydraulic conductivity values obtained are listed in table 3. Using the average of methods described by Luthin and Kirkham (1949) and Hvorslev (1951), the hydraulic conductivity of the unweathered till was calculated to range from 7.4×10^{-9} to 4.5×10^{-8} centimeters per second (cm/sec) with a geometric mean of 1.8×10^{-8} cm/sec. The hydraulic conductivity of the weathered till was calculated to range from 1.5×10^{-8} to 4.2×10^{-5} cm/sec with a geometric mean of 2.5×10^{-7} cm/sec (table 3). The range and geometric mean for the weathered till are exclusive of a calculated value of 1.7×10^{-3} cm/sec (Hvorslev method) for piezometer GT-LN-2H. The data from this piezometer were not suitable for analysis using the Luthin and Kirkham method, thus no average for the two methods could be obtained.

Hendry (1982) and Prudic (1982) both indicated that hydraulic conductivities in weathered till range up to 3 orders of magnitude higher than those for unweathered till. The unweathered till they were using for comparison had a hydraulic conductivity of 1.0×10^{-8} cm/sec, which is similar to the hydraulic conductivities determined for unweathered till for this report (table 3). The range in differences between weathered and unweathered till reported by Hendry (1982) and Prudic (1982) agrees favorably with those shown in table 3 (column labeled "Average of the two methods").

A core sample of unweathered till collected at a depth of 25 to 27.5 feet from site 1 was submitted to the U.S. Bureau of Reclamation, Engineering and Research Center, Soils Mechanics Section, in Denver, Colorado, for determination of hydraulic conductivity. The core was 5 inches in diameter and approximately 29 inches long and was collected from a test hole adjacent to the piezometers. The hydraulic conductivity was determined to be less than 9.6×10^{-8} cm/sec, the lower

detection limit of the laboratory equipment (L. Faris, U.S. Bureau of Reclamation lab, personal communication, 1986).

The sample was then submitted by the U.S. Bureau of Reclamation to the University of Colorado, Department of Civil, Environmental, and Architectural Engineering, for further attempts at determination of hydraulic conductivity using a different method. Results from the University of Colorado indicate a vertical hydraulic conductivity of 1.26×10^{-8} cm/sec (L. Faris, U.S. Bureau of Reclamation lab, personal communication, 1986). The horizontal hydraulic conductivity was not determined.

The estimates of hydraulic conductivity for unweathered till listed in table 3 and the estimate supplied by the U.S. Bureau of Reclamation are all within an order of magnitude and show that the unweathered till has a very low hydraulic conductivity.

Vertical Water Movement in Weathered Till

Rising water levels in piezometers completed in weathered till are the result of water in excess of soil storage capacity entering the ground surface. These fluctuations can be attributed to, and correlated with, recharge events caused by precipitation. The relatively rapid response of water levels in these piezometers is attributed to secondary permeability (fractures) in the weathered till. The similarity of water levels in most piezometers completed at different depths in weathered till is also attributed to fractures in the till.

The data may indicate that fracture density and/or continuity in weathered till decrease with depth and thus, affect vertical water movement in weathered till. Evidence supporting this conclusion is suggested by water level responses in piezometers GT-LN-1F and GT-LN-2A (figs. 12 and 13). These piezometers are the deepest completed in weathered till at sites 1 and 2. Water level responses from these piezometers are more representative of responses observed in unweathered till where fracture flow is thought to play an insignificant role in water movement.

Data gathered show that vertical water movement occurs in much of the weathered till, presumably through avenues of secondary permeability, as evidenced by fluctuating water levels in most of the piezometers in the weathered till.

Vertical Water Movement in Unweathered Till

Water levels in piezometers completed in unweathered till at the test sites did not reach equilibrium during the period of record shown in appendices D, E, and F, 19 to 23 months after piezometer completion. Thus, the vertical gradients at equilibrium could not be observed. The only way to evaluate resulting vertical gradients with available data is to assume possible ending equilibrium conditions and draw conclusions from the various possible scenarios. The same approach was taken by Barari and Hedges (1985) and the following quote is from their report.

> The potentiometric surface of water in the aquifer at the Lincoln County site is above the land surface. Thus, there can be no downward movement of ground water through the unweathered till. It is recognized that measured water levels in the till

probably have not reached equilibrium at the time of this writing (1 month after completion and evacuation of piezometers). However, the following scenarios can be examined using basic hydrologic principles which are based on the assumption that equilibrium has been established for the conditions described for each scenario.

Scenario 1

Water levels in piezometers constructed in unweathered till are lower than the water table in weathered till and do not show a consistent upward gradient.

This scenario shows that there is no upward movement of water in the unweathered till. If this scenario does in fact prove to be true at this location, then it shows that upward flow is nonexistent even though the potentiometric surface is above the ground level. Thus, a threshold gradient must be reached in low permeable material before actual movement of water occurs.

Scenario 2

Water levels from piezometers in the unweathered till are at essentially the same level as the water table in weathered till.

In this scenario, there can be no upward movement of water because water levels in unweathered and weathered till are equal.

Scenario 3

The water level in piezometers constructed in unweathered till come to equilibrium at higher levels than water levels in weathered till, and show progressively higher water levels in deeper piezometers.

In this scenario, upward movement of water may occur.

If it is assumed that the condition represented in scenario 3 is the resulting equilibrium condition, and using the geometric mean of the average vertical hydraulic conductivity values in table 3 for unweathered till (1.8×10^{-8} cm/sec) and assuming a very high hydraulic gradient of one (1.0), the upward movement of water through the unweathered till cannot exceed 0.6 cm per year (Darcy velocity).

Lateral Water Movement in the Till

Laboratory analysis of unweathered till core from east-central South Dakota in the CENDAK area (fig. 1) yielded a horizontal hydraulic conductivity of 1.2×10^{-8} cm/sec (Faris, 1986). If values of this magnitude stand the test of continuing research, the lateral movement in unweathered till cannot be significant under reasonable gradients.

Research activities for this report were not designed to gather evidence for lateral ground water movement through weathered till. In spite of this, a quantification of lateral flow in weathered till using a conceptual model and some known site parameters is presented. Calculations include a range of values for recharge and for possible maximum quantities of lateral flow under field conditions that existed at site 2. Site 2 was chosen for illustration because the best possible case for lateral ground water movement can be made at that site relative to the other two sites; the distance to a discharge point is shorter and the maximum theoretical horizontal gradient is highest. Water level rise reported in appendix E was used to calculate the recharge. A rise of 3.45 feet was measured in well GT-LN-2D between February 26, 1986, and April 16, 1986. It should be noted that this recharge occurred during a limited period of time and the annual recharge is greater than this value. Table 4 lists the volume of water recharging 1 square foot of land and also the volume of water recharging a strip of land 1 foot wide and 1,080 feet long, the distance between site 2 and a possible lateral discharge zone (Snake Creek). A water level rise of 3.45 feet and specific yield values of 1 and 10 percent were used for calculation. For comparison, testing in the CENDAK area showed a specific yield ranging from 2.2 to 13 and averaging between 5 and 6 (U.S. Bureau of Reclamation, 1986).

If the water is to move laterally and discharge at Snake Creek (fig. 15), then a minimum amount to be discharged from this strip of land has to be 37.26 cubic feet annually. To calculate the possible discharge of water to Snake Creek, Darcy's Law is employed. Assuming that Darcy's Law is applicable in fractured material of low permeability such as weathered till, then $Q = AKi$, where:

Q = *amount of flow in gallons per day*

A = *cross sectional area through which flow occurs in square feet*

K = *hydraulic conductivity in gallons per day per square foot*

i = *horizontal hydraulic gradient in feet per feet*

At site 2, values of hydraulic conductivity (Hvorslev method) for the weathered till were found to range from 1.7×10^{-3} to 1.7×10^{-8} cm/sec (table 3) with a geometric mean of 8.2×10^{-7} cm/sec and an average of 3.4×10^{-4} cm/sec. The maximum value of 1.7×10^{-3} cm/sec was from a piezometer which was 6 feet deep and thus closest to the water table at this site as compared to the completion depths of the other weathered till piezometers at this site. For comparison, values of hydraulic conductivity at site 1 from piezometers with depths of 3 and 6 feet were found to be on the order of 10^{-7} cm/sec, which is significantly less than 1.3×10^{-3} cm/sec but which is consistent with the calculated geometric mean for weathered till. For the purpose of this report, potential lateral movement of ground water in the weathered till assumes hydraulic conductivities ranging from 1.7×10^{-3} to 1.5×10^{-8} cm/sec, which brackets the experimental results for weathered till at sites 1 and 2.

The gradients assumed for the calculations are represented by assumed linear and nonlinear water table slopes on a flow path along the shortest distance between site 2 and Snake Creek to the south-southeast (figs. 15, 16, and 17). The vertical distance between ground surface at site 2 and the bottom of the intermittent stream (Snake Creek) is about 9 feet along a horizontal distance of 1,080 feet. Thus, the maximum gradient calculated for the linear water table slope is 0.0085 feet per foot (ft/ft). However, if it is assumed that the water level declines 4 feet in the last 200 feet from the creek, then the nonlinear gradient over that 200 feet is 0.02 ft/ft.

Estimates of potential lateral discharge of ground water were based on the assumption that the intermittent stream (Snake Creek) has an average water depth of 1 foot during the year (the vertical dimension of the seepage face is 1 foot). Table 5 summarizes the annual potential discharge from a 1 foot square cross sectional area of land (seepage face) along Snake Creek under the two assumed gradients.

Table 5 shows a maximum discharge to the creek of 14.95 cubic feet per year from 1 square foot of land (seepage face) under the assumed gradient of 8.5×10^{-3} (linear water table slope) and a hydraulic conductivity of 1.7×10^{-3} cm/sec. This discharge is much less than 37.26 cubic feet (table 4), the minimum calculated recharge to the water table.

It is recognized that the slope of the water table from site 2 to Snake Creek is probably not linear and that the slope will increase near the discharge point. Therefore, discharge calculations were made using the nonlinear gradient of 0.02 and a hydraulic conductivity of 1.7×10^{-3} cm/sec. This calculation yielded a discharge of 35.18 cubic feet per year. Under this scenario, the gradient would be less than 0.02 and the hydraulic conductivity would have to be greater than 1.7 x 10-3 cm/sec beyond 200 feet from the seepage face in order to balance the water budget. Thus, in order to dissipate a minimum calculated recharge in a lateral direction, the following conditions would have to be satisfied:

1. the till must possess a hydraulic conductivity greater than the maximum recorded in till in Lincoln County,

2. a lateral hydraulic gradient must be present in the till that is probably near the maximum possible under any circumstances for site 2, and

3. a consistently high enough water table must exist to create a seepage face along an intermittent stream.

This illustration indicates that even under the most favorable conditions, lateral movement is not capable of dissipating the minimum calculated recharge. Less favorable conditions of hydraulic conductivity and gradient would only widen the discrepancy. Thus, lateral movement of water is probably not the main factor for dissipating recharge water.

Water Chemistry

Bedrock

The Dakota Formation is the only bedrock unit in the till research area for which water quality data are available (Iles, 1984). These data are presented in table 6 and show that the water averages about 630 milligrams per liter (mg/L) dissolved solids. The water quality of this aquifer is generally good compared to water from the outwash and till.

OUTWASH

Two water samples were taken from the flowing wells completed in the outwash underlying the study area. One well is located approximately 1.5 miles north of site 2 and the other well is located approximately 1 mile south of site 3 (app. G). These wells were chosen for sampling because of their suitability for collecting samples for carbon-14 dating. The average water quality of these two samples is shown in table 6 and individual analyses are presented in appendix G. The stratigraphic correlation shown in figure 7 indicates that water in the buried outwash at the study site correlates to buried outwash in other parts of Lincoln County (Iles, in prep). The water from the outwash has generally higher concentrations of chemical constituents than water from the Dakota Formation and generally less than water from till.

TILL

Water from piezometers at sites 1 and 2 were sampled for chemical analysis (table 6). Water from the weathered till generally has higher concentrations of dissolved constituents than water from the underlying unweathered till, and water from both sources is more mineralized than water from either the Dakota Formation (bedrock aquifer) or the buried outwash (glacial aquifer). A complete listing of the chemical analyses of water from the till is presented in appendix G.

Analyses of water from weathered till for trace metals yielded concentrations ranging from <0.2 to 65 micrograms per liter (ug/L) for selenium and from $\leq$0.3 to 5.6 ug/L for arsenic. Concentrations in unweathered till ranged from $\leq$0.2 to 1.9 ug/L for selenium and from 1.2 to 22 ug/L for arsenic (app. G).

Age of Ground Water

Water from the Dakota Formation (Iles, 1984; data on file at the South Dakota Geological Survey) has been sampled and analyzed for the isotopes of carbon-14, oxygen-18, and deuterium. Water from the outwash and till has been sampled and analyzed for the isotopes of carbon-14, tritium, oxygen-18, and deuterium. Analytical results from the till and outwash are presented in table 7.

Water in the Dakota Formation in the immediate area was found to range between 30,000 and 40,000 years old (Iles, 1984; data on file at the South Dakota Geological Survey). The oxygen-18 and deuterium data from the Dakota Formation indicate that the mean annual air temperature ranged from 3 to 5°C when the water formed as precipitation (Iles, 1984).

Water samples from the outwash were collected from flowing wells. According to the carbon isotope data (table 7), the age of water in the outwash was found to range from 7,269 to 13,543 years old. The result of an analysis for tritium in a water sample from the outwash (table 7) is consistent with the carbon isotope data in that it indicates the outwash water is pre-1953 in age (Freeze and Cherry, 1979, and Fetter, 1988). The oxygen-18 and deuterium data from the outwash (table 7 and

fig. 18) indicate that the mean annual air temperature ranged from about 4½ to 7°C when the water formed as precipitation (Dansgaard, 1964).

Water in the unweathered till was found to range from 9,068 to 22,410 years old (table 7). Analyses for tritium (table 7) in water from the unweathered till indicate that the water is pre-1953 in age (Freeze and Cherry, 1979, and Fetter, 1988). Analyses for the isotopes of oxygen-18 and deuterium (table 7 and fig. 18) indicate that the mean annual temperature ranged from about -2 to 3°C when the water formed as precipitation (Dansgaard, 1964).

Water from weathered till was found to be too young to date using the carbon-14 method. Analysis for tritium (table 7) indicates that the water in the weathered till is post-1953 in age (Freeze and Cherry, 1979, and Fetter, 1988). Oxygen-18 and deuterium data (table 7 and fig. 18) indicate that the mean annual temperature ranged from about 4 to 5°C when the water formed as precipitation (Dansgaard, 1964).

The significant age differences and the distinct isotopic differences regarding oxygen-18 and deuterium in water from unweathered and weathered till support the interpretation that these are distinct hydrologic units which have little interaction of ground water between them. Also, the oxygen-18 and deuterium data for unweathered till and outwash indicate that there is little interaction of water between these units.

SUMMARY AND CONCLUSIONS

It is the intent of this report to present data and make interpretations regarding evaluation and validation of some concepts of ground water movement through till. Work conducted for this report is only part of a larger effort to understand the hydrogeology of till throughout the glaciated eastern half of South Dakota. Thus, all potentially related questions and problems were not addressed.

The following conclusions regarding the Lincoln County research area can be drawn from the preceding discussion and interpretations.

1. Some precipitation water migrates below the root zone into the weathered till.

2. A shallow water table exists in the weathered till at all times during the year.

3. No water migrates downward through the unweathered till.

4. A relatively insignificant amount of water may move upward through unweathered till, although neither the existence of movement nor rate of movement have been determined.

5. A relatively small amount of water may migrate laterally on a local scale through weathered till, however, probably not in sufficient quantity to dissipate all recharge water. Under normal field conditions, lateral movement of water through weathered till cannot account for dissipation of all recharge water.

The only direction for significant dissipation of water from the till appears to be upward. This is consistent with Barari and Hedges (1985) who tentatively concluded that the major portion of ground

water discharge from weathered till is upward movement of water by evaporation through the numerous cracks and fractures present in the upper weathered till. Although the above interpretations and conclusions may be subjected to modification as research continues, the interpretation that upward movement is the dominant mechanism for dissipation of recharge water to the water table in till seems appropriate based on the abundance and nature of supporting evidence gathered thus far. Future investigation activities will be concentrated on quantifying the magnitude of lateral movement and the component of upward movement.

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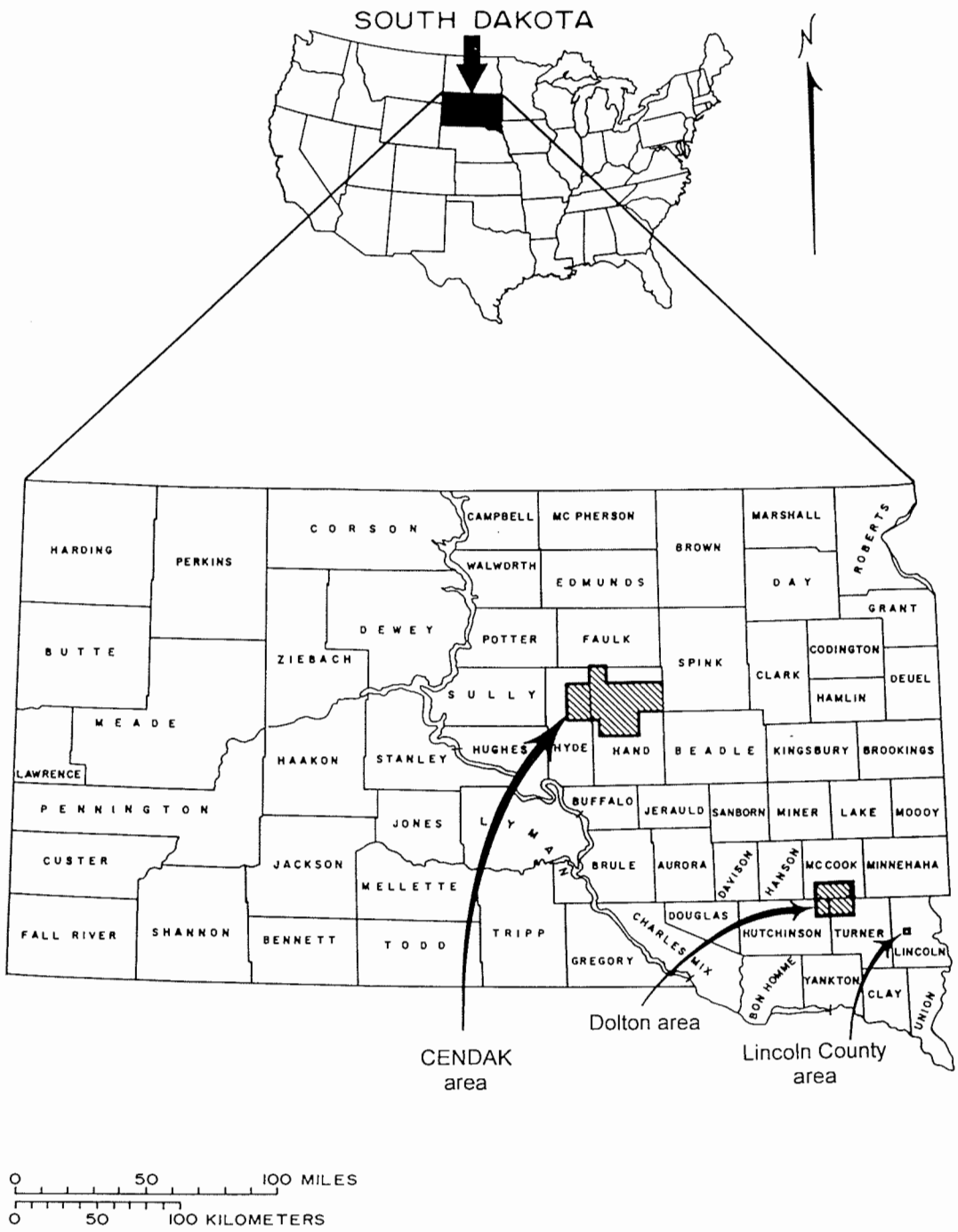
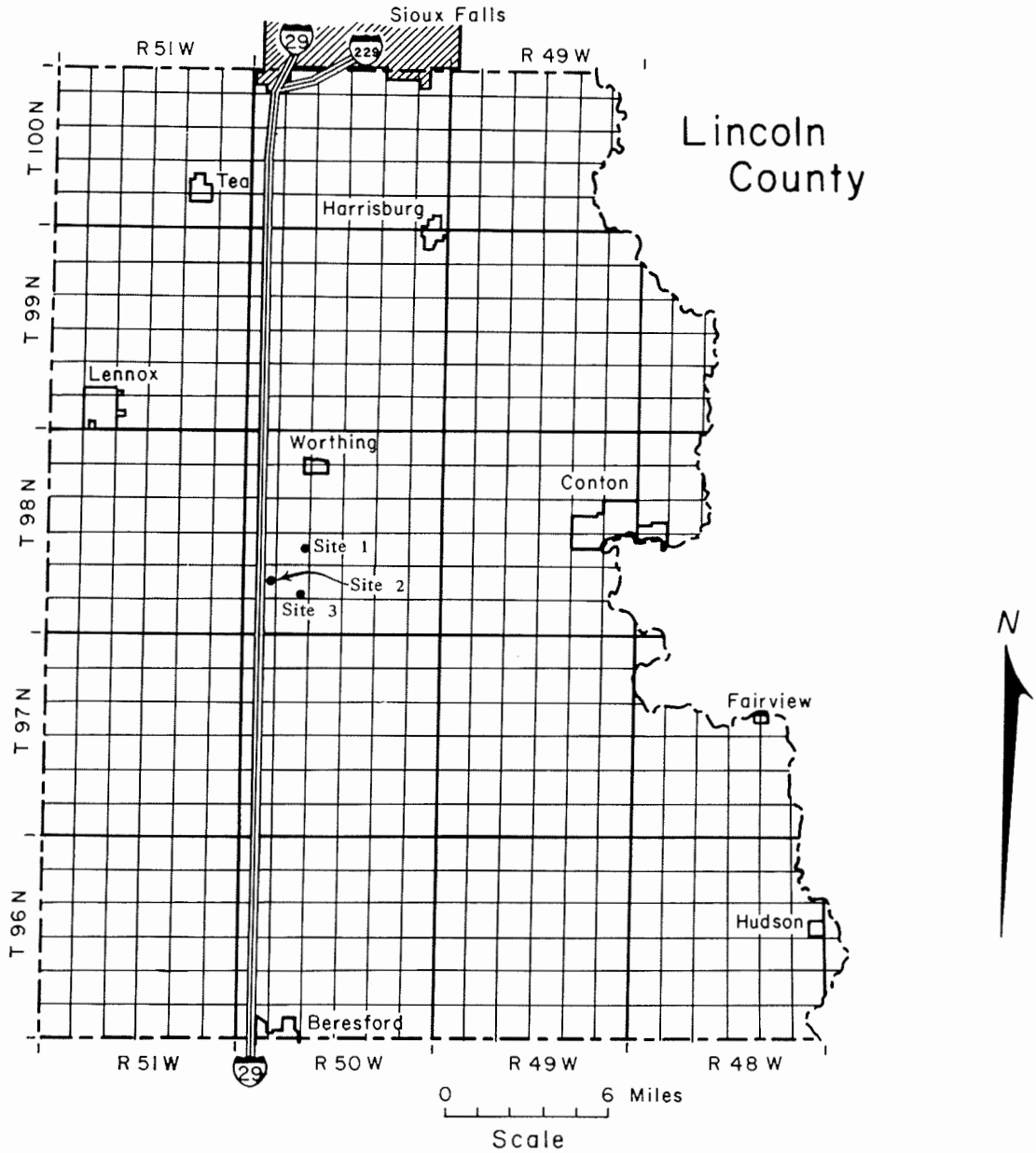
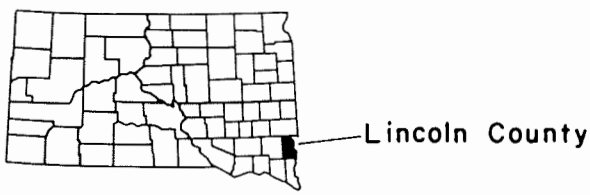


Figure 1. Locations of till research areas in South Dakota.





INDEX MAP SHOWING LOCATION OF LINCOLN COUNTY IN THE STATE OF SOUTH DAKOTA.

Site 1 ● Location at which nested piezometers were installed in the till.

Figure 2. Location of the study area and till piezometer sites.

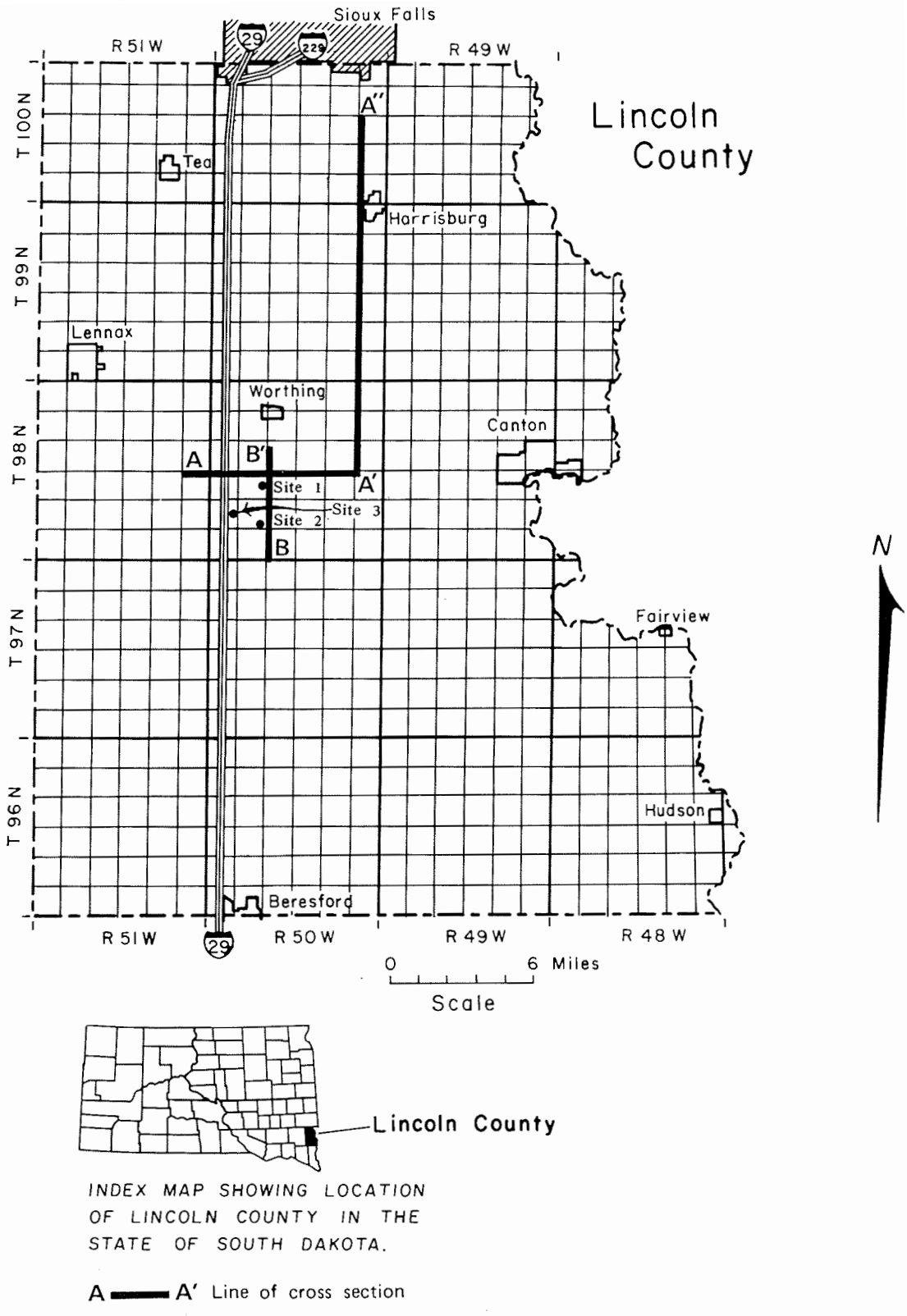
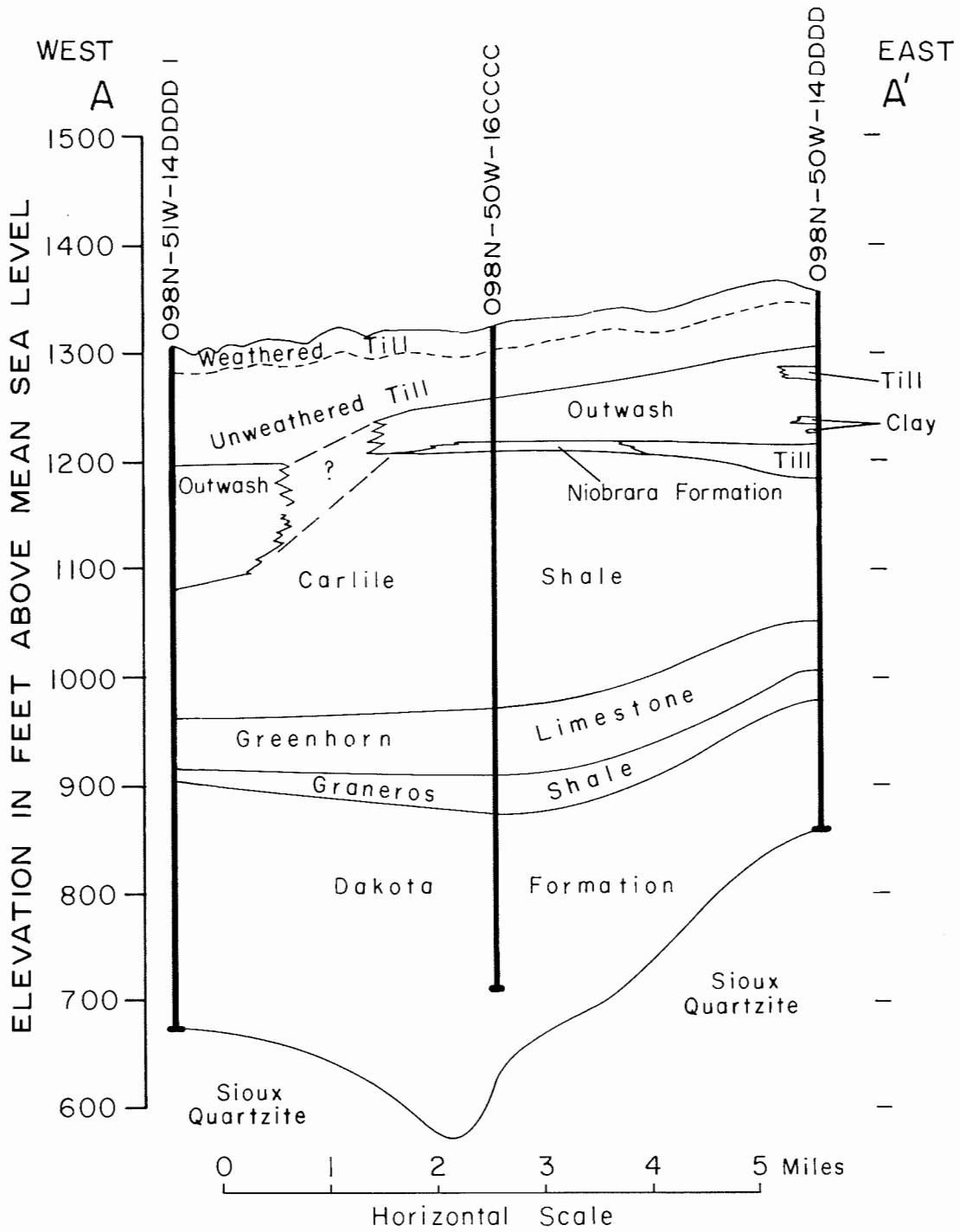


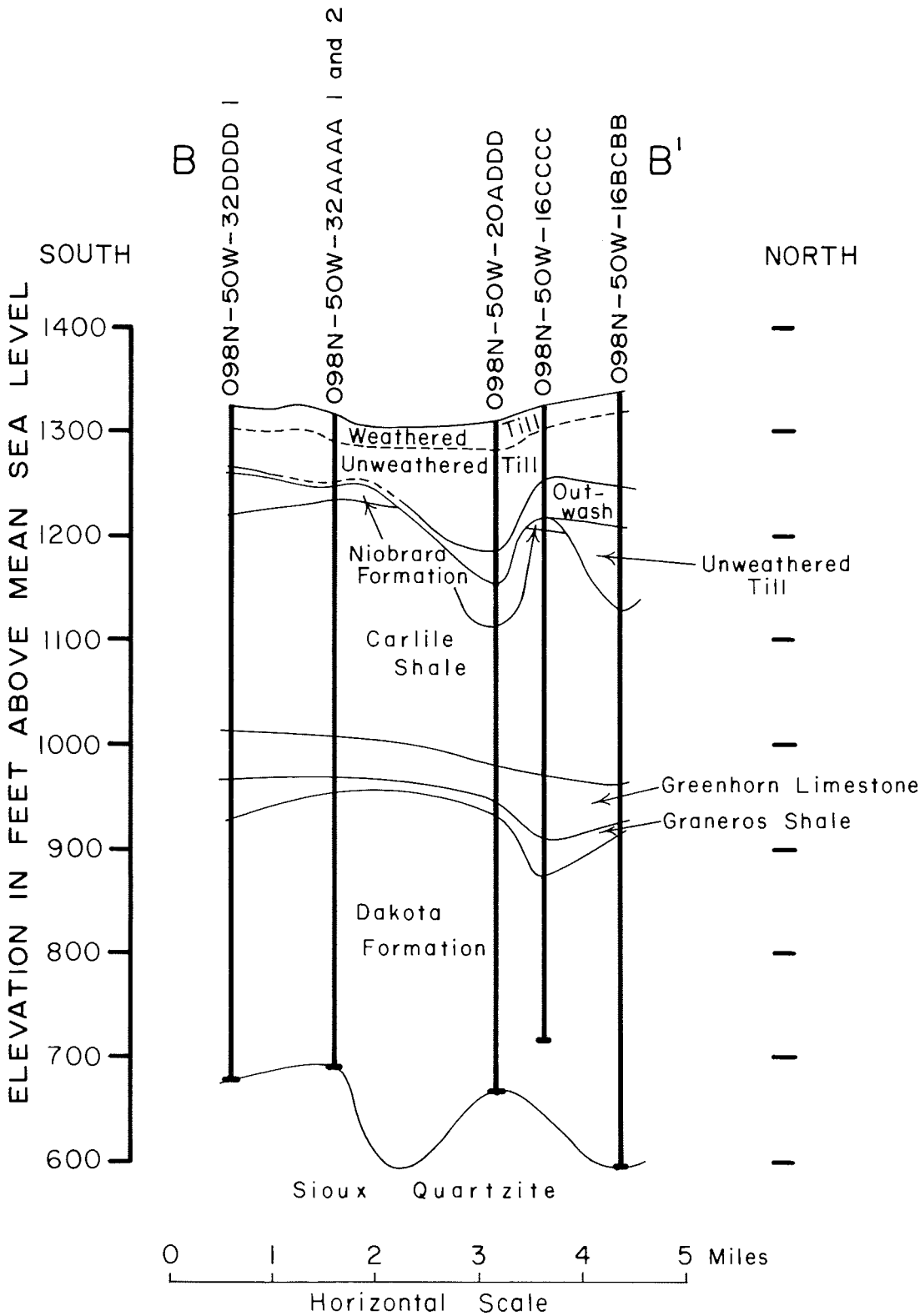
Figure 3. Locations of cross sections.



See appendix A for explanation of drill hole locations.

See figure 3 for location of cross section.

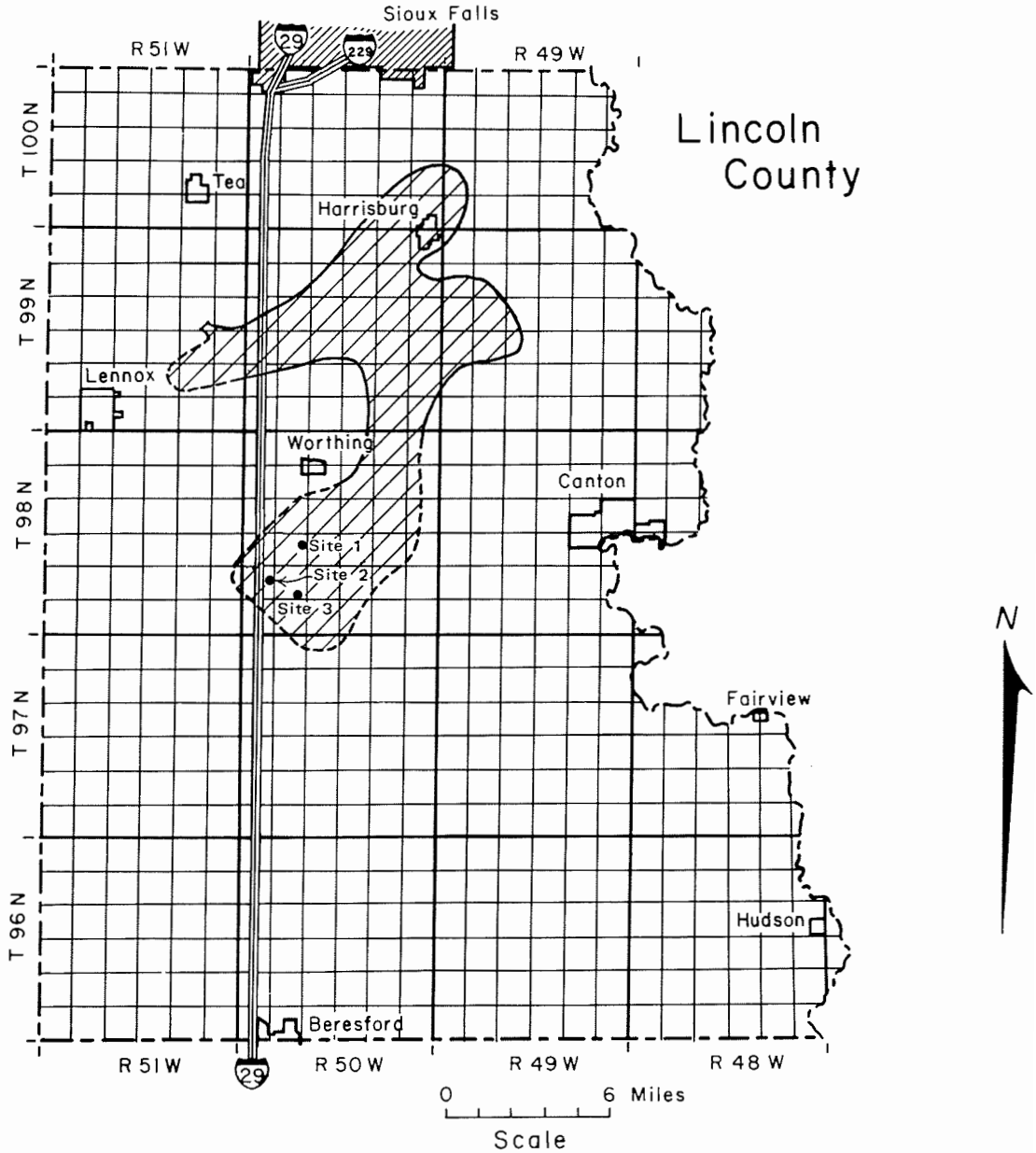
Figure 4. Cross section A-A'.

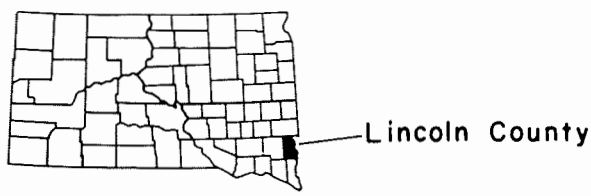


See appendix A for explanation of drill hole locations.

See figure 3 for location of cross section.

Figure 5. Cross section B-B'.

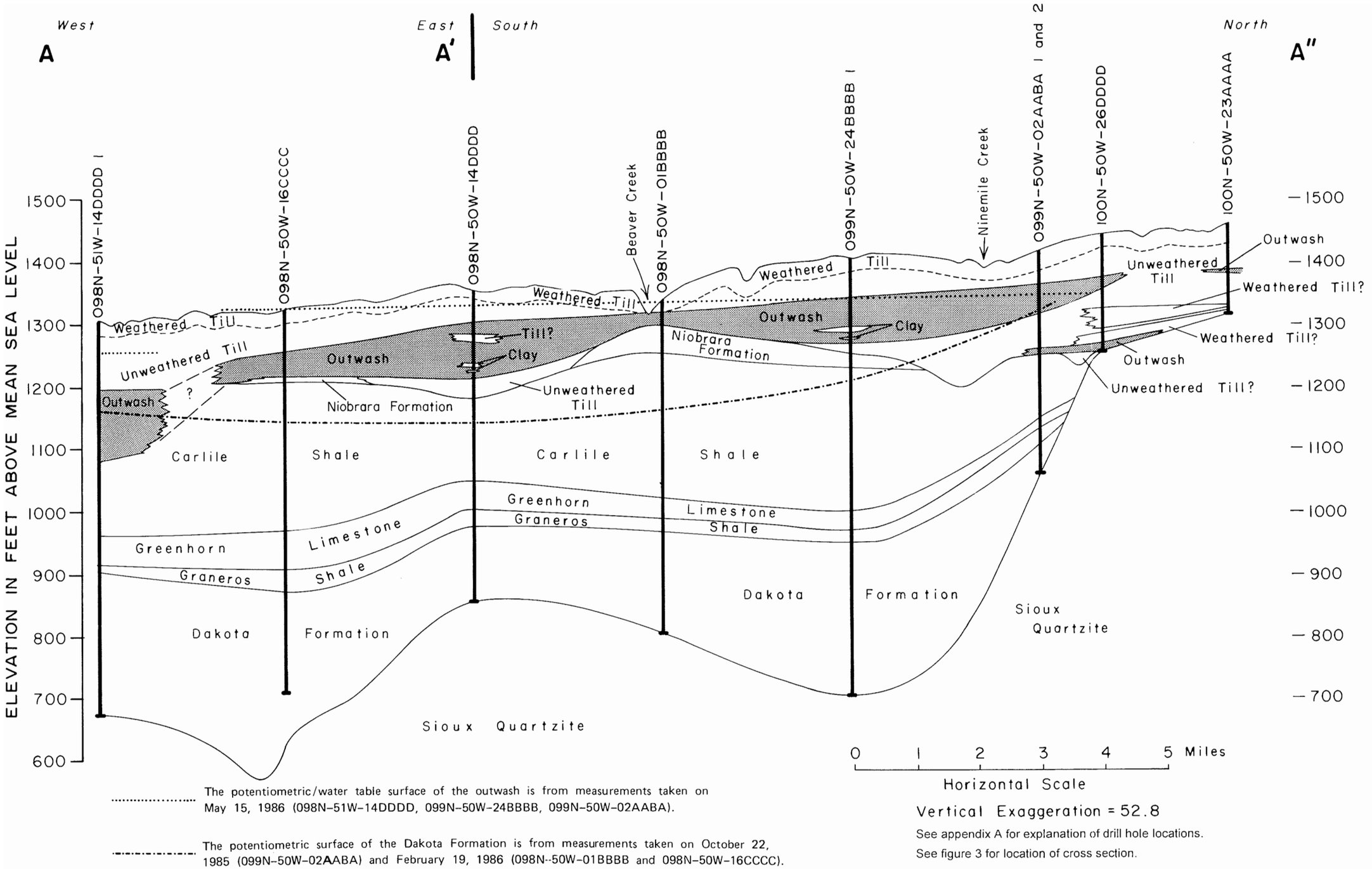




INDEX MAP SHOWING LOCATION OF LINCOLN COUNTY IN THE STATE OF SOUTH DAKOTA.

Area underlain by outwash. Boundary is dashed where it is less certain. Modified from Iles (in prep.)

Figure 6. Inferred extent of outwash which underlies sites 1, 2, and 3.



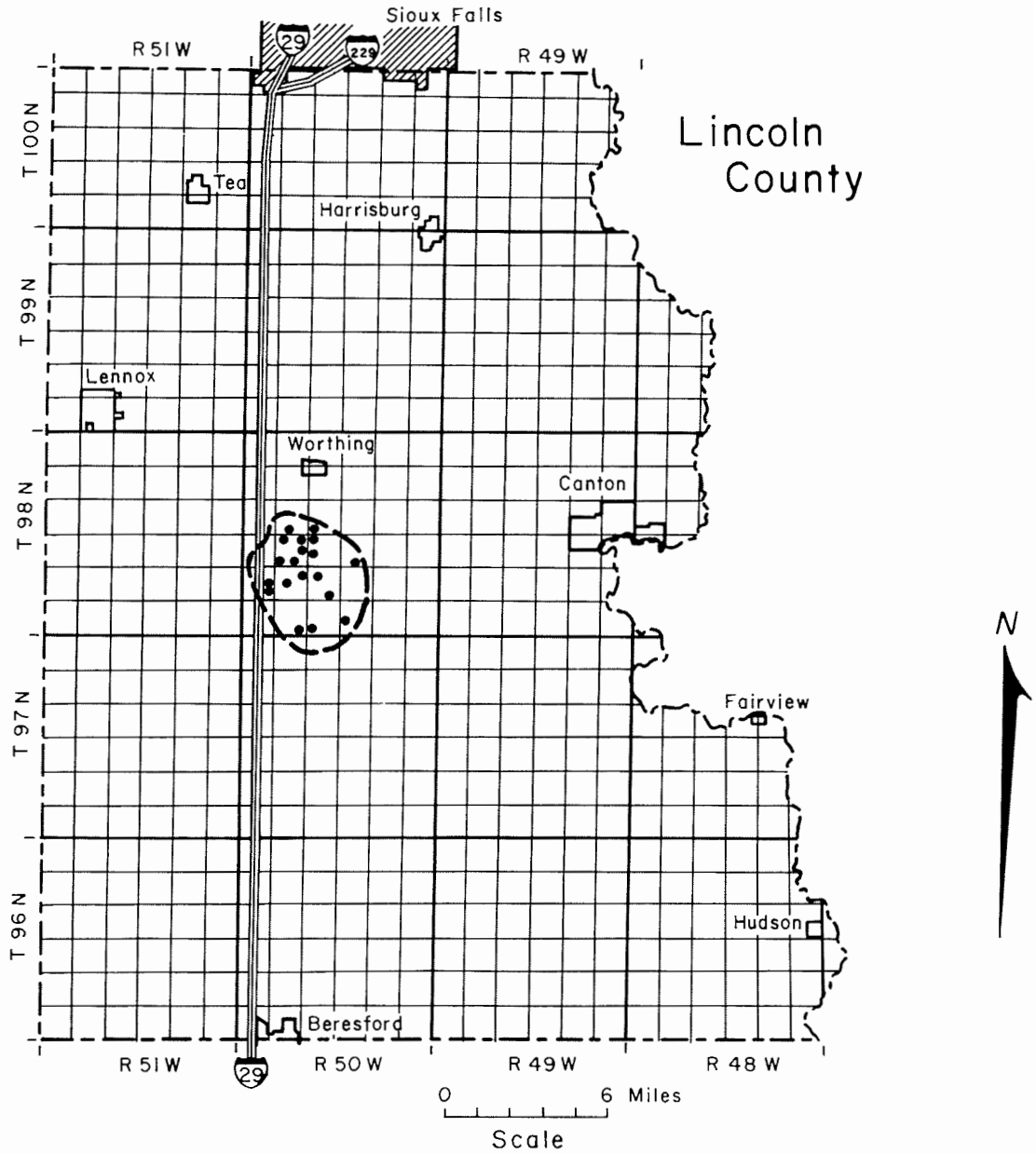
..... The potentiometric/water table surface of the outwash is from measurements taken on May 15, 1986 (098N–51W–14DDDD, 099N–50W–24BBBB, 099N–50W–02AABA).

-.-.-.-.-.- The potentiometric surface of the Dakota Formation is from measurements taken on October 22, 1985 (099N–50W–02AABA) and February 19, 1986 (098N–50W–01BBBB and 098N–50W–16CCCC).

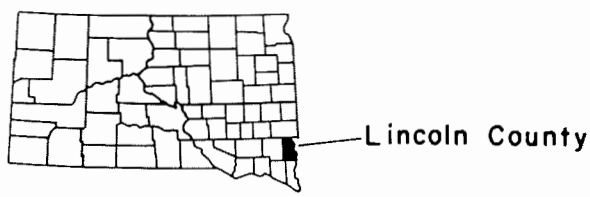
See appendix A for explanation of drill hole locations.

See figure 3 for location of cross section.

Figure 7. Cross section A-A'-A".



INDEX MAP SHOWING LOCATION OF LINCOLN COUNTY IN THE STATE OF SOUTH DAKOTA.



Approximate minimum area of "flowing" wells.

• Location where "flowing" well has been reported.

Figure 8. Area in which the potentiometric surface of a buried outwash is above land surface.

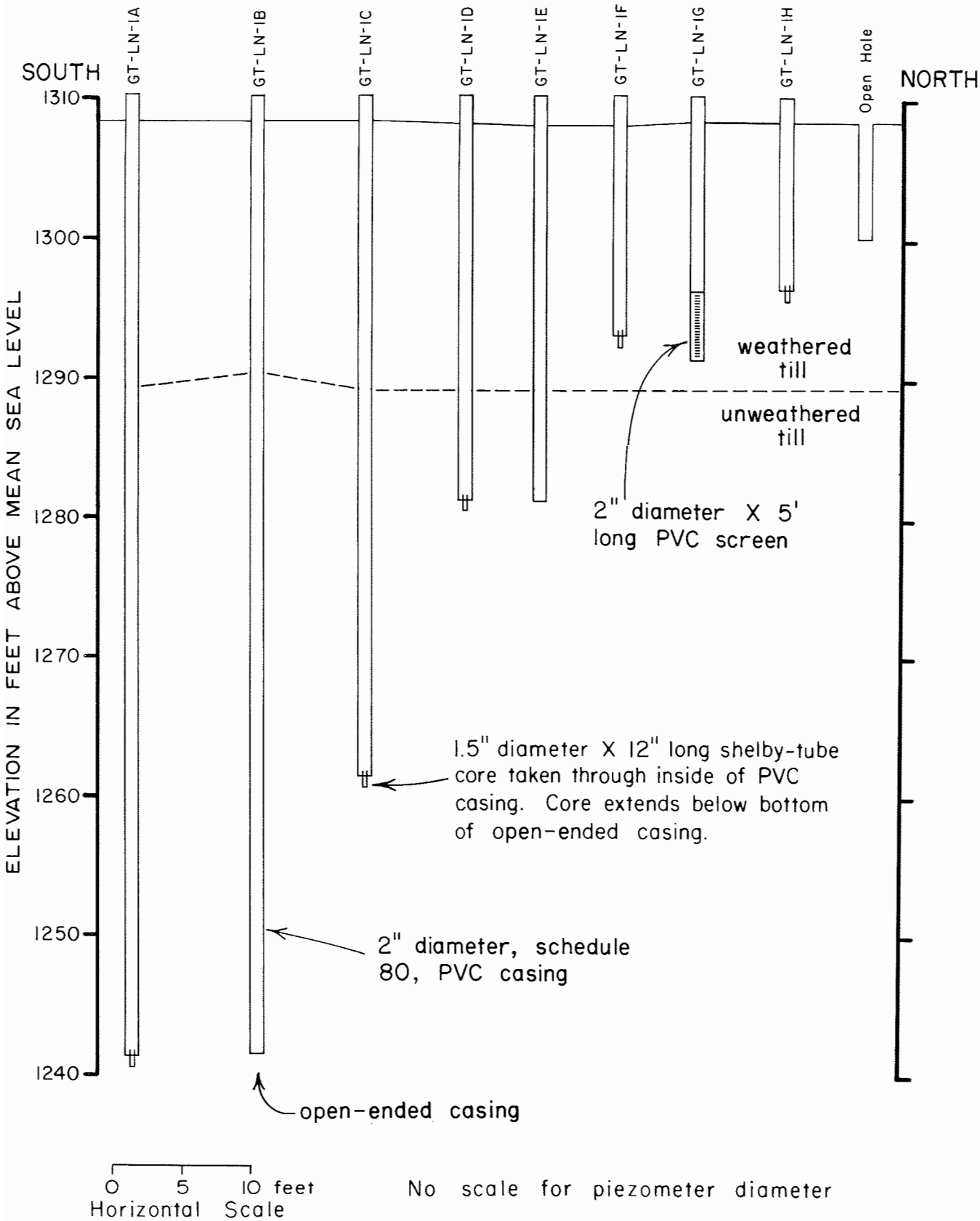


Figure 9. Till piezometers at site 1.

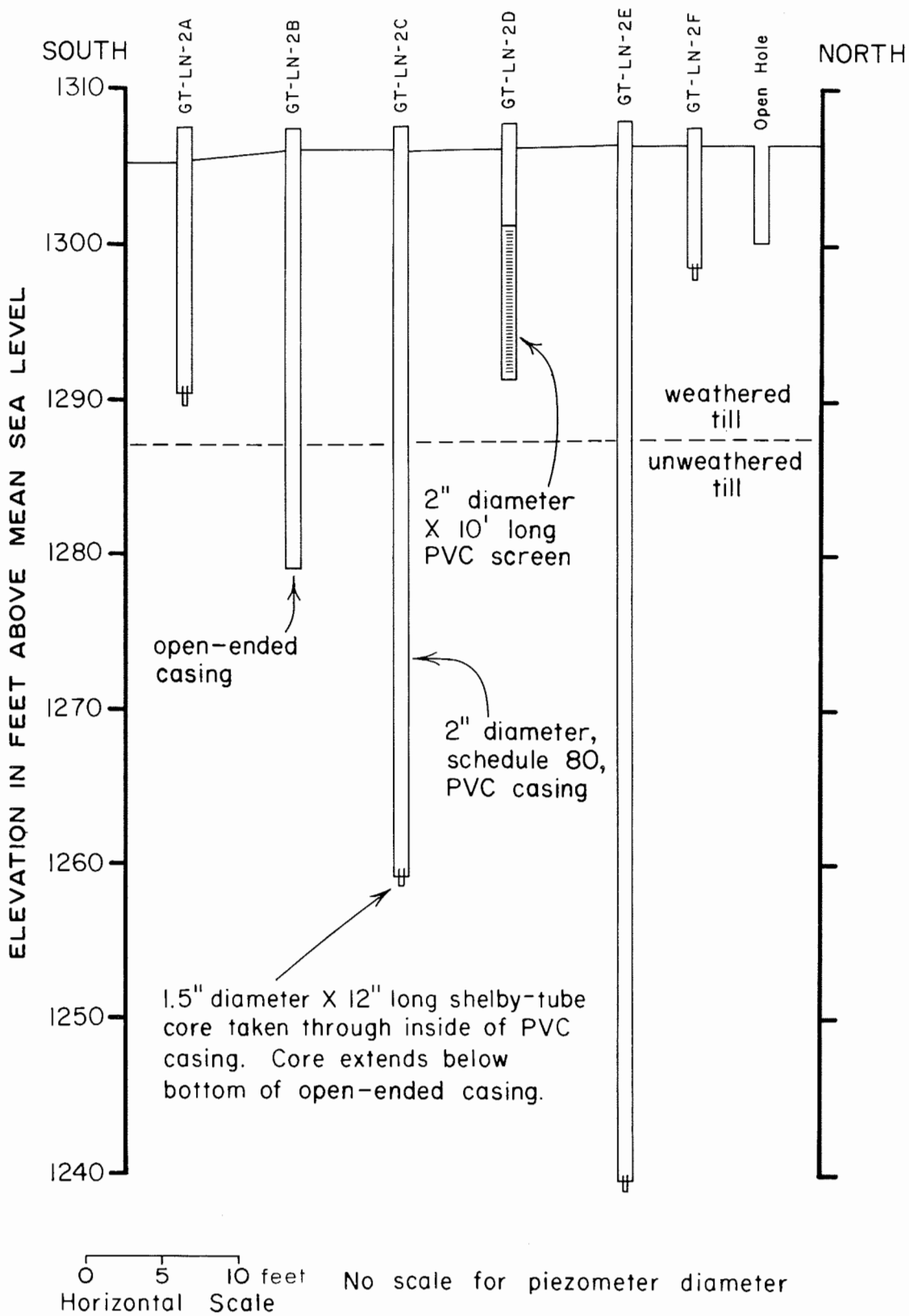


Figure 10. Till piezometers at site 2.

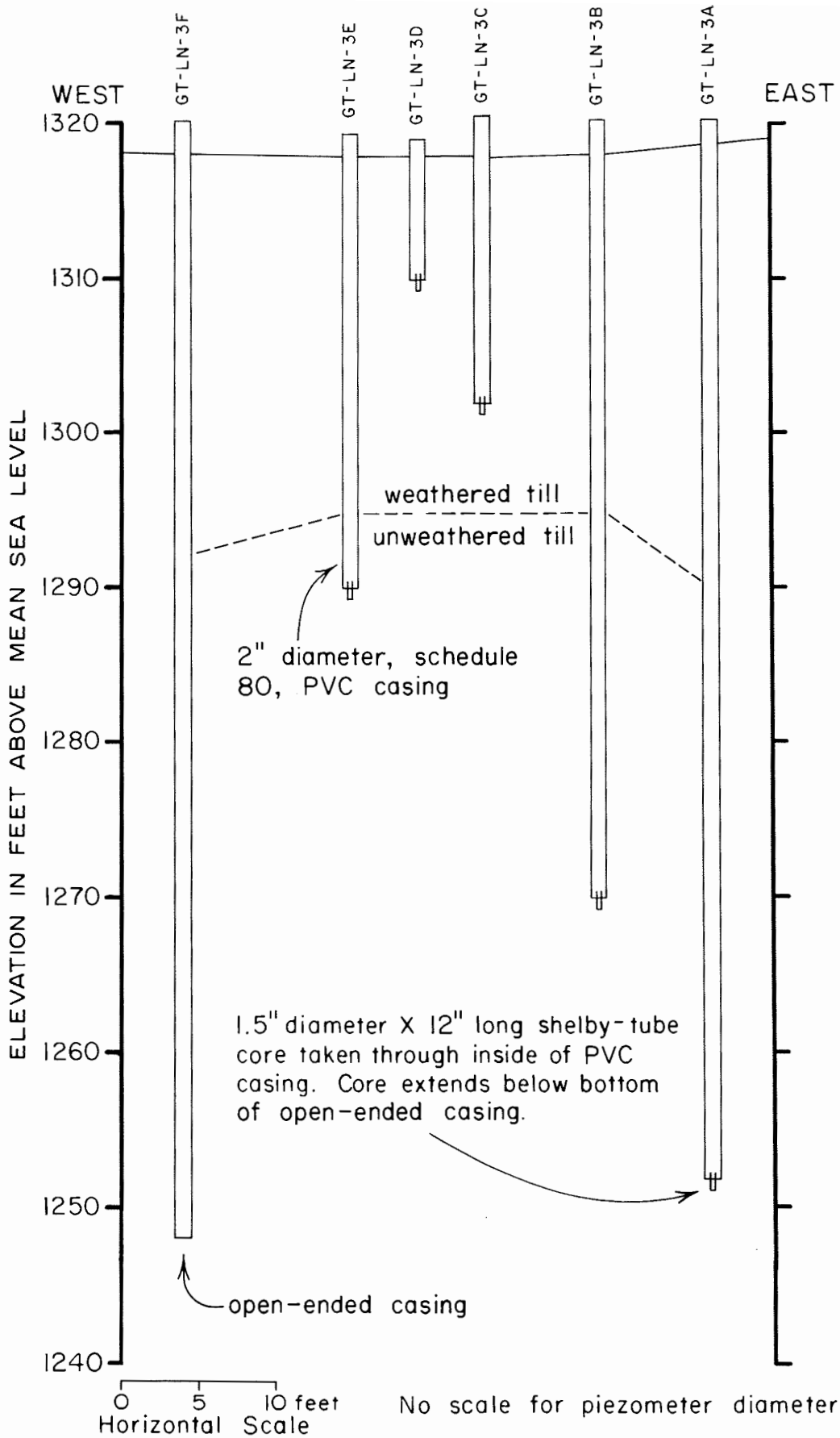


Figure 11. Till piezometers at site 3.

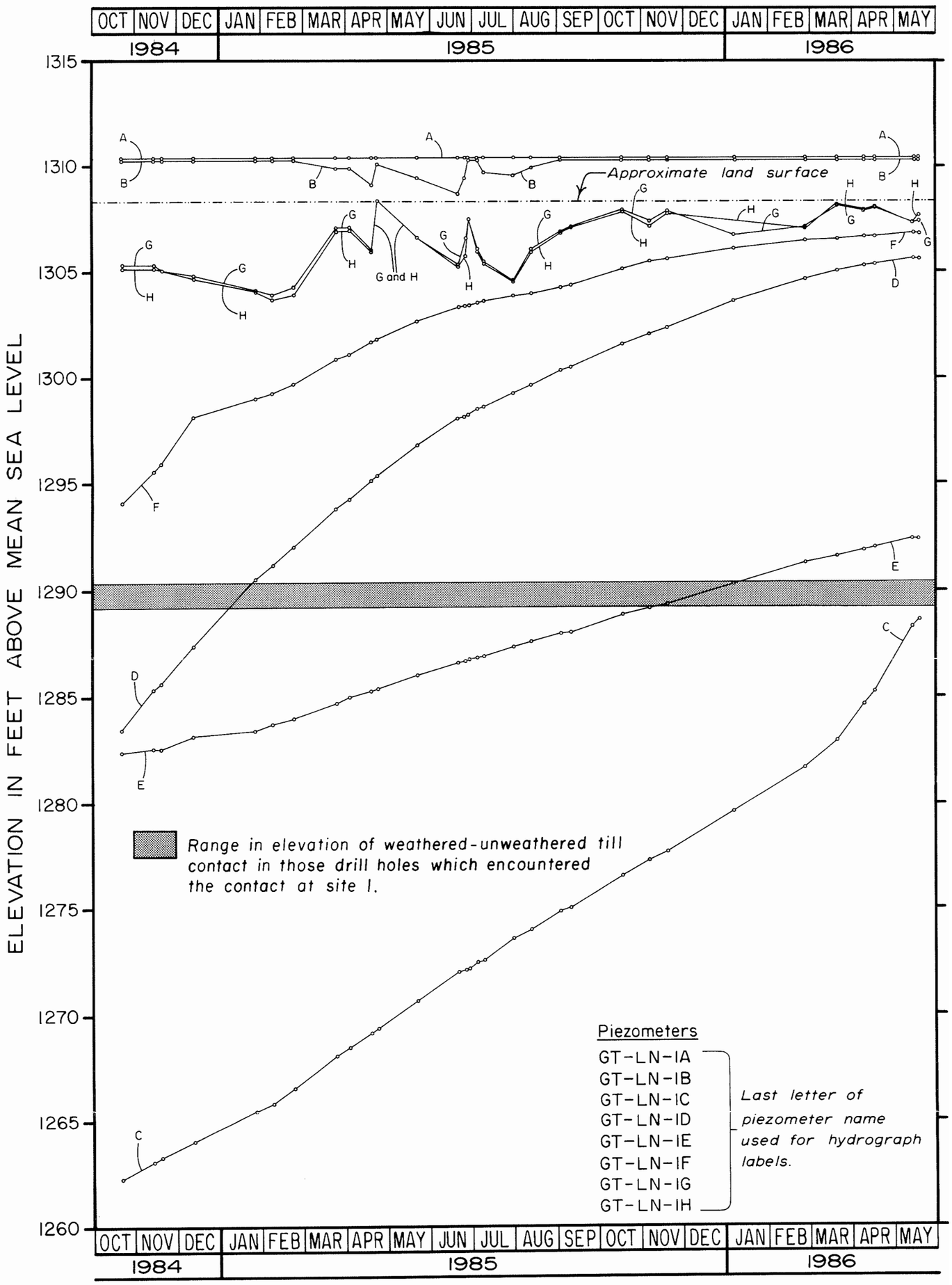


Figure 12. Hydrograph of till piezometers at site 1.

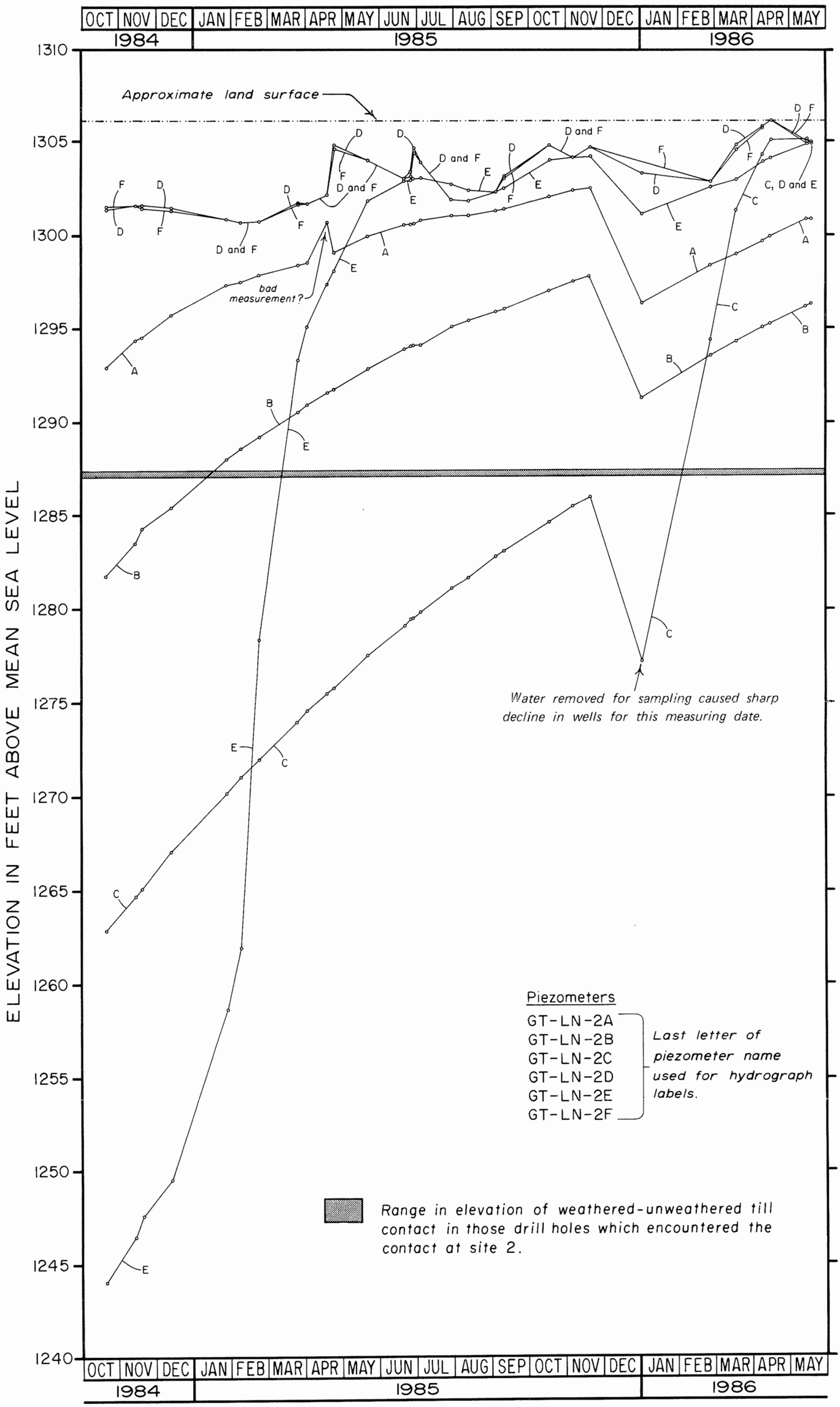


Figure 13. Hydrograph of till piezometers at site 2.

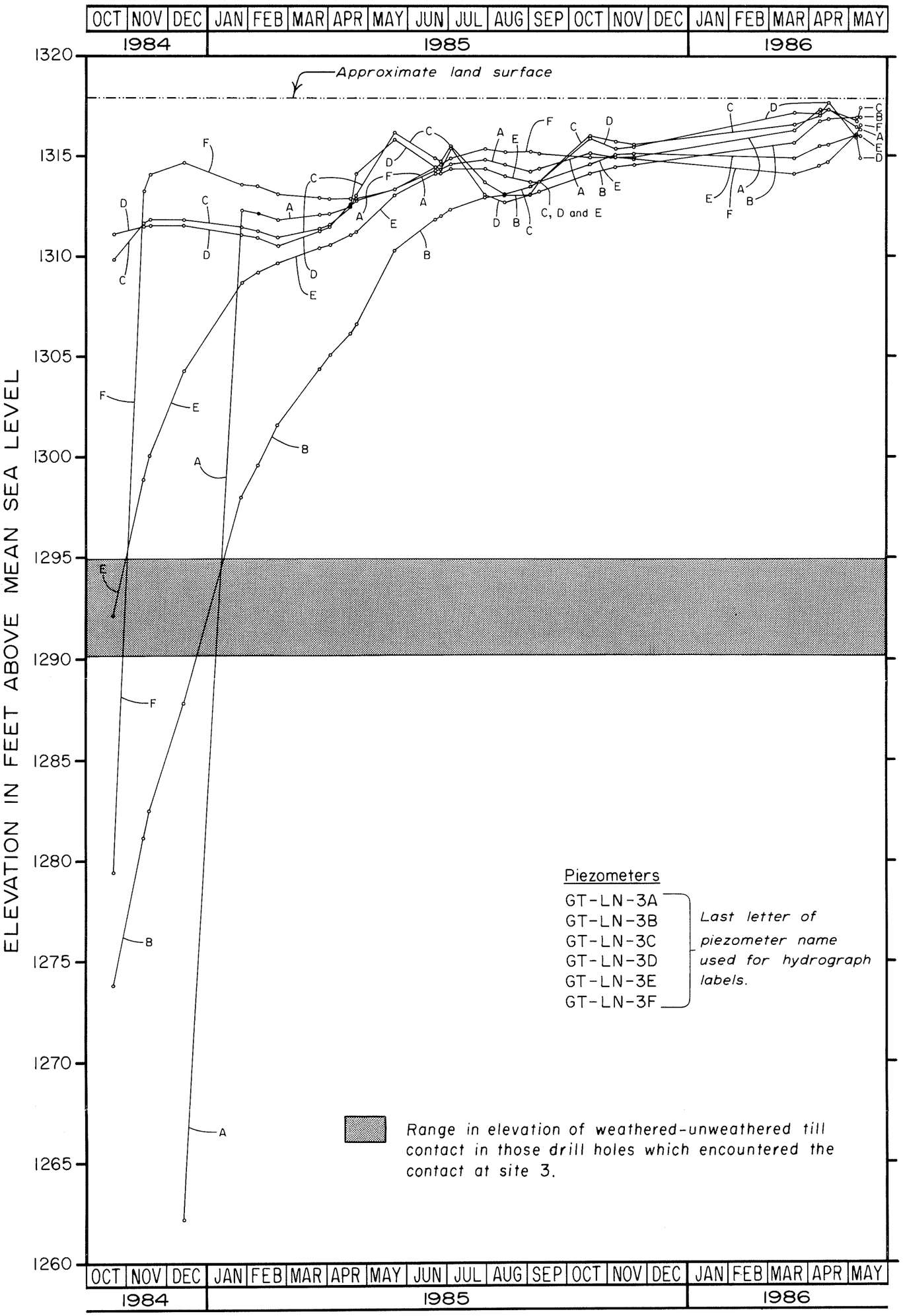


Figure 14. Hydrograph of till piezometers at site 3.

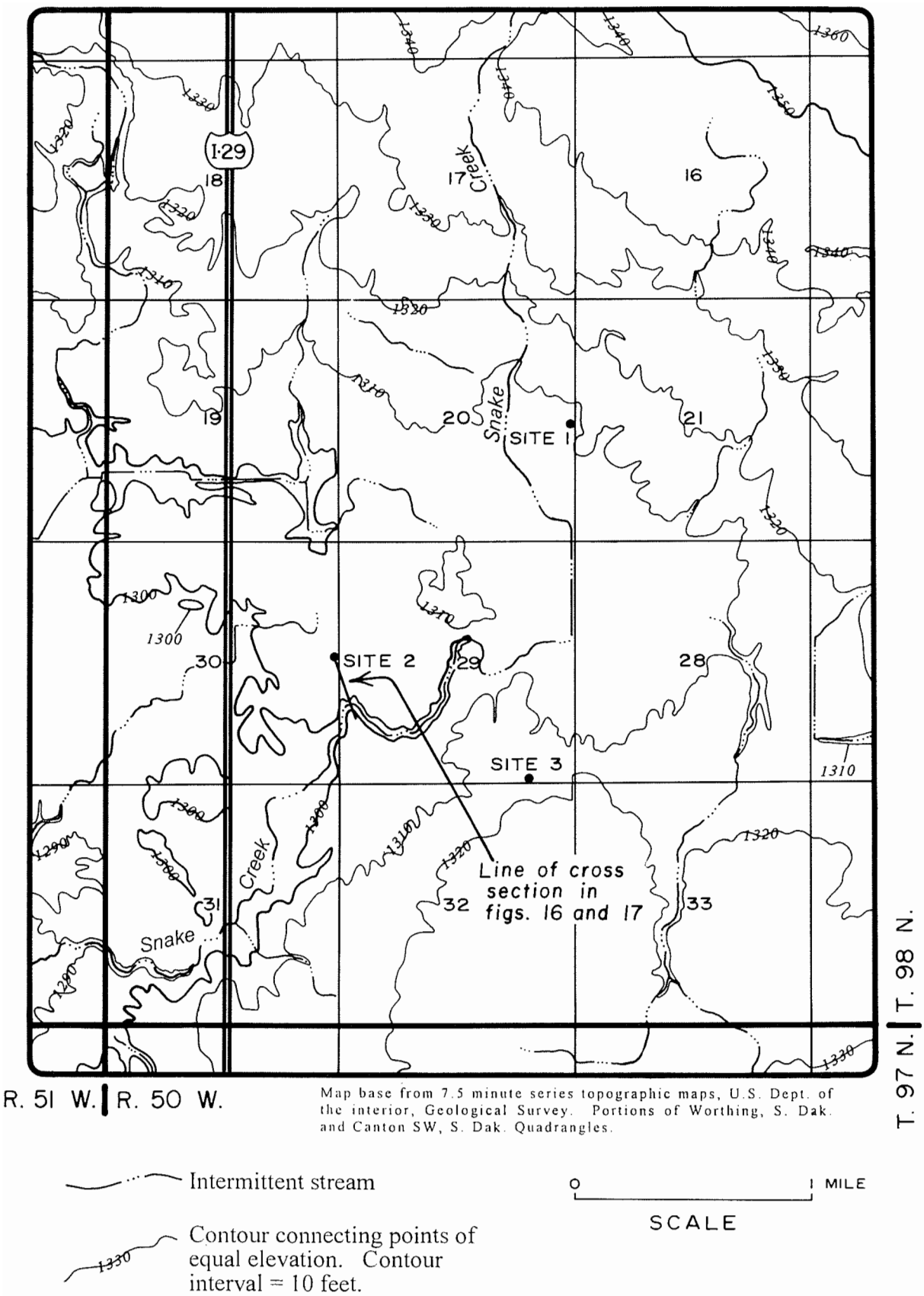
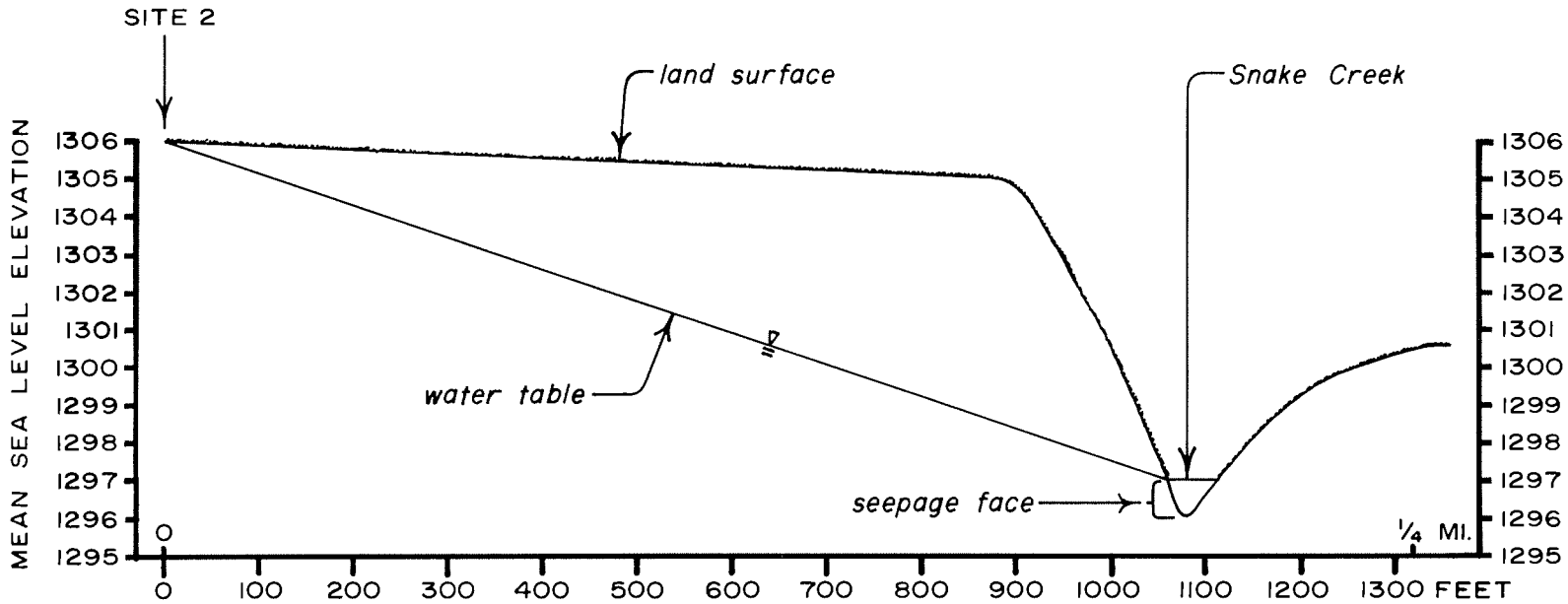


Figure 15. Topographic map of the study area.

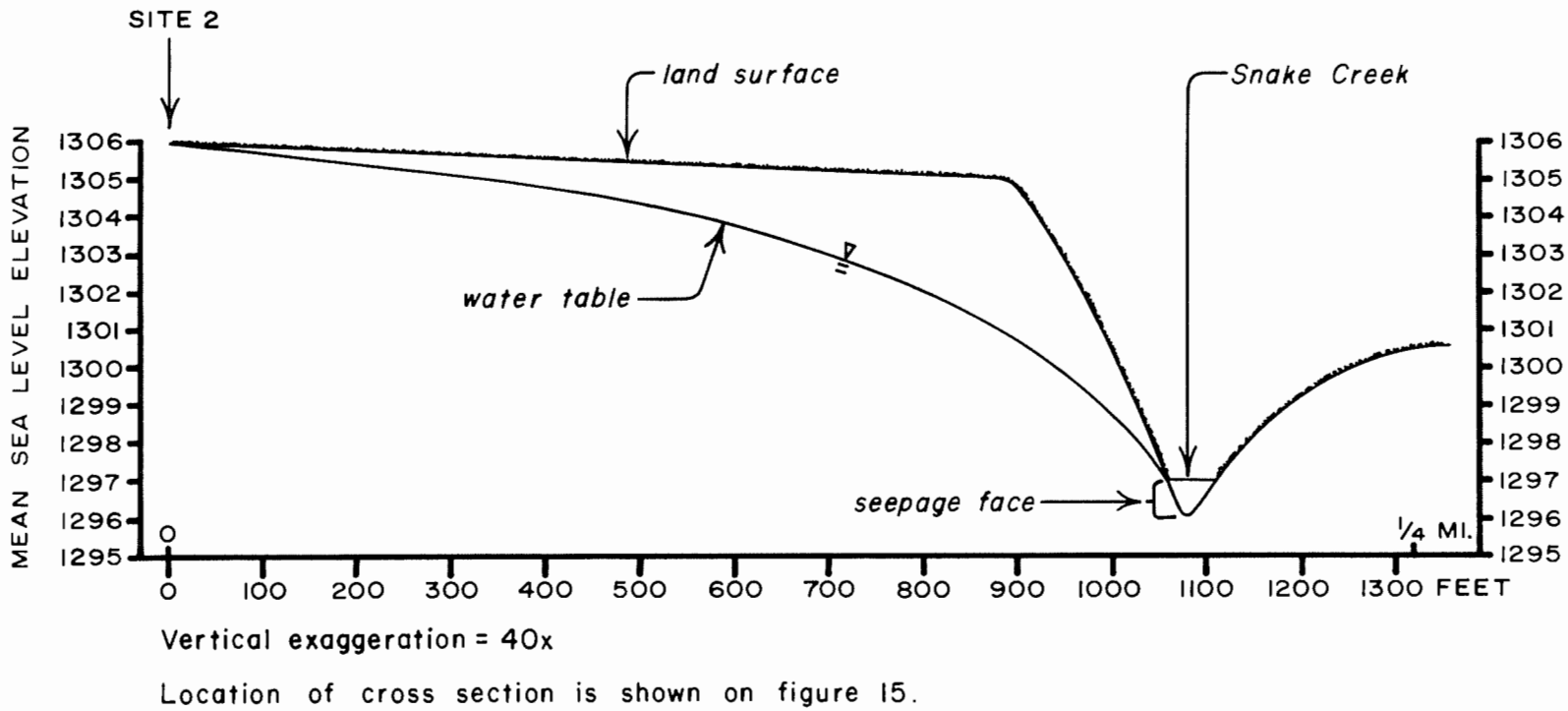
Figure 16. Idealized hydrologic cross section at site 2 assuming a linear water table slope.



Vertical exaggeration = 40x

Location of cross section is shown on figure 15.

Figure 17. Idealized hydrologic cross section at site 2 assuming a nonlinear water table slope.



Vertical exaggeration = 40x

Location of cross section is shown on figure 15.

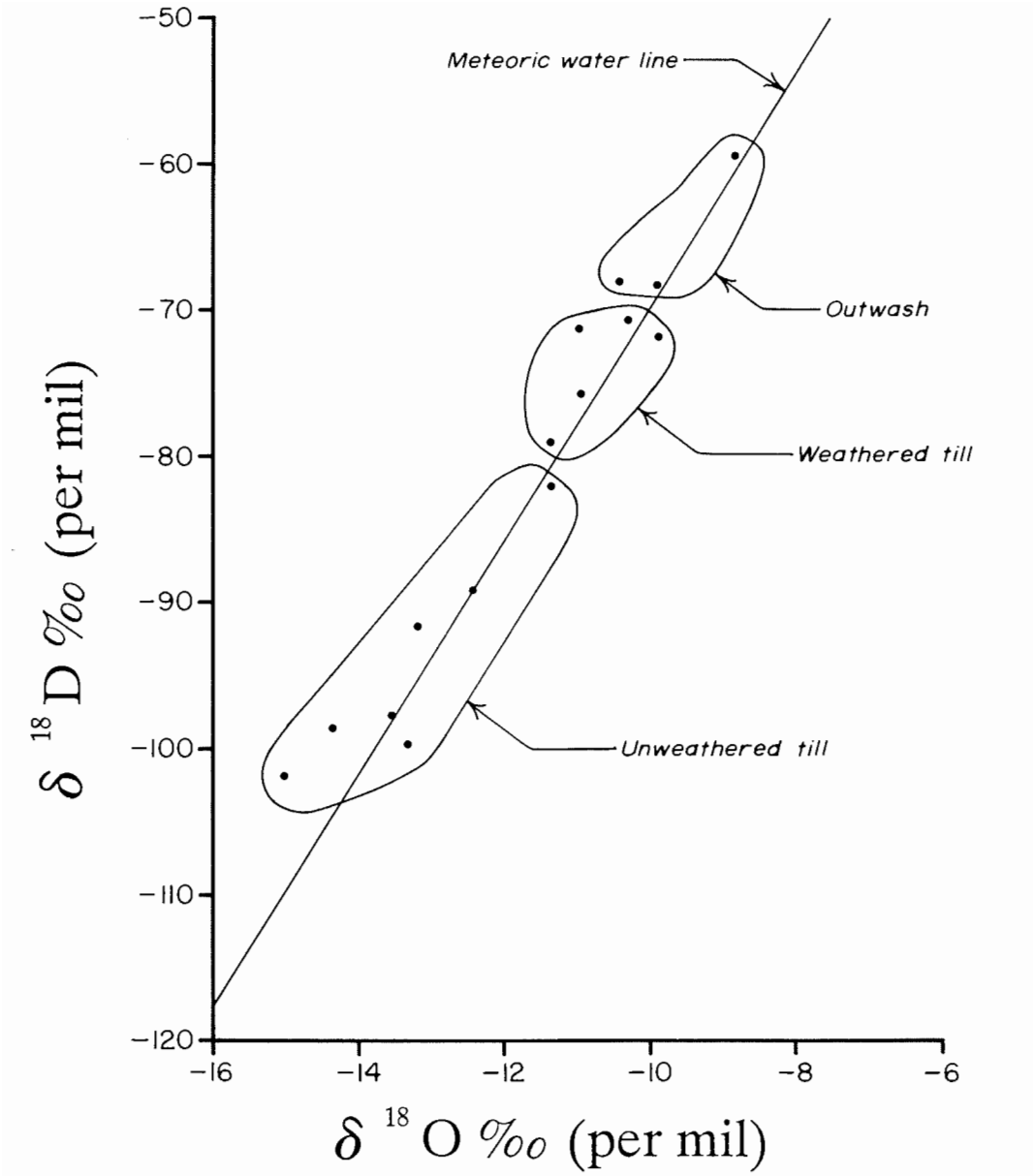


Figure 18. Oxygen-18 and deuterium values from weathered till, unweathered till, and outwash.

TABLE 1. Mineralogical data from two till samples

Mineralogy	Sample Number: 62Q-1 weathered till (Percentages[1])	Sample Number: 62Q-2 unweathered till (Percentages[1])
Clay minerals:		
Smectites[2]	15-20	10-15
Illite/micas[3]	10	10
Kaolinite	2- 3	5
Calcite	10-15	15
Dolomite	5	5-10
Quartz	25-30	25-30
Feldspars	5-10	5-10
Gypsum[4]	3- 4	2- 3
Pyrite	1- 2	2- 3
Iron oxides[5]	2- 3	Trace
Chlorite	Trace	Trace
Minor[6]	10	10

[1] Trace means less than 1 percent.

[2] Chiefly calcium montmorillonite, includes minor amounts of mixed and interlayered varieties.

[3] Chiefly illite, includes trace amounts of biotite and muscovite.

[4] During oven drying was converted to bassanite (plaster of paris - $CaSO_4 \times 0.5\ H_2O$).

[5] Chiefly amorphous iron oxides, includes trace amounts of hematite, magnetite, and ilmenite.

[6] Includes charcoal, calcareous, and siliceous foraminifera, epidote, garnet, apatite, zircon, zeolite, amphiboles (hornblende, actinolite, and occasionally glaucophane), pyroxenes, glauconite?, and trace amounts of water-soluble chloride and sulfate ions, unidentified clay, and clay-size minerals.

Data from U.S. Bureau of Reclamation, Engineering and Research Center, Soil Mechanics Section, Denver, Colorado.

Core samples were taken from a drill hole adjacent to piezometers at site 1:
Sample 62Q-1 from 5 to 7.5 feet
Sample 62Q-2 from 25 to 27.5 feet

TABLE 2. Vertical gradients between piezometers at sites 1, 2, and 3

Site	Piezometer	Piezometer depth (ft)[1]	Water elevation (ft) 5-19-86	Gradient direction between piezometers
1	Open hole	8	1305.93[2]	
1	GT-LN-1H[3]	13	1307.65	down
1	GT-LN-1F[3 & 4]	16	1306.84	
1	GT-LN-1G[5]	17	1307.47	down[6]
1	GT-LN-1E[7]	27	1292.45	
1	GT-LN-1D[3]	28	1305.66	down
1	GT-LN-1C[3]	48	1288.70	
1	GT-LN-1B[7 & 8]	67	>1318.28	up
1	GT-LN-1A[3 & 8]	68	>1310.34	
2	GT-LN-2F[3]	9	1304.96	
2	GT-LN-2D[5]	15	1304.94	down
2	GT-LN-2A[3 & 4]	16	1300.81	
2	GT-LN-2B[7]	27	1296.33	up[6]
2	GT-LN-2C[3]	48	1304.93	
2	GT-LN-2E[3]	68	1304.85	down
3	GT-LN-3D[3]	9	1314.76	
3	GT-LN-3C[3]	17	1317.36	up
3	GT-LN-3E[3]	29	1315.85	down[6]
3	GT-LN-3B[3]	49	1316.94	up
3	GT-LN-3A[3]	68	1316.26	down
3	GT-LN-3F[7]	70	1316.47	

[1] Depth is presented in feet below land surface.
[2] Calculated using average land surface elevation at the site.
[3] Piezometer construction included taking of shelby-tube core through inside of open-ended casing.
[4] Does not respond like a water-table well, as do the other wells completed in weathered till at that site.
[5] Piezometer construction included use of a well screen.
[6] Gradient is across weathered-unweathered till interface.
[7] Piezometer construction included use of only open-ended casing as water-intake area.
[8] Flowing well.

TABLE 3. Calculated hydraulic conductivity values of till

Hydrologic unit	Piezometer Name	Piezometer Depth (ft)[2]	Hydraulic conductivity in centimeters per second[1]: Luthin and Kirkham method	Hydraulic conductivity in centimeters per second[1]: Hvorslev method	Hydraulic conductivity in centimeters per second[1]: Average of the two methods
Weathered till	GT-LN-1F	16	1.5×10^{-8}	1.6×10^{-8}	1.5×10^{-8}
	GT-LN-1I	3	2.2×10^{-7}	1.4×10^{-7}	1.8×10^{-7}
	GT-LN-1J	6	1.9×10^{-7}	2.1×10^{-7}	2.0×10^{-7}
	GT-LN-1K	11	4.1×10^{-5}	4.3×10^{-5}	4.2×10^{-5}
	GT-LN-1L	13	1.5×10^{-7}	1.1×10^{-7}	1.3×10^{-7}
	GT-LN-1M	16	9.7×10^{-7}	9.4×10^{-7}	9.5×10^{-7}
	GT-LN-2A	16	1.7×10^{-8}	1.7×10^{-8}	1.7×10^{-8}
	GT-LN-2H	6		1.7×10^{-3}	
	GT-LN-2I	11	5.4×10^{-7}	4.4×10^{-7}	4.9×10^{-7}
	GT-LN-2J	13	4.1×10^{-7}	2.2×10^{-7}	3.0×10^{-7}
	GT-LN-2K	15	9.8×10^{-8}	1.3×10^{-7}	1.1×10^{-7}
	Geometric mean ...		2.6×10^{-7}	5.2×10^{-7}	2.5×10^{-7}
	Maximum		4.1×10^{-5}	1.7×10^{-3}	4.2×10^{-5}
	Minimum		1.5×10^{-8}	1.6×10^{-8}	1.5×10^{-8}
Unweathered till	GT-LN-1C	48	7.1×10^{-9}	7.8×10^{-9}	7.4×10^{-9}
	GT-LN-1D	28	1.5×10^{-8}	1.6×10^{-8}	1.5×10^{-8}
	GT-LN-2C	48	8.6×10^{-9}	9.3×10^{-9}	8.9×10^{-9}
	GT-LN-2E	68	5.7×10^{-8}	3.5×10^{-8}	4.5×10^{-8}
	GT-LN-3B	49	4.5×10^{-8}	3.1×10^{-8}	3.7×10^{-8}
	Geometric mean ...		1.9×10^{-8}	1.7×10^{-8}	1.8×10^{-8}
	Maximum		5.7×10^{-8}	3.5×10^{-8}	4.5×10^{-8}
	Minimum		7.1×10^{-9}	7.8×10^{-9}	7.4×10^{-9}

[1] Values determined using methods described by Luthin and Kirkham (1949) and Hvorslev (1951). Data obtained from Cowman (in prep.).

[2] Depth is presented in feet below land surface.

TABLE 4. Water level rise versus water volume

One-time rise in water level* (ft)	Specific yield (%)	Volume of water recharging 1-square foot of land (ft^3)	Volume of water recharging a strip of land 1 foot wide and 1,080 feet long (ft^3)
3.45	1	0.0345	37.26
3.45	10	0.3450	372.60

* Data from well GT-LN-2D; difference in water level between 2-26-86 and 4-16-86.

TABLE 5. Calculation of potential discharge to Snake Creek per square foot of seepage face

Area (ft^2)[1]	Hydraulic conductivity (cm/sec)[2]	Hydraulic conductivity (gpd/ft^2)[3]	Lateral hydraulic gradient (ft/ft)[4]	Discharge (gpd)[5]	Discharge (cubic feet per year)
1	1.7×10^{-3}	36.04	0.0085	3.063×10^{-1}	14.95
1	1.0×10^{-3}	21.20	0.0085	1.802×10^{-1}	8.79
1	1.0×10^{-4}	2.12	0.0085	1.802×10^{-2}	0.88
1	1.0×10^{-5}	0.212	0.0085	1.802×10^{-3}	0.088
1	1.0×10^{-6}	0.0212	0.0085	1.802×10^{-4}	0.0088
1	1.0×10^{-7}	0.00212	0.0085	1.802×10^{-5}	0.00088
1	1.5×10^{-8}	0.00032	0.0085	2.703×10^{-6}	0.00013
1	1.7×10^{-3}	36.04	0.02	7.208×10^{-1}	35.18
1	1.0×10^{-3}	21.20	0.02	4.240×10^{-1}	20.69
1	1.0×10^{-4}	2.12	0.02	4.240×10^{-2}	2.07
1	1.0×10^{-5}	0.212	0.02	4.240×10^{-3}	0.207
1	1.0×10^{-6}	0.0212	0.02	4.240×10^{-4}	0.0207
1	1.0×10^{-7}	0.00212	0.02	4.240×10^{-5}	0.00207
1	1.5×10^{-8}	0.00032	0.02	6.360×10^{-6}	0.00031

[1] ft^2 - square feet

[2] cm/sec - centimeters per second

[3] gpd/ft^2 - gallons per day per square foot

[4] ft/ft - feet per foot

[5] gpd - gallons per day

TABLE 6. Average water quality of selected hydrologic units

Hydrologic Unit	Number of samples		Conductivity (umhos)[2]	Parameter[1] with concentration in milligrams per liter													
				DS	Na	Ca	Mg	K	SO_4	Cl	F	NO_3-N + NO_2-N	Fe	Mn	$CaCO_3$	Alk-T	HCO_3
Weathered till	8	Average	5188	5473	411	411	518	14	3723	8	1.03	----	----	----	3159	368	448
		Maximum	8760	9710	813	466	1070	20	6700	17	2.36	0.71	2.21	1.69	5380	460	561
		Minimum	2580	2240	122	362	117	8	1420	3	0.28	<0.04	<0.05	<0.05	1390	294	358
Unweathered till	11	Average	3075	2602	345	297	106	22	1671	15	0.36	----	----	1.15	1179	295	359
		Maximum	4830	4390	527	470	224	30	3000	24	0.48	2.34	1.84	1.95	2100	496	605
		Minimum	2050	1640	139	220	66	18	896	6	0.26	<0.04	<0.05	0.69	821	216	263
Outwash	2	Average	2505	1935	116	376	128	15	1410	5	----	----	2.60	1.41	1465	323	394
Dakota Formation	23[3]	Average	----	634	122	69	24	---	227	26	1.46	----	----	----	270	---	---

[1] **DS** – dissolved solids; Na – sodium; **Ca** – calcium; **Mg** – magnesium; **K** – potassium; SO_4 – sulfate; **Cl** – chloride; **F** – fluoride; **NO_3-N + NO_2-N** – nitrate + nitrite; **Fe** – iron; **Mn** – manganese; **$CaCO_3$** – hardness as calcium carbonate; **Alk-T** – total alkalinity; **HCO_3** – bicarbonate.

[2] umhos – micromhos.

[3] Analytical results from 23 samples (Iles, in prep.) were used in averaging for the Dakota Formation except for fluoride where only 8 samples were available.

See appendix G for individual analyses from till and outwash.

TABLE 7. Isotope data for selected hydrologic units

Hydrologic unit[3]	Well or piezometer: Identification	Well or piezometer: Depth (ft)[4]	Date sampled	Carbon-isotope data[1]: Modern Carbon: Percent	Carbon-isotope data[1]: Modern Carbon: Error	Carbon-isotope data[1]: DELTA carbon-13	Carbon-isotope data[1]: Age[5]	Carbon-isotope data[1]: Lower age[5]	Carbon-isotope data[1]: Upper age[5]	DELTA oxygen-18 ‰	DELTA deuterium ‰	Tritium data[2]: Tritium units	Tritium data[2]: Error
Weathered till	GT-LN-1K	11	7-14-86	83.9	0.6	-7.4	-8616	-8675	-8557	-10.95	-71.25	64.7	1.7
	GT-LN-1L	13	7-14-86	--	--	---	---	---	---	-10.94	-75.7	51.3	1.3
	GT-LN-1M	16	7-15-86	43.9	0.4	-7.1	-3602	-3677	-3526	-9.88	-71.9	15.1	0.04
	GT-LN-2I	11	7-15-86	--	--	---	---	---	---	-11.31	-79.2	56	1.3
	GT-LN-2J	13	7-15-86	--	--	---	---	---	---	-10.28	-70.7	30.8	0.8
Unweathered till	GT-LN-1A[6]	68	7-14-86	9	0.2	-17.3	16869	16687	17055	-13.31	-99.8	-0.06	0.1
	GT-LN-1O	36	7-15-86	15.6	0.3	-58.6	22410	22252	22570	-12.41	-89.1	0.22	0.1
	GT-LN-1P	46	7-15-86	14.2	0.4	-13.1	10798	10568	11034	-13.19	-91.7	0.75	0.1
	GT-LN-1Q	56	7-15-86	16.2	0.3	-14.3	10433	10281	10588	-14.315	-98.6	0.19	0.09
	GT-LN-2L	26	7-15-86	9.8	0.3	-9.2	10942	10693	11199	-11.33	-82.18	1.14	0.11
	GT-LN-2N	46	7-15-88	15.9	0.3	-11.9	9068	8914	9226	-13.55	-97.85	1.99	0.09
	GT-LN-2O	56	7-15-86	12	0.3	-15.5	13581	13377	13791	-15.04	-101.98	3.06	0.1
Outwash	Schoffelman[7]	90	7-25-84	11.2	0.6	-14.4	13543	13111	13998	-9.88	-68.3	--	--
	Sweeter[7]	>110	7-15-86	9.5	0.2	-10.9	12602	12429	12778	-10.405	-68.1	0.04	0.11
	R. Suing[7]	70	7-26-84	19.1	0.7	-11.5	7269	6971	7578	-8.8	-59.5	--	--

[1] Analyses were performed by the Laboratory of Isotope Geochemistry, Department of Geosciences, University of Arizona, Tucson, Arizona.

[2] Analyses were performed by the Tritium Laboratory, University of Miami, Miami, Florida.

[3] The hydrologic units occur in the following descending stratigraphic order: weathered till, unweathered till, and outwash.

[4] Depth is presented in feet below land surface.

[5] Age is presented in years before present. The lower and upper ages are based on the error factor in the percent-modern carbon.

[6] The bottom-hole core in well GT-LN-1A showed the presence of a much siltier sediment than the rest of the unweathered till above it.

[7] The locations for the Schoffelman, Sweeter, and Suing wells are as follows:
Schoffelman ..... NE¼NE¼NW¼NW¼ sec. 20, T. 98 N., R. 50 W.
Sweeter ..... NE¼NE¼NE¼SE¼ sec. 20, T. 98 N., R. 50 W.
Suing ..... SW¼SW¼SW¼SW¼ sec. 33, T. 98 N., R. 50 W.

APPENDIX A

Logs of piezometers completed in till

Logs are arranged in order according to identifier under **OTHER WELL NAME.** The order is: GT-LN-1A....GT-LN-1Q; GT-LN-2A....GT-LN-2O; GT-LN-3A....GT-LN-3F. This identifier should be used to correlate with terminology used in text, figures, and tables.

LOCATION

Included are the township number, the range number, the section number, and the quarter section identifiers: NE = A; NW = B; SW = C; SE = D. A comparison of **LEGAL LOCATION** and **LOCATION** is as follows. A **LEGAL LOCATION** of NW¼SE¼NE¼SW¼ sec. 30, T. 99 N., R. 64 W. is the same os a **LOCATION** of 099N-64W-30CADB. In several **LOCATIONS**, the smallest quarter section is followed by the number 1 or 2 which indicates that more than one log may exist for that particular location.

LATITUDE and LONGITUDE

The format is **DD.MMSS** where **D** is degrees, **M** is minutes, and **S** is seconds.

DRILLING COMPANY

SDGS is an abbreviation for South Dakota Geological Survey.

TOTAL DRILL HOLE DEPTH, SCREEN LENGTH and CASING STICK-UP

The numbers are presented in feet.

SCREEN TYPE and CASING TYPE

PVC – polyvinyl chloride; **MFG.** – manufactured; **SCH.** – abbreviation for schedule and refers to casing thickness.

CASING TOP ELEVATION and GROUND SURFACE ELEVATION

The numbers are presented in feet above mean sea level. **I** - the elevation was determined using a surveying instrument. **T** - the elevation was estimated from a 7½-minute series topographic map.

CASING DIAMETER

The numbers are presented in inches.

AQUIFER

Till is listed here as an aquifer solely to satisfy the South Dakota Geological Survey database searching routines. It is not intended to define till as an aquifer.

County: LINCOLN
Location: 098N-50W-20DAAA 1
Legal Location: NE NE NE SE sec. 20, T. 098 N., R. 50 W.
Latitude: 42.1738
Longitude: 96.4602
Land Owner:
Project: GLACIAL TILL RESEARCH
Drilling Company: SDGS
Driller: S. MITCHELL
Driller's Log: X
Geologist: M. JARRETT
Geologist's Log:
Date Drilled: 08-22-1984
Drilling Method: AUGER
Ground Surface Elevation: 1308.35 I
Total Drill Hole Depth: 67
Test Hole Number: A1-84-270
Water Rights Well:
SDGS Well Name: A1-84-270
Other Well Name: GT-LN-1A
Basin: VERMILLION
Aquifer: TILL
Management Unit:
Screen Type:
Screen Length:
Casing Type: PVC
Casing Diameter: 2.0
Casing Top Elevation: 1310.34 I
Casing Stick-up: 1.99
Total Casing and Screen:
Well Maintenance Date:
USGS Hydrological Unit Code: 10170102
Electric Log Information:
Spontaneous Potential:
Single Point Resistivity:
Natural Gamma:
Extra:
Samples:

Well intake was constructed by taking a 12-inch long core at bottom of well using a 1.5-inch diameter shelby tube.

0	-	4	Silt, light-yellow-brown, clayey; very moist, oxidized
4	-	19	Clay, light-brown, silty, sandy, pebbly; oxidized (till)
19	-	67	Clay, gray, silty, sandy, pebbly, very silty near bottom; unoxidized (till)

County: LINCOLN
Location: 098N-50W-20DAAA 2
Legal Location: NE NE NE SE sec. 20, T. 098 N., R. 50 W.
Latitude: 42.1738
Longitude: 96.4602
Land Owner:
Project: GLACIAL TILL RESEARCH
Drilling Company: SDGS
Driller: L. THOMAS
Driller's Log: X
Geologist: M. JARRETT
Geologist's Log:
Date Drilled: 08-22-1984
Drilling Method: AUGER
Ground Surface Elevation: 1308.42 I
Total Drill Hole Depth: 67
Test Hole Number: A1-84-271
Water Rights Well:
SDGS Well Name: A1-84-271
Other Well Name: GT-LN-1B
Basin: VERMILLION
Aquifer: TILL
Management Unit:
Screen Type:
Screen Length:
Casing Type: PVC
Casing Diameter: 2.0
Casing Top Elevation: 1310.28 I
Casing Stick-up: 1.86
Total Casing and Screen:
Well Maintenance Date:
USGS Hydrological Unit Code: 10170102

Electric Log Information:
Spontaneous Potential: Single Point Resistivity:
Natural Gamma: Extra:
Samples:

0	-	1	Clay, black, silty, sandy (topsoil)
1	-	18	Clay, light-yellow-brown, silty, sandy, pebbly; oxidized (till)
18	-	67	Clay, gray, silty, sandy, pebbly; unoxidized, last 13 feet progressively siltier (till)

County: LINCOLN Location: 098N-50W-20DAAA 3
Legal Location: NE NE NE SE sec. 20, T. 098 N., R. 50 W.
Latitude: 42.1738 Longitude: 96.4602
Land Owner:
Project: GLACIAL TILL RESEARCH
Drilling Company: SDGS
Driller: S. MITCHELL Driller's Log: X
Geologist: M. JARRETT Geologist's Log:
Date Drilled: 08-23-1984 Drilling Method: AUGER
Ground Surface Elevation: 1308.40 I
Total Drill Hole Depth: 47 Test Hole Number: A1-84-272
Water Rights Well: SDGS Well Name: A1-84-272
Other Well Name: GT-LN-1C
Basin: VERMILLION Aquifer: TILL
Management Unit:
Screen Type: Screen Length:
Casing Type: PVC Casing Diameter: 2.0
Casing Top Elevation: 1310.28 I
Casing Stick-up: 1.88 Total Casing and Screen:
Well Maintenance Date:
USGS Hydrological Unit Code: 10170102
Electric Log Information:
Spontaneous Potential: Single Point Resistivity:
Natural Gamma: Extra:
Samples:

Well intake was constructed by taking a 12-inch long core at bottom of well using a 1.5-inch diameter shelby tube. Drilled hard at 40 feet.

0	-	19	Clay, light-yellow-brown, silty, sandy, pebbly; moist, oxidized (till)
19	-	47	Clay, gray, silty, sandy, pebbly; unoxidized (till)

County: LINCOLN Location: 098N-50W-20DAAA 4
Legal Location: NE NE NE SE sec. 20, T. 098 N., R. 50 W.
Latitude: 42.1738 Longitude: 96.4602
Land Owner:
Project: GLACIAL TILL RESEARCH
Drilling Company: SDGS
Driller: L. THOMAS Driller's Log: X
Geologist: M. JARRETT Geologist's Log:
Date Drilled: 08-23-1984 Drilling Method: AUGER
Ground Surface Elevation: 1308.23 I
Total Drill Hole Depth: 27 Test Hole Number: A1-84-273
Water Rights Well: SDGS Well Name: A1-84-273

Other Well Name: GT-LN-1D
Basin: VERMILLION
Aquifer: TILL
Management Unit:
Screen Type:
Screen Length:
Casing Type: PVC
Casing Diameter: 2.0
Casing Top Elevation: 1310.38 I
Casing Stick-up: 2.15
Total Casing and Screen:
Well Maintenance Date:
USGS Hydrological Unit Code: 10170102
Electric Log Information:
Spontaneous Potential:
Single Point Resistivity:
Natural Gamma:
Extra:
Samples:

Well intake was constructed by taking a 12-inch long core at bottom of well using a 1.5-inch diameter shelby tube.

0	-	19	Clay, light-yellow-brown, silty, sandy, pebbly; oxidized (till)
19	-	27	Clay, gray, silty, sandy, pebbly; unoxidized (till)

County: LINCOLN
Location: 098N-50W-20DAAA 5
Legal Location: NE NE NE SE sec. 20, T. 098 N., R. 50 W.
Latitude: 42.1738
Longitude: 96.4602
Land Owner:
Project: GLACIAL TILL RESEARCH
Drilling Company: SDGS
Driller: S. MITCHELL
Driller's Log: X
Geologist: M. JARRETT
Geologist's Log:
Date Drilled: 08-23-1984
Drilling Method: AUGER
Ground Surface Elevation: 1308.22 I
Total Drill Hole Depth: 27
Test Hole Number: A1-84-274
Water Rights Well:
SDGS Well Name: A1-84-274
Other Well Name: GT-LN-1E
Basin: VERMILLION
Aquifer: TILL
Management Unit:
Screen Type:
Screen Length:
Casing Type: PVC
Casing Diameter: 2.0
Casing Top Elevation: 1310.37 I
Casing Stick-up: 2.15
Total Casing and Screen:
Well Maintenance Date:
USGS Hydrological Unit Code: 10170102
Electric Log Information:
Spontaneous Potential:
Single Point Resistivity:
Natural Gamma:
Extra:
Samples:

0	-	19	Clay, light-yellow-brown, silty, sandy, pebbly; oxidized (till)
19	-	27	Clay, gray, silty, sandy, pebbly; unoxidized (till)

County: LINCOLN
Location: 098N-50W-20DAAA 6
Legal Location: NE NE NE SE sec. 20, T. 098 N., R. 50 W.
Latitude: 42.1738
Longitude: 96.4602
Land Owner:

Project: GLACIAL TILL RESEARCH
Drilling Company: SDGS
Driller: L. THOMAS
Geologist: M. JARRETT
Date Drilled: 08-23-1984
Ground Surface Elevation: 1308.22 I
Total Drill Hole Depth: 15
Water Rights Well:
Other Well Name: GT-LN-1F
Basin: VERMILLION
Management Unit:
Screen Type:
Casing Type: PVC
Casing Top Elevation: 1310.39 I
Casing Stick-up: 2.17
Well Maintenance Date:
USGS Hydrological Unit Code: 10170102
Electric Log Information:
Spontaneous Potential:
Natural Gamma:
Samples:

Driller's Log: X
Geologist's Log:
Drilling Method: AUGER

Test Hole Number: A1-84-275
SDGS Well Name: A1-84-275

Aquifer: TILL

Screen Length:
Casing Diameter: 2.0

Total Casing and Screen:

Single Point Resistivity:
Extra:

Well intake was constructed by taking a 12-inch long core at bottom of well using a 1.5-inch diameter shelby tube.

0 - 15 Clay, light-yellow-brown, silty, sandy, pebbly; oxidized (till)

County: LINCOLN
Legal Location: NE NE NE SE sec. 20, T. 098 N., R. 50 W.
Latitude: 42.1738
Land Owner:
Project: GLACIAL TILL RESEARCH
Drilling Company: SDGS
Driller: S. MITCHELL
Geologist: M. JARRETT
Date Drilled: 08-23-1984
Ground Surface Elevation: 1308.29 I
Total Drill Hole Depth: 17
Water Rights Well:
Other Well Name: GT-LN-1G
Basin: VERMILLION
Management Unit:
Screen Type: PVC, MFG.
Casing Type: PVC
Casing Top Elevation: 1310.21 I
Casing Stick-up: 1.92
Well Maintenance Date:
USGS Hydrological Unit Code: 10170102
Electric Log Information:
Spontaneous Potential:
Natural Gamma:
Samples:

Location: 098N-50W-20DAAA 7

Longitude: 96.4602

Driller's Log: X
Geologist's Log:
Drilling Method: AUGER

Test Hole Number: A1-84-276
SDGS Well Name: A1-84-276

Aquifer: TILL

Screen Length: 5.0
Casing Diameter: 2.0

Total Casing and Screen:

Single Point Resistivity:
Extra:

0 - 17 Clay, light-yellow-brown, silty, sandy, pebbly; oxidized (till)

County: LINCOLN
Location: 098N-50W-20DAAA 8
Legal Location: NE NE NE SE sec. 20, T. 098 N., R. 50 W.
Latitude: 42.1738
Longitude: 96.4602
Land Owner:
Project: GLACIAL TILL RESEARCH
Drilling Company: SDGS
Driller: M. JARRETT
Driller's Log:
Geologist: M. JARRETT
Geologist's Log: X
Date Drilled: 10-09-1984
Drilling Method: AUGER
Ground Surface Elevation: 1308.31 I
Total Drill Hole Depth: 12
Test Hole Number: A1-84-282
Water Rights Well:
SDGS Well Name: A1-84-282
Other Well Name: GT-LN-1H
Basin: VERMILLION
Aquifer: TILL
Management Unit:
Screen Type:
Screen Length:
Casing Type: PVC
Casing Diameter: 2.0
Casing Top Elevation: 1310.03 I
Casing Stick-up: 1.72
Total Casing and Screen:
Well Maintenance Date:
USGS Hydrological Unit Code: 10170102
Electric Log Information:
Spontaneous Potential:
Single Point Resistivity:
Natural Gamma:
Extra:
Samples:

Well intake was constructed by taking a 12-inch long core at bottom of well using a 1.5-inch diameter shelby tube.

0 - 12 Clay, brown, silty, pebbly (till)

County: LINCOLN
Location: 098N-50W-20DAAA19
Legal Location: NE NE NE SE sec. 20, T. 098 N., R. 50 W.
Latitude: 43.1737
Longitude: 96.4601
Land Owner:
Project: GLACIAL TILL RESEARCH
Drilling Company: SDGS
Driller: K. WUNDER
Driller's Log: X
Geologist: T. COWMAN
Geologist's Log:
Date Drilled: 05-20-1986
Drilling Method: AUGER
Ground Surface Elevation: 1308.00 T
Total Drill Hole Depth: 2
Test Hole Number: A1-86-13
Water Rights Well:
SDGS Well Name: A1-86-13
Other Well Name: GT-LN-1I
Basin: VERMILLION
Aquifer:
Management Unit:
Screen Type:
Screen Length:
Casing Type: PVC, SCH. 80
Casing Diameter: 2.0
Casing Top Elevation:
Casing Stick-up: 2.40
Total Casing and Screen: 4.4
Well Maintenance Date:
USGS Hydrological Unit Code: 10170102
Electric Log Information:
Spontaneous Potential:
Single Point Resistivity:

Natural Gamma: Extra:
Samples:

A 1 foot length of 1 1/2-inch shelby tube core was removed from the bottom of the well. This acts as a natural intake.

0	-	2	Clay, blackish-brown, silty, sandy, pebbly; oxidized, moist (till)

County: LINCOLN Location: 098N-50W-20DAAA14
Legal Location: NE NE NE SE sec. 20, T. 098 N., R. 50 W.
Latitude: 43.1737 Longitude: 96.4601
Land Owner:
Project: GLACIAL TILL RESEARCH
Drilling Company: SDGS
Driller: K. WUNDER Driller's Log: X
Geologist: T. COWMAN Geologist's Log:
Date Drilled: 05-19-1986 Drilling Method: AUGER
Ground Surface Elevation: 1308.00 T
Total Drill Hole Depth: 5 Test Hole Number: A1-86-12
Water Rights Well: SDGS Well Name: A1-86-12
Other Well Name: GT-LN-1J
Basin: VERMILLION Aquifer:
Management Unit:
Screen Type: Screen Length:
Casing Type: PVC, SCH. 80 Casing Diameter: 2.0
Casing Top Elevation:
Casing Stick-up: 1.60 Total Casing and Screen: 6.6
Well Maintenance Date:
USGS Hydrological Unit Code: 10170102
Electric Log Information:
Spontaneous Potential: Single Point Resistivity:
Natural Gamma: Extra:
Samples:

A 1 foot length of 1 1/2-inch shelby tube core was removed from the bottom of the well. This acts as a natural intake.

0	-	4	Clay, blackish-brown, silty, sandy, pebbly; oxidized, moist (till)
4	-	5	Clay, tan-brown, silty, sandy, pebbly; oxidized, moist (till)

County: LINCOLN Location: 098N-50W-20DAAA18
Legal Location: NE NE NE SE sec. 20, T. 098 N., R. 50 W.
Latitude: 43.1737 Longitude: 96.4601
Land Owner:
Project: GLACIAL TILL RESEARCH
Drilling Company: SDGS
Driller: L. SCHULZ Driller's Log: X
Geologist: T. COWMAN Geologist's Log:
Date Drilled: 05-19-1986 Drilling Method: AUGER
Ground Surface Elevation: 1308.00 T
Total Drill Hole Depth: 10 Test Hole Number: A2-86-19
Water Rights Well: SDGS Well Name: A2-86-19
Other Well Name: GT-LN-1K

Basin: VERMILLION
Management Unit:
Screen Type:
Casing Type: PVC, SCH. 80
Casing Top Elevation:
Casing Stick-up: 2.40
Well Maintenance Date:
USGS Hydrological Unit Code: 10170102
Electric Log Information:
Spontaneous Potential:
Natural Gamma:
Samples:

Aquifer:

Screen Length:
Casing Diameter: 2.0

Total Casing and Screen: 12.4

Single Point Resistivity:
Extra:

A 1 foot length of 1 1/2-inch shelby tube core was removed from the bottom of the well. This acts as a natural intake.

0	-	2	Topsoil
2	-	10	Clay, yellow-brown, silty, sandy, pebbly; oxidized, moist (till)

County: LINCOLN
Legal Location: NE NE NE SE sec. 20, T. 098 N., R. 50 W.
Latitude: 43.1737
Land Owner:
Project: GLACIAL TILL RESEARCH
Drilling Company: SDGS
Driller: L. SCHULZ
Geologist: T. COWMAN
Date Drilled: 05-19-1986
Ground Surface Elevation: 1308.00 T
Total Drill Hole Depth: 12
Water Rights Well:
Other Well Name: GT-LN-1L
Basin: VERMILLION
Management Unit:
Screen Type:
Casing Type: PVC, SCH. 80
Casing Top Elevation:
Casing Stick-up: 1.50
Well Maintenance Date:
USGS Hydrological Unit Code: 10170102
Electric Log Information:
Spontaneous Potential:
Natural Gamma:
Samples:

Location: 098N-50W-20DAAA17

Longitude: 96.4601

Driller's Log: X
Geologist's Log:
Drilling Method: AUGER

Test Hole Number: A2-86-18
SDGS Well Name: A2-86-18

Aquifer:

Screen Length:
Casing Diameter: 2.0

Total Casing and Screen: 13.5

Single Point Resistivity:
Extra:

A 1 foot length of 1 1/2-inch shelby tube core was removed from the bottom of the well. This acts as a natural intake.

0	-	2	Topsoil
2	-	12	Clay, yellow-brown, silty, sandy, pebbly; oxidized, moist (till)

County: LINCOLN
Legal Location: NE NE NE SE sec. 20, T. 098 N., R. 50 W.

Location: 098N-50W-20DAAA13

Latitude: 43.1737 Longitude: 96.4601
Land Owner:
Project: GLACIAL TILL RESEARCH
Drilling Company: SDGS
Driller: K. WUNDER Driller's Log: X
Geologist: T. COWMAN Geologist's Log:
Date Drilled: 05-19-1986 Drilling Method: AUGER
Ground Surface Elevation: 1308.00 T
Total Drill Hole Depth: 15 Test Hole Number: A1-86-11
Water Rights Well: SDGS Well Name: A1-86-11
Other Well Name: GT-LN-1M
Basin: VERMILLION Aquifer:
Management Unit:
Screen Type: Screen Length:
Casing Type: PVC, SCH. 80 Casing Diameter: 2.0
Casing Top Elevation:
Casing Stick-up: 2.50 Total Casing and Screen: 17.5
Well Maintenance Date:
USGS Hydrological Unit Code: 10170102
Electric Log Information:
Spontaneous Potential: Single Point Resistivity:
Natural Gamma: Extra:
Samples:

A 1 foot length of 1 1/2-inch shelby tube core was removed from the bottom of the well. This acts as a natural intake.

0	-	5	Clay, blackish-brown, silty, sandy, pebbly; oxidized, moist (till)
5	-	14	Clay, tan-brown, silty, sandy, pebbly; oxidized, moist (till)
14	-	15	Clay, dark-brown, silty, sandy, pebbly; partially oxidized, moist (till)

County: LINCOLN Location: 098N-50W-20DAAA12
Legal Location: NE NE NE SE sec. 20, T. 098 N., R. 50 W.
Latitude: 43.1737 Longitude: 96.4601
Land Owner:
Project: GLACIAL TILL RESEARCH
Drilling Company: SDGS
Driller: K. WUNDER Driller's Log: X
Geologist: T. COWMAN Geologist's Log:
Date Drilled: 05-19-1986 Drilling Method: AUGER
Ground Surface Elevation: 1308.00 T
Total Drill Hole Depth: 25 Test Hole Number: A1-86-10
Water Rights Well: SDGS Well Name: A1-86-10
Other Well Name: GT-LN-1N
Basin: VERMILLION Aquifer:
Management Unit:
Screen Type: Screen Length:
Casing Type: PVC, SCH. 80 Casing Diameter: 2.0
Casing Top Elevation:
Casing Stick-up: 2.40 Total Casing and Screen: 27.4
Well Maintenance Date:
USGS Hydrological Unit Code: 10170102
Electric Log Information:
Spontaneous Potential: Single Point Resistivity:

Natural Gamma: Extra:
Samples:

A 1 foot length of 1 1/2-inch shelby tube core was removed from the bottom of the well. This acts as a natural intake.

0	-	5	Clay, blackish-brown, silty, sandy, pebbly; oxidized, moist (till)
5	-	14	Clay, tan-brown, silty, sandy, very pebbly; oxidized, moist (till)
14	-	20	Clay, dark-brown, silty, sandy, pebbly; oxidized, moist (till)
20	-	25	Clay, gray, silty, sandy, pebbly; unoxidized, moist (till)

County: LINCOLN Location: 098N-50W-20DAAA16
Legal Location: NE NE NE SE sec. 20, T. 098 N., R. 50 W.
Latitude: 43.1737 Longitude: 96.4601
Land Owner:
Project: GLACIAL TILL RESEARCH
Drilling Company: SDGS
Driller: L. SCHULZ Driller's Log: X
Geologist: T. COWMAN Geologist's Log:
Date Drilled: 05-19-1986 Drilling Method: AUGER
Ground Surface Elevation: 1308.00 T
Total Drill Hole Depth: 35 Test Hole Number: A2-86-17
Water Rights Well: SDGS Well Name: A2-86-17
Other Well Name: GT-LN-1O
Basin: VERMILLION Aquifer:
Management Unit:
Screen Type: Screen Length:
Casing Type: PVC, SCH. 80 Casing Diameter: 2.0
Casing Top Elevation:
Casing Stick-up: 1.30 Total Casing and Screen: 36.3
Well Maintenance Date:
USGS Hydrological Unit Code: 10170102
Electric Log Information:
Spontaneous Potential: Single Point Resistivity:
Natural Gamma: Extra:
Samples:

A 1 foot length of 1 1/2-inch shelby tube core was removed from the bottom of the well. This acts as a natural intake.

0	-	2	Topsoil
2	-	15	Clay, brown-yellow, silty, sandy, pebbly; oxidized, moist (till)
15	-	20	Clay, dark-brown, silty, sandy, pebbly; partially oxidized, moist (till)
20	-	35	Clay, gray, silty, sandy, pebbly; unoxidized, moist (till)

County: LINCOLN Location: 098N-50W-20DAAA15
Legal Location: NE NE NE SE sec. 20, T. 098 N., R. 50 W.
Latitude: 43.1737 Longitude: 96.4601
Land Owner:
Project: GLACIAL TILL RESEARCH
Drilling Company: SDGS
Driller: L. SCHULZ Driller's Log: X
Geologist: T. COWMAN Geologist's Log:

Date Drilled: 05-19-1986
Drilling Method: AUGER
Ground Surface Elevation: 1308.00 T
Total Drill Hole Depth: 45
Test Hole Number: A2-86-16
Water Rights Well:
SDGS Well Name: A2-86-16
Other Well Name: GT-LN-1P
Basin: VERMILLION
Aquifer:
Management Unit:
Screen Type:
Screen Length:
Casing Type: PVC, SCH. 80
Casing Diameter: 2.0
Casing Top Elevation:
Casing Stick-up: 2.40
Total Casing and Screen: 47.4
Well Maintenance Date:
USGS Hydrological Unit Code: 10170102
Electric Log Information:
Spontaneous Potential:
Single Point Resistivity:
Natural Gamma:
Extra:
Samples:

A 1 foot length of 1 1/2-inch shelby tube core was removed from the bottom of the well. This acts as a natural intake.

0	-	2	Topsoil
2	-	14	Clay, brown, silty, sandy, pebbly; oxidized, moist (till)
14	-	45	Clay, gray, silty, sandy, pebbly; unoxidized, moist (till)

County: LINCOLN
Location: 098N-50W-20DAAA11
Legal Location: NE NE NE SE sec. 20, T. 098 N., R. 50 W.
Latitude: 43.1737
Longitude: 96.4601
Land Owner:
Project: GLACIAL TILL RESEARCH
Drilling Company: SDGS
Driller: K. WUNDER
Driller's Log: X
Geologist: T. COWMAN
Geologist's Log:
Date Drilled: 05-19-1986
Drilling Method: AUGER
Ground Surface Elevation: 1308.00 T
Total Drill Hole Depth: 55
Test Hole Number: A1-86-9
Water Rights Well:
SDGS Well Name: A1-86-9
Other Well Name: GT-LN-1Q
Basin: VERMILLION
Aquifer:
Management Unit:
Screen Type:
Screen Length:
Casing Type: PVC, SCH. 80
Casing Diameter: 2.0
Casing Top Elevation:
Casing Stick-up: 2.20
Total Casing and Screen: 57.2
Well Maintenance Date:
USGS Hydrological Unit Code: 10170102
Electric Log Information:
Spontaneous Potential:
Single Point Resistivity:
Natural Gamma:
Extra:
Samples:

A 1 foot length of 1 1/2-inch shelby tube core was removed from the bottom of the well. This acts as a natural intake.

0	-	5	Clay, blackish-brown, silty, sandy, pebbly; oxidized, moist (till)
5	-	14	Clay, tan-brown, silty, sandy, pebbly; oxidized, moist (till)
14	-	19	Clay, dark-brown-gray, silty, sandy, pebbly; partially oxidized, moist (till)
19	-	29	Clay, gray, silty, sandy, pebbly; unoxidized, moist (till)
29	-	55	Clay, gray, silty, slightly sandy, slightly pebbly; unoxidized, moist (till)

County: LINCOLN
Location: 098N-50W-30ADDD 1
Legal Location: SE SE SE NE sec. 30, T. 098 N., R. 50 W.
Latitude: 43.1648
Longitude: 96.4713
Land Owner:
Project: GLACIAL TILL RESEARCH
Drilling Company: SDGS
Driller: S. MITCHELL
Driller's Log: X
Geologist: M. JARRETT
Geologist's Log:
Date Drilled: 08-28-1984
Drilling Method: AUGER
Ground Surface Elevation: 1305.37 I
Total Drill Hole Depth: 15
Test Hole Number: A1-84-281
Water Rights Well:
SDGS Well Name: A1-84-281
Other Well Name: GT-LN-2A
Basin: VERMILLION
Aquifer: TILL
Management Unit:
Screen Type:
Screen Length:
Casing Type: PVC
Casing Diameter: 2.0
Casing Top Elevation: 1307.60 I
Casing Stick-up: 2.23
Total Casing and Screen:
Well Maintenance Date:
USGS Hydrological Unit Code: 10170102
Electric Log Information:
Spontaneous Potential:
Single Point Resistivity:
Natural Gamma:
Extra:
Samples:

Well intake was constructed by taking a 12-inch long core at bottom of well using a 1.5-inch diameter shelby tube.

0	-	1	Clay, black, silty, sandy (topsoil)
1	-	15	Clay, light-yellow-brown, silty, sandy, pebbly; oxidized (till)

County: LINCOLN
Location: 098N-50W-30ADDD 2
Legal Location: SE SE SE NE sec. 30, T. 098 N., R. 50 W.
Latitude: 43.1648
Longitude: 96.4713
Land Owner:
Project: GLACIAL TILL RESEARCH
Drilling Company: SDGS
Driller: L. THOMAS
Driller's Log: X
Geologist: M. JARRETT
Geologist's Log:
Date Drilled: 08-28-1984
Drilling Method: AUGER
Ground Surface Elevation: 1306.06 I
Total Drill Hole Depth: 27
Test Hole Number: A1-84-280
Water Rights Well:
SDGS Well Name: A1-84-280
Other Well Name: GT-LN-2B
Basin: VERMILLION
Aquifer: TILL
Management Unit:

Screen Type:
Casing Type: PVC
Casing Top Elevation: 1307.51 I
Casing Stick-up: 1.45
Well Maintenance Date:
USGS Hydrological Unit Code: 10170102
Electric Log Information:
Spontaneous Potential:
Natural Gamma:
Samples:

Screen Length:
Casing Diameter: 2.0

Total Casing and Screen:

Single Point Resistivity:
Extra:

0	-	1	Clay, black, silty, sandy (topsoil)
1	-	19	Clay, light-yellow-brown, silty, sandy, pebbly; oxidized (till)
19	-	27	Clay, gray, silty, sandy, pebbly; unoxidized (till)

County: LINCOLN
Legal Location: SE SE SE NE sec. 30, T. 098 N., R. 50 W.
Latitude: 43.1648
Land Owner:
Project: GLACIAL TILL RESEARCH
Drilling Company: SDGS
Driller: S. MITCHELL
Geologist: M. JARRETT
Date Drilled: 08-28-1984
Ground Surface Elevation: 1306.19 I
Total Drill Hole Depth: 47
Water Rights Well:
Other Well Name: GT-LN-2C
Basin: VERMILLION
Management Unit:
Screen Type:
Casing Type: PVC
Casing Top Elevation: 1307.60 I
Casing Stick-up: 1.41
Well Maintenance Date:
USGS Hydrological Unit Code: 10170102
Electric Log Information:
Spontaneous Potential:
Natural Gamma:
Samples:

Location: 098N-50W-30ADDD 3

Longitude: 96.4713

Driller's Log: X
Geologist's Log:
Drilling Method: AUGER

Test Hole Number: A1-84-279
SDGS Well Name: A1-84-279

Aquifer: TILL

Screen Length:
Casing Diameter: 2.0

Total Casing and Screen:

Single Point Resistivity:
Extra:

Well intake was constructed by taking a 12-inch long core at bottom of well using a 1.5-inch diameter shelby tube.

0	-	1	Clay, black, silty, sandy (topsoil)
1	-	19	Clay, light-yellow-brown, silty, sandy, pebbly; oxidized (till)
19	-	47	Clay, gray, silty, sandy, pebbly; unoxidized (till)

County: LINCOLN
Legal Location: SE SE SE NE sec. 30, T. 098 N., R. 50 W.
Latitude: 43.1648
Land Owner:
Project: GLACIAL TILL RESEARCH

Location: 098N-50W-30ADDD 4

Longitude: 96.4713

Drilling Company: SDGS
Driller: S. MITCHELL
Geologist: M. JARRETT
Date Drilled: 08-27-1984
Ground Surface Elevation: 1306.32 I
Total Drill Hole Depth: 15
Water Rights Well:
Other Well Name: GT-LN-2D
Basin: VERMILLION
Management Unit:
Screen Type: PVC, MFG.
Casing Type: PVC
Casing Top Elevation: 1307.88 I
Casing Stick-up: 1.56
Well Maintenance Date:
USGS Hydrological Unit Code: 10170102
Electric Log Information:
Spontaneous Potential:
Natural Gamma:
Samples:

Driller's Log: X
Geologist's Log:
Drilling Method: AUGER

Test Hole Number: A1-84-278
SDGS Well Name: A1-84-278

Aquifer: TILL

Screen Length: 10.0
Casing Diameter: 2.0

Total Casing and Screen:

Single Point Resistivity:
Extra:

0	-	1	Clay, black, silty, sandy (topsoil)
1	-	15	Clay, light-yellow-brown, silty, sandy, pebbly; oxidized (till)

County: LINCOLN
Legal Location: SE SE SE NE sec. 30, T. 098 N., R. 50 W.
Latitude: 43.1648
Land Owner:
Project: GLACIAL TILL RESEARCH
Drilling Company: SDGS
Driller: L. THOMAS
Geologist: M. JARRETT
Date Drilled: 08-27-1984
Ground Surface Elevation: 1306.43 I
Total Drill Hole Depth: 67
Water Rights Well:
Other Well Name: GT-LN-2E
Basin: VERMILLION
Management Unit:
Screen Type:
Casing Type: PVC
Casing Top Elevation: 1307.96 I
Casing Stick-up: 1.53
Well Maintenance Date:
USGS Hydrological Unit Code: 10170102
Electric Log Information:
Spontaneous Potential:
Natural Gamma:
Samples:

Location: 098N-50W-30ADDD 5

Longitude: 96.4713

Driller's Log: X
Geologist's Log:
Drilling Method: AUGER

Test Hole Number: A1-84-277
SDGS Well Name: A1-84-277

Aquifer: TILL

Screen Length:
Casing Diameter: 2.0

Total Casing and Screen:

Single Point Resistivity:
Extra:

Well intake was constructed by taking a 12-inch long core at bottom of well using a 1.5-inch diameter shelby tube.

0	-	1	Clay, black, silty, sandy (topsoil)

1 - 19 Clay, light-yellow-brown, silty, sandy, pebbly; oxidized (till)
19 - 67 Clay, gray, silty, sandy, pebbly; unoxidized (till)

County: LINCOLN
Location: 098N-50W-30ADDD 6
Legal Location: SE SE SE NE sec. 30, T. 098 N., R. 50 W.
Latitude: 43.1648
Longitude: 96.4713
Land Owner:
Project: GLACIAL TILL RESEARCH
Drilling Company: SDGS
Driller: M. JARRETT
Driller's Log:
Geologist: M. JARRETT
Geologist's Log: X
Date Drilled: 10-12-1984
Drilling Method: AUGER
Ground Surface Elevation: 1306.36 I
Total Drill Hole Depth: 8
Test Hole Number: A1-84-287
Water Rights Well:
SDGS Well Name: A1-84-287
Other Well Name: GT-LN-2F
Basin: VERMILLION
Aquifer: TILL
Management Unit:
Screen Type:
Screen Length:
Casing Type: PVC
Casing Diameter: 2.0
Casing Top Elevation: 1307.53 I
Casing Stick-up: 1.17
Total Casing and Screen:
Well Maintenance Date:
USGS Hydrological Unit Code: 10170102
Electric Log Information:
Spontaneous Potential:
Single Point Resistivity:
Natural Gamma:
Extra:
Samples:

Well intake was constructed by taking a 12-inch long core at bottom of well using a 1.5-inch diameter shelby tube.

0 - 8 Clay, yellow-brown, very silty, sandy; few pebbles (till)

County: LINCOLN
Location: 098N-50W-30ADDD15
Legal Location: SE SE SE NE sec. 30, T. 098 N., R. 50 W.
Latitude: 43.1648
Longitude: 96.4713
Land Owner:
Project: GLACIAL TILL RESEARCH
Drilling Company: SDGS
Driller: L. SCHULZ
Driller's Log: X
Geologist: T. COWMAN
Geologist's Log:
Date Drilled: 05-20-1986
Drilling Method: AUGER
Ground Surface Elevation: 1306.00 T
Total Drill Hole Depth: 2
Test Hole Number: A2-86-26
Water Rights Well:
SDGS Well Name: A2-86-26
Other Well Name: GT-LN-2G
Basin: VERMILLION
Aquifer:
Management Unit:
Screen Type:
Screen Length:
Casing Type: PVC, SCH. 80
Casing Diameter: 2.0
Casing Top Elevation:
Casing Stick-up: 2.50
Total Casing and Screen: 4.5

Well Maintenance Date:
USGS Hydrological Unit Code: 10170102
Electric Log Information:
Spontaneous Potential: Single Point Resistivity:
Natural Gamma: Extra:
Samples:

A 1 foot length of 1 1/2-inch shelby tube core was removed from the bottom of the well. This acts as a natural intake.

0 - 2 Topsoil

County: LINCOLN Location: 098N-50W-30ADDD14
Legal Location: SE SE SE NE sec. 30, T. 098 N., R. 50 W.
Latitude: 43.1648 Longitude: 96.4713
Land Owner:
Project: GLACIAL TILL RESEARCH
Drilling Company: SDGS
Driller: L. SCHULZ Driller's Log: X
Geologist: T. COWMAN Geologist's Log:
Date Drilled: 05-20-1986 Drilling Method:
Ground Surface Elevation: 1306.00 T
Total Drill Hole Depth: 5 Test Hole Number: A2-86-25
Water Rights Well: SDGS Well Name: A2-86-25
Other Well Name: GT-LN-2H
Basin: VERMILLION Aquifer:
Management Unit:
Screen Type: Screen Length:
Casing Type: PVC, SCH. 80 Casing Diameter: 2.0
Casing Top Elevation: 7.50
Casing Stick-up: 2.50 Total Casing and Screen:
Well Maintenance Date:
USGS Hydrological Unit Code: 10170102
Electric Log Information:
Spontaneous Potential: Single Point Resistivity:
Natural Gamma: Extra:
Samples:

A 1 foot length of 1 1/2-inch shelby tube core was removed from the bottom of the well. This acts as a natural intake.

0 - 3 Topsoil
3 - 5 Clay, yellow-brown, silty, sandy, pebbly; oxidized, moist (till)

County: LINCOLN Location: 098N-50W-30ADDD11
Legal Location: SE SE SE NE sec. 30, T. 098 N., R. 50 W.
Latitude: 43.1648 Longitude: 96.4713
Land Owner:
Project: GLACIAL TILL RESEARCH
Drilling Company: SDGS
Driller: L. SCHULZ Driller's Log: X
Geologist: T. COWMAN Geologist's Log:
Date Drilled: 05-20-1986 Drilling Method: AUGER

Ground Surface Elevation: 1306.00 T
Total Drill Hole Depth: 10
Test Hole Number: A2-86-22
Water Rights Well:
SDGS Well Name: A2-86-22
Other Well Name: GT-LN-2I
Basin: VERMILLION
Aquifer:
Management Unit:
Screen Type:
Screen Length:
Casing Type: PVC, SCH. 80
Casing Diameter: 2.0
Casing Top Elevation:
Casing Stick-up: 2.30
Total Casing and Screen: 12.3
Well Maintenance Date:
USGS Hydrological Unit Code: 10170102
Electric Log Information:
Spontaneous Potential:
Single Point Resistivity:
Natural Gamma:
Extra:
Samples:

A 1 foot length of 1 1/2-inch shelby tube core was removed from the bottom of the well. This acts as a natural intake.

0	-	2	Topsoil
2	-	10	Clay, yellow-brown, silty, very sandy, pebbly; oxidized, moist, saturated at 10 feet (till)

County: LINCOLN
Location: 098N-50W-30ADDD10
Legal Location: SE SE SE NE sec. 30, T. 098 N., R. 50 W.
Latitude: 43.1648
Longitude: 96.4713
Land Owner:
Project: GLACIAL TILL RESEARCH
Drilling Company: SDGS
Driller: L. SCHULZ
Driller's Log: X
Geologist: T. COWMAN
Geologist's Log:
Date Drilled: 05-20-1986
Drilling Method: AUGER
Ground Surface Elevation: 1306.00 T
Total Drill Hole Depth: 12
Test Hole Number: A2-86-21
Water Rights Well:
SDGS Well Name: A2-86-21
Other Well Name: GT-LN-2J
Basin: VERMILLION
Aquifer:
Management Unit:
Screen Type:
Screen Length:
Casing Type: PVC, SCH. 80
Casing Diameter: 2.0
Casing Top Elevation:
Casing Stick-up: 2.30
Total Casing and Screen: 14.3
Well Maintenance Date:
USGS Hydrological Unit Code: 10170102
Electric Log Information:
Spontaneous Potential:
Single Point Resistivity:
Natural Gamma:
Extra:
Samples:

A 1 foot length of 1 1/2-inch shelby tube core was removed from the bottom of the well. This acts as a natural intake.

0	-	2	Topsoil
2	-	12	Clay, yellow-brown, silty, sandy, pebbly; oxidized, moist, saturated at 11 feet (till)

County: LINCOLN
Legal Location: SE SE SE NE sec. 30, T. 098 N., R. 50 W.
Latitude: 43.1648
Land Owner:
Project: GLACIAL TILL RESEARCH
Drilling Company: SDGS
Driller: L. SCHULZ
Geologist: T. COWMAN
Date Drilled: 05-20-1986
Ground Surface Elevation: 1306.00 T
Total Drill Hole Depth: 15
Water Rights Well:
Other Well Name: GT-LN-2K
Basin: VERMILLION
Management Unit:
Screen Type:
Casing Type: PVC, SCH. 80
Casing Top Elevation:
Casing Stick-up: 2.60
Well Maintenance Date:
USGS Hydrological Unit Code: 10170102
Electric Log Information:
Spontaneous Potential:
Natural Gamma:
Samples:

Location: 098N-50W-30ADDD 9
Longitude: 96.4713
Driller's Log: X
Geologist's Log:
Drilling Method: AUGER
Test Hole Number: A2-86-20
SDGS Well Name: A2-86-20
Aquifer:
Screen Length:
Casing Diameter: 2.0
Total Casing and Screen: 17.6
Single Point Resistivity:
Extra:

A 1 1/2-inch shelby tube core was attempted from the bottom of the well. No core was returned. A less than 6-inch open hole is presumed. This would act as a natural intake.

0	-	4	Topsoil
4	-	15	Clay, yellow-brown, very silty, very sandy, pebbly; oxidized, moist, saturated at 11 feet

County: LINCOLN
Legal Location: SE SE SE NE sec. 30, T. 098 N., R. 50 W.
Latitude: 43.1648
Land Owner:
Project: GLACIAL TILL RESEARCH
Drilling Company: SDGS
Driller: L. SCHULZ
Geologist: T. COWMAN
Date Drilled: 05-20-1986
Ground Surface Elevation: 1306.00 T
Total Drill Hole Depth: 25
Water Rights Well:
Other Well Name: GT-LN-2L
Basin: VERMILLION
Management Unit:
Screen Type:
Casing Type: PVC, SCH. 80
Casing Top Elevation:
Casing Stick-up: 1.40
Well Maintenance Date:

Location: 098N-50W-30ADDD13
Longitude: 96.4713
Driller's Log: X
Geologist's Log:
Drilling Method: AUGER
Test Hole Number: A2-86-24
SDGS Well Name: A2-86-24
Aquifer:
Screen Length:
Casing Diameter: 2.0
Total Casing and Screen: 26.4

USGS Hydrological Unit Code: 10170102
Electric Log Information:
Spontaneous Potential: Single Point Resistivity:
Natural Gamma: Extra:
Samples:

A 1 foot length of 1 1/2-inch shelby tube core was removed from the bottom of the well. This acts as a natural intake.

0	-	3	Topsoil
3	-	21	Clay, yellow-brown, silty, very sandy, pebbly; oxidized, moist, saturated 9 to 11 feet (till)
21	-	25	Clay, gray, silty, sandy, pebbly; unoxidized, moist (till)

County: LINCOLN Location: 098N-50W-30ADDD12
Legal Location: SE SE SE NE sec. 30, T. 098 N., R. 50 W.
Latitude: 43.1648 Longitude: 96.4713
Land Owner:
Project: GLACIAL TILL RESEARCH
Drilling Company: SDGS
Driller: L. SCHULZ Driller's Log: X
Geologist: T. COWMAN Geologist's Log:
Date Drilled: 05-20-1986 Drilling Method: AUGER
Ground Surface Elevation: 1306.00 T
Total Drill Hole Depth: 35 Test Hole Number: A2-86-23
Water Rights Well: SDGS Well Name: A2-86-23
Other Well Name: GT-LN-2M
Basin: VERMILLION Aquifer:
Management Unit:
Screen Type: Screen Length:
Casing Type: PVC, SCH. 80 Casing Diameter: 2.0
Casing Top Elevation:
Casing Stick-up: 2.50 Total Casing and Screen: 37.5
Well Maintenance Date:
USGS Hydrological Unit Code: 10170102
Electric Log Information:
Spontaneous Potential: Single Point Resistivity:
Natural Gamma: Extra:
Samples:

A 1 foot length of 1 1/2-inch shelby tube core was removed from the bottom of the well. This acts as a natural intake.

0	-	3	Topsoil
3	-	21	Clay, yellow-brown, silty, very sandy, pebbly; oxidized, moist, saturated 8 to 11 feet
21	-	25	Clay, gray-brown, silty, sandy, pebbly; partially oxidized, moist (till)
25	-	35	Clay, gray, silty, sandy, pebbly; unoxidized, moist (till)

County: LINCOLN Location: 098N-50W-30ADDD 8
Legal Location: SE SE SE NE sec. 30, T. 098 N., R. 50 W.
Latitude: 43.1648 Longitude: 96.4713
Land Owner:
Project: GLACIAL TILL RESEARCH
Drilling Company: SDGS

Driller: K. WUNDER
Geologist: T. COWMAN
Date Drilled: 05-20-1986
Ground Surface Elevation: 1306.00 T
Total Drill Hole Depth: 45
Water Rights Well:
Other Well Name: GT-LN-2N
Basin: VERMILLION
Management Unit:
Screen Type:
Casing Type: PVC, SCH. 80
Casing Top Elevation:
Casing Stick-up: 1.90
Well Maintenance Date:
USGS Hydrological Unit Code: 10170102
Electric Log Information:
Spontaneous Potential:
Natural Gamma:
Samples:

Driller's Log: X
Geologist's Log:
Drilling Method: AUGER

Test Hole Number: A1-86-15
SDGS Well Name: A1-86-15

Aquifer:

Screen Length:
Casing Diameter: 2.0

Total Casing and Screen: 46.9

Single Point Resistivity:
Extra:

A 1 foot length of 1 1/2-inch shelby tube core was removed from the bottom of the well. This acts as a natural intake.

0	-	3	Clay, black, silty, sandy; organic, oxidized, moist (topsoil)
3	-	7	Clay, tan-brown, silty, sandy, pebbly; oxidized, moist (till)
7	-	9	Clay, tan-brown, silty, very sandy; oxidized, saturated (till)
9	-	14	Clay, dark-brown, silty, sandy, pebbly; oxidized, very moist (till)
14	-	24	Clay, tan-brown, silty, very sandy, slightly pebbly; oxidized very moist (till)
24	-	45	Clay, brownish-gray, very silty, very sandy; unoxidized, very moist to saturated (till)

County: LINCOLN
Legal Location: SE SE SE NE sec. 30, T. 098 N., R. 50 W.
Latitude: 43.1648
Land Owner:
Project: GLACIAL TILL RESEARCH
Drilling Company: SDGS
Driller: K. WUNDER
Geologist: T. COWMAN
Date Drilled: 05-20-1986
Ground Surface Elevation: 1306.00 T
Total Drill Hole Depth: 55
Water Rights Well:
Other Well Name: GT-LN-2O
Basin: VERMILLION
Management Unit:
Screen Type:
Casing Type: PVC, SCH. 80
Casing Top Elevation:
Casing Stick-up: 2.40
Well Maintenance Date:
USGS Hydrological Unit Code: 10170102
Electric Log Information:
Spontaneous Potential:
Natural Gamma:

Location: 098N-50W-30ADDD 7

Longitude: 96.4713

Driller's Log: X
Geologist's Log:
Drilling Method: AUGER

Test Hole Number: A1-86-14
SDGS Well Name: A1-86-14

Aquifer:

Screen Length:
Casing Diameter: 2.0

Total Casing and Screen: 57.4

Single Point Resistivity:
Extra:

Samples:

A 1 foot length of 1 1/2-inch shelby tube core was removed from the bottom of the well. This acts as a natural intake.

0	-	3	Clay, blackish-brown, silty, sandy, pebbly; oxidized, moist (till)
3	-	16	Clay, tan-brown, silty, very sandy, pebbly; oxidized, moist (till)
16	-	19	Clay, tan-brown, very silty, sandy, slightly pebbly; oxidized, very moist (till)
19	-	25	Clay, tan-brown, very silty, very sandy; oxidized, saturated (till)
25	-	34	Clay, brownish-gray, silty, sandy, pebbly; unoxidized, very moist (till)
34	-	40	Clay, greenish-gray, silty, sandy, pebbly; unoxidized, very moist (till)
40	-	45	Clay, greenish-gray, very silty, very sandy; unoxidized, saturated
45	-	48	Clay, greenish-gray, silty, sandy, pebbly; unoxidized, very moist (till)
48	-	55	Clay, greenish-gray, very silty, slightly sandy; unoxidized, saturated (till)

County: LINCOLN
Location: 098N-50W-29DDCD 1
Legal Location: SE SW SE SE sec. 29, T. 098 N., R. 50 W.
Latitude: 43.1620
Longitude: 96.4610
Land Owner:
Project: GLACIAL TILL RESEARCH
Drilling Company: SDGS
Driller: M. YESKE
Driller's Log: X
Geologist: M. JARRETT
Geologist's Log:
Date Drilled: 12-11-1984
Drilling Method: AUGER
Ground Surface Elevation: 1318.16 I
Total Drill Hole Depth: 67
Test Hole Number: A1-84-295
Water Rights Well:
SDGS Well Name: A1-84-295
Other Well Name: GT-LN-3A
Basin: JAMES
Aquifer: TILL
Management Unit:
Screen Type:
Screen Length:
Casing Type: PVC
Casing Diameter: 2.0
Casing Top Elevation: 1320.22 I
Casing Stick-up: 2.06
Total Casing and Screen:
Well Maintenance Date:
USGS Hydrological Unit Code: 10170102
Electric Log Information:
Spontaneous Potential:
Single Point Resistivity:
Natural Gamma:
Extra:
Samples:

Well intake was constructed by taking a 12-inch long core at bottom of well using a 1.5-inch diameter shelby tube.

0	-	2	Topsoil, brown, silty, clayey
2	-	19	Clay, yellow-brown, pebbly, silty, slightly sandy; oxidized (till)
19	-	28	Clay, brown, silty, slightly sandy, slightly pebbly; oxidized (till)
28	-	67	Clay, gray, very silty, slightly sandy, slightly pebbly; unoxidized, core sample at bottom of hole was very silty (till)

County: LINCOLN
Location: 098N-50W-29DDCD 2
Legal Location: SE SW SE SE sec. 29, T. 098 N., R. 50 W.
Latitude: 43.1620
Longitude: 96.4610

Land Owner:
Project: GLACIAL TILL RESEARCH
Drilling Company: SDGS
Driller: M. JARRETT
Geologist: M. JARRETT
Date Drilled: 10-11-1984
Ground Surface Elevation: 1317.94 I
Total Drill Hole Depth: 48
Water Rights Well:
Other Well Name: GT-LN-3B
Basin: VERMILLION
Management Unit:
Screen Type:
Casing Type: PVC
Casing Top Elevation: 1320.17 I
Casing Stick-up: 2.23
Well Maintenance Date:
USGS Hydrological Unit Code: 10170102
Electric Log Information:
Spontaneous Potential:
Natural Gamma:
Samples:

Driller's Log:
Geologist's Log: X
Drilling Method: AUGER

Test Hole Number: A1-84-283
SDGS Well Name: A1-84-283

Aquifer: TILL

Screen Length:
Casing Diameter: 2.0

Total Casing and Screen:

Single Point Resistivity:
Extra:

Well intake was constructed by taking a 12-inch long core at bottom of well using a 1.5-inch diameter shelby tube.

0	-	2	Clay, whitish-yellow, pebbly (topsoil)
2	-	23	Clay, light-brown, silty, slightly pebbly, slightly sandy (till)
23	-	48	Clay, gray, silty, slightly pebbly, sandy (till)

County: LINCOLN
Legal Location: SE SW SE SE sec. 29, T. 098 N., R. 50 W.
Latitude: 43.1620
Land Owner:
Project: GLACIAL TILL RESEARCH
Drilling Company: SDGS
Driller: M. JARRETT
Geologist: M. JARRETT
Date Drilled: 10-11-1984
Ground Surface Elevation: 1317.79 I
Total Drill Hole Depth: 14
Water Rights Well:
Other Well Name: GT-LN-3C
Basin: VERMILLION
Management Unit:
Screen Type:
Casing Type: PVC
Casing Top Elevation: 1320.48 I
Casing Stick-up: 2.69
Well Maintenance Date:
USGS Hydrological Unit Code: 10170102
Electric Log Information:
Spontaneous Potential:
Natural Gamma:

Location: 098N-50W-29DDCD 3

Longitude: 96.4610

Driller's Log:
Geologist's Log: X
Drilling Method: AUGER

Test Hole Number: A1-84-284
SDGS Well Name: A1-84-284

Aquifer: TILL

Screen Length:
Casing Diameter: 2.0

Total Casing and Screen:

Single Point Resistivity:
Extra:

Samples:

Well intake was constructed by taking a 12-inch long core at bottom of well using a 1.5-inch diameter shelby tube.

0	-	2	Clay, whitish-yellow, pebbly (topsoil)
2	-	14	Clay, yellow-brown, silty, slightly sandy, slightly pebbly (till)

County: LINCOLN
Location: 098N-50W-29DDCD 4
Legal Location: SE SW SE SE sec. 29, T. 098 N., R. 50 W.
Latitude: 43.1620
Longitude: 96.4610
Land Owner:
Project: GLACIAL TILL RESEARCH
Drilling Company: SDGS
Driller: M. JARRETT
Driller's Log:
Geologist: M. JARRETT
Geologist's Log: X
Date Drilled: 10-11-1984
Drilling Method: AUGER
Ground Surface Elevation: 1317.75 I
Total Drill Hole Depth: 8
Test Hole Number: A1-84-285
Water Rights Well:
SDGS Well Name: A1-84-285
Other Well Name: GT-LN-3D
Basin: VERMILLION
Aquifer: TILL
Management Unit:
Screen Type:
Screen Length:
Casing Type: PVC
Casing Diameter: 2.0
Casing Top Elevation: 1319.04 I
Casing Stick-up: 1.29
Total Casing and Screen:
Well Maintenance Date:
USGS Hydrological Unit Code: 10170102
Electric Log Information:
Spontaneous Potential:
Single Point Resistivity:
Natural Gamma:
Extra:
Samples:

Well intake was constructed by taking a 12-inch long core at bottom of well using a 1.5-inch diameter shelby tube.

0	-	2	Clay, whitish-yellow, very silty, pebbly (topsoil)
2	-	8	Clay, yellow-brown, very silty, slightly sandy, slightly pebbly; oxidized (till)

County: LINCOLN
Location: 098N-50W-29DDCD 5
Legal Location: SE SW SE SE sec. 29, T. 098 N., R. 50 W.
Latitude: 43.1620
Longitude: 96.4610
Land Owner:
Project: GLACIAL TILL RESEARCH
Drilling Company: SDGS
Driller: M. JARRETT
Driller's Log:
Geologist: M. JARRETT
Geologist's Log: X
Date Drilled: 10-11-1984
Drilling Method: AUGER
Ground Surface Elevation: 1317.84 I
Total Drill Hole Depth: 28
Test Hole Number: A1-84-286
Water Rights Well:
SDGS Well Name: A1-84-286
Other Well Name: GT-LN-3E

Basin: VERMILLION
Management Unit:
Screen Type:
Casing Type: PVC
Casing Top Elevation: 1319.31 I
Casing Stick-up: 1.47
Well Maintenance Date:
USGS Hydrological Unit Code: 10170102
Electric Log Information:
Spontaneous Potential:
Natural Gamma:
Samples:

Aquifer: TILL
Screen Length:
Casing Diameter: 2.0
Total Casing and Screen:
Single Point Resistivity:
Extra:

Well intake was constructed by taking a 12-inch long core at bottom of well using a 1.5-inch diameter shelby tube.

0	-	2	Clay, whitish-yellow, pebbly; moist (topsoil)
2	-	18	Clay, yellow-brown to whitish-yellow, very silty, slightly sandy; few pebbles (till)
18	-	23	Clay, brown, sandy, very silty; few pebbles (till)
23	-	28	Clay, brownish-gray, sandy, silty; few pebbles; unoxidized (till)

County: LINCOLN
Legal Location: SE SW SE SE sec. 29, T. 098 N., R. 50 W.
Latitude: 43.1620
Land Owner:
Project: GLACIAL TILL RESEARCH
Drilling Company: SDGS
Driller: D. IVERSON
Geologist: S. CRAVENS/A. BARARI
Date Drilled: 10-18-1984
Ground Surface Elevation: 1318.04 I
Total Drill Hole Depth: 70
Water Rights Well:
Other Well Name: GT-LN-3F
Basin: VERMILLION
Management Unit:
Screen Type:
Casing Type: PVC
Casing Top Elevation: 1320.18 I
Casing Stick-up: 2.14
Well Maintenance Date:
USGS Hydrological Unit Code: 10170102
Electric Log Information:
Spontaneous Potential:
Natural Gamma:
Samples:

Location: 098N-50W-29DDCD 6
Longitude: 96.4610
Driller's Log: X
Geologist's Log:
Drilling Method: AUGER
Test Hole Number: R20-84-379
SDGS Well Name: R20-84-379
Aquifer: TILL
Screen Length:
Casing Diameter: 2.0
Total Casing and Screen:
Single Point Resistivity:
Extra:

0	-	1	Topsoil
1	-	26	Clay, yellow-brown, pebbly (till)
26	-	70	Clay, gray, pebbly (till)

APPENDIX B

Logs of drill holes used in figures 4, 5, and 7

LOCATION

The logs are listed by smallest township number, then the smallest range number, the smallest section number, and then by quarter section: NE = A; NW = B; SW = C; SE = D. A comparison of **LEGAL LOCATION** and **LOCATION** is as follows. A **LEGAL LOCATION** of NW¼SE¼NE¼SW¼ sec. 30, T. 99 N., R. 64 W. is the same as a **LOCATION** of 099N-64W-30CADB. In some **LOCATIONS**, the smallest quarter section may be followed by the number 1 or 2 which indicates that more than one log may exist for that particular location.

LATITUDE and LONGITUDE

The format is **DD.MMSS** where **D** is degrees, **M** is minutes, and **S** is seconds.

DRILLING COMPANY

SDGS is an abbreviation for South Dakota Geological Survey.

TOTAL DRILL HOLE DEPTH and SCREEN LENGTH

The numbers are presented in feet.

SCREEN TYPE and CASING TYPE

PVC – polyvinyl chloride; **MFG.** – manufactured; **SCH.** – abbreviation for schedule and refers to casing thickness; **HM.** – homemade.

CASING TOP ELEVATION and GROUND SURFACE ELEVATION

The numbers are presented in feet above mean sea level. **I** - the elevation was determined using a surveying instrument. **T** - the elevation was estimated from 7½-minute series topographic map.

CASING DIAMETER

The numbers are presented in inches.

County: LINCOLN
Location: 098N-50W-01BBBB
Legal Location: NW NW NW NW sec. 01, T. 098 N., R. 50 W.
Latitude: 43.2038
Longitude: 96.4225
Land Owner:
Project: SIOUX FALLS-BRANDON STUDY
Drilling Company: SDGS
Driller: E. KOGLIN/L. HELSETH
Driller's Log:
Geologist: D. ILES
Geologist's Log: X
Date Drilled: 07-16-1980
Drilling Method: ROTARY
Ground Surface Elevation: 1341.00 T
Total Drill Hole Depth: 537
Test Hole Number: SFB-174
Water Rights Well: LN-80J
SDGS Well Name:
Other Well Name:
Basin: BIG SIOUX
Aquifer: DAKOTA
Management Unit:
Screen Type: PVC, MFG.
Screen Length: 10.0
Casing Type: PVC
Casing Diameter: 2.0
Casing Top Elevation: 1344.53 I
Casing Stick-up:
Total Casing and Screen:
Well Maintenance Date:
USGS Hydrological Unit Code: 10170203
Electric Log Information:
Spontaneous Potential: X
Single Point Resistivity: X
Natural Gamma: X
Extra:
Samples:

Bottom of well at 527 feet. Two 5-foot sandpoints glued together.

0	-	10	Clay, tan, silty, very sandy; drills fast (till?)
10	-	21	Clay, tan, silty (till?)
21	-	41	Sand and gravel, fine sand to coarse gravel; with clay layers
41	-	51	Clay, white-tan, silty; calcareous, some sand (Niobrara Formation)
51	-	87	Clay, medium-brown, silty; calcareous (Niobrara Formation)
87	-	140	Clay, light-gray, silty (Carlile Shale)
140	-	205	Clay, light- to medium-gray, silty; hard layer at 156 feet (Carlile Shale)
205	-	280	Clay, medium-gray, silty, sandy (Carlile Shale)
280	-	314	Clay, medium-brown, silty; calcareous (Carlile Shale)
314	-	349	Clay, medium-brown; white flecks, grainy texture, very calcareous (Greenhorn Limestone)
349	-	370	Clay, light-gray, silty (Graneros Shale)
370	-	465	Sand, fine; interbedded with gray clay (Dakota Formation)
465	-	536	Sand, fine; hard layers at 477 feet and 525 feet, hard layer with pyrite at 535 feet (Dakota Formation)
536	-	537	Quartzite; hard, there was actually no penetration in this interval and no sample was obtained (Sioux Quartzite)

County: LINCOLN
Location: 098N-50W-14DDDD
Legal Location: SE SE SE SE sec. 14, T. 098 N., R. 50 W.
Latitude: 43.1803
Longitude: 96.4227
Land Owner:
Project: SIOUX FALLS-BRANDON STUDY
Drilling Company: SDGS
Driller: E. KOGLIN/M. KOFFLER
Driller's Log:
Geologist: D. ILES
Geologist's Log: X

Date Drilled: 08-08-1980
Drilling Method: ROTARY
Ground Surface Elevation: 1354.00 T
Total Drill Hole Depth: 495
Test Hole Number: SFB-183
USGS Hydrological Unit Code: 10170203
Electric Log Information:
Spontaneous Potential: X
Single Point Resistivity: X
Natural Gamma: X
Extra:
Samples:

0	-	12	Clay, tan, silty, sandy, pebbly (till)
12	-	29	Clay, medium-gray, silty, sandy, pebbly (till)
29	-	32	Sand, fine to medium
32	-	40	Clay, medium-gray, silty, sandy, pebbly (till)
40	-	49	Silt, gray; with very fine sand
49	-	68	Sand, medium
68	-	83	Clay, medium-gray, silty (till?)
83	-	117	Sand and gravel, fine sand to fine gravel
117	-	124	Clay, gray
124	-	127	Sand
127	-	130	Clay, gray
130	-	139	Sand
139	-	166	Clay, light-gray, very sandy; shaley (till)
166	-	167	Unknown; hard layer, many pink chips in cuttings, probably a quartzite boulder
167	-	170	Sand(?)
170	-	301	Clay, light- to dark-gray, silty (Carlile Shale)
301	-	350	Clay, medium-brown, silty; grainy texture, very calcareous (Greenhorn Limestone)
350	-	363	Clay, light-gray, silty (Graneros Shale)
363	-	374	Clay, light-gray; with fine quartz sand (Graneros Shale)
374	-	387	Sand, fine (Dakota Formation)
387	-	401	Clay, gray; with some sand layers (Dakota Formation)
401	-	411	Sand (Dakota Formation)
411	-	421	Sand, clayey (Dakota Formation)
421	-	428	Sand (Dakota Formation)
428	-	433	Clay, gray, sandy (Dakota Formation)
433	-	450	Sand (Dakota Formation)
450	-	459	Clay, gray; sand in the upper part (Dakota Formation)
459	-	461	Sand(?); very hard (Dakota Formation)
461	-	465	Sand (Dakota Formation)
465	-	470	Clay, dark-gray (Dakota Formation)
470	-	477	Clay, gray, sandy (Dakota Formation)
477	-	480	Sand (Dakota Formation)
480	-	485	Clay, dark-gray, sandy; with white clay mixed in
485	-	494	Quartzite(?); weathered(?)
494	-	495	Quartzite; hard, there was actually no penetration in this interval and no sample was obtained (Sioux Quartzite)

County: LINCOLN
Location: 098N-50W-16BCBB
Legal Location: NW NW SW NW sec. 16, T. 098 N., R. 50 W.
Latitude: 43.1844
Longitude: 96.4559
Land Owner:
Project: SIOUX FALLS-BRANDON STUDY
Drilling Company: SDGS
Driller: L. HELSETH/M. KOFFLER
Driller's Log:
Geologist: D. ILES
Geologist's Log: X

Date Drilled: 08-13-1980
Drilling Method: ROTARY
Ground Surface Elevation: 1343.00 T
Total Drill Hole Depth: 762
Test Hole Number: SFB-186
USGS Hydrological Unit Code: 10170102
Electric Log Information:
Spontaneous Potential: X
Single Point Resistivity: X
Natural Gamma: X
Extra:
Samples:

0	-	10	Clay, light-gray to brown, silty, sandy, pebbly (till)
10	-	25	Clay, yellowish-brown, silty, sandy, pebbly (till)
25	-	94	Clay, gray, silty, pebbly; rock at 86 feet (till)
94	-	129	Sand and gravel, medium sand to coarse gravel; with cobbles and much coal
129	-	150	Clay, gray; with light-gray chalk cuttings, calcareous (till?)
150	-	212	Clay, gray, silty, pebbly; noncalcareous (till)
212	-	378	Clay, gray; noncalcareous, hard layer from 288 to 292 feet (Carlile Shale)
378	-	416	Chalk(?), dark-gray to brown; with white flecks, also some pieces of white chalk or limestone in the samples (Greenhorn Limestone)
416	-	430	Clay, light- to dark-gray; slightly calcareous (Graneros Shale)
430	-	444	Sand, white, fine (Dakota Formation)
444	-	449	Clay, gray (Dakota Formation)
449	-	452	Sand (Dakota Formation)
452	-	456	Clay, gray (Dakota Formation)
456	-	472	Sand (Dakota Formation)
472	-	486	Clay, gray; interbedded with sand (Dakota Formation)
486	-	511	Sand (Dakota Formation)
511	-	538	Sand; with some clay (Dakota Formation)
538	-	546	Sand (Dakota Formation)
546	-	615	Clay, gray; interbedded with some sand (Dakota Formation)
615	-	620	Sand (Dakota Formation)
620	-	634	Clay, gray; interbedded with some sand (Dakota Formation)
634	-	639	Sand (Dakota Formation)
639	-	647	Clay, gray (Dakota Formation)
647	-	654	Sand (Dakota Formation)
654	-	658	Clay, gray (Dakota Formation)
658	-	752	Sand (Dakota Formation)
752	-	761	Clay, white, sandy; hard, weathered quartzite(?) (Sioux Quartzite)
761	-	762	Quartzite; hard, there was actually no penetration in this interval and no sample was obtained (Sioux Quartzite)

County: LINCOLN
Location: 098N-50W-16CCCC
Legal Location: SW SW SW SW sec. 16, T. 098 N., R. 50 W.
Latitude: 43.1806
Longitude: 96.4558
Land Owner:
Project: WATER RIGHTS
Drilling Company: HURON DRILLING
Driller: S. KUEHL
Driller's Log: X
Geologist:
Geologist's Log:
Date Drilled: 06-16-1977
Drilling Method: ROTARY
Ground Surface Elevation: 1327.00 T
Total Drill Hole Depth: 615
Test Hole Number:
Water Rights Well: LN-77A
SDGS Well Name:
Other Well Name:
Basin: VERMILLION
Aquifer: DAKOTA

Management Unit:
Screen Type:
Casing Type: STEEL
Casing Top Elevation: 1330.64 I
Casing Stick-up:
Well Maintenance Date:
USGS Hydrological Unit Code: 10170102
Electric Log Information:
Spontaneous Potential:
Natural Gamma: X
Samples:

Screen Length:
Casing Diameter: 2.0

Total Casing and Screen: 609.0

Single Point Resistivity:
Extra:

This lithologic log differs from the original driller's log and reflects a reinterpretation of the gamma geophysical log by D. Iles, 1981. Worthing Quadrangle.

0	-	24	Clay, yellow (till)
24	-	70	Clay, blue (till)
70	-	80	Sand, fine
80	-	108	Sand, coarse
108	-	120	Chalk (Niobrara Formation)
120	-	355	Shale (Carlile Shale)
355	-	417	Limestone, shaley
417	-	455	Shale (Graneros Shale)
455	-	485	Sand; hard (Dakota Formation)
485	-	495	Sand; fair (Dakota Formation)
495	-	515	Shale; interbedded with sand (Dakota Formation)
515	-	535	Shale (Dakota Formation)
535	-	560	Shale; sand streak at 550 feet (Dakota Formation)
560	-	615	Sand; fair (Dakota Formation?)

County: LINCOLN
Legal Location: SE SE SE NE sec. 20, T. 098 N., R. 50 W.
Latitude: 43.1741
Land Owner:
Project: WATER RIGHTS
Drilling Company: HURON DRILLING
Driller:
Geologist:
Date Drilled: 02-27-1979
Ground Surface Elevation: 1312.09 I
Total Drill Hole Depth: 641
Water Rights Well: LN-79B
Other Well Name:
Basin: VERMILLION
Management Unit:
Screen Type:
Casing Type: PVC
Casing Top Elevation: 1315.69 I
Casing Stick-up: 3.60
Well Maintenance Date: 10-06-1981
USGS Hydrological Unit Code: 10170102
Electric Log Information:
Spontaneous Potential:
Natural Gamma: X

Location: 098N-50W-20ADDD

Longitude: 96.4602

Driller's Log: X
Geologist's Log:
Drilling Method: ROTARY

Test Hole Number:
SDGS Well Name:

Aquifer: DAKOTA

Screen Length:
Casing Diameter: 2.0

Total Casing and Screen: 612.0

Single Point Resistivity: X
Extra:

Samples:

This log differs from the original driller's log and reflects a reinterpretation by D. Iles using the geophysical log. Worthing Quadrangle.

0	-	3	Topsoil
3	-	24	Clay, yellow
24	-	120	Clay, blue
120	-	156	Sand and gravel
156	-	328	Clay (Carlile Shale)
328	-	360	Limestone, shaley (Greenhorn Limestone)
360	-	374	Clay (Graneros Shale)
374	-	394	Sand (Dakota Formation)
394	-	496	Sand, clayey; interbedded with clay and sand layers (Dakota Formation)
496	-	555	Sand; hard from 517 to 523 feet (Dakota Formation)
555	-	640	Sand, clayey; interbedded with clay (Dakota Formation)
640	-	641	Quartzite; hard, no sample was obtained and penetration was only a few inches (Sioux Quartzite)

County: LINCOLN
Location: 098N-50W-32AAAA 1
Legal Location: NE NE NE NE sec. 32, T. 098 N., R. 50 W.
Latitude: 43.1618
Longitude: 96.4602
Land Owner:
Project: SOUTH LINCOLN RURAL WATER
Drilling Company: HURON DRILLING
Driller: S. KUEHL
Driller's Log:
Geologist:
Geologist's Log:
Date Drilled: 06-17-1977
Drilling Method: ROTARY
Ground Surface Elevation: 1315.00 T
Total Drill Hole Depth: 635
Test Hole Number:
Water Rights Well: LN-77B
SDGS Well Name:
Other Well Name:
Basin: VERMILLION
Aquifer: DAKOTA
Management Unit:
Screen Type:
Screen Length:
Casing Type: PVC
Casing Diameter: 2.0
Casing Top Elevation: 1319.20
Casing Stick-up: 1.60
Total Casing and Screen: 599.0
Well Maintenance Date: 07-20-1983
USGS Hydrological Unit Code: 10170102
Electric Log Information:
Spontaneous Potential:
Single Point Resistivity: X
Natural Gamma: X
Extra:
Samples:

Worthing Quadrangle.

0	-	3	Topsoil
3	-	18	Clay, yellow
18	-	35	Clay, blue
35	-	50	Clay, blue; with sand streaks
50	-	63	Clay, blue
63	-	72	Chalk
72	-	351	Shale

351	-	627	Sandstone; with shale layers and silt (Dakota Formation)
627	-	635	Quartzite

County: LINCOLN
Location: 098N-50W-32AAAA 2
Legal Location: NE NE NE NE sec. 32, T. 098 N., R. 50 W.
Latitude: 43.1618
Longitude: 96.4602
Land Owner:
Project: WATER RIGHTS
Drilling Company: HURON DRILLING
Driller: L. PETERSON
Driller's Log:
Geologist: J. GOODMAN
Geologist's Log: X
Date Drilled: 08-06-1979
Drilling Method: ROTARY
Ground Surface Elevation: 1317.00 T
Total Drill Hole Depth: 383
Test Hole Number:
Water Rights Well: LN-79H
SDGS Well Name:
Other Well Name: LN-79-9
Basin: VERMILLION
Aquifer: DAKOTA
Management Unit:
Screen Type: PVC, MFG.
Screen Length: 20.0
Casing Type: PVC
Casing Diameter: 6.0
Casing Top Elevation: 1318.68 I
Casing Stick-up:
Total Casing and Screen: 382.0
Well Maintenance Date: 08-09-1979
USGS Hydrological Unit Code: 10170102
Electric Log Information:
Spontaneous Potential:
Single Point Resistivity: X
Natural Gamma: X
Extra:
Samples:

Continuous recorder installed. Worthing Quadrangle.

0	-	25	Clay, yellow-brown, silty, pebbly (till)
25	-	68	Clay, gray; gravelly till from 50 feet; numerous chalk pebbles (till)
68	-	82	Clay, gray-white; effervesces (Niobrara Formation)
82	-	310	Clay, gray; greasy, good shale cuttings; also sandstone layer at 162 feet (Carlile Shale)
310	-	349	Limestone, gray and white chips; oil stain on drilling mud (Greenhorn Limestone)
349	-	365	Clay, gray-black; brittle, good shale cutting (Graneros Shale)
365	-	383	Sandstone, fine to medium; drilling speed indicates good open sand; hard zones (Dakota Formation)

County: LINCOLN
Location: 098N-50W-32DDDD 1
Legal Location: SE SE SE SE sec. 32, T. 098 N., R. 50 W.
Latitude: 43.1528
Longitude: 96.4602
Land Owner:
Project:
Drilling Company: SDGS
Driller: L. HELSETH
Driller's Log:
Geologist: D. ILES
Geologist's Log: X
Date Drilled: 11-07-1977
Drilling Method: ROTARY
Ground Surface Elevation: 1327.17 I
Total Drill Hole Depth: 651
Test Hole Number: LN-#2
Water Rights Well: LN-77C
SDGS Well Name:
Other Well Name:

Basin: VERMILLION
Aquifer: DAKOTA
Management Unit:
Screen Type: PVC, MFG. AND HM.
Screen Length: 24.0
Casing Type: PVC, SCH. 80
Casing Diameter: 2.0
Casing Top Elevation: 1329.27 I
Casing Stick-up: 2.10
Total Casing and Screen: 654.0
Well Maintenance Date:
07-20-1983
USGS Hydrological Unit Code: 10170102
Electric Log Information:
Spontaneous Potential: X
Single Point Resistivity: X
Natural Gamma: X
Extra:
Samples:

The screen consists of a 4-foot sandpoint and 20 feet of slotted casing above sandpoint.
Worthing Quadrangle.

0	-	2	Topsoil, black
2	-	23	Clay, yellow-brown (till)
23	-	37	Clay, gray, silty, pebbly (till)
37	-	59	Clay, light-gray; and white marl
59	-	66	Sand and gravel, medium to coarse
66	-	75	Clay, light-gray; and white marl
75	-	105	Clay, gray (Niobrara Formation)
105	-	140	Clay, dark-gray (Carlile Shale)
140	-	315	Clay, gray; softer than interval from 105 to 140 feet, sandy in spots? (Carlile Shale)
315	-	323	Clay, brown; fairly hard, very calcareous (Greenhorn Limestone)
323	-	358	Limestone; cemented, very hard (Greenhorn Limestone)
358	-	400	Clay, gray, silty; slightly calcareous, hard spot at 380 feet (Graneros Shale)
400	-	513	Sand, white, fine, clayey; some clay layers (Dakota Formation)
513	-	555	Sand, fine (Dakota Formation)
555	-	562	Clay (Dakota Formation)
562	-	608	Sand, fine (Dakota Formation)
608	-	621	Clay (Dakota Formation)
621	-	632	Sand, fine (Dakota Formation)
632	-	637	Sand, fine; some white gritty clay, harder than interval from 621 to 632 feet (Dakota Formation)
637	-	650	Sand; hard, weathered quartzite? (Dakota Formation?)
650	-	651	Quartzite; hard, no cuttings were obtained (Sioux Quartzite)

County: LINCOLN
Location: 098N-51W-14DDDD 1
Legal Location: SE SE SE SE sec. 14, T. 098 N., R. 51 W.
Latitude: 43.1806
Longitude: 96.4933
Land Owner:
Project: SIOUX FALLS-BRANDON STUDY
Drilling Company: SDGS
Driller: E. KOGLIN/M. KOFFLER
Driller's Log:
Geologist: D. ILES
Geologist's Log: X
Date Drilled: 07-31-1980
Drilling Method: ROTARY
Ground Surface Elevation: 1305.00 T
Total Drill Hole Depth: 631
Test Hole Number: SFB-180
USGS Hydrological Unit Code: 10170102
Electric Log Information:
Spontaneous Potential: X
Single Point Resistivity: X
Natural Gamma: X
Extra:

Samples:

0	-	16	Clay, tan, silty, sandy, pebbly (till)
16	-	20	Sand, fine to medium
20	-	22	Clay, tan, silty, sandy, pebbly (till)
22	-	73	Clay, medium-gray, silty, sandy, pebbly (till)
73	-	107	Clay, tan-green, silty, pebbly; calcareous, drills slower than interval from 22 to 73 feet (till)
107	-	223	Sand and gravel, fine sand to coarse, gravel; with some clay and some clay layers
223	-	342	Clay, gray; some sand (Carlile Shale)
342	-	389	Clay, medium-brown, silty; calcareous, harder than interval from 223 to 342 feet (Greenhorn Limestone)
389	-	397	Clay, gray (Graneros Shale)
397	-	423	Sand; interbedded with gray clay (Dakota Formation)
423	-	442	Sand; some clay (Dakota Formation)
442	-	446	Coal(?), black; soft (Dakota Formation)
446	-	462	Sand (Dakota Formation)
462	-	468	Clay, gray (Dakota Formation)
468	-	487	Sand (Dakota Formation)
487	-	509	Clay, gray; decreasing in sand content towards the bottom of the interval (Dakota Formation)
509	-	514	Sand (Dakota Formation)
514	-	517	Clay, gray (Dakota Formation)
517	-	525	Sand (Dakota Formation)
525	-	598	Clay, gray; sandy in spots (Dakota Formation)
598	-	630	Sand, fine to coarse; with white clay
630	-	631	Quartzite; hard, there was actually no penetration in this interval and no sample was obtained (Sioux Quartzite)

County: LINCOLN
Location: 099N-50W-02AABA 1
Legal Location: NE NW NE NE sec. 02, T. 099 N., R. 50 W.
Latitude: 43.2553
Longitude: 96.4237
Land Owner:
Project: SIOUX FALLS-BRANDON STUDY
Drilling Company: SDGS
Driller: C. BRONICK
Driller's Log:
Geologist: D. ILES
Geologist's Log: X
Date Drilled: 09-25-1979
Drilling Method: ROTARY
Ground Surface Elevation: 1418.00 T
Total Drill Hole Depth: 352
Test Hole Number: SFB-121
Water Rights Well: LN-79I
SDGS Well Name:
Other Well Name:
Basin: BIG SIOUX
Aquifer: DAKOTA
Management Unit:
Screen Type: PVC, MFG.
Screen Length: 10.0
Casing Type: PVC
Casing Diameter: 2.0
Casing Top Elevation: 1418.90 I
Casing Stick-up:
Total Casing and Screen:
Well Maintenance Date:
USGS Hydrological Unit Code: 10170203
Electric Log Information:
Spontaneous Potential: X
Single Point Resistivity: X
Natural Gamma:
Extra:
Samples:

Bottom of well at approximately 349 feet. Two 5-foot sandpoints glued together.

0	-	2	Topsoil
2	-	14	Clay, tan, silty, sandy (till)
14	-	18	Clay, brown-gray, silty, sandy (till)
18	-	28	Clay, red-brown, silty (till)
28	-	30	Clay, brown-tan, silty, sandy, gravelly; hard layer at 28 feet (till)
30	-	52	Clay, gray, silty (till)
52	-	74	Sand, medium to coarse; with gravel that coarsens downward
74	-	104	Sand and gravel, medium sand to medium gravel, slightly clayey
104	-	154	Clay, gray, silty (till)
154	-	162	Gravel, medium to coarse; with some coal
162	-	265	Clay, gray (Carlile Shale)
265	-	281	Limestone; with shale (Greenhorn Limestone)
281	-	309	Clay, gray; with some hard spots (Graneros Shale)
309	-	351	Sand, fine to medium; with some shale, much coal from 345 to 351 feet (Dakota Formation)
351	-	352	Quartzite; hard, there was actually no penetration in this interval and no sample was obtained (Sioux Quartzite)

County: LINCOLN
Location: 099N-50W-02AABA 2
Legal Location: NE NW NE NE sec. 02, T. 099 N., R. 50 W.
Latitude: 43.2553
Longitude: 96.4237
Land Owner:
Project: SE SO. DAK. UNIT STUDY
Drilling Company: SDGS
Driller: L. HELSETH
Driller's Log:
Geologist: D. ILES
Geologist's Log: X
Date Drilled: 10-22-1981
Drilling Method: ROTARY
Ground Surface Elevation: 1420.00 T
Total Drill Hole Depth: 85
Test Hole Number:
Water Rights Well:
SDGS Well Name: SESD-20
Other Well Name:
Basin: BIG SIOUX
Aquifer: HARRISBURG
Management Unit:
Screen Type: PVC, MFG.
Screen Length: 5.0
Casing Type: PVC
Casing Diameter: 2.0
Casing Top Elevation: 1420.42
Casing Stick-up:
Total Casing and Screen:
Well Maintenance Date:
USGS Hydrological Unit Code: 10170203
Electric Log Information:
Spontaneous Potential:
Single Point Resistivity:
Natural Gamma:
Extra:
Samples:

Bottom of well at 85 feet.

0	-	6	Clay, yellowish-brown, silty, sandy, pebbly (till)
6	-	19	Clay, brownish-gray, silty, sandy, pebbly (till)
19	-	36	Clay, brown, silty, sandy, pebbly (till)
36	-	54	Clay, gray, silty, sandy, pebbly (till)
54	-	85	Sand, medium to coarse

County: LINCOLN
Location: 099N-50W-24BBBB 1
Legal Location: NW NW NW NW sec. 24, T. 099 N., R. 50 W.
Latitude: 43.2317
Longitude: 96.4225
Land Owner:
Project: SIOUX FALLS-BRANDON STUDY
Drilling Company: SDGS
Driller: E. KOGLIN/M. KOFFLER
Driller's Log:
Geologist: D. ILES
Geologist's Log: X
Date Drilled: 06-30-1980
Drilling Method: ROTARY
Ground Surface Elevation: 1406.00 T
Total Drill Hole Depth: 698
Test Hole Number: SFB-165
USGS Hydrological Unit Code: 10170203
Electric Log Information:
Spontaneous Potential: X
Single Point Resistivity: X
Natural Gamma:
Extra:
Samples:

0	-	13	Clay, tan, silty, sandy, pebbly; with some pieces of white clay (till)
13	-	17	Clay, gray-brown, silty, sandy, pebbly; very shaley (till)
17	-	69	Clay, medium-gray, silty, sandy, pebbly (till)
69	-	100	Sand, fine to medium
100	-	108	Sand, fine to medium, clayey
108	-	117	Clay, medium-gray, silty, sandy, pebbly (till)
117	-	123	Sand, fine to medium
123	-	126	Clay, dark-gray, very silty (till)
126	-	133	Gravel, coarse
133	-	151	Clay, light- to medium-gray, silty, sandy (till)
151	-	175	Clay, dark-gray; very calcareous (Niobrara Formation)
175	-	195	Clay, dark-gray; noncalcareous (Carlile Shale)
195	-	402	Clay, gray; noncalcareous, very sticky, some light-gray marl cuttings in the samples (Carlile Shale)
402	-	432	Clay, dark-gray to light-gray to gray-brown; very calcareous to slightly calcareous, hard (Greenhorn Limestone)
432	-	453	Clay, light- to dark-gray; easy drilling with occasional hard spots (Graneros Shale)
453	-	470	Sand (Dakota Formation)
470	-	476	Clay, gray (Dakota Formation)
476	-	490	Sand, clayey (Dakota Formation)
490	-	495	Clay, gray (Dakota Formation)
495	-	520	Sand; slightly cemented (Dakota Formation)
520	-	525	Clay, gray (Dakota Formation)
525	-	536	Sand; slightly cemented, hard layer at 536 feet (Dakota Formation)
536	-	548	Sand, clayey (Dakota Formation)
548	-	562	Clay, gray; hard, slightly calcareous (Dakota Formation)
562	-	589	Clay, gray, sandy; hard, noncalcareous (Dakota Formation)
589	-	600	Sand, clayey; drilled slightly faster than interval from 562 to 589 feet (Dakota Formation)
600	-	638	Sand; cemented, some clay (Dakota Formation)
638	-	651	Clay, gray; very hard (Dakota Formation)
651	-	697	Sand; cemented, interbedded with gray clay (Dakota Formation)
697	-	698	Quartzite; hard, there was actually no penetration in this interval and no sample was obtained (Sioux Quartzite)

County: LINCOLN
Location: 100N-50W-23AAAA
Legal Location: NE NE NE NE sec. 23, T. 100 N., R. 50 W.

Latitude: 43.2829 Longitude: 96.4227
Land Owner:
Project: SIOUX FALLS-BRANDON STUDY
Drilling Company: SDGS
Driller: C. BRONICK Driller's Log:
Geologist: D. ILES Geologist's Log: X
Date Drilled: 08-07-1979 Drilling Method: ROTARY
Ground Surface Elevation: 1463.00 T
Total Drill Hole Depth: 143 Test Hole Number: SFB-113
USGS Hydrological Unit Code: 10170203
Electric Log Information:
Spontaneous Potential: X Single Point Resistivity: X
Natural Gamma: Extra:
Samples:

0	-	31	Clay, light-brown-tan, silty, sandy, gravelly (till)
31	-	42	Clay, medium-gray, silty, sandy (till)
42	-	72	Clay, darker gray than interval from 31 to 42 feet, silty, sandy (till)
72	-	79	Sand and gravel, fine sand to medium gravel
79	-	95	Clay, medium-gray to dark-gray, silty, sandy (till)
95	-	129	Clay, light-gray, very sandy, silty, gravelly; calcareous (till)
129	-	135	Clay, tan, silty, sandy; calcareous (till)
135	-	137	Clay, medium-gray to dark-gray, silty, sandy; calcareous (till)
137	-	142	Clay, yellow-brown, silty, sandy; calcareous (till)
142	-	143	Quartzite, pink; hard, there was actually only a few inches of penetration achieved (Sioux Quartzite)

County: LINCOLN Location: 100N-50W-26DDDD
Legal Location: SE SE SE SE sec. 26, T. 100 N., R. 50 W.
Latitude: 43.2646 Longitude: 96.4231
Land Owner:
Project: SE SO. DAK. UNIT STUDY
Drilling Company: SDGS
Driller: L. HELSETH Driller's Log:
Geologist: D. ILES Geologist's Log: X
Date Drilled: 10-21-1981 Drilling Method: ROTARY
Ground Surface Elevation: 1448.00 T
Total Drill Hole Depth: 187 Test Hole Number: SESD-19
USGS Hydrological Unit Code: 10170203
Electric Log Information:
Spontaneous Potential: Single Point Resistivity: X
Natural Gamma: X Extra:
Samples:

0	-	24	Clay, yellow, silty, pebbly (till)
24	-	66	Clay, gray, silty, pebbly; rock at 63 feet (till)
66	-	83	Sand and gravel, medium to coarse sand and medium gravel
83	-	116	Silt, gray, clayey
116	-	151	Silt, yellow, clayey, pebbly
151	-	158	Silt, gray, clayey, pebbly
158	-	174	Clay, yellow, silty, pebbly
174	-	186	Sand, fine to medium; rock at 181 feet
186	-	187	Quartzite, pink; hard, there was actually only a few inches of penetration in this interval (Sioux Quartzite)

APPENDIX C

Soil property data for two till samples

(Core samples were taken from a drill hole adjacent to piezometers at site 1)

(All data in this appendix are from the
U.S. Bureau of Reclamation, Soil Mechanics Section, Denver, Colorado)

Description of soil trimmings from core samples of the till:

Sample 62Q-1: (weathered till from 5 to 7.5 feet) Grayish orange; poorly consolidated; structureless; chiefly silt- and clay-sized with minor amounts of sand-sized material and a few, subangular to subrounded, granitic rock fragments to about 3/4 inch in diameter; slightly ferruginous; moderately to highly effervescent in dilute hydrochloric acid; few small charcoal fragments; moderately to highly water absorptive; unctuous to plastic and sticky when wet

Sample 62Q-2: (unweathered till from 25 to 27.5 feet) Light gray; poorly consolidated; structureless; chiefly silt- and clay-sized with minor amounts of sand-sized material and a few, subangular to subrounded, granitic rock fragments to about 3/8 inch in diameter; moderately to highly effervescent in dilute hydrochloric acid; few small charcoal fragments; moderately to highly water absorptive; unctuous to plastic and sticky when wet

	Sample Number	
Soil Property	62Q-1	62Q-2
Liquid limit	45	42
Plastic limit	21	20
Plasticity index	24	22
Specific gravity	2.63	2.63
Free swell expansion value	50	55

APPENDIX D

Water level data from site 1

Depth to water (ft)*

Date	Piezometer Name								
	GT-LN-1A	GT-LN-1B	GT-LN-1C	GT-LN-1D	GT-LN-1E	GT-LN-1F	GT-LN-1G	GT-LN-1H	Open hole
10-22-84	flow	flow	47.94	27.00	28.00	16.33	4.88	4.83	3.20
11-14-84	flow	flow	47.17	25.13	27.87	14.76	4.87	4.88	3.20
11-19-84	--	--	47.00	24.76	27.85	14.45	5.08	5.00	3.30
12-13-84	ice	ice	46.24	23.00	27.72	13.15	5.33	5.30	3.60
01-28-85	ice	ice	44.83	19.87	26.97	11.41	5.98	6.02	--
02-08-85	ice	ice	44.18	19.19	26.70	11.09	6.23	6.28	--
02-22-85	--	--	43.72	18.33	26.40	10.72	5.94	6.10	--
03-25-85	flow	0.41	42.14	16.55	25.66	9.60	3.16	3.18	--
04-03-85	flow	0.35	41.76	16.06	25.48	9.28	3.15	3.09	--
04-18-85	flow	1.20	41.05	15.22	25.14	8.73	4.13	4.08	2.25
04-23-85	flow	0.17	40.84	14.96	25.04	8.58	1.85	1.74	0.00
05-22-85	flow	0.84	39.58	13.54	24.42	7.68	3.59	3.43	1.63
06-21-85	flow	1.61	38.31	12.33	23.82	7.05	4.91	4.79	--
06-26-85	flow	0.82	38.13	12.17	23.72	6.99	3.75	4.27	1.80
06-28-85	flow	flow	38.05	12.09	23.68	6.95	2.71	2.62	0.78
07-04-85	flow	flow	37.83	11.90	23.60	6.86	4.06	4.01	2.05
07-08-85	flow	0.60	37.65	11.74	23.49	6.78	4.74	4.64	2.70
07-31-85	flow	1.27	36.73	11.06	23.06	6.60	5.60	5.58	--
08-13-85	flow	0.86	36.24	10.72	22.82	6.54	4.11	4.13	2.14
09-04-85	flow	flow	35.39	10.01	22.42	6.13	3.31	3.22	1.40
09-11-85	flow	flow	35.16	9.90	22.32	6.01	2.99	2.90	1.01
10-18-85	flow	flow	33.70	8.80	21.58	5.22	2.33	2.24	0.30
11-06-85	flow	flow	32.97	8.27	21.20	4.90	2.85	2.80	0.90
11-20-85	flow	flow	32.54	7.98	21.00	4.77	2.35	2.30	--
01-07-86	ice	ice	30.65	6.80	20.06	4.28	3.53	--	--
02-02-86	ice	ice	28.60	5.73	19.04	3.94	2.99	2.92	--
03-21-86	ice	ice	27.30	5.35	18.77	3.85	2.14	1.90	0.30
04-09-86	flow	flow	25.57	5.02	18.48	3.68	2.33	2.08	0.40
04-16-86	flow	flow	24.98	4.95	18.39	3.67	2.18	1.94	0.20
05-15-86	flow	flow	22.02	4.65	17.97	3.56	2.86	2.62	0.91
05-19-86	flow	flow	21.58	4.72	17.92	3.55	2.74	2.38	0.70

* Depth to water in piezometers was measured from casing top.
Depth to water in open hole was measured from ground surface.
--: no measurement taken
flow: water was flowing over casing top
ice: water in casing was frozen

APPENDIX E

Water level data from site 2

Depth to water (ft)*

Date	Piezometer Name						
	GT-LN-2A	GT-LN-2B	GT-LN-2C	GT-LN-2D	GT-LN-2E	GT-LN-2F	Open hole
10-22-84	14.80	25.77	44.77	6.50	63.95	6.05	4.70
11-14-84	13.28	24.05	42.87	6.25	61.43	5.97	4.70
11-19-84	13.00	23.70	42.45	6.30	60.68	6.06	4.80
12-13-84	11.86	22.12	40.62	6.48	58.43	6.24	--
01-28-85	10.33	19.46	37.38	7.02	49.32	6.75	--
02-08-85	10.09	18.89	36.63	7.21	46.09	6.97	--
02-22-85	9.83	18.26	35.65	7.14	29.60	6.88	--
03-25-85	9.16	16.88	33.61	6.19	14.64	5.92	--
04-03-85	9.02	16.55	33.08	6.22	12.81	5.87	--
04-18-85	6.89	15.95	32.12	5.70	10.52	5.41	4.10
04-23-85	8.58	15.75	31.84	3.08	9.88	2.95	1.60
05-22-85	7.73	14.69	30.10	3.84	6.04	3.51	2.20
06-21-85	7.05	13.66	28.45	4.87	5.03	4.57	3.40
06-26-85	6.98	13.49	28.18	4.52	5.03	4.36	3.05
06-28-85	6.94	13.44	28.08	3.30	4.95	3.17	2.05
07-04-85	6.84	13.38	27.78	4.12	4.89	3.78	2.55
07-31-85	6.53	12.45	26.41	5.98	5.23	5.64	4.45
08-13-85	6.47	12.15	25.86	6.04	5.59	5.74	4.45
09-04-85	6.30	11.62	24.80	5.52	5.62	5.25	4.00
09-11-85	6.24	11.49	24.54	4.65	5.49	4.42	3.12
10-18-85	5.53	10.50	22.90	3.09	3.98	2.80	1.35
11-06-85	5.22	10.00	22.10	3.66	3.75	3.33	2.20
11-20-85	5.11	9.73	21.61	3.18	3.72	2.87	--
01-07-86	11.28	16.23	30.33	4.60	6.81	--	--
02-26-86	9.23	13.90	13.20	5.10	5.35	4.70	--
03-21-86	8.65	13.18	6.29	3.05	5.00	2.95	1.90
04-09-86	7.95	12.49	3.57	2.10	4.03	1.80	0.50
04-16-86	7.75	12.27	3.07	1.65	3.74	1.31	0.00
05-15-86	6.82	11.31	2.40	2.98	3.02	2.53	1.18
05-19-86	6.79	11.18	2.67	2.94	3.11	2.57	--

* Depth to water in piezometers was measured from casing top.
Depth to water in open hole was measured from ground surface.
--: no measurement taken

APPENDIX F

Water level data from site 3

Depth to water (ft)*

Date	Piezometer Name					
	GT-LN-3A	GT-LN-3B	GT-LN-3C	GT-LN-3D	GT-LN-3E	GT-LN-3F
10-22-84	--	46.35	10.68	7.81	27.08	40.72
11-14-84	--	39.00	8.77	7.45	20.37	6.85
11-19-84	--	37.72	8.71	7.46	19.21	6.08
12-13-84	58.02	32.42	8.65	7.55	15.00	5.52
01-28-85	7.90	22.18	9.02	7.96	10.64	6.56
02-08-85	8.00	20.53	9.22	8.18	10.09	6.73
02-22-85	8.40	18.62	9.52	8.52	9.63	6.95
03-25-85	8.14	15.75	9.10	7.72	8.88	7.32
04-03-85	8.00	15.10	8.86	7.52	8.70	7.34
04-18-85	7.76	13.97	7.91	6.30	8.26	7.43
04-23-85	7.46	13.47	7.34	4.80	8.07	7.42
05-22-85	6.84	9.85	4.32	3.24	6.20	6.75
06-21-85	5.88	8.31	5.55	4.68	5.22	5.81
06-26-85	5.63	8.15	5.83	4.79	5.17	5.66
07-04-85	5.45	7.84	4.98	3.65	4.99	5.37
07-31-85	5.72	7.29	6.77	5.93	5.02	4.92
08-13-85	6.05	7.22	7.43	6.32	5.35	4.94
09-04-85	5.90	7.05	7.06	5.85	5.57	5.00
09-11-85	5.11	5.60	5.31	6.70	6.97	5.81
10-18-85	5.15	5.96	4.48	3.19	4.71	5.26
11-06-85	5.30	5.63	4.83	3.78	4.31	5.28
11-20-85	5.30	5.53	4.95	3.65	4.21	5.38
03-21-86	3.97	4.52	4.00	1.88	4.55	6.10
04-09-86	2.90	3.47	3.50	1.92	3.84	5.67
04-16-86	2.88	3.36	3.15	1.36	3.70	5.51
05-15-86	3.56	3.40	4.13	3.17	3.20	4.18
05-19-86	3.96	3.23	3.12	4.28	3.46	3.71

* Depth to water in piezometers was measured from casing top.
--: no measurement taken

APPENDIX G. Water quality analyses from till and outwash

Hydrologic unit	Sample ID	Piezometer or well: Name	Piezometer or well: Depth (ft)[3]	Date sampled	Conductivity (umhos)[4]	Concentration in milligrams per liter[1]: DS	Na	Ca	Mg	K	SO_4	Cl	F	NO_3-N + NO_2-N	Fe	Mn	$CaCO_3$	Alk-T	HCO_3	Concentration in micrograms per liter[2]: Se	As
Weathered till	GTR-86-110	LN-1K	11	08-25-86	3160	2900	148	404	226	8.0	1900	8	0.28	0.68	<0.05	0.10	1940	460	561	5.6	≤0.3
	GTR-86-111	LN-1L	13	08-25-86	3200	2910	180	427	159	11	1810	7	0.44	0.08	≤0.05	0.09	1720	384	468	≤0.2	0.3
	GTR-86-112	LN-1M	16	08-25-86	2580	2240	122	362	117	13	1420	4	0.49	<0.04	0.33	1.58	1390	346	422	<0.2	0.7
	GTR-85-096	LN-2A	16	11-20-85	5190	5280	545	437	416	20	3600	7	0.69	0.50	0.43	1.68	2800	408	497	0.5	1.9
	GTR-85-099	LN-2D	15	11-20-85	4640	5160	288	466	463	10	3420	3	1.84	<0.2	2.21	1.69	3070	315	384	0.3	5.6
	GTR-85-101	LN-2F	9	11-20-85	6170	6880	519	410	712	13	4730	6	2.36	<0.2	<0.05	<0.05	3960	294	358	0.6	1.2
	GTR-86-117	LN-2I	11	08-27-86	7800	8700	672	391	979	15	6200	13	1.12	0.71	<0.05	≤0.05	5010	307	374	65	0.6
	GTR-86-118	LN-2J	13	08-27-86	8760	9710	813	390	1070	18	6700	17	1.00	0.49	<0.05	0.06	5380	426	519	55	0.6
Unweathered till	GTR-86-113	LN-1N	26	08-25-86	2050	1640	139	250	74	19	896	6	0.30	0.05	0.08	1.25	929	310	378	0.2	4.3
	GTR-86-114	LN-1O	36	08-26-86	2230	1780	205	238	70	20	1090	9	0.31	1.47	<0.05	0.69	883	248	302	0.8	1.3
	GTR-86-115	LN-1P	46	08-26-86	2390	1900	243	238	66	20	1240	12	0.38	≤0.04	1.51	1.18	866	230	280	≤0.2	19
	GTR-86-116	LN-1Q	56	08-26-86	2490	2030	245	257	68	18	1320	16	0.34	<0.04	1.84	1.20	922	216	263	<0.2	22
	GTR-85-097	LN-2B	27	11-20-85	3610	3180	417	372	123	22	2040	11	0.31	0.3	0.55	1.26	1440	341	416	0.3	4.7
	GTR-85-098	LN-2C	48	11-20-85	2640	2120	380	220	66	20	1280	16	0.40	<0.2	0.60	0.91	821	255	311	0.2	17
	GTR-85-100	LN-2E	68	11-20-85	3940	3600	527	362	164	22	2390	13	0.48	<0.2	0.50	1.93	1580	325	396	≤0.2	8.6
	GTR-86-119	LN-2L	26	08-27-86	4830	4390	527	470	224	26	3000	24	0.26	0.13	<0.05	1.95	2100	496	605	1.9	1.4
	GTR-86-120	LN-2M	36	08-27-86	3670	3140	393	355	134	30	2000	23	0.31	0.36	<0.05	0.70	1440	346	422	0.9	1.5
	GTR-86-121	LN-2N	46	08-27-86	3040	2460	371	272	89	22	1600	19	0.42	2.34	<0.05	0.73	1050	256	312	1.0	1.2
	GTR-86-122	LN-2O	56	08-27-86	2930	2380	352	228	90	21	1530	21	0.45	1.20	<0.05	0.84	940	217	265	0.7	1.5
Outwash	GTR-84-001	Schoffelman[5]	90	06-18-84	2120	1700	117	323	107	15	1200	6	<0.06	<0.2	4.34	0.19	1250	326	397	---	---
	GTR-84-002	Suing[5]	70	06-14-84	2890	2170	114	428	149	15	1620	3	<0.06	<0.2	0.86	2.62	1680	320	390	---	---

[1] **DS**- dissolved solids; **Na** - sodium; **Ca** - calcium; **Mg** - magnesium; **K** - potassium; **SO_4** - sulfate; **Cl** - chloride; **F** - fluoride; **NO_3-N + NO_2-N** - nitrate + nitrite as nitrogen; **Fe** - iron; **Mn** - manganese; **$CaCO_3$** - hardness as calcium carbonate; **Alk-T** - total alkalinity; **HCO_3** - bicarbonate

[2] **Se** - selenium; **As** - arsenic

[3] Depth is presented in feet below surface.

[4] umhos - micromhos

[5] See table 7 for the locations of the Schoffelman and Suing wells.