Open File Report 8BAS

# Comparison of Irrigated Land in Southern Alberta, Canada, with the CENDAK Area, South Dakota

by


CENDAK Drainage Steering Committee

James Verzuh, Chairman

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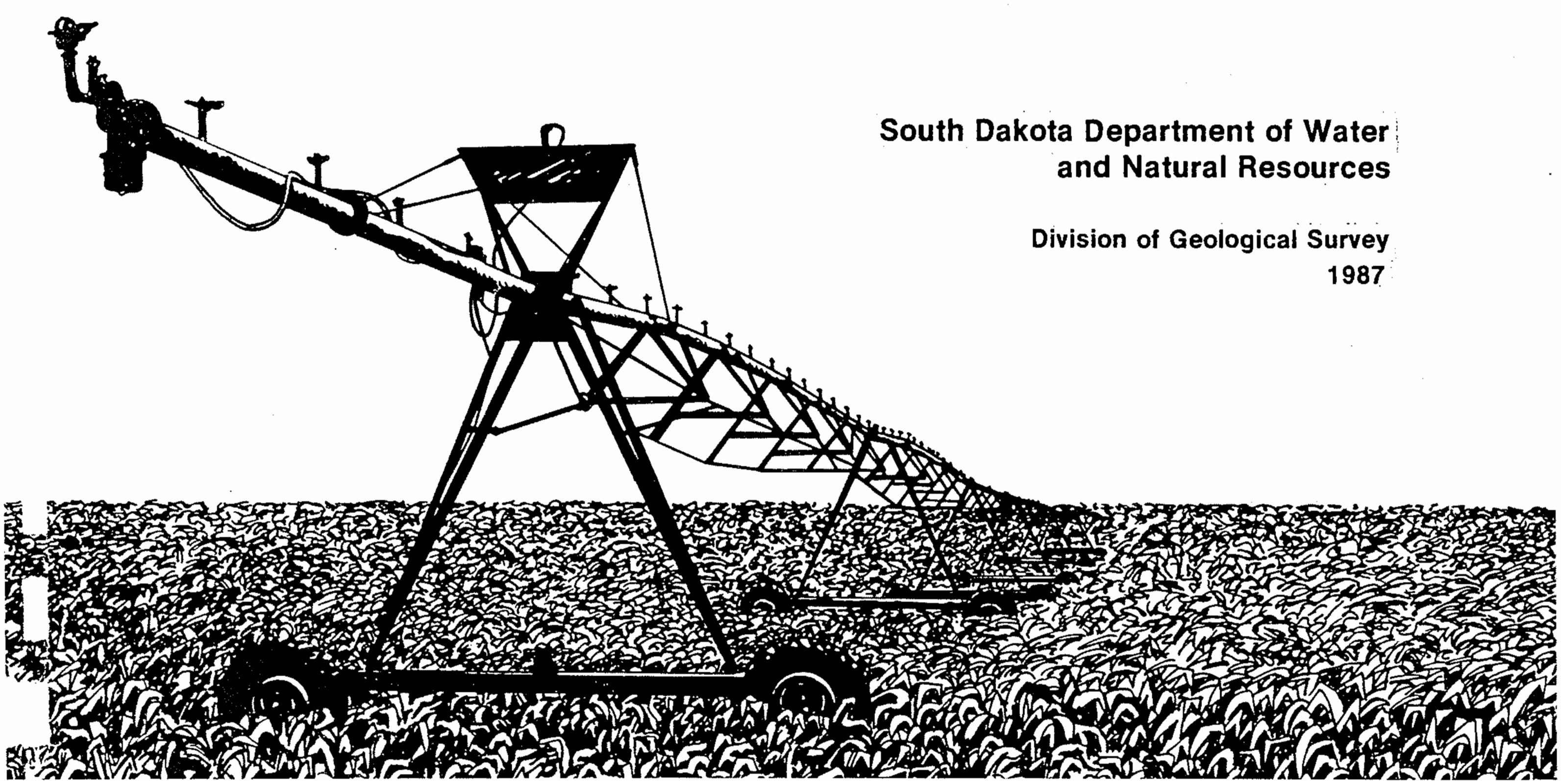


South Dakota Department of Water and Natural Resources

Division of Geological Survey
1987

STATE OF SOUTH DAKOTA
George S. Mickelson, Governor

DEPARTMENT OF WATER AND NATURAL RESOURCES
John J. Smith, Secretary

DIVISION OF GEOLOGICAL SURVEY
Merlin J. Tipton, State Geologist

Open-File Report 8-BAS

# COMPARISON OF IRRIGATED LAND IN SOUTHERN ALBERTA, CANADA, WITH THE CENDAK AREA, SOUTH DAKOTA

by

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Compiled by
South Dakota Department of Water and Natural Resources
Division of Geological Survey
Science Center
University of South Dakota
Vermillion, South Dakota

1987

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# EXECUTIVE SUMMARY

by

CENDAK DRAINAGE STEERING COMMITTEE

1987

# EXECUTIVE SUMMARY

Since 1985, the CENDAK Drainage Steering Committee has been involved in a number of investigations aimed at providing an improved understanding of the drainage requirements for the proposed CENDAK project. One aspect of these efforts has focused on the comparison of glacial till irrigation in southern Alberta, Canada, with the proposed irrigation of apparently similar soils in central South Dakota. This report presents the findings and conclusions of that effort.

Agriculture - Irrigation development in southern Alberta began around 1900, and today lands in excess of 1.0 million acres are under irrigation. Most of these irrigated lands have soils developed on glacial till or where till is present at shallow depths.

In the CENDAK area, irrigation started in the early 1960's and approximately 40,000 acres are currently being irrigated. Most of this development has occurred since 1976. The majority of the irrigated soils are either derived from glacial till or comprised of lacustrine deposits over till. The CENDAK project is designed to irrigate up to 474,000 acres of land in east-central South Dakota.

It is common practice in southern Alberta to limit irrigation applications so that the water-holding capacity of the soil profile is not exceeded. This optimizes crop water-use efficiencies and limits deep percolation losses during the active growing season. A 4-year study of center-pivot irrigation systems showed the following water applications: alfalfa, 6.6 inches; wheat, 4.5 inches; barley, 2.7 inches; corn silage, 5.6 inches. Conveyance system efficiencies range from 40 to 77 percent, while on-farm efficiencies range from 35 to 58 percent.

Irrigators in the CENDAK area reportedly apply 8 to 16 inches of water annually, primarily by center-pivot sprinklers. On-farm efficiencies are estimated to range from 65 to 80 percent. It is anticipated that future irrigation development will continue to incorporate center-pivot systems.

Surface water supplies in southern Alberta are very good with total dissolved solids ranging from 300 to 500 ppm. The primary source of irrigation water in the CENDAK area is ground water, which generally exceeds 1,000 ppm total dissolved solids. Project development is based on using Missouri River water from Oahe Reservoir which averages around 500 ppm total dissolved solids.

According to data provided by T. G. Sommerfeldt (Canada Department of Agriculture), salinity and drainage problems have been reported on anywhere from 10 to 25 percent of the irrigated lands in southern Alberta. This includes the nonirrigated land within the irrigation districts (estimate of dry land salinity in southern Alberta is approximately 10 percent). Sommerfeldt suggests that a more accurate range of the problem areas due to irrigation is 12 to 15 percent, or approximately 180,000 acres, based on his own experiences and knowledge of the area. It is estimated that 80 percent of the problem areas are the result of canal seepage with the remainder caused by on-site irrigation practices. Artificial drains have been installed on nearly 15,000 to 20,000 acres according to most recent estimates. On-farm drainage facilities are financed directly by the growers, while distribution system rehabilitation work is cost-shared 86 percent and 14 percent, by the provincial government and the water district, respectively. A long-term study (60+ years) of salt distribution within the soil profile indicated that total soluble salt has either been reduced or remained relatively unchanged since the introduction of irrigation. Experience has shown, contrary to previous predictions, that irrigation with very limited artificial drainage has been successful on till derived from both marine shales and non-marine deposits in southern Alberta.

Virtually no artificial drains have been installed in the irrigated lands within the CENDAK project area, and no appreciable salinity or water table problems have been reported to date.

Lands (soils) - All soils evaluated in both southern Alberta and the CENDAK area are underlain by till at depths of less than 5 feet and in numerous situations at depths of 3 feet. Many of the soils in southern Alberta are derived from thin lacustrine deposits over till, while in the CENDAK area, soils are developed directly from till material or loess deposits over till. Soil color, thickness of horizon, organic matter content, B-horizon development, textures, etc., although slightly variable, are not considered of major importance from an irrigation standpoint. Sodium soils do not occur in the CENDAK area or are of limited extent.

In general, the soils of the proposed CENDAK project are considered to be slightly more desirable for irrigation than the soils presently being irrigated in southern Alberta based on slightly lower clay contents, bulk densities, and the degree to which the soils have been reworked. All of these factors are conducive to a more favorable plant environment.

Climate - Although both areas have continental climates, several differences exist in the two areas. Temperatures in the CENDAK area are considerably warmer than in southern Alberta with a difference of 19 degrees F in the average annual growing season temperature. The CENDAK area averages 14 inches of growing season precipitation, while southern Alberta averages only 11 inches. The CENDAK area generally experiences more snowfall, and does not receive the warm chinook winds during the winter months as does southern Alberta. Annual evapotranspiration potential is nearly the same for both areas, with CENDAK averaging 36 inches per year and southern Alberta 37 inches.

Topography - Minimum and maximum elevations in the Plains region of southern Alberta are about 1,000 feet higher than elevations in the CENDAK area. On a regional scale, relief is greater in Alberta due to the deep incision of the major streams. Local relief on the rolling glacial plains is very similar, generally less than 100 feet in both areas. The topography of the two areas is very similar, consisting of flat lake plains and rolling glacial topography with closed depressions. Natural surface runoff to river systems is low in both areas, amounting to about 17 acre-feet per mile (0.3 inches) in the CENDAK area and about 20 acre-feet per mile (0.4 inches) in southern Alberta. The small amount of surface runoff in both areas is attributed to low relief and containment of water in local depressions prior to infilatration into the soil and/or evaporation.

Hydrogeology - The Cretaceous sequence in southern Alberta consists of a mixture of marine and non-marine shales and sandstones. In the CENDAK area the Cretaceous rocks are largely marine shales and sandstones. The Dakota Formation-Inyan Kara Group and the Milk River Formation are sandstone aquifer units at or near the base of the Cretaceous rocks, which provide flowing-well conditions over parts of both regions. The low hydraulic conductivity of the confining shale units and/or high potentiometric surface of the aquifer units prevent the downward movement or water through the bedrock.

Glacial drift source rocks for both areas are Canadian Shield rock types and Paleozoic carbonates, and local rock types consisting primarily of the Cretaceous units. The major glaical drift units, till, outwash, and lacustrine deposits, were deposited by one of three ice advances during the late Wisconsin time about 24,000 to 11,000 years ago.

Till underlies nearly the entire land surface in both areas. It is overlian with scattered thin outwash to a minor extent in southern Alberta and over about 4 percent in the CENDAK area. Till is overlain by lacustrine deposits in about 60 percent of southern Alberta and about 4 percent in the CENDAK area. Although quite extensive in southern Alberta, the lacustrine deposits which overlie the till, average less than 3.5 feet in thickness. Bulk physical, chemical, and textural properties of tills from both areas are very similar. The weathered till is normally highly factured, but fractures are not visually apparent in unweathered till.

The hydraulic conductivity of weathered till is up to four orders of magnitude higher than the hydraulic conductivity of the unweathered till. The higher conductivity of weathered till is attributed primarily to fractures, while the lower conductivity of unweathered till indicates intergranular flow. Unweathered till hydraulic conductivity values range from 7.1 x 10(-10) to 2.9 x 10(-5) cm/sec in the CENDAK area and from less than 1.0 x 10(-8) to 5.0 x 10(-5) cm/sec in southern Alberta.

Water movement in till is a critical factor for understanding drainage issues and estimating the extent of artificial drainage needed to remove deep percolation in excess of the capacity of the natural system. However, until recently there has been little understanding of the mechanisms of water movement in till. Recent investigations conducted in southern Alberta and South Dakota have led to the following conclusions with regard to water movement through till:

1. Downward movement of water through unweathered till is insignificant or nonexistent as far as drainage requirements are concerned. This conclusion is based on aquifer tests, in situ and laboratory permeability tests on till, and chemical analyses of water from both till and underlying outwash. Water analyses included carbon-14 age dating, analysis for tritium content, and general chemical analysis for dissolved constituents. This conclusion implies that drainage of agricultural lands in the CENDAK area by pumping from glacial aquifers is not considered to be technically feasible where the aquifers are overlain by unweathered till. It also implies that the impact of irrigation on the buried aquifer will be minimal.

2. Current data and interpretation strongly indicate that lateral flow cannot account for discharge of all water penetrating below the root zone in either natural or irrigated conditions. This conclusion is based on calculations using lateral permeability, water-table gradient measurements, and water-quality relationships. Groundwater flow modeling has also led to the same conclusions in southern Alberta. However, it should be pointed out that conclusions for lateral flow are not as well documented as conclusions for vertical flow.

3. If downward and/or lateral movement does not account for significant dissipation of water from the water table, the only remaining avenue for discharge is upward movement by capillary action, evapotranspiration, and evaporation from below the root zone. Research is in progress and additional work is planned to determine the magnitude of, and mechanism(s) for, upward movement of water from below the root zone.

It should be noted that part of the CENDAK Drainage Steering Committee's water balance study and the South Dakota Geological Survey's till research is designed to quantify the amount of water reaching the water table and to determine the avenue for dissipation of this water.

Also, present data indicate that salt is being deposited below the root zone. However, it is necessary to quantify the accumulated salts. This research is being pursued by the CENDAK Drainage Steering Committee's investigation of salt profiles conducted by South Dakota State University in cooperation with the Bureau of Reclamation and the South Dakota Geological Survey.

Based on the similarities between the two geographic areas and results of research providing a better understanding of the natural hydrologic system, it is currently believed that artificial drainage will be required in significantly less than 100 percent of the entire CENDAK area, assuming that sprinkler irrigation systems and good irrigation management practices are incorporated.

In summary, the overall CENDAK area is comparable to southern Alberta with respect to drainage requirements if water applications (quantity and quality) are similar to Alberta. This conclusion is predicated upon the similarities of the physical systems and the apparent lack of extensive drainage and salinity problems experienced to date in both Alberta and the CENDAK area.

# CHAPTER 1

# INTRODUCTION

by

CENDAK DRAINAGE STEERING COMMITTEE

1987

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# 1.1
# INTRODUCTION

The CENDAK project proposes to irrigate up to 474,000 acres of glaciated land in central South Dakota using Missouri River water. The predominant geologic deposit at or near the land surface in this area is till. Thus, till is the parent material for most of the soils.

The CENDAK Drainage Steering Committee was organized in 1985 to direct investigations of drainage characteristics and needs of the project lands. In August, 1985, this committee visited irrigation projects and reviewed research activities on glaciated lands in southern Alberta, Canada. Irrigation in this area has been practiced since 1898, and presently in excess of 1 million acres of land is under irrigation with only minimal amounts of artificial drainage. In southern Alberta, till is also the predominant glacial deposit at or near the land surface.

To facilitate the understanding of drainage requirements of CENDAK, the Committee decided to prepare a report comparing these two geographic areas relative to physical conditions and the hydrologic framework. Furthermore, this report should identify the possible mechanisms responsible for successful irrigation with minimal artificial drainage. The implications of these comparisons are that if the two areas are similar physically and if it is determined that the same mechanisms are applicable in both areas, then a better understanding of drainage requirements of CENDAK will be possible.

It was decided that different parts of this report should be prepared by people with experience in the physical conditions examined. Because of the geographic separation of authors and the short time-frame in which this report has been written, this arrangement has resulted in some repetition and different writing styles. The following paragraphs provide historical perceptions, and results of recent research regarding the drainage issue.

In 1954 a consulting board was appointed by the U.S. Bureau of Reclamation to evaluate the irrigation potential of the Oahe Unit. These board members (including S. T. Harding, J. R. Iakisch, and C. E. Jacob) were recognized authorities in the field of irrigation, soils, salinity, ground water and drainage. They concluded that neither aquifer lands nor non-aquifer lands covered with glacial till could be drained by drain tiles, nor could aquifer lands be drained by pumping aquifer wells.

C. R. Maierhofer, then Chief, Office of Drainage and Groundwater Engineering, U.S. Bureau of Reclamation, predicted that irrigated lands in southern Alberta would experience serious subsurface drainage problems, due largely to a gradually rising zone of saturation (Maierhofer, 1956). Six years later, Lee, Maierhofer, Langley, Maletic and Woltersdrof (1962) spent a week in the same area of southern Alberta and concluded that till derived from fresh-water deposits can be profitably farmed under irrigation, but that land developed on till derived from marine-shale would "require such extensive drainage work, to maintain lands in permanent productivity that economic justification is highly questionable." The group then visited the proposed Oahe unit in South Dakota, and concluded that because till in central South Dakota was derived from marine-shale it should not be irrigated.

Experience has shown that irrigation with only limited artificial drainage has also been successful on till derived from marine shale and nonmarine deposits in southern Alberta. Irrigation of till lands derived from marine shale, which has no artificial drainage, has also been successful in central South Dakota.

Success of irrigation in southern Alberta was also partly attributed to the presence of draws and coulees present in part of the area acting as drains for natural or man-induced water entering the regional ground water flow system. However, recent research conducted in southern Alberta shows that lateral ground-water flow in weathered and unweathered till is not adequate to dissipate all of the estimated deep percolation from the irrigated lands although some ground-water discharge may be detected near the draws and coulees.

Previous predictions of failure of irrigating till lands were made on limited knowledge of water movement in till. This lack of understanding led to the conclusion that all water reaching the water table should be removed by artificial drainage. Removal of all water requires close drain spacing in slowly permeable material and led to the conclusion that it would be uneconomical to drain till lands.

Barari (1983) concluded that actual drainage requirements of till lands under irrigation cannot be adequately determined until the movement of water, whether from precipitation or irrigation, after reaching the water table is adequately understood. Barari and Hedges (1985) then questioned the generally accepted conceptual hydrologic model which attributed the main dissipation of water below the root zone to downward movement through unweathered till or lateral movement through weathered and unweathered till. They suggested that upward movement by capillary action, evapotranspiration, and evaporation from below the root zone, accounts for much more water discharge than heretofore thought. The implication of this conclusion, if it is proven correct and can be quantified, is that it may not be necessary to remove all the water reaching the water table. This would reduce artificial drainage needs.

To determine the movement of water through till, the South Dakota Geological Survey began research projects in three areas of eastern South Dakota which have different hydrogeologic frame-works. Parts of these studies were coordinated with research being conducted by the CENDAK Drainage Steering Committee.

The following chapters of this document each contain a descriptive section of the CENDAK area (sec. A) and southern Alberta (sec. B) with a comparison summary (sec. C). An executive summary of the entire document has also been prepared and is presented at the front of this report. The Table of Contents and the title page for each chapter show the names of those organizations or people responsible for its preparation.

## 1.2
## REFERENCES CITED

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CHAPTER 2.A.

# CLIMATE OF CENDAK AREA, SOUTH DAKOTA

by

SOUTH DAKOTA
DEPARTMENT OF WATER AND NATURAL RESOURCES
DIVISION OF GEOLOGICAL SURVEY

1987

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ILLUSTRATION



TABLE

2.A.1

# CLIMATE OF CENDAK AREA, SOUTH DAKOTA

The climate of the CENDAK area is a continental-type which is characterized by cold winters and warm to hot summers. The temperature varies greatly from summer to winter. Precipitation occurs in the form of rain or snow with the greatest amounts in the form of rain recorded during the months of April through September. Rates of annual potential evapotranspiration exceed the annual precipitation.

The average annual temperature for the CENDAK area is 45 degrees F (fig. 1) with daily extremes that range from less than -20 degrees F to over 100 degrees F. The average temperature during the growing season, from April through September, is 62 degrees F.

Annual precipitation averages approximately 18 inches, ranging from approximately 17 to 21 inches over the area (fig. 1). However, annual precipitation can fluctuate greatly from the average precipitation as indicated in table 1. During the growing season, from April through September, approximately 14 inches of precipitation are recorded on the average with a range of 13 to 16 inches (fig. 1).

The average annual growing season is 150 days. The average latest killing frost (28 degrees F) in the spring occurs on May 6, while the average first killing frost in the fall occurs on October 2.

**Table 1. Precipitation data**

| | Minimum and maximum precipitation in CENDAK area | | | |
|---|---|---|---|---|
| | ANNUAL | | GROWING SEASON (April - September) | |
| Station | Min. (year) | Max. (year) | Min. (year) | Max. (year) |
| Faulkton | 9.64 (1934) | 28.21 (1915) | 6.99 (1934) | 24.86 (1942) |
| Highmore | 9.28 (1976) | 28.80 (1957) | 4.92 (1976) | 23.49 (1920) |
| Huron | 9.72 (1952) | 31.71 (1962) | 6.01 (1952) | 26.03 (1914) |
| Miller | 7.60 (1976) | 29.29 (1957) | 4.05 (1976) | 24.26 (1968) |
| Pierre | 4.58 (1892) | 29.59 (1982) | 3.38 (1892) | 20.62 (1975) |
| Redfield | 11.45 (1934) | 30.76 (1900) | 7.58 (1934) | 26.61 (1900) |

TABLE 1 -- continued.

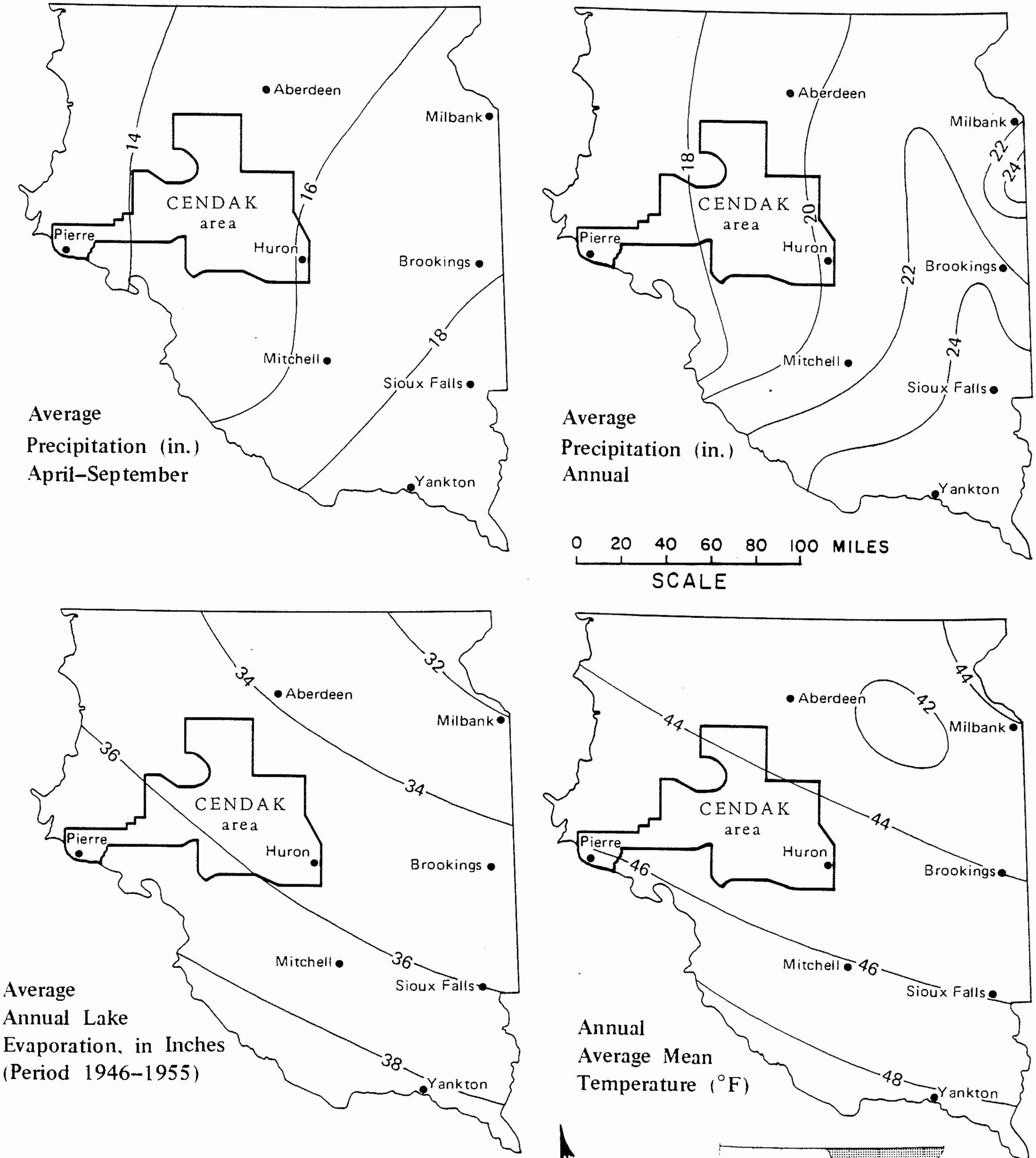
All maximums and minimums incorporate data beginning in 1900 except for the Pierre station which had earlier records and the Miller station which wasn't in operation until 1922. All stations are located within the CENDAK area.

All data are from the South Dakota Agricultural Research Station, Brookings, South Dakota, personal communication, 1986.

Only part of the annual precipitation is effective in supplying the consumptive use requirement for crops. The rest is unavailable because of deep percolation beyond the root zone or surface runoff. Effective precipitation was computed by the CIR77 Program, using Bureau of Reclamation criteria (USBR, 1986). Table 2 shows the average effective precipitation during the year for each climate zone:

**Table 2. Average Effective Precipitation**
(inches)

| Month | Faulkton Zone | Huron Zone | Highmore Zone | Pierre Zone |
|---|---|---|---|---|
| January | .36 | .41 | .34 | .40 |
| February | .42 | .58 | .46 | .52 |
| March | .85 | 1.05 | .94 | .90 |
| April | 1.61 | 1.56 | 1.57 | 1.42 |
| May | 1.96 | 1.88 | 1.89 | 2.08 |
| June | 2.47 | 2.27 | 2.43 | 2.35 |
| July | 1.72 | 1.69 | 1.81 | 1.66 |
| August | 1.76 | 1.61 | 1.72 | 1.54 |
| September | 1.10 | 1.30 | 1.13 | 1.08 |
| October | 1.03 | 1.08 | 1.06 | .86 |
| November | .51 | .58 | .47 | .42 |
| December | .31 | .46 | .34 | .43 |
| | ----- | ----- | ----- | ----- |
| Potential infiltration of annual precipitation | 14.10 | 14.46 | 14.15 | 13.67 |
| Effective precipitation used by crop | 9.48 | 9.00 | 9.48 | 9.24 |




Modified from Spuhler and others (1971).

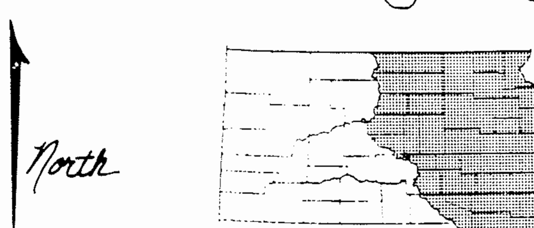



Figure 1. Climatological maps of eastern South Dakota showing the CENDAK area.

Actual values for evaporation and transpiration are not known because of insufficient data. However, values for lake evaporation can be used as a good estimate for potential evapotranspiration (Cruff and Thompson, 1967). Lake evaporation is found by multiplying the class A pan evaporation results times 0.7. The average annual lake evaporation and, hence, potential evapotranspiration (fig. 1) is approximately 36 inches in the CENDAK area with an estimated growing season potential evapotranspiration of 33 inches. In the Planning Report for the CENDAK project the Bureau of Reclamation (USBR, 1986) used their computer program CIR77 which computed the evapotranspiration using the Jensen-Haise method and came up with a range of values from 36.37 to 41.66 inches with an average of 38.43 inches. Results of both methods indicate that average annual potential evapotranspiration is greater than annual precipitation.

A degree day is defined as a departure of temperature of 1 degree from some reference or base temperature during a day. Degree days are obtained by first calculating the mean daily temperature by adding the minimum temperature to the maximum temperature and dividing the total by 2. The reference or base temperature is then subtracted from the mean and each degree Fahrenheit or Celsius above (or below) that reference is counted as 1 degree day. As an example, on a day when the maximum temperature is 65 degrees F, the minimum temperature is 35 degrees F, the daily mean is 50 degrees F, and the base temperature is 40 degrees F, the number of degree days is calculated to be 10 (Canadian Climate Centre, 1982).

Degree days used in agriculture are called growing degree days and can be used in the planning and operation of growing a crop. The selection of a base temperature depends on the type of crop grown. For the CENDAK area, 40 degrees F is used as a base temperature because of the various crops grown in the area. Growing degree days can be used to schedule planting, predict various plant growth stages and by recording them throughout the growing season, it is possible to forecast harvesting dates. The average number of growing degree days during the growing season (April to September), based on 40 degrees F, from Faulkton, Highmore, Huron, Miller, Pierre, and Redfield stations is 4,356 days.

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CHAPTER 2.B.

# CLIMATE OF THE LETHBRIDGE AREA, ALBERTA, CANADA

by

SOUTH DAKOTA
DEPARTMENT OF WATER AND NATURAL RESOURCES
DIVISION OF GEOLOGICAL SURVEY

1987

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ILLUSTRATION

## 2.B.1
## CLIMATE OF THE LETHBRIDGE AREA, ALBERTA, CANADA

The irrigated area of Alberta, near Lethbridge, has a continental-type climate with warm to hot summers and cold winters. Precipitation occurs in the form of rain or snow with the greatest amounts recorded during the months of April through September.

Temperatures vary greatly from less than -40 degrees F in the winter to over 100 degrees F in the summer. The average annual temperature for the irrigated area is 28 degrees F. The average temperature over the growing season, from April through September, is 43 degrees F. The average number of growing degree days at Lethbridge during the growing season (April to September), using a base temperture of 5 degrees C, is 2,902. See Chapter 2A for a discussion on how the growing degree day is defined.

Annual precipitation ranges from approximately 12 to 18 inches with an average of approximately 16 inches. The April through September amounts of precipitation range from approximately 8 to 13 inches and average 11 inches (fig. 1).

The average annual growing season ranges from 121 to 145 days across the irrigated area. The average latest killing frost in the spring at Lethbridge occurs on May 7, while September 25 is the average date of the first killing frost in the fall.

Lake evaporation, which can be used as an estimate for potential evapotranspiration, has a range of 27 to 40 inches per year with an average of approximately 37 inches. The estimated growing season evapotranspiration is 34 inches.

Chinook winds occur along a 700 mile-long area on the leeward (east) side of the Rocky Mountains which is centered on Calgary. These Chinook winds are the result of air which loses moisture as it flows over the Rocky Mountains and descends down the leeward side of the mountains while warming at a dry adiabatic lapse rate. The Chinooks are particularly warm and dry and temperature rises of 40 degrees F in five minutes have been observed (Barry and Chorley, 1970). The word Chinook is Indian for snow eater because these winds generally occur during the months of December through February and cause considerable melting of snow. Using an arbritary criterion of winter days with a maximum temperature of at least 40 degrees F for a definition of Chinooks, it has been shown that Chinooks occur 40 percent of the days in the period of December through February at Lethbridge, Alberta (Longley, 1967). Chinook Winds add greatly to evaporation during winter but are not recorded on annual evaporation data because official data are taken from Class A pans that are operated only during nonfreezing periods.

## 2.B.2
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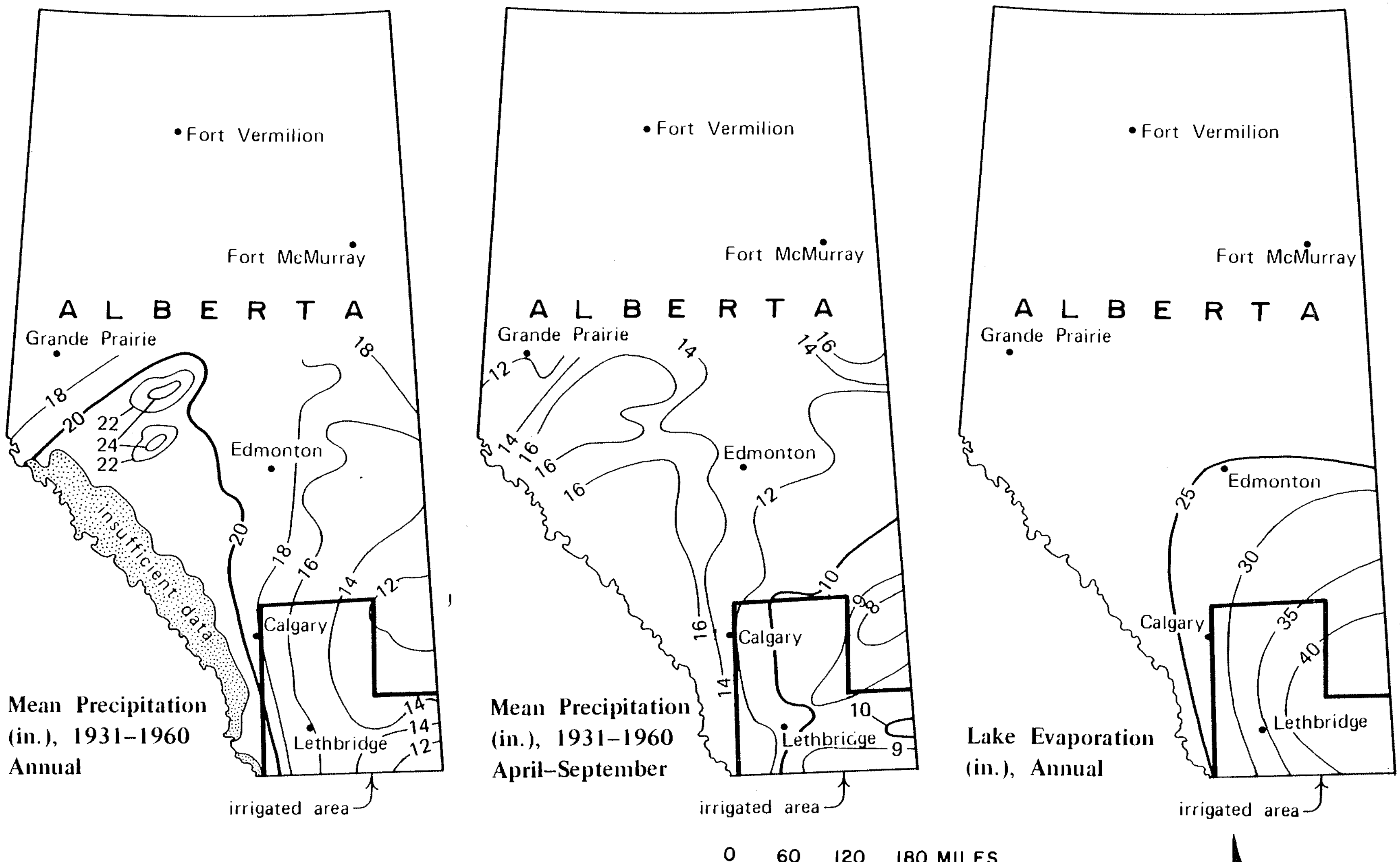


Modified from Meterological Branch, Toronto (1965), and Bruce, J.P. and B. Weisman (1967).

Figure 1. Climatological maps of Alberta, Canada, showing the irrigated area.

CHAPTER 2.C.

# COMPARISON OF CLIMATES IN CENDAK AREA, SOUTH DAKOTA AND LETHBRIDGE AREA, ALBERTA, CANADA

by

SOUTH DAKOTA
DEPARTMENT OF WATER AND NATURAL RESOURCES
DIVISION OF GEOLOGICAL SURVEY

1987

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TABLE

## 2.C.1
## COMPARISON OF CLIMATES IN CENDAK AREA, SOUTH DAKOTA AND LETHBRIDGE AREA, ALBERTA, CANADA

Although both areas have continental-type climates, yearly average climatological values show some differences (table 1).

Temperatures in the CENDAK area are considerably warmer than in the Lethbridge area with a difference of 17 degrees F for the annual temperature and a 19 degrees F difference during the growing season. The annual precipitation is greater in the CENDAK area with an average of 18 inches (extreme variation from the mean occurs frequently) as compared with 16 inches for the Lethbridge area. During the growing season there is a difference in precipitation with 14 inches being the average in the CENDAK area compared to a 11-inch average in the Lethbridge area. South Dakota generally has more snowfall in the winter months with no chinook winds. Lake evaporation is approximately the same in both areas, averaging 37 and 36 inches per year in the Lethbridge and CENDAK areas, respectively.

Temperature differences between CENDAK and the Lethbridge area can be evaluated by comparing the growing degree days. Chapter 2A discussed how the growing degree day is defined. The average number of growing degrees days during the growing season (April to September) is 4,356 days for the CENDAK area and 2,902 days for the Lethbridge area.

**Table 1. Comparison of climatological data from the CENDAK and Lethbridge areas.**

| | CENDAK * | Lethbridge area ** |
|---|---|---|
| Average annual temperature (degrees F) ...................... | 45 | 28 |
| Average temperature during growing season (degrees F) ....... | 62 | 43 |
| Average annual precipitation (inches) ......................... | 18 | 16 |
| Average growing season precipitation (inches) ........... | 14 | 11 |
| Estimated annual potential evapotranspiration (inches) ...... | 36 | 37 |

Table 1 -- continued.

| | CENDAK * | Lethbridge area ** |
|---|---|---|
| Estimated growing season potential evapotranspiration .......... | 33 | 34 |
| Average annual growing season (days) ........................... | 150 | 121-145 |
| Average latest killing frost in spring ........................ | May 6 (Highmore) | May 7 (Lethbridge) |
| Average first killing frost in fall .......................... | Oct. 2 (Highmore) | Sept. 25 (Lethbridge) |
| Average growing season growing degree days (base: 40 degrees F) | 4,356 *** | 2,902 (Lethbridge) |

* Spuhler and others (1971) Highmore Station
** Canadian Climate Centre (1982)
*** Composite of Faulkton, Highmore, Huron, Miller, Pierre, and Redfield stations.

## 2.C.2
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CHAPTER 3.A.

# TOPOGRAPHY AND SURFACE DRAINAGE OF THE CENDAK AREA, SOUTH DAKOTA

by

SOUTH DAKOTA
DEPARTMENT OF WATER AND NATURAL RESOURCES
DIVISION OF GEOLOGICAL SURVEY

1987

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ILLUSTRATIONS

3.A.1

# TOPOGRAPHY AND SURFACE DRAINAGE OF THE CENDAK AREA, SOUTH DAKOTA

The majority of the CENDAK area lies between the Missouri River to the west, and the James River to the east. Approximately the western half of the CENDAK area is in the Coteau du Missouri division of the Great Plains physiographic province and the remainder of the area is in the James Basin division of the Central Lowland physiographic province. The Lake Dakota Plain subdivision of the James Basin occupies a portion of northern Beadle and central Spink Counties (fig. 1). Maximum topographic relief within the CENDAK area is approximately 900 feet, ranging from about 1,250 elevation at the bottom of the James River trench to about 2,150 feet in the Ree Hills in Hand County.

The Coteau du Missouri is composed of glacial drift from the late Wisconsin glaciation. It rises 300 feet above the Missouri River to a general elevation of about 1,800 feet and then slopes to the east at a gradient of about 8 feet per mile to the James Basin and James River.

The Coteau du Missouri is nearly level to gently sloping with the exception of several areas where relief becomes more prominent. These areas include the Ree Hills, Orient Hills, Medicine Knoll, the Great Ree Valley and the Wessington Hills. The Wessington Hills form a well-defined escarpment which forms part of the boundary between the Coteau du Missouri and the James Basin. The Orient Hills in southern Faulk and northern Hyde and Hand Counties, and the Ree Hills in southwestern Hand and southeastern Hyde Counties form glacial drift covered highlands with elevations over 2,000 feet.

Maximum local relief on Coteau du Missouri is about 200 feet, however, much of the area is typical hummocky glaciated plains with less than 100 feet local relief. Many shallow depressions, a few intermittently flowing streams, and gentle slopes typify the ground moraine.

The James Basin is defined approximately by those lands lying between about 1,300 feet and 1,500 feet in elevation and are typical hummocky glacial plains with local relief generally less than 50 feet. The Basin boundary is sharply defined around the base of the Orient Hills, Ree Hills, and Wessington Hills but is an indistinct gradual transition throughout the central part of the area.

The James Basin in the CENDAK area covers most of Beadle County, roughly the eastern half of Hand and Faulk Counties, and the western quarter of Spink County. The area is drained to the south by the James River, which occupies a steep-walled, narrow trench 40 to 80 feet deep. The James River has an average gradient of 5 inches per mile in South Dakota (Flint, 1955). The shallow gradient results in certain drainage areas actually drying up during drought years (Hoffman, E. B., and others, 1982). The lowest point in the CENDAK area is reached where the James River enters Sanborn County at 1,200 feet.

The James Basin is smoothly rolling with very broad, low sub-parallel ridges, trending eastward and lying convex toward the south, and with local relief rarely exceeding 20 to 30 feet and in places, no more than 10 feet. The ridges are end moraines that formed as the glacier retreated. In detail, the area reveals thousands of barely perceptible closed depressions.

Two hilly areas lie in the vicinity of the CENDAK area in the James Basin. Both are near Redfield in Spink County. Bald Mountain, with a 1,480-foot elevation, is 6 miles southwest of Redfield. The Redfield Hills, lying south and east of Redfield, is a very irregular knobby ridge 8 miles long, 1 to 2 miles wide, and with a maximum relief of 80 feet. Most, if not all, of these high areas on both the James Basin and the Coteau du Missouri have a bedrock core overlain by glacial drift, and contains a few areas of exposed bedrock (Flint, 1955).

The Lake Dakota Plain, the floor of an abandoned glacial lake, is located within the James Basin, but is distinctly differentiated from the rest of the Basin by its flatness. Its elevation is approximately 1,300 feet, with local relief generally less than 10 feet. The sediment laid down in the glacial lake covered the irregularities of the morainic surface below.

The Lake Dakota Plain is dissected by the James River and its tributaries, with the tributaries following generally a straight course towards the south. The James River is a steep-walled, half-mile wide trench which has incised the Lake Dakota Plain and the glacial drift plain to depths ranging from about 40 to 80 feet. Within the CENDAK area, the Lake Dakota Plain is restricted to north central Beadle County and the central portion of Spink County.

Throughout the CENDAK area the proposed irrigable lands occupy the flatter areas and there is little noticeable difference between much of those lands in the Coteau du Missouri and the James Basin, except for the flat Lake Dakota Plain.

Large portions of the CENDAK area are poorly drained and have internal drainage into depressions, ponds, marshes and lakes. Locations of internal drainage areas are indicated by the dashed, rounded shapes (representing the larger depressions in the area) and also by the areas without any intermittent streams (fig. 2). Most surface drainage on the Coteau du Missouri is south and west to the Missouri River. Surface drainage from the eastern part of the Coteau du Missouri and the James Basin is generally eastward to the James River. The duration of streamflow in most of the streams in this area is very short. This means that the contribution of ground water to the streams is small. During the periods of no flow in a stream, the ground-water discharge is practically nonexistent. The James River is the main stream in eastern part

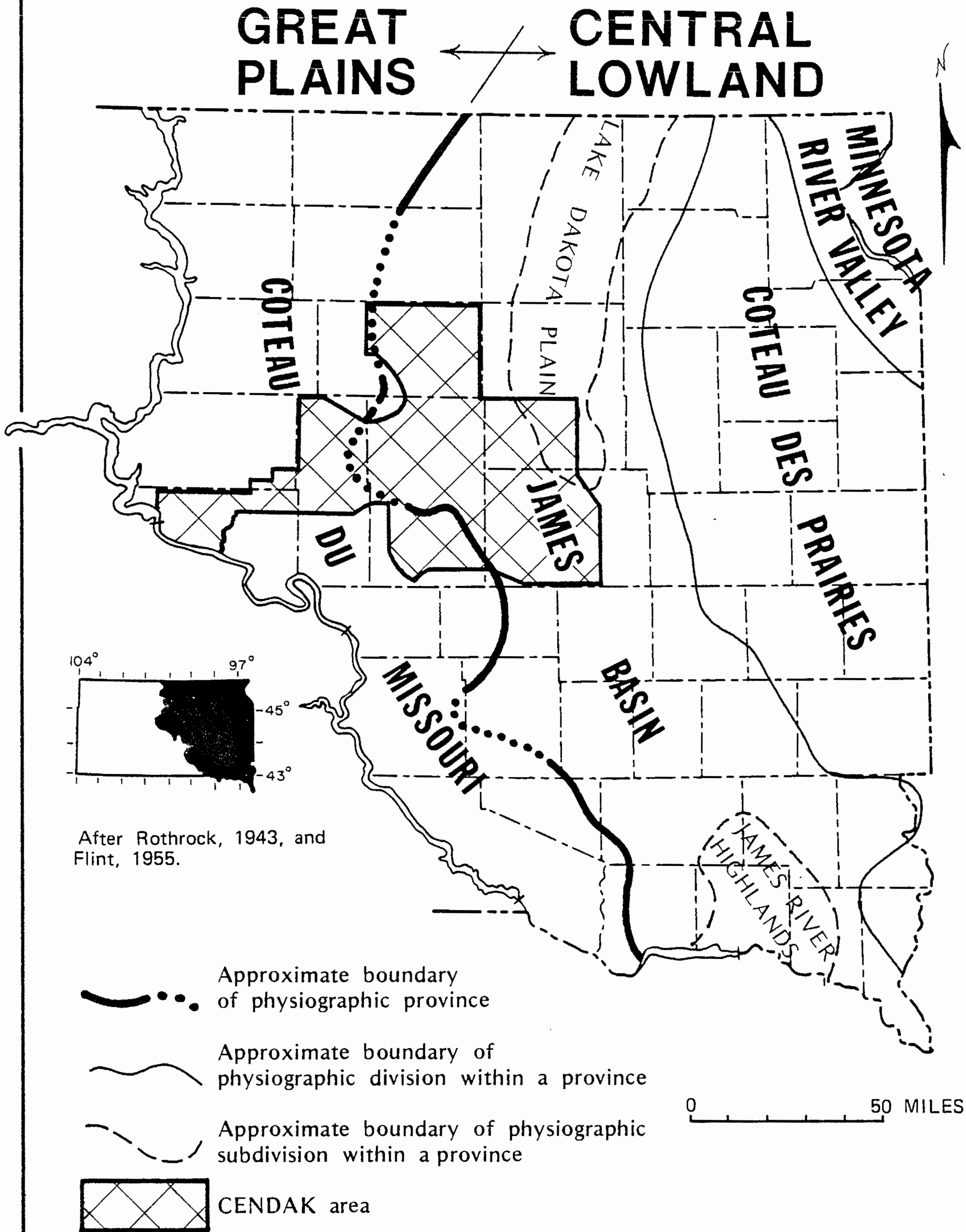
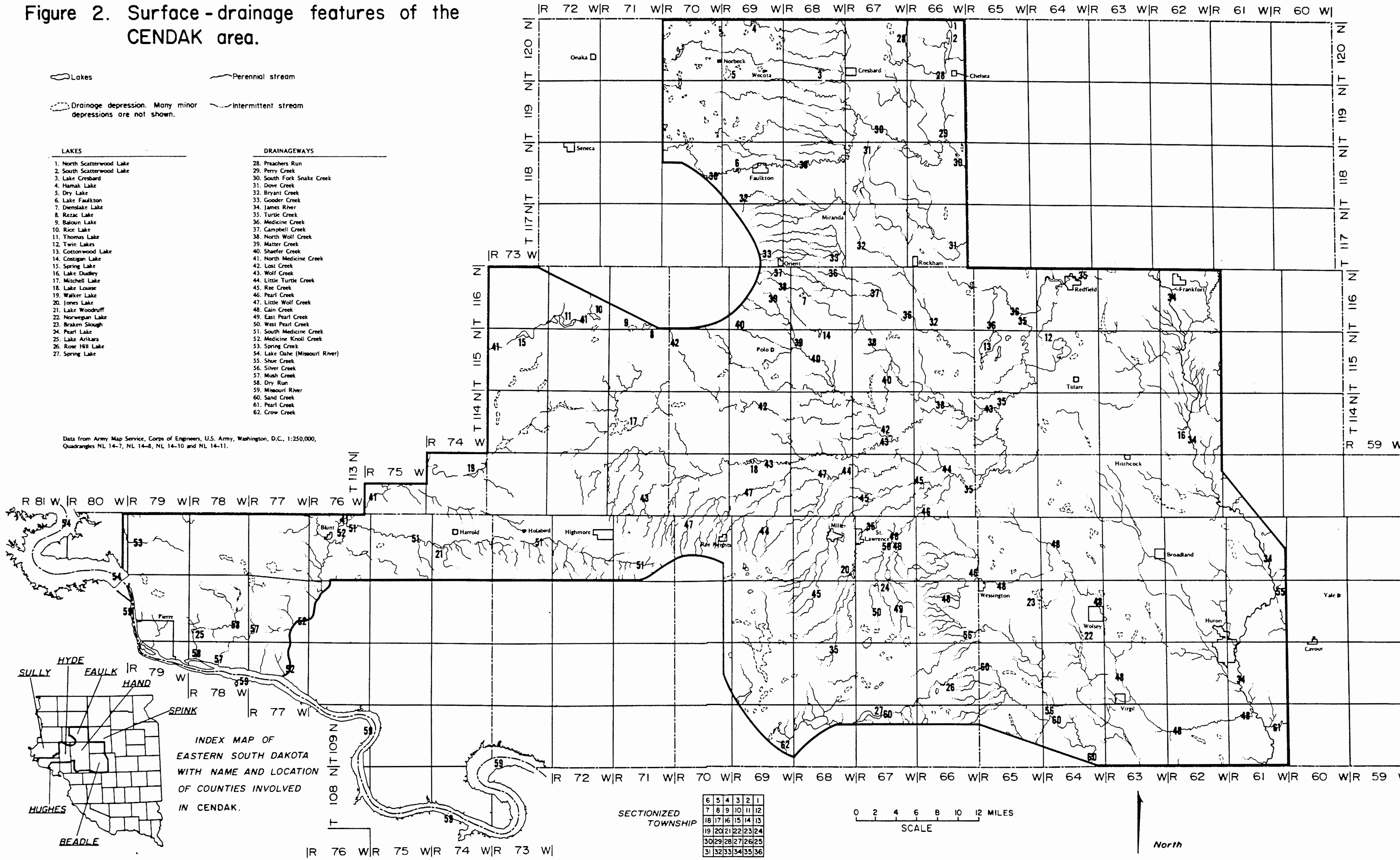



Figure 1. Physiographic divisions of eastern South Dakota showing location of the CENDAK area.

Figure 2. Surface-drainage features of the CENDAK area.



of the CENDAK area and has one of the flattest slopes of similarly sized streams in North America. Historically, the gaging station at Huron has recorded many days of no flow.

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CHAPTER 3.B.

# TOPOGRAPHY AND SURFACE DRAINAGE OF THE SOUTHERN ALBERTA PLAINS REGION

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1987

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## ILLUSTRATION

## 3.B.1
## TOPOGRAPHY AND SURFACE DRAINAGE OF THE SOUTHERN ALBERTA PLAINS REGION

The elevation of the Plains Region of southern Alberta is typically more than 3,000 feet at the edge of the Rocky Mountain foothills in the west and decreases to less than 2,500 feet along the Alberta/Saskatchewan border in the east. This gentle easterly slope controls the general alignment of the major rivers. There are two major topographic highs in this region. These are the Cypress Hills and the Milk River Ridge (Figure 1). The Cypress Hills rise more than 1,650 feet above the broad prairie surface in the southeastern part of the province and extend into southwestern Saskatchewan. Parts of the crest of the Cypress Hills were not glaciated. The Milk River Ridge is an east-west trending bedrock high located between Lethbridge and the International border. It forms the divide between drainage into the Hudson Bay and the Gulf of Mexico (the Saskatchewan and Missouri River systems, respectively). Parts of the western end of the Milk River Ridge and adjacent lowlands were not glaciated, notably the area around Del Bonita (Figure 1).

Local relief over the plains of southern Alberta is limited. It is typically a rolling to undulating surface with relief being less than 100 feet. In contrast, the larger river systems (i.e., Oldman, Milk, South Saskatchewan) have incised segments of their valleys to over 300 feet.

Natural runoff to river systems is low; Nielsen [1970] reports about 20 acre-feet per square mile or 0.38 inches annually. This small amount of runoff is attributed to the lack of regional overland flow to the river valleys. In most cases runoff moves overland to minor depressional areas where it undergoes evapotranspiration or infiltrates into the soil zone.

## 3.B.2
## REFERENCES CITED


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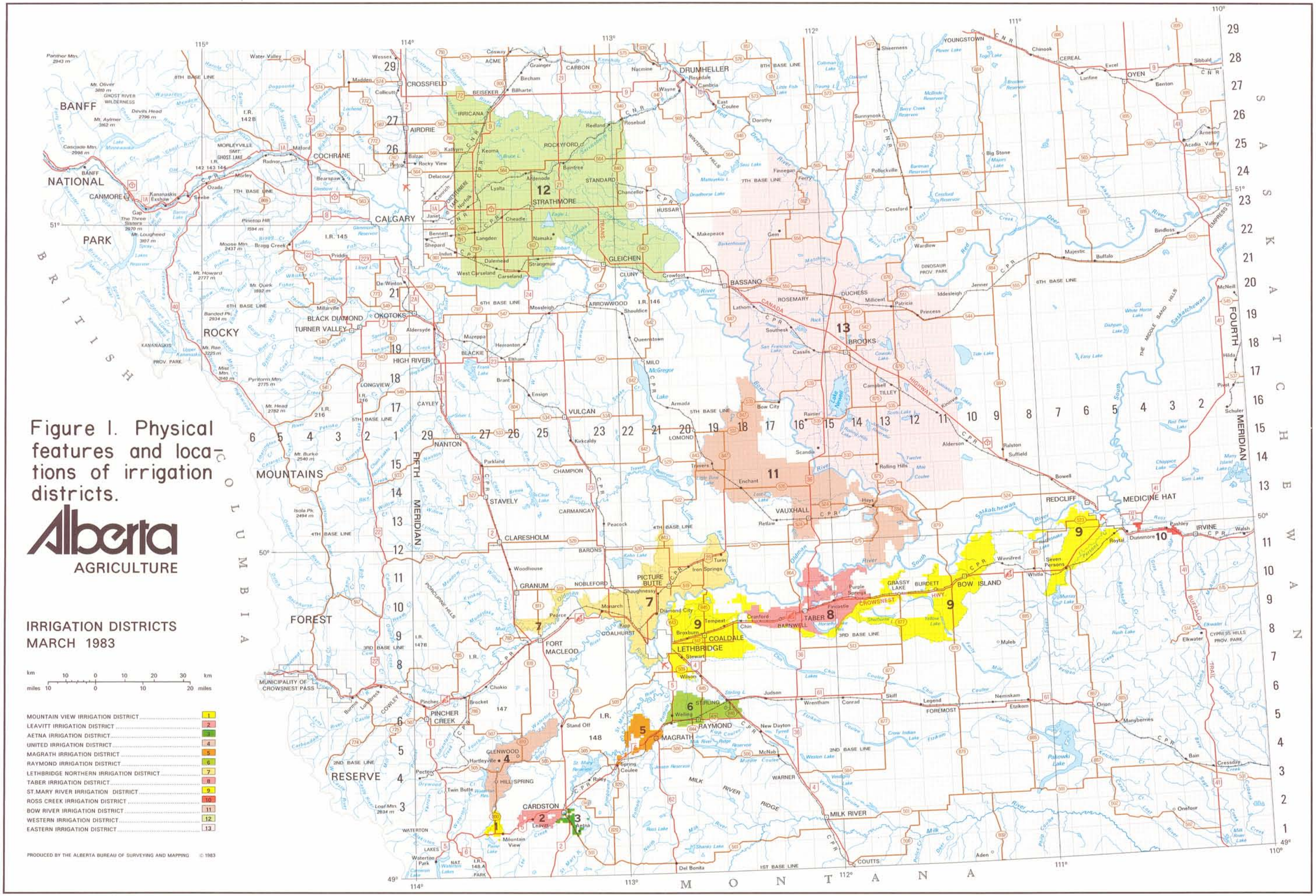


Figure 1. Physical features and locations of irrigation districts.

CHAPTER 3.C.

# COMPARISON OF TOPOGRAPHY AND SURFACE DRAINAGE IN THE CENDAK AREA, SOUTH DAKOTA, AND THE PLAINS REGION OF SOUTHERN ALBERTA

by

SOUTH DAKOTA
DEPARTMENT OF WATER AND NATURAL RESOURCES
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## 3.C.1
## COMPARISON OF TOPOGRAPHY AND SURFACE DRAINAGE IN THE CENDAK AREA AND THE PLAINS REGION OF SOUTHERN ALBERTA

Minimum and maximum elevations in the Plains Region of southern Alberta are about 1,000 feet higher than elevations in the CENDAK area. On a regional scale, relief is higher in Alberta due to deep incision of the major streams. Local relief on the rolling glacial plains is very similar, generally less than 100 feet in both areas. The topography of the irrigated and proposed irrigated areas is very similar, consisting of flat lake plains and rolling glacial landscape with closed depressions.

Natural surface runoff to river systems in both areas is low, amounting to about 17 acre feet per square mile (0.3 inches) in CENDAK and about 20 acre feet per square mile (0.4 inches) in Alberta. The small amount of surface runoff in both areas is attributed to low relief and containment of water in depressions prior to evapotranspiration and infilitration into the soil.

CHAPTER 4.A.

# POTENTIALLY IRRIGATED LANDS IN CENTRAL SOUTH DAKOTA

by

U.S. BUREAU OF RECLAMATION
MB LAND CLASSIFICATION BRANCH

1987

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TABLE

## 4.A.1
## LOCATION

The proposed CENDAK irrigation project area is located in central South Dakota. It is mainly comprised of 160-acre individual parcels of land totaling up to 474,000 acres dispersed through the counties of Hughes, Hyde, Hand, Faulk, Spink, and Beadle.

## 4.A.2
## GEOLOGY

The geologic history of the area is predominantly one of sedimentary deposition since the Cambrian Period. Deposition of sedimentary rocks occurred through a progression of transgressive-regressive depositional sequences from Cambrian through Miocene time. Exposures of these rocks are rare (due to the extensive overlying glacial deposits) except along trenches cut by the Missouri River and larger streams. Subsurface drilling indicates that the bedrock has a gentle dip to the northwest. The Pierre Shale, a dark-gray, bentonitic, calcareous, moderately soft clay shale, underlies nearly the entire study area.

Drainage systems that had developed in late Tertiary time were destroyed or interrupted by the glacial advances. Prior to the Pleistocene, drainages flowed eastward through most of South Dakota to the area near the James River. Drainages north of the White River, which is located approximately 40 miles south of the CENDAK area, flowed north into Hudson Bay, while the White River and others to the south flowed southeastward to the Gulf of Mexico.

Several ice sheets advanced over the area east of the Missouri River during the Pleistocene epoch, each leaving its load of debris in forms of glacial till (gravelly clay loams) and zones of outwash (sand and gravel) and lacustrine materials (laminated clay, silt, and sand). These deposits are up to 500 feet thick in places. These advances went far enough south and west to block the flows of the above-mentioned drainages. As these streams were blocked, lakes and ponds developed ahead of the ice sheets. Water topping the divides soon cut a new channel forming the present Missouri River trench. During the intervals between advances, deposits of loessial material (dominantly silt-size particles) were widely distributed, especially on the leeward side of major drainages. There are also areas of significant loess deposits just east of the Missouri River.

New drainages, depositing Holocene alluvium, have developed east of the Missouri River since the end of the Pleistocene epoch. Most flow southward, but a few flow northward. They are controlled chiefly by topographic highs constructed by glacial deposits.

A more detailed description of the geology of the CENDAK area is provided in Chapter 5.A.

## 4.A.3
## TOPOGRAPHY

The prevailing topography of the glaciated lands of the CENDAK area is typical of eastern South Dakota as well as much of the section of the Northern Great Plains over which the late Wisconsin ice sheet passed. The general overall slope is to the east and averages approximately 8 feet per mile. It is dominated by hummocky morainic topography, that has been but little modified by erosional forces since the close of the glacial epoch. Surface conditions vary from smooth to rolling with undulating conditions predominating. The area is dotted with numerous small enclosed basins or "potholes" which were formed by blocks of ice of varying sizes breaking off from the glacier and being buried under the till. Subsequent melting of the ice caused sinking of the surface, leaving the potholes. Although "swell and swale" topography predominates on the glaciated portions of the unit, there are sizeable areas that are relatively flat and smooth. Flint (1955) described three major surficial physiographic divisions within the area, i.e., the Coteau du Missouri, the James River Lowland, and Lake Dakota Plain. A detailed description of these are provided in Chapter 3.

Relief, or the lay of the land, influences soil formation through its effect on drainage, runoff, erosion, plant cover and soil temperature. The relief of the CENDAK area varies from nearly level to undulating with very few small areas that are moderately sloping or gently rolling. Soils formed on steeper slopes lose more rainfall to runoff, which decreases the amount of moisture entering the soil and increases the amount of soil lost through erosion. The reduced leaching and poor plant growth typically results in a soil calcareous at or near the surface with a thin dark surface layer. Soils, such as Houdek, Hand, and Williams, which occur on nearly level to undulating slopes, have slower runoff with more moisture entering the soil, which contributes to greater soil development. This process is associated with thicker dark soil horizons with carbonates leached to a greater depth. Beotia and Prosper soils formed in swales or toe slopes on the lower portion of the landscape that receive runoff water from adjacent soils. The additional moisture leaches lime to greater depths and produces more grass, adding more organic matter to the soil which results in a thick dark layer. On bottom lands, where drainage is impeded and water table is high, the fluctuating water table favors the concentration of salts. The many small to large closed depressions have deep, dark-colored soils that frequently have a claypan in the subsoil such as the Tetonka soil.

The elevation ranges from about 2,150 in the Ree Hills area to 1,259 feet above mean sea level along the James River.

## 4.A.4
## SOILS

Soil is produced by processes acting on materials deposited or accumulated by geologic agents. The characteristics of the soil at any given point are determined by the physical and mineral composition of the parent material, the climate under which the soil material has accumulated and existed since accumulation, the plant and animal life on and in the soil, the relief of the land, and length of time the forces of soil formation have acted on the soil material.

Climate, plant, and animal life are the active factors of soil formation. They act on the parent material that has accumulated through the weathering of rocks and slowly change it to a natural body with genetically related horizons. The effects of climate and plant and animal life are conditioned by relief which mainly determines soil drainage. The parent material, to a great degree, determines the texture and mineralogical composition of the soil profile. Time is always required for differentiation of soil horizons. For example, a soil on a flood plain which received annual increments of alluvium has little or no genetic horizon development, although it may have strata of contrasting alluvium, while a soil on a terrace usually has a genetically related horizon sequence.

The factors of soil formation are so closely interrelated in their effects on the soil that few generalizations can be made regarding the effect of one factor unless conditions are specified for the others. Many soil forming processes are unknown or poorly understood.

In the following paragraphs, the factors of soil formation as they apply to CENDAK are briefly described.

Most of the soils within the CENDAK area are derived from materials that were ground up, transported, and deposited during glaciation of the area. The CENDAK area is almost completely covered by glacial drift. Till constitutes the greater bulk of the drift and is predominantly fine textured. This reflects the derivation of the till in large part from the local shale bedrock. Some of these materials were later transported and sorted by water and wind action.

In 1982, the Bureau of Reclamation completed a reconnaissance-level land-classification survey on approximately 15 percent of the sign-up lands scattered across each county within the CENDAK Project. The major soil series that were encountered were derived from varying types of glacial deposits. Till provides the parent material for the largest number of soil series. These included the Beadle, Dudley, Stickney, Williams, Houdek, Max, Niobell, Noonan, Zahl, and Glenham soil series. The Eakin and Walke series have silty parent material underlain by till.

Outwash deposits over till or drift are the parent materials of Carthage soils, while outwash reworked by the wind is the parent material for Maddock, Hammar, and Hecla soils. Soils formed in glacial drift include Bonilla, Hand, and Highmore.

Tetonka, Nishon, LaDelle, and Hoven soils formed in alluvium. Prosper, Arnegard, Bowbells, and Williams formed in alluvium and till.

Soils formed within the CENDAK area on the Lake Dakota Plain are primarily of glacio-lacustrine origin. The major series encountered included Harmony, Great Bend, and Beotia.

Climate is a factor in soil formation because it directly influences the rate of chemical and physical weathering.

The CENDAK area has a continental-type climate characterized by long, cold winters; hot summers; little winter precipitation and marginal rainfall during the growing season.

Extreme temperatures of over 100 degrees F occasionally occur during summer months. Temperatures frequently fall below 0 degrees F in most years. The ground freezes to a depth of 3 to 6 feet in winter. The average temperature is 45 degrees F and average temperatures from June to September are between 68 degrees and 70 degrees F. The growing season, based on temperatures above 28 degrees F, averages 150 days at the Highmore station.

Normal annual precipitation is 18 inches. This amount of precipitation is sufficient to leach carbonates to a depth of 10 to 25 inches. On the average, 75 to 80 percent of the annual precipitation occurs from April through September. Generally, precipitation increases from northwest to southeast. Occasional storms may drop 3 or more inches of rain within a 24-hour period. During the growing season, most precipitation comes from showers of short duration, rather than from steady, less intense rainfall lasting several hours. Most of the winter precipitation is snow. The strong winds accompanying most heavy snows cause considerable drifting. Sheltered areas may be covered by deep drifts while wide, exposed areas retain little or no snow.

The prevailing wind is southerly from May through October and northwesterly during the remainder of the year. The average wind speed is 10 to 13 miles per hour. Winds of 50 miles per hour or more may occur in any month.

Winds are lightest in July and August and highest velocities may be expected in March, April, and May.

The percentage of possible sunshine is about 70 to 75 percent in the summer and about 55 to 60 percent in the winter. Due to the latitude and high percentage of possible sunshine, there are long hours of sunshine, permitting the growth of a variety of crops if sufficient moisture is present.

The summer relative humidity varies from 84 percent in the morning to 45 percent in the afternoon. Evaporation from water surfaces will vary throughout the area, being locally dependent on temperature, humidity, wind speed, and vapor pressure. Average annual evaporation from water surfaces is about 36 inches, but may exceed 50 inches during years of low precipitation and high temperatures. About 80 percent of the annual evaporation takes place from May through October.

The length of time that soil material has been exposed to other soil-forming factors determines in part the type of soils that form. Soil formation and erosion may go on at about the same rate on undulating topography. On flat slopes, destructive processes are minimized and deeper soils develop, which are relatively older from the standpoint of soil formation, than the soils formed on undulating and rolling topography. The time factor is relative and varies across materials of the same geologic age. Most of the soils in CENDAK are on relatively young landscapes that date back to the late Wisconsin glaciation.

The tall and mixed grass prairie vegetation of the CENDAK area, consisting of western wheatgrass, big bluestem, blue grama, needle and thread, green needlegrass, and porcupine grass, has had more influence on soil formation than other living organisms. The roots and other portions of the plants are the main source of organic matter found in the dark colored surface layers. Earthworms, cicada, and burrowing animals help to keep the soil open and porous. Bacteria, fungi, and other micro-organisms decompose organic residue and release nutrients in a form available for plants.

Cultivation and intensive grazing over the last 100 years have reduced the abundance and vigor of desirable native vegetation and increased the abundance of less desirable plants. Tree claims and shelterbelts have introduced new species to the area. Due to the short time involved, cultivation, intensive grazing, and introduced vegetation have had little effect on soil form beyond the mixing and destruction of the upper horizons.

Soils are classified according to characteristics that are the result of different soil formation factors. In the case where differences in otherwise similar soils are the result of topographic location and/or drainage, the group of soils is termed a catena, or toposequence. Soils that have developed in one area from the same parent material, but under different topographic conditions, will exhibit differences attributable to differing rates of erosion, accumulation, water movement, slope aspects, and the vegetation that occurs under these varying conditions.

The catenas that exist in the CENDAK area are influenced primarily by the differing rates of erosion, accumulation, and water movement, including runoff and drainage. One example in Faulk and Hand Counties is the Zahl-Williams-Bowbells-Nishon toposequence. All four series are derived from loam till on uplands, with local alluvium forming the Nishon and some of the Bowbells soils. The Zahl soils are excessively drained soils on steep slopes. The Williams soils are well-drained soils found on the undulating to nearly level areas. The Bowbells soils are moderately well-drained soils in swales and on footslopes, and the Nishon soils are poorly drained soils in depressions.

The toposequence can be easily explained if one visualizes a cross-section of a landscape that includes a hilly area leveling off to and including a depression. Precipitation falling over the landscape will tend to erode the soils on the steeper slopes, thereby retarding the development of that soil. The soils on the undulating to level areas are more developed as there is less erosion. The soils in the swales and on footslopes have material added to them from the steeper slopes as do those formed in depressions.

The amount of water influencing these soils increases as one moves downslope. Runoff from the hilly areas accumulates in the depressions. This further influences the differing development of these soils from the same parent materials.

Examples of toposequences in the CENDAK area include (ordered from upland slopes to depressions): Houdek-Prosper-Tetonka (till and alluvium derived soils with the Tetonka soils being formed in depressions), Betts-Java-Glenham-Hoven (till and local alluvium derived) and Hand-Bonilla-Tetonka (glacial drift and local alluvium derived).

Table 1 is a taxonomic listing of the soil series encountered during the 1982 Bureau of Reclamation reconnaissance level survey (USDA Soil Conservation Service South Dakota, 1975a, 1975b, 1979, and 1981). Available water capacities are also listed. The Houdek and Williams soils are the most frequently encountered series in the CENDAK area.

Profile descriptions of the predomiant series are listed after table 1.

## 4.A.4.1
## Beadle Series

The Beadle Series consist of deep, well drained, moderately slowly permeable soils formed in glacial till. These soils are on uplands. Slopes range from 0 to 9 percent.

Beadle soils are near Houdek, Lane, and Prosper soils. Houdek soils have less clay in the B2t horizon than Beadle soils. Lane and Prosper soils are moderately well drained and have a mollic epipedon that is more than 20 inches thick.

Typical pedon of Beadle loam, 0 to 2 percent slopes, is located 1,100 feet west and 180 feet north of the southeast corner of section 18, T. 113 N., R. 61 W.

Table 1. Classification of soil into higher catergories

| Series | Family | Subgroup | Order | Available Water Capacity (Inches per 5 feet) |
|---|---|---|---|---|
| Arnegard | Fine-loamy, mixed | Pachic Haploborolls | Mollisols | 8.02 - 8.98 |
| Beadle | Fine, montmorillonitic, mesic | Typic Argiustolls | Mollisols | 7.41 - 8.97* |
| Beotia | Fine-silty, mixed | Pachic Udic Haploborolls | Mollisols | 8.62 - 10.06 |
| Bonilla | Fine-loamy, mixed, mesic | Pachic Haplustolls | Mollisols | 6.35 - 9.71* |
| Bowbells | Fine-loamy, mixed | Pachic Argiborolls | Mollisols | 8.27 - 9.60 |
| Carthage | Coarse-loamy, mixed mesic | Pachic Haplustolls | Mollisols | 5.36 - 8.64 |
| Cavour | Fine, montmorillonitic | Udic Natriborolls | Mollisols | 6.63 - 9.99 |
| DeGrey | Fine, montmorillonitic, mesic | Typic Natrustolls | Mollisols | 5.74 - 7.38 |
| Dudley | Fine, montmorillonitic, mesic | Typic Natrustolls | Mollisols | 6.69 - 9.65 |
| Eakin | Fine-silty, mixed, mesic | Typic Argiustolls | Mollisols | 8.42 - 9.86 |
| Glenham | Fine-loamy, mixed, mesic | Typic Argiustolls | Mollisols | 8.31 - 9.72 |
| Great Bend | Fine-silty, mixed | Udic Haploborolls | Mollisols | 8.48 - 9.92 |
| Hand | Fine-loamy, mixed, mesic | Typic Haplustolls | Mollisols | 7.50 - 9.44 |
| Harmony | Fine, montmorillonitic | Pachic Udic Argiborolls | Mollisols | 8.37 - 9.81 |
| Hecla | Sandy, mixed | Aquic Haploborolls | Mollisols | 4.44 - 5.80 |
| Highmore | Fine-silty, mixed, mesic | Typic Argiustolls | Mollisols | 8.40 - 9.78 |
| Houdek | Fine-loamy, mixed, mesic | Typic Argiustolls | Mollisols | 6.58 - 10.18* |
| LaDelle | Fine-silty, mixed | Cumulic Udic Haploborolls | Mollisols | 8.52 - 9.96 |
| Max | Fine-loamy, mixed | Typic Haploborolls | Mollisols | 7.96 - 8.92 |
| Miranda | Fine-loamy, mixed | Leptic Natriborolls | Mollisols | 6.72 - 10.08 |
| Niobell | Fine-loamy, mixed | Glossic Natriborolls | Mollisols | 7.86 - 9.18 |
| Nishon | Fine-montmorillinitic, figid | Typic Albaqualfs | Alfisols | 6.18 - 8.12 |
| Noonan | Fine-loamy, mixed | Typic Natriborolls | Mollisols | 7.50 - 8.57 |
| Prosper | fine-loamy, mixed, mesic | Pachic Argiustolls | Mollisols | 8.74 - 10.28 |
| Stickney | fine, montmorillonitic, mesic | Glossic Natrustolls | Mollisols | 7.46 - 9.23 |
| Tetonka | Fine, monmorillonitic, mesic | Argiaquic Argialbolls | Mollisols | 6.96 - 9.42 |
| Williams | Fine-loamy, mixed | Typic Argiborolls | Mollisols | 6.41 - 9.77 |
| Zahl | Fine-loamy, mixed | Entic Haploborolls | Mollisols | 7.80 - 8.76 |

* Available Water Capacity includes the extremes of typical pedons published in more than one county soil survey.

A1 -- 0 to 7 inches; dark gray (10YR 4/2) clay loam, faces of peds very dark brown (10YR 2/2) moist, dark brown (10YR 3/3) rubbed and moist; moderate medium prismatic structure parting to moderate medium subangular blocky; hard, firm, sticky and plastic; neutral; gradual smooth boundary.

B21t -- 7 to 14 inches; dark grayish brown (10YR 4/2) clay, faces of peds very dark grayish brown (10YR 3/2) moist, dark brown (10YR 3/3) rubbed and moist; moderate medium prismatic structure parting to moderate medium subangular blocky; hard, firm, sticky, and plastic; neutral; gradual wavy boundary.

B22t -- 14 to 17 inches; dark grayish brown (10YR 4/2) clay, faces of peds very dark grayish brown (10YR 3/2) moist, dark brown (10YR 3/3) rubbed and moist; moderate medium prismatic structure parting to moderate medium subangular blocky; hard, firm, sticky and plastic; neutral; gradual wavy boundary.

B3ca -- 17 to 30 inches; grayish brown (2.5Y 5/2) clay, dark grayish brown (2.5Y 4/2) moist; weak medium prismatic structure parting to moderate medium subangular blocky; hard, friable, sticky and plastic; many fine segregations of lime; strong effervescence; mildly alkaline; gradual wavy boundary.

Clca -- 30 to 36 inches; light brownish gray (2.4Y 6/2) clay loam, dark grayish brown (2.5Y 4/2) moist; massive; slightly hard, friable, sticky and plastic; few fine segregations of lime; strong effervescence; mildly alkaline; gradual wavy boundary.

C2 -- 36 to 60 inches; light brownish gray (2.5Y 6/2) and grayish brown (2.5Y 5/2) clay loam, grayish brown (2.5Y 5/2) and dark grayish brown (2.5Y 4/2) moist; massive; slightly hard, friable, slightly sticky and slightly plastic, slight effervescence; moderately alkaline.

The thickness of the solum ranges from 16 to 45 inches. The mollic epipedon is 8 to 20 inches thick and includes all or part of the B2t horizon. The depth to free carbonates ranges from 12 to 25 inches.

The A horizon has color value of 3 or 4 (2 or 3 moist) and chroma of 1 or 2. It typically is loam but is silt loam in some pedons. It is slightly acid or neutral and is 6 to 11 inches thick. The B2t horizon has hue of 10YR or 2.5Y, value of 3 to 5 (2 to 4 moist), and chroma of 2 or 3. It is clay loam or clay averaging between 35 and 45 percent clay and is neutral or mildly alkaline. The B3ca and Clca horizons have hue to 10YR or 2.5Y, value of 5 to 7 (4 or 5 moist), and chroma of 2 or 3. The B3ca and C horizons are mildly alkaline or moderately alkaline. The C horizon has hue of 2.5Y or 5Y, value of 5 to 7 (4 or 5 moist), and chroma of 2 to 4. Iron oxide stains inherent in the parent material, shale fragments, and nests of gypsum are in some pedons.

## 4.A.4.2
## Bonilla Series

The Bonilla Series consists of deep, moderately well drained soils in upland swales and on flats and foot slopes. These soils formed in stratified loamy glacial drift. Permeability is moderate in the solum and moderate or moderately slow in the underlying material. Slopes range from 0 to 6 percent.

Bonilla soils are similar to Davis and Prosper soils and are near Davison and Hand soils. Davis soils formed in alluvium and typically are deeper to free carbonates than Bonilla soils. Davison soils have calcic horizons. Hand soils have a mollic epipedon that is less than 20 inches thick. Prosper soils have argillic horizons.

Typical pedon of Bonilla loam, in an area of Hand-Bonilla loams, 0 to 3 percent slopes, is located 1,180 feet west and 210 feet north of the southeast corner of sec. 2, T. 112 N., R. 63 W.

Ap -- 0 to 7 inches; dark gray (10YR 4/1) loam, black (10YR 2/1) moist; weak fine granular structure; slightly hard, friable, slightly sticky; neutral; abrupt smooth boundary.

A12 -- 7 to 9 inches; dark grayish brown (10YR 4/2) loam, black (10YR 2/1) moist; weak fine subangular blocky structure parting to moderate medium granular; slightly hard, friable, slightly sticky; neutral; gradual smooth boundary.

B2 -- 9 to 18 inches; dark grayish brown (10YR 4/2) loam, very dark grayish brown (10YR 3/2) moist; weak medium prismatic structure parting to weak medium subangular blocky; slightly hard, friable, slightly sticky; neutral; gradual wavy boundary.

B22 -- 18 to 23 inches; grayish brown (2.5Y 5/2) loam, very dark grayish brown (2.5Y 3/2) moist; weak medium prismatic structure parting to moderate medium subangular blocky; slightly hard, friable, slightly sticky; neutral; gradual wavy boundary.

B3ca -- 23 to 29 inches; light brownish gray (2.5Y 6/2) loam, dark grayish brown (2.5Y 4/2) moist; weak medium prismatic structure parting to weak fine subangular blocky; slightly hard, friable, slightly sticky; common fine segregations of lime; strong effervescence; mildly alkaline; gradual wavy boundary.

C1ca -- 29 to 38 inches; light gray (2.5Y 7/2) clay loam, light olive brown (2.5Y 5/4) moist; few fine faint mottles of dark yellowish brown (10YR 4/6); massive; hard, friable, slightly sticky and slightly plastic; common fine and medium segregations of lime; strong effervescence; mildly alkaline; gradual wavy boundary.

C2 -- 38 to 60 inches; pale yellow (2.5Y 7/4) clay loam, light olive brown (2.5Y 5/4) moist; few fine faint mottles of light olive brown (2.5Y 5/6); massive; hard, friable, slightly sticky and slightly plastic; few fine segregations of lime; strong effervescence; mildly alkaline.

The thickness of the solum ranges from 20 to 47 inches. The thickness of the mollic epipedon and the depth to free carbonates range from 20 to 34 inches.

The A horizon has color value of 3 or 4 (2 or 3 moist) and chroma of 1 or 2. It is fine sandy loam in some pedons. It is slightly acid or neutral and is 6 to 10 inches thick. The B2 horizon has hue of 10YR or 2.5Y, value of 4 or 5 (2 to 4 moist), and chroma of 1 or 2. It is clay loam in some pedons. It is neutral or mildly alkaline. The B3ca and C horizons have hue of 2.5Y or 5Y, value of 6 or 7 (4 or 5 moist), and chroma of 1 to 4. They are loam, clay loam, or silty clay loam and in some pedons are stratified with thin layers or coarser or finer material. The B3ca and C horizons are mildly alkaline or moderately alkaline. The C horizon has nests of gypsum and iron stains in some pedons.

## 4.A.4.3
## Bowbells Series

The Bowbells Series consists of deep, moderately well drained soils formed in loamy alluvium and glacial till in swales and on foot slopes. Permeability is moderate in the subsoil and moderately slow in underlying material. Slopes range from 0 to 3 percent.

The Bowbells soils in this area are taxadjuncts to the Bowbells Series because they have lower chroma in the A horizon than is defined as the range for the series. This difference, however, does not alter the usefulness or behavior of the soils.

Bowbells soils are similar to Arnegard and Grassna soils and commonly are near Niobell, Noonan, and Williams soils. Arnegard and Grassna soils do not have an argillic horizon. The well drained Williams soils are higher on the landscape than the Bowbells soils. Niobell and Noonan soils have a natric horizon. They are on flats, lower side slopes, and in swales.

Typical pedon of Bowbells loam, in an area of Williams-Bowbells loams, 1 to 6 percent slopes, is located 900 feet east and 140 feet south of the northwest corner of sec. 15, T. 119 N., R. 69 W.

Ap -- 0 to 6 inches; dark gray (10YR 4/1) loam, black (10YR 2/1) moist; moderate fine granular structure; slightly hard, friable; slightly acid; abrupt smooth boundary.

A -- 6 to 11 inches; dark gray (10YR 4/1) loam, black (10YR 2/1) moist; weak medium subangular blocky structure parting to moderate medium granular; slightly hard, friable; slightly acid; clear smooth boundary.

Bt1 -- 11 to 17 inches; dark grayish brown (10YR 4/2) clay loam, very dark grayish brown (10YR 3/2) moist; moderate medium prismatic structure parting to moderate medium subangular blocky; hard, friable, slightly sticky and slightly plastic; neutral; clear wavy boundary.

Ck -- 27 to 41 inches; light brownish gray (2.5Y 6/2) clay loam, light olive brown (2.5Y 5/4) moist; few medium prominent strong brown (7.5YR 5/8) mottles; massive; hard, friable; common fine accumulations of carbonate; strong effervescence; moderately alkaline; gradual wavy boundary.

C -- 41 to 60 inches; light yellowish brown (2.5Y 6/4) clay loam, light olive brown (2.5Y 5/4) moist; many fine and medium prominent strong brown (7.5YR 5/8) mottles; massive; hard, friable; few fine accumulations of carbonate; strong effervescence; moderately alkaline.

The thickness of the solum ranges from 22 to 38 inches. The depth to free carbonates ranges from 22 to 36 inches. The thickness of the mollic epipedon ranges from 16 to 27 inches.

The A horizon has value of 3 or 4 (2 or 3 moist). It is 8 to 15 inches thick. It is loam, silt loam, or clay loam. It is slightly acid or neutral. The Bt horizon has hue of 10YR or 2.5Y, value of 4 to 6 (2 or 3 moist), and chroma of 2 or 3. It is clay loam or loam. It is slightly acid or neutral.

Some pedons have a BC horizon. The C horizon has value of 4 to 6 (3 to 5 moist) and chroma of 2 to 4. It is a loam or clay loam.

## 4.A.4.4
## Eakin Series

The Eakin Series consists of deep, well drained, nearly level to sloping or undulating silty soils on uplands. These soils formed in silty materials and the underlying loam or clay loam glacial till.

In a representative profile, the surface layer is dark grayish-brown silt loam about 7 inches thick. The subsoil, about 15 inches thick, is silty clay loam that is dark grayish-brown in the upper part, grayish-brown in the middle part, and light brownish-gray in the lower part. The upper part is slightly hard when dry and friable when moist. The middle and lower parts are calcareous. In addition, the lower part contains spots and streaks of soft lime that extend into the underlying material. The underlying material is light brownish-gray, calcareous silty clay loam to a depth of 33 inches. Below this is grayish-brown and light olive-gray, calcareous glacial till of heavy clay loam texture.

Eakin soils are medium in fertility and moderate in organic-matter content. Permeability is moderate in the surface layer and subsoil and moderately slow in the underlying glacial till. Surface runoff is slow or medium, depending on the slope. Available water capacity is high.

Most areas are cultivated. Principal crops are small grain, corn, alfalfa, and sorghums. Some areas are in native grass and are used for grazing and hay. The native vegetation is a mixture of mid and short grasses.

Representative profile of Eakin silt loam from an area of Eakin-Raber silt loams, 2 to 5 percent slopes, in native grass, is located 1,000 feet west and 88 feet south of the northeast corner of sec. 2, T. 109 N., R. 74 W.

A1 -- 0 to 7 inches; dark grayish-brown (10YR 4/2) silt loam, very dark brown (10YR 2/2) moist; weak, fine, subangular blocky and moderate, fine, granular structure; soft, very friable; neutral; clear, smooth boundary.

B2t -- 7 to 13 inches; dark grayish-brown (10YR 4/2) silty clay loam, very dark grayish brown (10YR 3/2) moist; moderate, medium, prismatic structure; slightly hard, friable; mildly alkaline; clear, wavy boundary.

B31 -- 13 to 18 inches; grayish-brown (10YR 5/2) silty clay loam, dark grayish brown (10YR 4/2) moist; weak, medium, prismatic structure parting to weak, medium and fine, subangular blocky; slightly hard, friable, slight effervescence; mildly alkaline; clear, wavy boundary.

B32Ca -- 18 to 22 inches; light brownish-gray (10YR 6/2) silty clay loam, dark grayish brown (10YR 4/2) moist; weak, medium, subangular blocky structure; hard, friable; many medium segregations of lime; strong effervescence; moderately alkaline; clear, smooth boundary.

Clca -- 22 to 33 inches; light brownish-gray (10YR 6/2) silty clay loam, dark grayish brown (10YR 4/2) moist; moderate, medium prismatic structure; very hard, firm; many medium segregations of lime; strong effervescence; moderately alkaline; clear, wavy boundary.

IIC2 -- 33 to 50 inches; grayish-brown (2.5Y 5/2) heavy clay loam, dark grayish brown (2.5Y 4/2) moist; weak, medium, subangular blocky structure; hard, firm; few, fine, yellowish-brown (10YR 5/6) iron stains; few fine segregations of lime, slight effervescence; moderately alkaline; gradual wavy boundary.

II C3 -- 50 to 60 inches; light olive gray (5Y 6/2) heavy clay loam, olive gray (5Y 4/2) moist; massive; hard, firm; slight effervescence; moderately alkaline.

Depth to free carbonates ranges from 10 to 18 inches. Depth to underlying glacial till ranges from 20 to 40 inches. The A horizon ranges from dark gray to grayish brown in hue of 10YR and is 5 to 8 inches thick. The B2t horizon is dark grayish brown or grayish brown in hues of 10YR or 2.5Y. Estimated clay content ranges from 25 to 35 percent, but is typically about 28 percent. The IIC horizon ranges from grayish brown to light olive gray in hues of 10YR through 5Y. It is commonly clay loam, but has a thin stratum of loam or silt loam in some places.

Eakin soils are mapped with or near Glenham, Highmore, Onita, and Raber soils. They contain more silt and less sand in the B horizon than Glenham soils. They are shallower over glacial till than Highmore soils. They contain less clay in the B horizon than Onita and Raber soils.

## 4.A.4.5
## Hand Series

The Hand Series consists of deep, well drained, moderately permeable soils formed in stratified loamy glacial drift. These soils are on uplands. Slopes range from 0 to 9 percent.

Hand soils are near Betts, Bonilla, Ethan, and Houdek soils. Betts and Ethan soils have free carbonates within a depth of 10 inches. In addition, Betts soils lack a mollic epipedon. Bonilla soils have a mollic epipedon that is more than 20 inches thick. Houdek soils have argillic horizons.

Typical pedon of Hand loam, in an area of Hand-Bonilla loams, 3 to 6 percent slopes, is located 2,500 feet east and 310 feet south of the northwest corner of sec. 32, T. 111 N., R. 64 W.

A1 -- 0 to 9 inches; dark grayish brown (10YR 4/2) loam, very dark brown (10YR 2/2) moist; weak medium granular structure; slightly hard, friable, slightly sticky; neutral; gradual smooth boundary.

B21 -- 9 to 14 inches; dark grayish brown (10YR 4/2) loam, very dark grayish brown (10YR 3/2) moist; weak medium prismatic structure parting to moderate medium subangular blocky; slightly hard, friable, slightly sticky; neutral; gradual smooth boundary.

B22 -- 14 to 28 inches; grayish brown (10YR 5/2) loam, dark grayish brown (10YR 4/2) moist; weak medium and coarse prismatic structure parting to moderate medium subangular blocky; slightly hard, friable, slightly sticky; neutral; gradual wavy boundary.

B3ca -- 18 to 29 inches; light gray (2.5Y 7.2) light clay loam, grayish brown (2.5Y 5/2) moist; weak medium and coarse prismatic structure parting to weak medium subangular blocky; slightly hard, friable, slightly sticky; thin lenses of very fine sandy loam; common fine and few medium segregations of lime; strong effervescence; moderately alkaline; gradual wavy boundary.

C -- 29 to 60 inches; light brownish gray (2.5Y 6/2) clay loam, olive brown (2.5Y 4/4) moist; massive; slightly hard, friable, slightly sticky; thin lenses of loam and very fine sandy loam; strong effervescence; mildly alkaline.

The thickness of the solum ranges from 20 to 38 inches. The depth to free carbonates is 12 to 24 inches. The mollic epipedon is 8 to 20 inches thick and extends into the B2 horizon.

The A horizon has color value of 4 or 5 (2 or 3 moist) and chroma of 1 or 2. It is silt loam in some pedons and is medium acid to neutral. It is 6 to 10 inches thick. The B2 horizon has hue of 10YR or 2.5Y, value of 4 or 5 (3 or 4 moist) and chroma of 2 or 3. It is silt loam in some pedons and is slightly acid or neutral. The B3ca horizon has color value of 6 or 7 (4 or 5 moist) and chroma of 2 or 3. It is mildly alkaline or moderately alkaline. The C horizon has color value of 6 or 7 (4 or 5 moist) and chroma of 1 to 4. It commonly is stratified with material as coarse as loamy fine sand, but in some pedons it is loam or clay loam glacial till. It is mildly alkaline or moderately alkaline.

## 4.A.4.6
## Houdek Series

The Houdek Series consists of deep, well drained soils formed in glacial till. These soils are on uplands. Permeability is moderate in the solum and moderately slow in the underlying glacial till. Slopes range from 0 to 9 percent.

Houdek soils are near Beadle, Betts, Ethan, Hand, and Prosper soils. Beadle soils are fine textured. Betts, Ethan, and Hand soils lack argillic horizons. In addition, Betts and Ethan soils have free carbonates within a depth of 10 inches. Prosper soils have a mollic epipedon that is more than 20 inches thick.

Typical pedon of Houdek loam, in an area of Houdek-Prosper loams, 0 to 2 percent slopes, is located 2,375 north and 462 feet west of the southeast corner of sec. 15, T. 112 N., R. 62 W.

Ap -- 0 to 7 inches; dark gray (10YR 4/1) loam, black (10YR 2/1) moist; weak fine granular structure; slightly hard, friable, slightly sticky; neutral; abrupt smooth boundary.

B21t -- 7 to 15 inches; dark grayish brown (10YR 4/2) clay loam, very dark grayish brown (10YR 3/2) moist; moderate medium prismatic structure parting to moderate medium and fine subangular blocky; hard, friable, slightly sticky and slightly plastic; neutral; clear wavy boundary.

B22t -- 15 to 20 inches; grayish brown (2.5Y 5/2) clay loam; dark grayish brown (2.5Y 4/2) moist; dark grayish brown (10YR 4/2) coats on faces of peds; moderate medium prismatic structure parting to moderate medium and fine subangular blocky; hard, friable, slightly sticky and slightly plastic; mildly alkaline; clear wavy boundary.

B3ca -- 20 to 29 inches; light brownish gray (2.5Y 6/2) clay loam, light olive brown (2.5Y 5/4) moist; weak medium prismatic structure parting to moderate medium and fine subangular blocky; hard, friable, slightly sticky and slightly plastic; common fine and medium segregations of lime; strong effervescences; moderately alkaline; gradual wavy boundary.

C1ca -- 29 to 37 inches; light brownish gray (2.5Y 6/2) clay loam, olive brown (2.5Y 4/4) moist; weak medium and coarse subangular blocky structure; hard, friable, slightly sticky and slightly plastic; common medium and fine segregations of lime; strong effervescence; mildly alkaline; gradual wavy boundary.

C2 -- 37 to 60 inches; light brownish gray (2.5Y 6/2) clay loam, olive brown (2.5Y 4/4) moist; weak coarse subangular blocky structure; hard, friable, slightly sticky and slightly plastic; common dark stains (oxides); few fine nests of gypsum; few fine segregations of lime; strong effervescence; moderately alkaline.

The solum is 22 to 32 inches thick. The depth to free carbonates is 14 to 24 inches. The mollic epipedon is 8 to 20 inches thick.

The A horizon has color value of 3 to 5 (2 or 3 moist) and chroma of 1 or 2. It is silt loam in some pedons and is slightly acid or neutral. It is 5 to 8 inches thick. The B2t horizon has color value of 3 to 5 (2 to 4 moist) and chroma of 2 or 3. It is neutral to moderately alkaline. The B3ca horizon has hue to 10YR or 2.5Y, value of 4 to 6 (4 or 5 moist), and chroma of 2 to 4. It is mildly alkaline or moderately alkaline. The C horizon has hue of 2.5Y or 5Y, value of 5 to 7 (4 to 5 moist), and chroma of 2 to 4. It is mildly alkaline or moderately alkaline.

## 4.A.4.7
## Prosper Series

The Prosper Series consists of deep, moderately well drained soils formed in alluvium and glacial till. These soils are on foot slopes and in swales on uplands. Permeability is moderate in the upper part and moderately slow in the lower part. Slopes range from 0 to 6 percent.

Prosper soils are similar to Bonilla soils and are near Beadle, Davison, and Houdek soils. Beadle and Houdek soils have a mollic epipedon that is less than 20 inches thick. Bonilla soils lack argillic horizons. Davison soils have calcic horizons.

Typical pedon of Prosper loam, in an area of Houdek-Prosper loams, 0 to 2 percent slopes, is located 2,475 feet south and 255 feet east of the northwest corner of sec. 11, T. 109 N., R. 61 W.

Ap -- 0 to 7 inches; dark gray (10YR 4/1) loam, black (10YR 2/1) moist; weak fine granular structure; slightly hard, friable, slightly sticky; slightly acid; abrupt smooth boundary.

A12 -- 7 to 10 inches; dark gray (10YR 4/1) loam, black (10YR 2/1) moist; weak medium subangular blocky structure parting to weak fine granular; slightly hard, friable, slightly sticky; slightly acid; gradual smooth boundary.

B21t -- 10 to 20 inches; dark gray (10YR 4/1) clay loam, very dark gray (10YR 3/1) moist; weak medium prismatic structure parting to moderate medium subangular blocky; hard, friable, slightly sticky and slightly plastic; neutral; gradual wavy boundary.

B22t -- 20 to 23 inches; grayish brown (2.5Y 5/2) clay loam, very dark grayish brown (2.5Y 3/2) moist; moderate medium prismatic structure parting to moderate medium subangular blocky; hard, firm, slightly sticky and slightly plastic; neutral; gradual wavy boundary.

B31 -- 23 to 27 inches; grayish brown (2.5Y 5/2) clay loam, dark grayish brown (2.5Y 4/2) moist); weak medium prismatic structure parting to moderate medium subangular blocky; hard, firm slightly sticky and slightly plastic; few fine striations of lime; slight effervescence; mildly alkaline; gradual wavy boundary.

B32ca -- 27 to 34 inches; light brownish gray (2.5Y 6/2) clay loam, grayish brown (2.5Y 5/2) moist; weak medium coarse blocky structure; hard, friable, slightly sticky and slighty plastic; common medium and fine segregations of lime; strong effervescence; moderately alkaline; gradual wavy boundary.

C1 -- 34 to 43 inches; pale yellow (2.5Y 7/4) clay loam, light olive brown (2.5Y 5/4) moist; common medium distinct mottles of light gray (2.5Y 7/2); massive; hard, friable, slightly sticky and slightly plastic; few fine segregations of lime; strong effervescence; moderately alkaline; gradual wavy boundary.

C2 -- 43 to 60 inches; pale yellow (2.5Y 7/4) clay loam, light olive brown (2.5Y 5/4) moist; common medium distinct mottles of light gray (2.5Y 7/2) and yellowish brown (10YR 5/6); masive; hard, friable, slightly sticky and slightly plastic; strong effervescence; moderately alkaline.

The thickness of the solum ranges from 24 to 48 inches. The depth to free carbonates ranges from 20 to 34 inches. The mollic epipedon is 20 to 30 inches thick and extends into the B2t horizon.

The A horizon has color value of 3 or 4 (2 or 3 moist) and chroma of 1 or 2. It is silt loam in some pedons and is slightly acid or neutral. Jt is 7 to 13 inches thick. The B2t horizon has color value of 3 to 5 (2 to 4 moist) and chroma of 1 to 3. It is silty clay loam in some pedons and is neutral or mildly alkaline. The B3ca and C horizon have hue of 10YR or 2.5Y, value of 5 to 7 (4 to 6 moist), and chroma of 2 to 4. They are mildly alkaline or moderately alkaline.

## 4.A.4.8
## Williams Series

The Williams Series consists of deep, well drained soils formed in loamy glacial till on uplands. Permeability is moderate in the subsoil and moderately slow in the underlying material. Slopes range from 0 to 15 percent.

Williams soils are similar to Max, Raber, and Vida soils and commonly are near Bowbells Noonan, Tonka, Vida, and Zahl soils. The moderately well drained Bowbells soils have dark colors that extend below a depth of 16 inches. They are in swales. Max soils do not have an argillic horizon. Noonan soils have a natric horizon. They are in small depressions. The poorly drained Tonka soils are in depressions. Raber soils contain more clay in the subsoil than the Williams soils. Vida and Zahl soils have free carbonates within a depth of 10 inches. They are in positions on the landscape similar to those of the Williams soils.

Typical pedon of Williams loam, in an area of Williams-Bowbells loams, 0 to 3 percent slopes, is located 660 feet north and 132 feet west of the southeast corner of sec. 9, T. 120 N., R. 70 W.

A -- 0 to 7 inches; dark grayish brown (10YR 4/2) loam, very dark brown (10YR 2/2) moist; weak medium and fine granular structure; slightly hard, friable; neutral; abrupt smooth boundary.

Bt1 -- 7 to 12 inches; dark grayish brown (10YR 4/2) clay loam, very dark grayish brown (10YR 3/2) moist; moderate medium prismatic structure parting to strong medium and fine subangular blocky; hard, firm, sticky and plastic; shiny film on faces of peds; neutral; clear wavy boundary.

Bt2 -- 12 to 18 inches; brown (10YR 5/3) clay loam; dark brown (10YR 3/3) crushing to brown (10YR 4/3) moist; moderate medium prismatic structure parting to strong medium and fine subangular blocky; hard, firm, sticky and plastic; shiny films on faces of peds; neutral, abrupt wavy boundary.

BCk -- 18 to 30 inches; light olive brown (2.5Y 5/4) clay loam, olive brown (2.5Y 4/4) moist; moderate coarse prismatic structure parting to moderate coarse and medium subangular blocky; hard, friable, slightly sticky and slightly plastic; common fine and medium accumulations of carbonate; slight effervescence; mildly alkaline; gradual wavy boundary.

Ck -- 30 to 38 inches; pale yellow (2.5Y 7/4) clay loam, light yellowish brown (2.5Y 6/4) moist; common fine and medium distinct strong brown (7.5 YR 5/8) mottles; massive; hard, friable, slightly sticky and slightly plastic; common fine accumulations of carbonate; strong effervescence; moderately alkaline; gradual wavy boundary.

C -- 38 to 60 inches; pale yellow (2.5Y 7/4) clay loam, light yellowish brown (2.5Y 6/4) moist; common fine and medium distinct strong brown (7.5YR 5/8) mottles; massive; hard, friable, slightly sticky and slightly plastic; strong effervescence; moderately alkaline.

The thickness of the solum ranges from 15 to 30 inches. The thickness of the mollic epipedon ranges from 10 to 16 inches. The depth of free carbonates ranges from 10 to 24 inches.

The A horizon has value of 3 or 4 (2 or 3 moist). It is loam, stony loam, very stony loam, silt loam, or clay loam and is 4 to 9 inches thick.

The Bt horizon has hue of 2.5Y, value of 4 or 5 (3 or 4 moist), and chroma of 2 or 3. It is loam or clay loam and is neutral or mildly alkaline. Some pedons do not have a BC horizon. The C horizon has hue of 2.5 Y or 5Y, value of 6 or 7 (4 to 6 moist), and chroma of 2 to 4. It is loam or clay loam.

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CHAPTER 4.B.

# IRRIGATED LANDS OF ALBERTA

by

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## 4.B.1
## INTRODUCTION

Irrigated agriculture is an important segment of agriculture in Alberta. Less than 4 percent of the arable land is irrigated from which comes about 20 percent of the agricultural product (van Schaik, 1973). Irrigation, on an organized program, began in 1898 when people were brought in from Utah to develop lands for the Canadian Pacific Railway. At that time there was no concern over the irrigability of the soil. If water could be applied to the land by gravity, it was considered irrigable. Since the turn of the century more land has been developed for irrigation. The last major development was in the 1950's when the St. Mary River project was developed. Since then limited acreage has been brought under irrigation through pumping, primarily high land, both within and outside the irrigation districts.

Concern over the suitability of land for irrigation started in the late 1940's. It was not until 1969 that it became mandatory that land be rated suitable before it could be irrigated. Had this law been in effect in the beginning, much of the land currently being successfully irrigated would have been declared unsuitable.

The permanency and prosperity of irrigation in Alberta has been questioned by Maierhofer (1956) and Stanley/SLN Consultants Ltd. (1978). They maintained that the irrigated and potentially irrigated lands would experience serious subsurface drainage problems, attributable to the till at shallow depth. Depth to till varies from near the surface to more than 6 feet, but mostly between 2 to 5 feet. The tills are generally considered to have very low water transmissivity capacity. This conclusion was derived from soil hydraulic conductivity studies, primarily on disturbed samples. Many of these soils with shallow till have been successfully irrigated for more than 50 years. In a block of land north of Vauxhall, more than 3.5 townships in area and till depth was less than 3.5 feet over most of the area, the average water table depth for the 15-year study was 3.5 $\pm$ 0.3 feet (Rapp and van Schaik, 1972). Sommerfeldt and Oosterveld (1977) found that when till was at 5 feet and deeper there seemed to be no threat of salinization of the land under normal irrigation. With till at 2 to 4 feet in depth, there was a tendency for the soil to salinize. When the till depth was less than 2 feet the tendency for soil salinization was greater than where till was at 2 to 4 feet depth.

Studies carried out over the years, collated and reported by Chang and Sommerfeldt (1985, included as appendix A) indicate that irrigation has not created the problems projected. Rather, long term irrigation in Alberta generally has not been detrimental to the land. The weathered tills were found to be structured and have fractures through which the water percolates (Hendry, 1982). The saturated hydraulic conductivity of the till matrix averages 1.4 x 10(-5) inches/hr, while that of the small fractures is 7.1 x 10(-4) inches/hr and that of the large fractures is 2.8 x 10(-2) inches/hr (Hendry, 1982). Successful irrigation of these lands in Alberta is attributed to these fractures in the till to provide the needed internal drainage (Hendry, 1982). The hydraulic conductivity of the unweathered till is 1.4 x 10(-5) inches/hr (1 x 10(-8) cm/sec). There is evidence of some water movement in the unweathered till (M. J. Hendry, Hydrologist, Drainage Branch, Alberta Agriculture, Lethbridge, Alberta, personal communication).

The major sources of waterlogging and salinity problems is from canal seepage (Sadler, 1966; Chang et al., 1985). The soil has capacity to accommodate the irrigation water when applied judiciously. When excessive amounts of water were applied there was a tendency for the water table to rise. But, when water was applied judiciously the water table depth receded (Rapp and van Schaik, 1972). Because of the climate in the region, irrigation requirements are not as great as in warmer, drier climates. The growing season is short, followed by a long season for drainage to lower the water table that may have built up during the irrigation season (Nielsen, 1971). Rapp and van Schaik (1972) found the water table in land north of Vauxhall varied from near the surface after irrigation to 4 feet before the next irrigation. During the winter months period of no irrigation, the water table receded to more than 10 feet in depth. Under normal irrigation there is evidence of sufficient leaching to generally maintain good salt balance in the soil (Chang et al, 1982). Some of this leaching can be attributed to precipitation, which has a desirable distribution. The mean annual precipitation at Lethbridge is 16.7 inches, with peak precipitation in the months of May and June, a period when the soil is usually saturated from fall, winter and early spring precipitation, to cause some leaching. This, along with excess waters from normal irrigation is sufficient to provide the necessary leaching to maintain a good salt balance in the soil. Also the water used for irrigation is of excellent quality so that excessive amounts of salts are not being applied to the soils from this source. The amount of precipitation varies among irrigation districts, varying from 16.7 inches at Lethbridge to 13.7 inches at Medicine Hat. Distribution of precipitation throughout is similar to that around Lethbridge.

Estimates of 10 to 25 percent of the land reportedly has become salinized over the several decades of irrigating these lands. Probably 12 to 15 percent would be a better estimate because the higher estimates include nonirrigated land contained within the irrigation district. It is also recognized that about 10 percent of the nonirrigated land in southern Alberta is salinized. Some districts report less than 10 percent of their land has become salinized, while other districts report more than 20 percent. Most of the problems can be attributed to canal seepage and mismanagement of the water.

## 4.B.2
## LOCATION AND OVERVIEW

There are 13 irrigation districts in Alberta, comprising an area of over 1,000,000 acres of land (table 1). These districts are located throughout an area between 110 degrees and 114 degrees longitude and 49 degrees and 51 degrees 30 minutes north latitude (fig. 1 and app. B).

Table 1

**Assessed acreage of land in the major irrigation districts in southern Alberta 1979 - 1980**

| Irrigation District | Acres (thousands) |
|---|---|
| Aetna | 3.1 |
| Bow River | 150.2 |
| Eastern | 227.3 |
| Leavitt | 4.5 |
| Lethbridge Northern | 111.9 |
| Magrath | 10.8 |
| Mountain View | 3.7 |
| Raymond | 31.5 |
| Ross Creek | 1.8 |
| St. Mary | 287.3 |
| Taber | 69.8 |
| United | 33.5 |
| Western | 74.5 |
| TOTAL | 1,009.9 |

The value of irrigation in Alberta was demonstrated by individuals on small acreages in the late 19th century. As early as

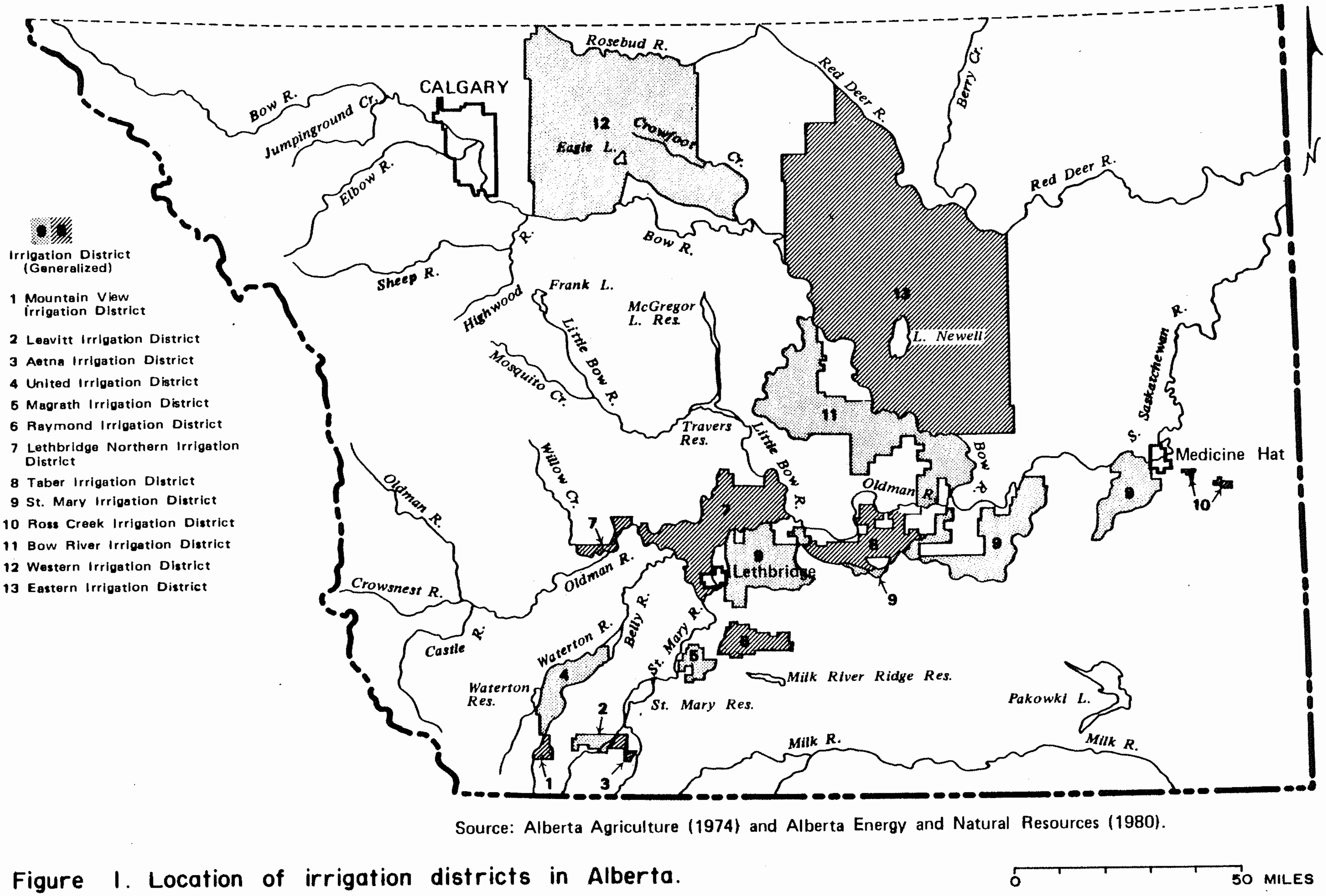
1894 the Government of Canada passed the Northwest Irrigation Act. This was superceded by the Alberta Irrigation Act in 1906, after Alberta became a province in 1905. In 1915 the Alberta Irrigation Districts Act was passed. This was superceded by the Water Resources Act in 1931. In 1968 all former acts governing irrigation districts were repealed by the Alberta Government and replaced by a new Irrigation Act.

As already stated, irrigation in Alberta is of major importance. In 1975 the Water Resources Act was revised to where water for irrigation was designated third in allocation, after domestic and municipal use. Industrial, power, and recreation use have lower priority.

Since the beginning of organized irrigation in Alberta, in 1900, the area of land irrigated has increased steadily (table 2). The assessed acreage (table 3) is more than the irrigated acreage. This reflects climatic and economic conditions. In seasons of low rainfall and in times of good economic conditions more land is irrigated than in other times.

The discrepancy among some dates of origin in the text and in table 3 are due to dates of actually forming the districts. For instance, there is record of irrigation in the Eastern and Western Irrigation District areas near the turn of the century, yet the districts were not organized, as we know them now, until 1935 and 1944, respectively.

The Mountain View, Leavitt, Aetna and United irrigation districts are located south and west of Lethbridge, in the thin black soil zone. It is underlain with bedrock of the Willow Creek formation (non-marine in origin, and consists of alternate beds of sands, clays and sandy clays). The soils, alluvial-lacustrine over till and till in origin, are mostly loams to clay loams in texture. The United irrigation district was organized and constructed in 1921, the Mountain View and Leavitt districts were established during the 1930's and the Aetna district was established in the 1940's. All these districts are small. The irrigation water from the headwaters of the Belly River is of excellent quality (200 to 300 ppm TDS). The growing season is short, 90 to 100 days, frost free period. Because of the short growing season, and because these districts are located in the higher rainfall area, the dependency on irrigation here is not as great as it is farther east. The crops grown are primarily forage, for hay and pasture, and cereal grains. The topography in the Mountain View, Leavitt and Aetna districts varies from hilly to undulating, and sloughs, used for livestock watering, are frequent. The amount of salinity within these districts is small, estimated at less than 2 percent. The topography in United irrigation district is mostly undulating to flat with some long sloping hills. The bedrock under these irrigation districts is the St. Mary River formation, non-marine in origin.




Source: Alberta Agriculture (1974) and Alberta Energy and Natural Resources (1980).

Figure I. Location of irrigation districts in Alberta.

Table 2

**Area of land actually irrigated in Alberta over the years**

| Irrigation District | Acres Irrigated | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1930 | 1940 | 1950 | 1960 | 1970 | 1975 | 1980 | 1985 |
| Aetna | ---- | ---- | ---- | 440 | 2,523 | 2,400 | 2,500 | 2,933 |
| Bow River | 31,207 | 37,906 | 36,508 | 71,392 | 77,580 | 98,332 | 134,493 | 174,087 |
| Eastern | 89,913 | 146,211 | 180,000 | 189,761 | 199,729 | 179,095 | 212,524 | 244,763 |
| Leavitt | ---- | ---- | 2,500 | 1,542 | 4,523 | 4,430 | 4,476 | 3,664 |
| Lethbridge Northern | 70,007 | 72,492 | 78,721 | 71,006 | 49,783 | 70,859 | 95,979 | 114,635 |
| Magrath | 5,167 | 3,700 | 3,500 | 5,000 | 5,000 | 6,000 | 8,000 | 13,000 |
| Mountain View | ---- | 3,000 | 3,300 | 2,789 | 2,789 | 3,000 | 2,900 | 3,184 |
| Raymond | 7,000 | 13,000 | 12,000 | 15,200 | 15,000 | 21,500 | 19,137 | 36,286 |
| Ross Creek | ---- | ---- | ---- | 200 | 1,000 | 600 | 600 | 700 |
| St. Mary River | 67,004 | 75,766 | 77,674 | 179,477 | 134,982 | 175,883 | 251,914 | 305,560 |
| Taber | 19,322 | 21,391 | 21,864 | 29,448 | 50,094 | 44,606 | 63,202 | 70,133 |
| United | 5,847 | 10,500 | 9,758 | 16,536 | 15,019 | 4,952 | 12,607 | 12,620 |
| Western | 41,570 | 20,134 | 23,100 | 12,000 | 15,000 | 34,036 | 43,986 | 49,666 |
| TOTAL | 337,031 | 404,973 | 448,925 | 594,791 | 573,022 | 641,693 | 852,318 | 1,031,231 |

Table 3

**Assessed acres of irrigated land in Alberta**

| Irrigation District | Year Organized | Assessed Acres 1970 | 1975 | 1980 | 1985 |
|---|---|---|---|---|---|
| Aetna | 1945 | 6,673 | 3,081 | 3,104 | 3,399 |
| Bow River | 1909* | 23,783 | 131,764 | 164,889 | 185,034 |
| Eastern | 1935 | 199,729 | 212,982 | 229,110 | 246,658 |
| Leavitt | 1944 | 4,523 | 4,430 | 4,477 | 4,460 |
| Lethbridge Northern | 1920 | 89,360 | 108,106 | 112,562 | 118,883 |
| Magrath | 1898** | 8,506 | 8,871 | 10,797 | 14,218 |
| Mountain View | 1920 | 3,719 | 3,720 | 3,710 | 3,710 |
| Raymond | 1898** | 20,847 | 26,920 | 33,681 | 44,990 |
| Ross Creek | 1949 | 2,068 | 2,068 | 1,776 | 1,319 |
| St. Mary River | 1898** | 197,540 | 252,019 | 293,126 | 328,065 |
| Taber | 1919 | 57,484 | 62,692 | 70,368 | 73,063 |
| United | 1920 | 33,353 | 33,358 | 33,544 | 33,854 |
| Western | 1944 | 44,006 | 45,311 | 76,029 | 85,698 |
| TOTAL | | 691,591 | 895,322 | 1,037,173 | 1,143,349 |

* Bow River Irrigation District increased 94,000 acres in 1974 with the amalgamation of the Bow River Irrigation District and the Bow River (Federal) Project.

** Originally the Magrath, Raymond, and St. Mary River projects were known as the Lethbridge Section CPR. The St. Mary River Irrigation District as now known was not formed until 1968.

The Western irrigation district was developed in 1905. It has over 83,000 acres, located east of Calgary on the eastern boundary of the thin black soil zone and the western boundary of the dark brown soil zone, and has many of the properties of the Mountain View, Leavitt, Aetna and United irrigation districts. It has a short growing season, higher rainfall, rough topography in places, and demand for irrigation is not as great as in other districts. Crops grown are primarily forages and cereal grains. The bedrock is primarily of the Paskapoo formation, non-marine in origin. Sloughs and water bodies are scattered throughout. Some areas are salt affected, especially near Calgary.

The Magrath, Raymond and Western block of the St. Mary River (Lethbridge area) districts, located primarily in the dark brown soil zone, were developed from 1898 to 1901. The soils are mostly of alluvial-lacustrine over till in origin and vary from sandy to clays in texture. The topography is mostly flat to undulating with some rolling and hilly topography. Rainfall is marginal and there is dependency on irrigation. Irrigation water is from the St. Mary River system. The water quality is excellent, around 400 ppm TDS. The growing season varies from about 112 frost free days at Magrath and Raymond to 118 days at Lethbridge. At one time horticultural crops and sugar beets were grown in these districts. There was a sugar factory at Raymond and a vegetable cannery at Magrath to process these crops. Growing of these crops has moved to irrigation districts farther east, into the brown soil zone, where the growing season is longer and the temperatures are hotter. The crops grown now are mainly forages and cereal crops. The bedrocks under these districts are St. Mary River (non-marine, alternating hard sandstones and soft sands, shales and sandy shales), Bear Paw (marine, shale and argillaceous sandstone with seams of bentonite) and Oldman (non-marine, brackish at surface depths argillaceous sandstones and sandy shale) formations. Bedrock around Stirling is at shallow depth, being exposed in some places. Salinity is frequent throughout this area. Depth to till varies from less than 2 feet, south and east of Lethbridge, to more than 6 feet. The water table is high, within 4 feet of the surface in much of the Magrath and Raymond districts and more than 20 percent of the land is salt affected, primarily because of canal seepage and poor internal and surface drainage, and some mismanagement. Most of the Magrath and Raymond irrigation districts and much of the western block of the St. Mary River irrigation district would be considered unsuitable for irrigation, according to today's irrigability standards. Measures, such as canal rehabilitation and relocation, better water management and a very limited amount of drainage, are being taken to control the water table and to improve management of the land. Irrigated agriculture should continue indefinitely to be an important component of the agricultural economy in this area. It is because of the high water table conditions in this district that J. G. van Schaik, Associate Director of Land Resources Research Institute, Agriculture Canada, Otawa, Ontario (personal communication) some time ago concluded that the critical groundwater depth in southern Alberta seems to be around 4 feet.

Evidently there is sufficient leaching in the off season to maintain the required net downward flow of salt.

The Lethbridge Northern irrigation district, established in 1923, and located north of Lethbridge, has many of the features of the St. Mary River (western block) irrigation district. Irrigation water is from the Oldman River and has about 400 ppm TDS. The soil is alluvial-lacustrine over till and till in origin, and is mostly medium textured. The topography is mostly flat to undulating with some rolling land. The bedrock is mainly Bear Paw formation (marine shale and argillaceous sandstone with seams of bentonite). Depth to till varies from less than 2 to more than 6 feet. Less than 10 percent of the land for the total district is salinized. The greatest salinity problems are in the lands underlain by Bear Paw formation, where an estimated 20 percent of the land is salt affected (F. A. Ross, Manager, Lethbridge Northern Irrigation District, Lethbridge, Alberta, personal communication). The causes are about 50 percent seepage and 50 percent mismanagement. Forages, cereal grains and sugar beets are grown in the district. At one time there was a sugar factory at Picture Butte. It has been closed and the growing of sugar beets will probably become phased out and moved to districts with longer growing season and hotter temperatures.

The Eastern irrigation district, located in the Brooks area, was initiated in 1909. It is the largest irrigation district, in one block, in Alberta (table 1). Source of irrigation water is from the Bow River. It contains about 400 to 450 ppm TDS. The soils are primarily coarse to fine textured brown Chernozems and Solonetzic. Precipitation is limited and there is dependency on irrigation. The growing season and temperatures increase across the district from northwest to southeast. The growing season in the northwest is several days less than in the southeast, where it is about 120 days at Brooks. The topography is mostly flat to undulating, with some rolling land. Depth to till varies from less than 2 feet to more than 6 feet. Bedrock under the district is mostly Bear Paw (marine, shale and argillaceous sandstone with seams of bentonite), and some Oldman (non-marine, brackish at surface depths, argillaceous sandstone and sandy shale) formations. Crops grown in the district are forage, cereal grains, potatoes and vegetables. Canal seepage is a major problem, waterlogging much of the land, and causing considerable salinity throughout the district.

The Bow River (initiated in 1909), Taber (established 1919 to 1921), and St. Mary River (eastern block, Grassy Lake to Medicine Hat, developed late 1950's and early 1960's) are important districts. The soils are primarily brown Chernozems with some Solonetzic, especially in the Bow River irrigation district. Precipitation is from 11.8 to 13.8 inches, the growing season is 130 days and longer and the temperatures are warmer than in other districts. Consequently most of the specialty crops once grown in the other districts are now grown here. Canal seepage in the districts causes waterlogging and salinity. An estimated 10 percent of the land is salinized, primarily from canal seepage. Bedrock in these districts is Foremost (non-marine, mixture of fresh water and brackish water deposits, shaley siltstones and sandstones) and Oldman (non-marine, brackish at surface depths, argillaceous sandstones and sandy shale) formation. Depth to bedrock varies from 3 to 4 feet, southeast of Taber, to over 50 feet throughout the area. Where the bedrock is at shallow depths there are salinity problems. Depth to till varies from less than 2 feet to more than 6 feet. Because of the favorable soil and climatic conditions in these districts, farming is intensive. Specialty crops not suited to the other districts are grown here.

Canal seepage is the major cause of waterlogging and salinity among all the districts. If seepage were controlled a major portion of the salinity problems would be resolved. F. A. Ross, Manager, Lethbridge Northern Irrigation District, Lethbridge, Alberta, (personal communication) reports they have been able to reclaim about 50 percent of the saline waterlogged land in the Lethbridge Northern Irrigation District through controlling seepage and better water management. These same results or better could be expected in the other districts also. Upgrading of the distribution systems has high priority to reduce seepage. Limited drainage has been installed, where necessary. An estimated 15,000 to 20,000 acres of land have been subsurface drained throughout the irrigation districts (B. A. Paterson, Head, Drainage Branch, Alberta Agriculture, Lethbridge, Alberta, personal communication). There is need for more drainage, but the greatest need is to control canal seepage. In those places where seepage control is not feasible, drainage would be the only alternative. Probably less than 50,000 acres of the land will eventually be subsurface drained. Improved management such as land levelling for better distribution and control of water applied by gravity and irrigation by sprinker also help to control waterlogging and salinization of the land. Within the past few decades water managers and farmers have become aware of damages from mismanagement of irrigation water. With improved management of the irrigation water and control of canal seeage less land is becoming effected with waterlogging and salinity. Some lands that had become salinized through mismanagement and seepage have been reclaimed through controlling seepage and better management (F. A. Ross, Manager, Lethbridge Northern Irrigation District, Lethbridge, Alberta, personal communication).

Prior to the 1970's, before land prices escallated, conservation of land had low priority. It was simpler to abandon land that had gone out of production and buy new. When land prices soared upward and new land became less available, greater attention was given to preserving the developed land. The problems are primarily caused through insufficient attention to seepage and water management. F. A. Ross, Manager, Lethbridge Northern Irrigation District, Lethbridge, Alberta (personal communication) reported that at one time more than 10,000 acres of land in the Lethbridge Northern irrigation district had been waterlogged and saline, and the problem was increasing. With better water management and canal seepage control they have arrested the problem and have reclained 4,000 to 5,000 acres of the land previously affected. With due care and attention, irrigation should play an important role in the economy of Alberta for years to come. Each year the irrigation districts are expanding, taking water to new lands. At the present, the ability to deliver water is limiting the rate of expansion.

## 4.B.3
## GEOLOGY

### 4.B.3.1
### Bedrock

The general slope of the bedrock is in an east northeasterly direction. The incised river beds flowed from west to east in the western segment of the study area and then flowed northerly east of Bow Island (fig. 2). The immediate underlying bedrock in most of southern Alberta is in non-marine and brackish water origin, upper cretaceous in age (fig. 3). There is a narrow block of bedrock of marine origin, extending from Montana through Lethbridge and across much of Saskatchewan, Manitoba and the Dakotas (fig. 4). Some of the Raymond and St. Mary River (Lethbridge block) irrigation districts and much of the Lethbridge Northern, Bow River and Eastern irrigation districts are underlain by this formation. Depth to bedrock in southern Alberta varies from isolated surface outcrops to over 100 feet. In most of the region bedrock depth is more than 50 feet.

#### 4.B.3.1.1
#### Bear Paw

(marine) - dark grey, brownish grey, rubbly and flaky shale; grey argillaceous sandstone; ironstone concretionary bands; bentonite layers. Core samples from a well near Taber showed irregular fractures filled with calcite. Continuous bands of carbonates are plentiful. Seams of bentonite 1 or 2 inches thick are common, but seams 4 to 6 inches thick are present. Gypsum is prevalent.

#### 4.B.3.1.2
#### Foremost

(non-marine, brackish) - grey and pale brown sandstone; grey and green siltstone; green and grey shale; dark grey carbonaceous shale; ironstone; coal seams. The Foremost formation contains much shale, but is predominantly arenaceous. The beds contain a mixture of brackish water and fresh water deposits and consist of shaly siltstones, sandstones, coal seams, ironstone concretions and silicified oyster-shell beds.

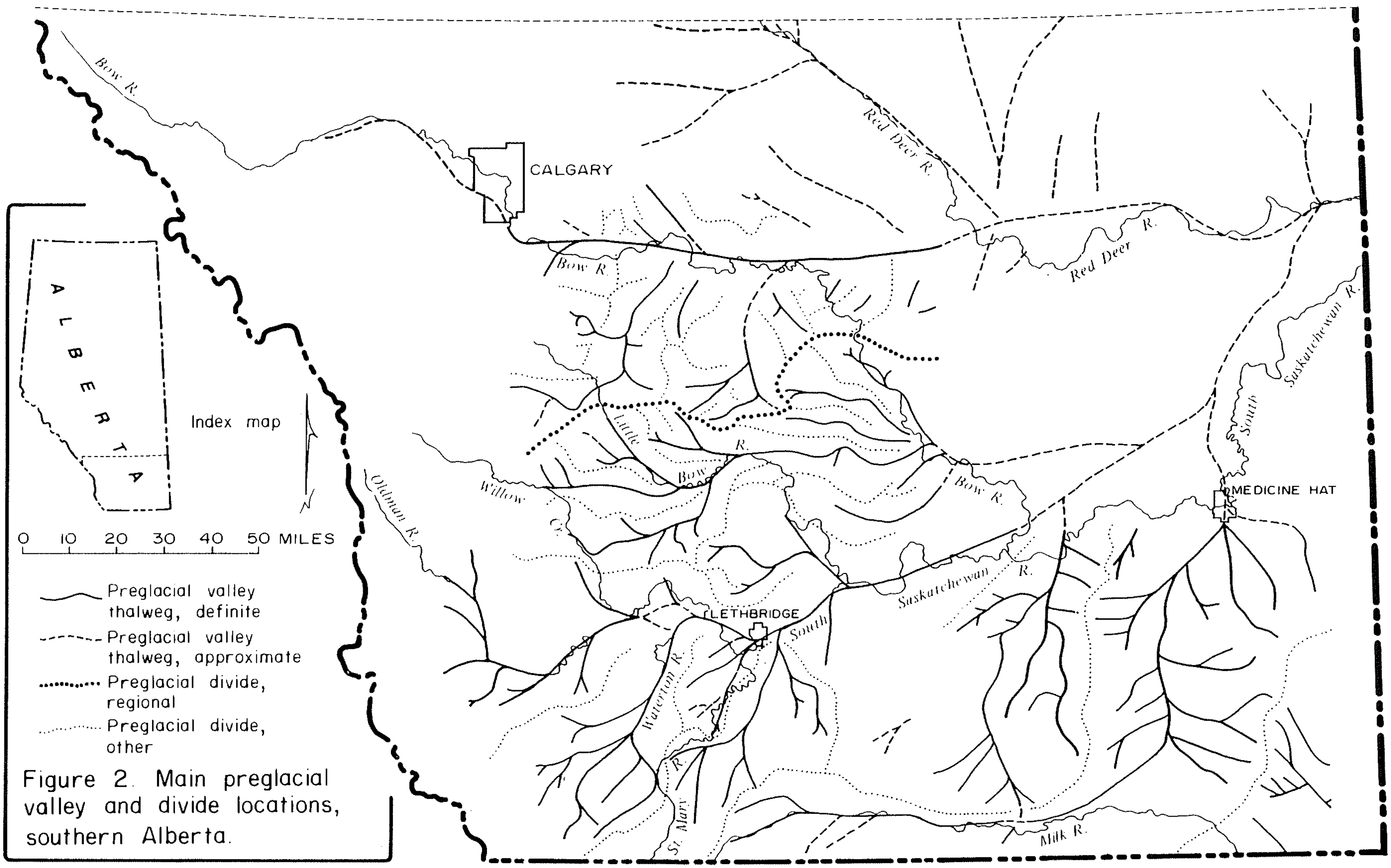



Figure 2. Main preglacial valley and divide locations, southern Alberta.

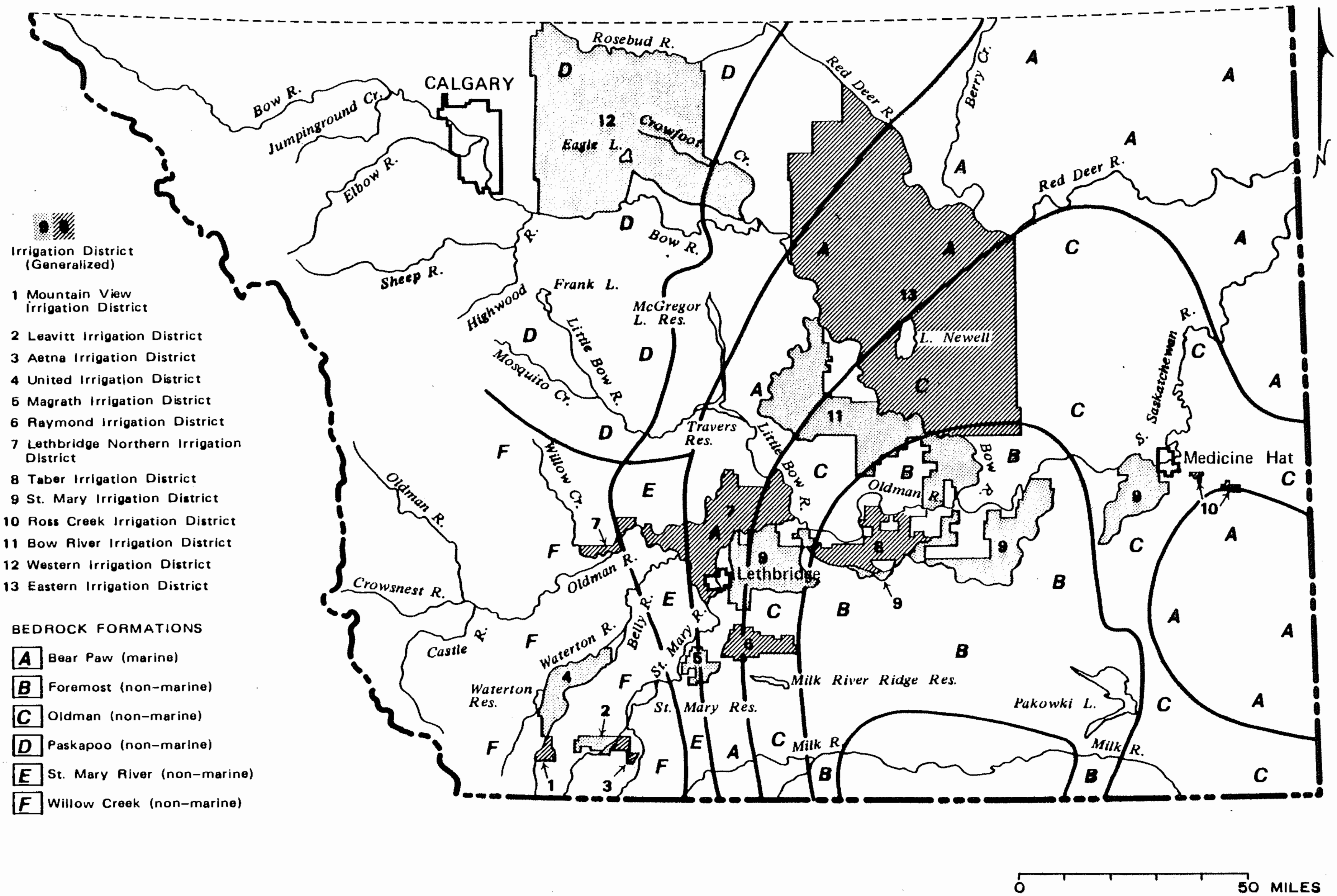
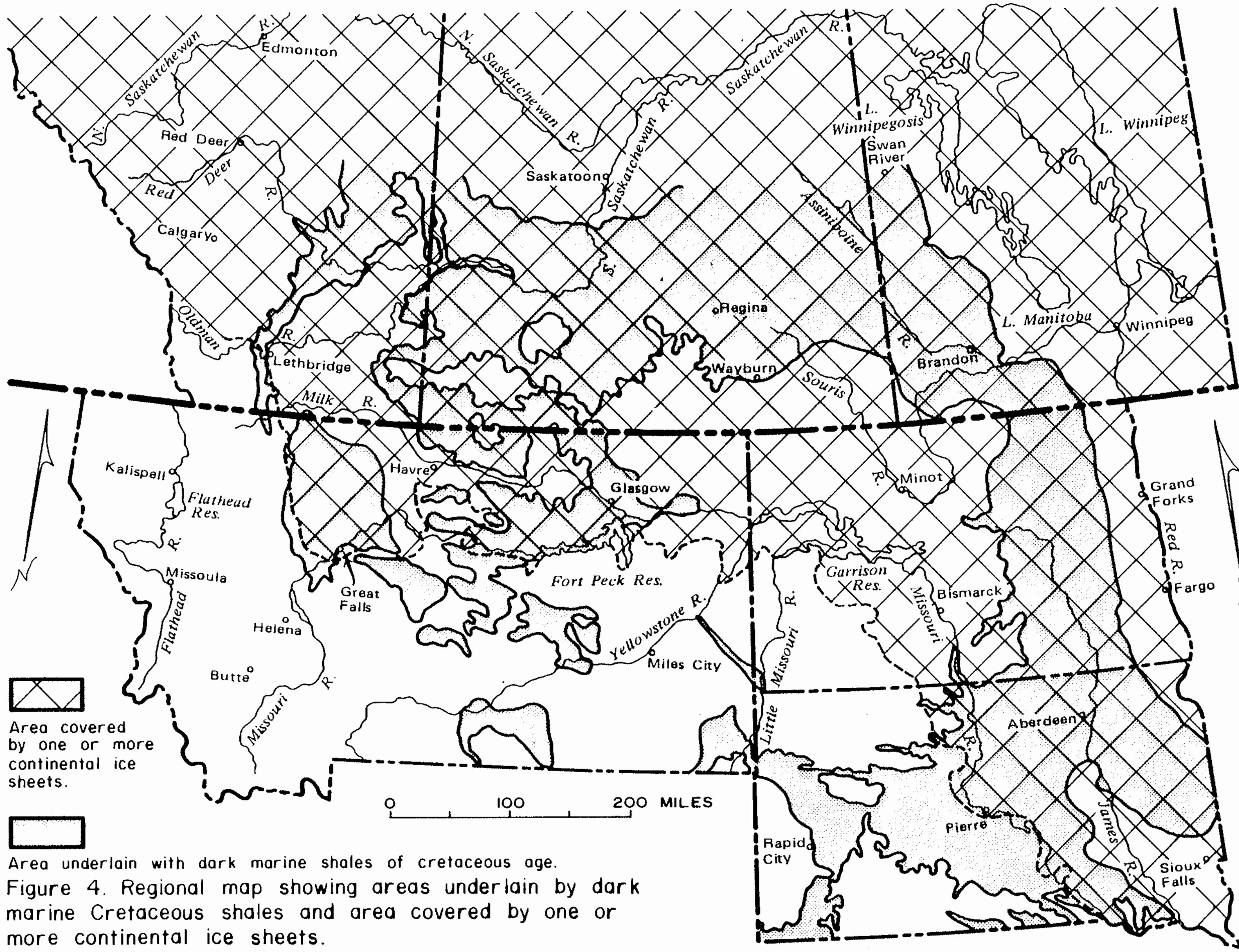


Figure 3. Generalized bedrock formations within the irrigation districts of Alberta.




Area covered by one or more continental ice sheets.

Area underlain with dark marine shales of cretaceous age.

Figure 4. Regional map showing areas underlain by dark marine Cretaceous shales and area covered by one or more continental ice sheets.

4.B.3.1.3
Oldman

(Judith River, non-marine, brackish in uppermost section) - massive crossbedded medium to coarse grained, light grey weathering sandstone; clayey siltstone, grey; green and grey shale; and ironstone concretionary beds. The typical rocks are light-colored, argillaceous sandstone, interbedded with green, sandy shales. Coal seams are present in the upper part of the formation.

4.B.3.1.4
Paskapoo

(non-marine) - sandstone, grey buff-weathering; grey and green siltstone; grey, green and brown shale; pebble conglomerate.

4.B.3.1.5
St. Mary River

(non-marine) - hard green and grey, grey and buff weathering, fine grained calcareous sandstone; friable green and grey silty shale; fissile grey shale; coal. The St. Mary River formation consists largely of alternating series of hard, dun-colored, and grey sandstones with soft, grey, brown, and greenish sands, shales and sandy shales.

4.B.3.1.6
Willow Creek

(non-marine) - red shales and sands; red and grey sandstones and shales. The Willow Creek formation consists of thin alternating beds of sands, clays, and sandy clays; the colors are purplish, reddish brown, grey and green.

## 4.B.3.2
## Glaciation

All of the area has been glaciated at least one time, mostly by the continental ice mass, the Wisconsin stage being the most recent. Glaciation extended into Montana and North and South Dakota (fig. 4). Thickness of till varies from zero to over 100 feet. Most is more than 50 feet thick. Prior to the advance of the continental ice sheet and resultant glaciation, a well defined drainage network had been developed throughout southern Alberta, flowing easterly from the Rocky Mountains to Bow Island and then north (fig. 2). The channels were several hundred feet deep in places. During glaciation these channels were filled and covered with drift, the bottom being filled with sands and gravels, known as the Saskatchewan gravels. Often these channels form aquifers and are a source of ground water, primarily for livestock and domestic use.

### 4.B.3.2.1
### Glacial deposits

Till was deposited throughout the study area. Three tills have been identified in the Lethbridge area, basal, lower and upper. This report deals primarily with the upper tills. The tills are made up mostly of local bedrock materials (about 80 percent), with some (about 20 percent) derived from the Canadian Shield. The direction of ice movement in southern Alberta was a combination of both advance and retreat. The advance was in a southerly and southeastern direction. Many directions show a fan-like distribution. This feature in conjunction with an analysis of transverse elements suggest that most of these directions were created by local rejuvenations of the ice during general retreat.

Parts of southern Alberta are characterized by broad areas of flat to gently rolling ground moraine. The moraine varies from being almost featureless to development of till ridges and washboard moraines of low relief, usually less than 10 feet.

Through the push and pull action of the ice during its advance and retreat and because of the high montmorillonite content of the till, (which causes swelling and shrinking) natural fractures developed in the tills, with the cleavage lines running vertically and horizontally. The permeability of the tills is attributed to this fracturing and the cleavage lines created, along which the water flows. The tills can be subdivided into weathered (top) and non-weathered (bottom) zones. Fracturing is most visible in the weathered tills.

### 4.B.3.2.2
### Post glacial deposition

In post glacial times there was considerable sorting and transporting of surface materials by water and wind. Large areas of aeolian, alluvial and lacustrine depositions were left, varying in thickness from only a few inches to several feet. Most of the irrigated soils in Alberta are located in these areas.

### 4.B.3.2.3
### Post glacial drainage

The study area slopes easterly (about 5 feet per mile average) and the lakes that were ponded between the retreating ice margin and the higher land to the west were quickly drained through outlets around the terminus of the northward retreating ice. Consequently, there were not large bodies of water entrapped for extended periods of time. The ice-marginal lakes were relatively small and short lived, yet they were of sufficient size and duration to deposit a mantle of aeolian, lacustrine and alluvial material over the tills.

Natural drainage from the irrigation districts is into the Saskatchewan River system, with the Red Deer River bordering the north and the St. Mary, Oldman, South Saskatchewan Rivers bordering the south. The Bow River, Little Bow, Waterton, Belly and Oldman (west of Lethbridge) Rivers provide drainage within the region. Many coulees and draws terminate in these river valleys. The land gradients generally dip toward one of the coulees or river channels. These coulees and drainage ways have been credited for much of the success and longevity of irrigation in southern Alberta (Nielsen, 1971), providing drainage for surface and subsurface water. Subsurface drainage into these coulees and river valleys can be seen in numerous springs and seeps along the banks and in bedrock seams exposed along river banks. However, Nielsen (1971) considers only part of the ground water is discharged directly into the coulees and rivers. Seemingly, the rest of the ground water percolates downward to the permanent ground water system that apparely surfaces in Saskatchewan and Manitoba. M. J. Hendry, Hydrologist, Drainage Branch, Alberta Agriculture, Lethbridge, Alberta (personal communication) indicates there is evidence that water moves through the tills into the permanent ground water system.

Where natural drainage is not effective, and drainage is a problem, installation of surface and/or subsurface drainage is required.

## 4.B.4
## TOPOGRAPHY

### 4.B.4.1
### General Description

The irrigation districts are located in the Alberta Plains physiographic region. A ridge-like landform with long relatively smooth slopes is common throughout the irrigation districts. The slopes vary from less than 1 percent to more than 10 percent. Most of the irrigated land has less than 5 percent slope. The topography varies from flat to undulating with some rolling and hilly land.

### 4.B.4.2
### Relief Effects on Soil Development

Because of the general flatness of the land, there was considerable sorting of material in post glacial times, as well as post glacial deposition in some areas. These depositions, which are relatively smooth, vary in thickness of less than a few inches to several feet. The irrigation districts are located primarily in these relatively smooth areas of aeolian, alluvial and lacustrine depositions. More recently, pumping has taken irrigation to till lands also.

## 4.B.5
## SOILS

### 4.B.5.1
### Pedogenic Processes

The soil is the product of the climate, topography, chemical, physical and biological processes acting on the parent material over a period of time. The climatic factors are mainly through precipitation and temperature. Climate determines the chemical, physical, vegetative and micro-biological activities.

#### 4.B.5.1.1
#### Parent Materials

The more level till areas have been subjected to post-glacial sorting or deposition from which the parent materials developed. Those parent materials of most importance in the irrigation districts are aeolian, fluvial, fluvial-aeolian, fluvial-lacustrine, lacustrine and veneers of these depositions over till. Generally the most desirable soils are of fluvial and lacustrine origin, depth to till is most often less than 5 feet. The soils are mostly typic Haploborolls.

#### 4.B.5.1.2
#### Climate

The climate is continental throughout all irrigation districts, characterized by warm summers and cold winters that are typical of the prairies. The area is primarily semiarid. At Lethbridge the average annual precipitation is 16.7 inches, and at Medicine Hat it is 13.7 inches; mean July temperatures are 65 and 68 degrees F., and the average annual water deficiencies are 6 and 10 inches, respectively. The average frost free period varies from less than 100 days in the Mountain View district and near Calgary to 118 days at Lethbridge, about 120 days at Brooks and 124 days at Medicine Hat. The growing season, from killing frost to killing frost, is about 3 weeks longer than the number of frost free days. Winds of high velocity are relatively frequent. If the soil is not protected, erosion from wind can result. Recently there are those who advocate there is more water erosion in the area than most people think. Conservation tillage is being stressed.

### 4.B.5.1.3
### Relief

There are a limited number of coulees and draws and stream channels throughout the irrigation districts. However, these plus irrigation canals and drainage ditches, provide sufficient relief for most conditions (Nielsen, 1971).

### 4.B.5.1.4
### Plant and Animal Life

The climate is typical continental. Vegetation before man came was prairie short grasses and semiarid prairie flora with a few poplar and willow trees along the rivers. The soils are mostly Chernozemic (typic Haploborolls). Solonetizic soils are frequent in the Bow River and Eastern irrigation districts. Forage crops and grain are grown in all districts. Potatoes are grown in the Eastern, Bow River, Taber and St. Mary River (eastern block) irrigation districts. Sugar beets are grown in the Lethbridge Northern, the St. Mary River (east and Lethbridge block), Taber and Bow River irrigation districts. Fresh vegetables are grown in the Taber, St. Mary River (eastern block) and Eastern irrigation districts. Vegetables for canning are grown mostly in the Taber, Bow River and St. Mary River (eastern block) irrigation districts. Because of the desirable climate, crops such as tomatoes are grown around Medicine Hat. Orchard crops do not grow well in this area because winter chinooks break dormancy of the trees during mid-winter and the trees winter kill.

Wild animals in the area include whitetail and mule deer, antelope, fox, coyote, rabbits, gophers (Richardson squirrel), mice and other prairie animals. Domesticated animals are mostly beef and dairy cattle.

### 4.B.5.1.5
### Time

In terms of geological time the soils are relatively young, dating back some 20,000 years to the Wisconsin glaciation period. Though the soils are relatively young, they and their subsoils are usually structured. Internal drainage is generally adequate in the major soils throughout the irrigation districts.

### 4.B.5.1.6
### Permeability of the Soils (saturated hydraulic conductivity)

The saturated hydraulic conductivity of surficial till (disturbed samples) has been reported to vary from less than 0.0017 to 1 inch/hr. Until 1983, a saturated hydraulic conductivity of 0.042 inch/hr was considered minimal for irrigated land. Since 1983, the standard has been lowered, allowing irrigation of soils having hydraulic conductivities of 0.0021 to 0.0167 inches/hr. The assumption is that with the long period of no irrigation there is abundant time for the water, that may build up while irrigating, to drain out of the system. There is evidence to indicate that the former standard of 0.0417 inch/hr exceeded the minimum requirement.

Saturated hydraulic conductivities of tills under Chin and Cavendish soils, the better soils in the St. Mary River and the Bow River irrigation districts, have been reported to be in the range of 0.1 to 0.8 inch/hour. Tills under some other irrigated soils, such as Coaldale and Wardlow, have hydraulic conductivities of near 0 to 0.8 inch/hour. Sommerfeldt and Chang (1980) worked with a saline soil at Vauxhall and measured its hydraulic conductivity by ponding in the field, insitu with a falling head-permeameter, and in the laboratory using disturbed samples. By the ponding method the intake rate was 0.0625 inches/hr. They concluded that the rate would be sufficient under good irrigation management and that the salinity problems were caused by mismanagement. This intake rate was governed by the least permeable layer in the profile. Hydraulic conductivities by the falling head-permeameters, were 0.0833, 0.125, and 0.4167 inches/hr for the Ah, Btj and till (2-2.5 ft. depth) layers, respectively. The higher hydraulic conductivity value for the till is attributed to fracturing. By the disturbed sample method these values were 0.8333, 0.3333, and 0.1042 inches/hr, respectively. The falling head-permeameter data indicate the water intake from the basins was limited by the surface layers. Hendry (1982) reported three hydraulic conductivities of tills. One was 1.25 x 10(-5) inches/hr for the till matrix, determined with disturbed samples. Another was 8.33 x 10(-5) inches/hr, for small-scale fractures in undisturbed till. These fractures typically were 0.4 inches apart in a cubical network. The other, 0.292 inch/hr, for large-scale fractures spaced 0.8 to more than 24 inches apart in undisturbed till. These large-scale fractures trend in subvertical and subhorizontal directions. The large-scale fractures, lined with gypsum and organics, are considered to be the main conduits through which infiltrating water is transmitted to the groundwater.

## 4.B.5.2
## Catinas or Topographic Sequences

The tills and thin veneers are generally found at the higher elevations and the deeper fluvial-lacustrine deposits are at the base of the slopes. The cause for the thin veneers and till at the top of the slopes and the deep depositions at the base of the slopes has been attributed to erosion. However, some of this phenomenon could be attributable to moisture. Water from the high land drains down slope to the soils at lower elevation, providing more water for plant use and the weathering processes than at the higher land.

One of the major soil sequences in the brown soil zone (Typic Haploboroll) is Maleb (till), Cranford (medium-fine textured veneer over till) and Chin (medium-fine textured soil over fine loamy fluvial or lacustrine material). The till occurs in the higher land of rougher topography. The Chin is found in the lower smooth land and Cranford is intermediate. The Chin soil, one of the more abundant soils in the Taber, St. Mary (eastern), Bow River and Eastern irrigation districts, is considered to be one of the better soils for irrigation. The Hughenden, Whiteney and Lethbridge sequence is the equivalent to the Maleb, Cranford and Chin sequence, but in the dark brown soil zone.

In the Bow River and Eastern irrigation districts, these soils are found in association with coarse textured soils such as Cavendish or with Solonetzic soils. There is some evidence to suggest Solonetzic soils under irrigation may ameliorate with time. With good management some of the Solonetzic soils can be quite productive.

Subsurface drainage, where needed, is usually most effective in the deeper coarser textured soils, with the drains placed at 5 feet depth and greater. Most often in the irrigated soils of Alberta, till is at a depth shallower than 5 feet. In these instances drains placed at till depth have been effective in providing the necessary drainage to control salinity and waterlogging. Salts have been removed from the tills 3 to 4 feet below drain depth. The important thing is to place the drains in the most permeable water-bearing layer and as deep as possible. Frequently subsurface interceptor drainage, to intercept incoming seepage water, is effective in controlling water table.

Vegetables crops are successfully grown in the Cavendish fine sandy loam soils around Barnwell. Potatoes are successfully grown in the sandy soils such as the Purple Springs loamy sands north and east of Taber and in the Bow River, Eastern and St. Mary River (eastern block) irrigation districts. These soils have low water holding capacity and require frequent light applications of irrigation water. Center pivot irrigation systems, because of the frequence of application, are often most suitable for applying water to these soils.

The following are descriptions of major soils in the dark brown and brown soil zones, listed in alphabetic order. More than 70 different soil series have been identified, many of which are small in area.

### 4.B.5.2.1
### Bingville Series

Location: SW22, Twp 23, Rge 16, W4
Classification: Orthic Brown Chernozemic (irrigated)
Parent material: Coarse loamy fluvial

| Horizon | Depth cm | |
|---|---|---|
| Ah1 | 0- 5 | Dark brown (10YR 3/3 m), dark grayish brown (10YR 4/2 d); sandy loam; compound, very weak, coarse prismatic, and single grain; loose; nonplastic; plentiful, fine and very fine, random roots; abrupt, smooth boundary; 2-6 cm thick; neutral. |
| Ah2 | 5-11 | Dark yellowish brown (10YR 3/4 m), brown to dark brown (10YR 4/3 d); loamy sand to sandy loam; single grain; very friable; nonplastic; plentiful, very fine, vertical roots; gradual, wavy boundary; 4-8 cm thick; slightly acid. |
| Ah3 | 11-18 | Dark brown (10YR 3/3 m), brown to dark brown (10YR 4/3 d); loamy sand to sandy loam; compound, weak, medium, angular blocky, and single grain; very friable; nonplastic; plentiful, very fine, vertical roots; gradual, wavy boundary; 0-9 cm thick; slightly acid. |
| Btj | 18-34 | Dark yellowish brown (10YR 4/4 m, d); sandy loam; compound, weak, medium prismatic, and weak, medium, subangular blocky; friable; slightly plastic; few, very fine, vertical roots; diffuse, wavy boundary; 10-18 cm thick; slightly acid. |
| BC | 34-64 | Dark yellowish brown (10YR 4/4 m), yellowish brown (10YR 5/4 d); sandy loam; compound, weak, medium, subangular blocky, and very fine, single grain; very friable; nonplastic; few, very fine, vertical roots; clear, wavy boundary; 15-34 cm thick; neutral. |
| Cca | 64-89 | Light brownish gray (10YR 6/2 m), pale brown (10YR 6/3 d); sandy loam; compound, weak massive, and very fine, single grain; friable; very few, very fine, vertical roots; weak effervescence; gradual, wavy boundary; 18-28 cm thick; mildly alkaline. |
| Ck | 89+ | Light brownish gray (10YR 6/2 m), light gray (10YR 7/2 d); sandy loam; compound, weak massive, and very fine, single grain; very friable; very weak effervescence; moderately alkaline. |

## 4.B.5.2.2
## Cavendish Series

Location: SE14, Twp 21, Rge 17, W4
Classification: Orthic Brown Chernozemic
Parent material: Sandy fluvial or eolian

| Horizon | Depth cm | |
|---|---|---|
| Ah | 0-23 | Dark brown (10YR 3/3 m), dark grayish brown (10YR 4/2 d); loamy sand; single grain; very friable; plentiful, medium, fine, and very fine, random roots in upper portion, becoming fine and very fine, vertical in lower portion; clear, smooth boundary; 14-26 cm thick; slightly acid. |
| Bm2 | 23-61 | Dark brown to brown (10YR 4/3 m), brown (10YR 5/3 d); sand; single grain; very friable; plentiful, fine and very fine, vertical roots; gradual, wavy boundary; 25-45 cm thick; neutral. |
| C | 61-76+ | Dark yellowish brown to yellowish brown (10YR 4/4-5/4 m), brown to pale brown (10YR 5/3-6/3 d); sand; single grain; loose; few, very fine, vertical roots, neutral. |

## 4.B.5.2.3
## Cecil Series

Location: SW28, Twp 16, Rge 11, W4
Classification: Solonetzic Brown Chernozemic (formerly Eluviated Brown Chernozemic)
Parent material: Till

| Horizon | Depth cm | |
|---|---|---|
| Ah | 0- 14 | Brown to dark brown (10YR 4/3 m), brown (10YR 5/3 d); loam; weak, fine granular; very friable; abundant, fine, random roots; few, fine pores; clear, smooth boundary; 8-15 cm thick; mildly alkaline. |
| Ae | 14- 20 | Brown to dark brown (10YR 4/3 m), grayish brown to light brownish gray (10YR 5/2-6/2 d); loam; moderate, fine platy; very friable; plentiful, fine, random roots; common, fine, vesicular pores, abrupt, smooth boundary; 2-10 cm thick; neutral. |
| Bt | 20- 29 | Brown to dark brown (10YR 4/3 d); loam to clay loam; moderate, fine, subangular blocky; |

| | | |
|---|---|---|
| | | slightly hard; plentiful, fine, inped and exped, vertical roots; clear, smooth boundary; 8-20 cm thick; mildly alkaline. |
| Cca | 29- 46 | Brown (10YR 5/3 d); loam to clay loam; weak, medium, subangular blocky; hard, plentiful, fine, vertical roots; few pores; moderate effervescence; abrupt, smooth boundary; 17-50 cm thick; moderately alkaline. |
| Ck | 46- 96 | Brown to dark brown (10YR 4/3 d); loam to clay loam; moderate, medium, subangular blocky; hard; plentiful, fine, vertical roots; contains CaCO3 blotches, stones, coal flecks and ironstone flecks; weak effervescence; clear, smooth boundary; 25-52 cm thick; moderately alkaline. |
| Csk | 96-100 | Dark brown (10YR 3/3 d); clay loam; massive; slightly hard; few, fine vertical roots; contains CaCO3 blotches, small stones, coal and ironstone flecks; weak effervescence; mildly alkaline. |

## 4.B.5.2.4
## Chin Series

Location: SW33, Twp 16, Rge 13, W4
Classification: Orthic Brown Chernozemic
Parent material: Fluvial or lacustrine

| Horizon | Depth cm | |
|---|---|---|
| Ah | 0- 13 | Very dark grayish brown (10YR 3/2 m), brown to dark brown (10YR 4/3 d); silt loam; weak, fine granular; very friable; abundant, very fine and fine, random roots; gradual, smooth boundary; 10-15 cm thick; mildly alkaline. |
| Bm | 13- 33 | Dark yellowish brown (10YR 4/4 m), yellowish brown (10YR 5/4 d); silt loam; compound, weak, medium prismatic, and weak, medium prismatic, and weak, medium subangular blocky; friable; plentiful, very fine, vertical roots, clear, smooth boundary; 15-23 cm thick; mildly alkaline. |
| Ca1 | 33- 53 | Yellowish brown (10YR 5/4 m,d); silt loam; very weak massive; very friable; plentiful, very fine, vertical roots; moderate effervescence; gradual, wavy boundary; 15-23 cm thick; mildly alkaline. |

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|---|---|---|
| Cca2 | 53- 86 | Yellowish brown (10YR 5/4 m,d); silt loam; very weak massive; very friable; few, very fine, vertical roots; moderate effervescence; diffuse, wavy boundary; 25-38 cm thick; mildly alkaline. |
| Ck1 | 86-109 | Olive brown (2.5Y 4/4 m); silt loam; very weak massive; very friable; few, vertical roots; weak effervescence; diffuse, wavy boundary; 20-36 cm thick; mildly alkaline. |
| Ck2 | 109-140 | Olive brown (2.5Y 4/4 m); silt loam; laminated massive; very friable; few, very fine, vertical roots, weak effervescence; clear, wavy boundary; 25-38 cm thick; mildly alkaline. |

## 4.B.5.2.5
## Cranford Series

Location: SW11, Twp 14, Rge 14, W4
Classification: Orthic Brown Chernozemic
Parent material: Fluvial or lacustrine veneer over till

| Horizon | Depth cm | |
|---|---|---|
| Ah1 | 0- 3 | Brown (10YR 5/3 d); loam; very weak, very fine granular; loose; abundant, fine, random roots; clear, wavy boundary; 2-4 cm thick; neutral. |
| Ah2 | 3- 10 | Brown (10YR 4.5/3 d); loam; moderate, medium, subangular blocky; slightly hard; abundant, fine, vertical roots; gradual, wavy boundary; 5-8 cm thick; neutral. |
| Bm | 10- 21 | Dark brown (10YR 4/3 d); loam; weak to moderate, fine to medium, subangular blocky; slightly hard; plentiful, very fine, vertical roots; clear, wavy boundary; 12-15 cm thick; neutral. |
| BCk | 21- 32 | Yellowish brown (10YR 5/4 d); silt loam; weak to moderate, medium, subangular blocky; slightly hard; plentiful, very fine, vertical roots; moderate effervescence; clear, wavy boundary; 7-12 cm thick; mildly alkaline. |
| IICca | 32- 50 | Pale brown (10YR 6/3 d); loam till; weak to moderate, fine to medium, subangular blocky; slightly hard; very few, very fine, vertical roots; moderate effervescence; contains 20 percent by volume of gravelly and angular |

| | | |
|---|---|---|
| | | gravelly fragments; gradual, irregular boundary; 14-18 cm thick; moderately alkaline. |
| IICk | 50+ | Brown to pale brown (10YR 5.5/3 d); clay loam; weak to moderate, fine to medium, subangular blocky; slightly hard; very few, very fine, vertical roots; moderate effervescence; contains 20 percent by volume of gravelly and angular gravelly fragments; moderately alkaline. |

## 4.B.5.2.6
## Hemaruka Series

Location: SE6, Twp 20, Rge 15, W4
Classification: Brown Solodized Solonetz
Parent material: Till

| Horizon | Depth cm | |
|---|---|---|
| Ah | 0- 3 | Brown to dark brown (10YR 4/3 d); loam; weak, fine, granular; loose; abundant, fine, random roots; abrupt, smooth boundary; 2-4 cm thick; neutral. |
| Ae | 3- 7 | Grayish brown (10YR 5/2 d); loam; moderate, fine platy; soft; abundant, fine and medium, vertical roots; abrupt, smooth boundary; 2-5.5 cm thick; neutral. |
| Bnt1 | 7- 17 | Dark grayish brown (2.5Y 4/2 m); clay loam; strong, medium, columnar; extremely hard; plentiful, fine and medium, vertical, exped roots, often compressed; abrupt, smooth boundary; 8-12 cm thick; neutral. |
| Bnt2 | 17- 25 | Brown to dark brown (10YR 4/3 d); clay; strong, medium to coarse, angular blocky; very hard; plentiful, fine and medium, vertical roots; clear, smooth boundary; 6-10 cm thick; mildly alkaline. |
| Cca | 25- 40 | Light olive brown (2.5Y 5/4 d); clay loam; moderate, medium, subangular blocky; very hard; plentiful, fine and medium, vertical roots; moderate effervescence; clear, smooth boundardy; 12-18 cm thick; moderately alkaline. |
| Ck1 | 40- 60 | Dark grayish brown (2.5Y 4/2 d); loam; moderate, coarse, angular blocky; very hard; plentiful, fine and medium, vertical roots; weak effervescence; clear, smooth boundary; 16-24 cm thick; moderately alkaline. |

| | | |
|---|---|---|
| Ck2 | 60- 78 | Dark grayish brown (2.5Y 4/2 d); clay loam; weak, medium to coarse, angular blocky; very hard; few, fine, vertical roots; weak effervescence; abrupt, smooth boundary; 16-20 cm thick; moderately alkaline. |

### 4.B.5.2.7
### Hughendon Series
### (Map symbol Hn)

Extent: 6920 ha (1.13 percent of Newell County)
Classification: Orthic Dark Brown Chernozemic
Usual surface texture: Loam
Major associated series: Flagstaff, Brownfield, Whitney
Parent material: Fine loamy till
Associated landform: Undulating and hummocky
Slope range: 2-30 percent
Drainage: Well drained
Agricultural capability: 3 m
Irrigation rating: Good
Grazing carrying capacity: 10-12 ha/AUY

Hughendon soils have a dark brown Ah horizon 10-15 cm thick. It is a very friable loam with a slightly acid to neutral reaction. The B horizon, usually about 15-20 cm thick, is dark grayish brown and has a fairly distinct prismatic structure which breaks easily to subangular blocky. The loam to clay loam texture continues into the Cca horizon at about 35 cm below the surface. The neutral to mildly alkaline reaction of the B horizon changes abruptly to moderately alkaline in the lime horizon. Pale brown colors are common in this horizon which is generally very weak blocky to massive. With increasing depth the lime content and hence the pH value decrease. At these lower depths the texture continues to be loam to clay loam in a pale brown till. Except for a darker and thicker Ah horizon, the Hughendon soil is very similar to the Brown Chernozemic Maleb series.

Hughendon soils are among the best in the county for both irrigated and dryland agriculture. Although it is not a severe problem in this county, some Hughendon areas may be stony, which of course results in a less desirable soil for agriculture.

### 4.B.5.2.8
### Lethbridge Series
### (Map symbol Let)

Extent: 525 ha (0.09 percent of Newell County)
Classification: Orthic Dark Brown Chernozemic
Usual surface texture: Silt loam
Major associated series: Whitney
Parent material: Fine loamy fluvial or lacustrine
Associated landform: Level, undulating, and low-relief hummocky

Slope range: 0.5-9 percent
Drainage: Well drained
Agricultural capability: 3 m
Irrigation rating: Good
Grazing carrying capacity: 9-11 ha/AUY

Lethbridge, like Chin, its Brown Chernozemic counterpart, can be recognized by its brownish solum and deep uniform parent material. Differences occur in the A horizon, which in the Lethbridge soil is both darker brown and thicker. Other major profile characteristics are similar to those of the Chin profile.

Sometime during the post-glacial past, portions of the southwestern part of the Crawling Valley Upland were inundated by waters that deposited fluvial or lacustrine materials. Thus, fine loamy materials of variable thickness were deposited over the lower portions of this till area. Subsequent soil formation produced a Lethbridge soil on deeper overlay deposits, Whitney on thinner deposits, and Hughendon where there was no overlay.

Some Lethbridge soils were mapped in the valley of Bow River at the western edge of the map area. These were mainly on valley terraces where the associated soils were Chokio and Scollard. Toward the northern end of Crawling Valley, another Lethbridge area was mapped on a fluvial terrace, also in association with Scollard soils.

Because of their uniformity in texture and parent material, Lethbridge soils have a high irrigation rating. They also have a relatively high capability for both grazing and dryland farming.

### 4.B.5.2.9
### Maleb Series
### (Map symbol Mb)

Extent: 28 615 ha (4.6 percent of Newell County)
Classification: Orthic Brown Chernozemic
Usual surface texture: Loam
Major associated series: Cecil, Ronalaine, Cranford, Halliday
Parent material: Fine loamy till
Associated landform: Undulating and hummocky
Slope range: 2-30 percent
Drainage: Well drained
Agricultural capability: 4 m
Irrigation rating: Good
Grazing carrying capacity: 14-19 ha/AUY

Maleb soils are characterized by brown colors, a friable structure, and a prominent lime horizon. This Chernozemic profile has developed on a fine loamy till similar to the till that is prevalent in the Crawling Valley Upland. Acidic pH values in the A horizon increase to alkaline values below the B horizon. It should be noted that the described soil has a thinner than normal

Ah horizon as well as an abnormally shallow depth to lime, which is usually encountered below the 25-cm depth. Salts may or may not be present in Maleb subsoils.

### 4.B.5.2.10
### Seven Persons Series
### (Map symbol Sp)

Extent: 3,765 ha (0.61 percent of Newell County)
Classification: Orthic Brown Chernozemic
Usual surface texture: Silty clay loam
Major associated series: Millicent, Rosemay, Tilley, Chin
Parent material: Fine clayey lacustrine
Associated landform: Level and undulating
Slope range: 0.5-5 percent
Drainage: Moderately well drained
Agricultural capability: 3 c
Irrigation rating: Good
Grazing carrying capacity: 14-19 ha/AUY

The most significant feature of the Seven Persons soils is its fine texture. It has a grayish brown Ah horizon about 10 cm thick with a granular structure and a silty clay loam texture. The B horizon is dark grayish brown silty clay loam to silty clay. This horizon, about 25 cm thick, is further characterized by a blocky to irregular prismatic structure. A lime horizon usually occurs at the 35-40 cm depth, in olive brown silty clay loam. Similar-textured materials continue to 1 m and below. Salts sometimes occur at these lower depths.

Seven Persons soils are among the best agricultural soils in the county. The fine texture and associated high water-holding capacity make them more desirable for dryland farming than most other soils.

### 4.B.5.2.11
### Tilley Series

Location: NE8, Twp 19, Rge 13, W4
Classification: Solonetzic Brown Chernozemic (formerly Eluviated Brown Chernozemic)
Parent material: Fluvial or lacustrine

| Horizon | Depth cm | |
|---|---|---|
| Ah1 | 0- 5 | Brown to dark brown (10YR 4/3 m), grayish brown (10YR 5/2 d); silt loam; weak, medium granular; very friable; abundant, fine, random roots; clear, smooth boundary; 3-6 cm thick; neutral. |

| | | |
|---|---|---|
| Ah2 | 5- 15 | Brown (10YR 5/3 m); silt loam; moderate, medium, subangular blocky; friable; abundant, fine, vertical roots; clear, smooth boundary; 8-12 cm thick; neutral. |
| Ae | 15- 22 | Grayish brown (10YR 5/2 m); silt loam; weak, fine platy; friable; plentiful, fine, vertical roots, clear, wavy boundary; 4-7 cm thick; neutral. |
| Bt | 22- 43 | Dark brown (10YR 3/3 m); silty clay loam; compound, moderate, medium prismatic, and moderate, fine, subangular blocky; friable; plentiful, fine, vertical roots; gradual, wavy boundary; 16-24 cm thick; mildly alkaline. |
| Csk1 | 43- 60 | Yellowish brown (10YR 5/4 m); silt loam; massive; very friable; few, very fine, vertical roots; weak effervescence; gradual, wavy boundary; 18-25 cm thick; moderately alkaline. |
| Csk2 | 60- 94+ | Pale brown (10YR 6/3 m); silt loam; massive; very friable; moderate effervescence; moderately alkaline. |

### 4.B.5.2.12
### Wardlow Series

Location: NW1, Twp 17, Rge 11, W4
Classification: Brown Solodized Solonetz
Parent material: Fluvial or lacustrine

| Horizon | Depth cm | |
|---|---|---|
| Ah | 0- 5 | Brown to dark brown (10YR 4/3 m), grayish brown (10YR 5/2 d); silt loam; weak, fine granular; very friable; abundant, very fine, random roots; abrupt, smooth boundary; 4-8 cm thick; slightly acid. |
| Ae | 5- 10 | Brown to dark brown (10YR 4/3 m), light brownish gray (10YR 6/2 d); silt loam; weak, fine platy; friable; abundant, very fine, randon roots; abrupt, smooth boundary; 4-6 cm thick; neutral. |
| Bnt | 10- 30 | Brown to dark brown (10YR 4/3 m, d), dark brown (10YR 3/3 ped); silty clay loam; compound, moderate, medium columnar, and moderate, medium, subangular blocky; very firm; abundant, very fine, vertical, exped roots; |

| | | |
|---|---|---|
| | | many, moderately thick, clay films; clear, wavy boundary; 15-20 cm thick; neutral. |
| Ck | 30- 41 | Brown (10YR 5/3 m), light brownish gray (10YR 6/2 d); silty clay loam to silty clay; moderate, medium to coarse, subangular blocky; firm; plentiful, very fine, vertical roots; moderate effervescence; gradual, wavy boundary; 8-12 cm thick; moderately alkaline. |
| Csk1 | 41-107 | Light brownish gray (10YR 6/2 m), light gray (10YR 7/2 d); silty clay loam; massive; firm; few, very fine, vertical roots; strong effervescence; abrupt, wavy boundary; 60-70 cm thick; moderately alkaline. |
| Csk2 | 107-163 | Pale brown (10YR 6/3 m), very pale brown (10YR 7/3 d); silty clay loam; massive; firm; very few, very fine, vertical roots; very weak effervescence; abrupt, wavy boundary; 50-60 cm thick; mildly alkaline. |
| Csk3 | 163-274 | Pale brown (10YR 6/3 m), very pale brown (10YR 7/3 d); silty clay loam; massive; firm; very weak effervescence; mildly alkaline. |

### 4.B.5.2.13
### Whitney Series
### (Map symbol Wy)

Extent: 1,375 ha (0.22 percent of Newell County)
Classification: Orthic Dark Brown Chernozemic
Usual surface texture: Silt loam
Major associated series: Hughendon, Flagstaff, Lethbridge
Parent material: Fine loamy fluvial or lacustrine over till
Associated landform: Level, undulating, and low-relief hummocky
Slope range: 0.5-9 percent
Drainage: Well drained
Agricultural capability: 3 m
Irrigation rating: Good
Grazing carrying capacity: 10-12 ha/AUY

The main characteristic of the Whitney soil is that it consists of an upper fluvial or lacustrine material and underlying till at less than 1 m. In this respect it resembles the Cranford series, its Brown Chernozemic counterpart. Whitney has a dark grayish brown Ah horizon, about 10-15 cm thick, with a fine granular to subangular blocky structure and a loam to silt loam texture. The B horizon, usually about 15 cm thick, is dark brown, friable prismatic silt loam. The color gradually changes to yellowish brown, which continues until the underlying brown till is reached usually at or near 50-60 cm. Above the clay loam till, textures are usually silt loam to silty clay loam with an abrupt boundary between the two materials. Although lime may occur in the upper material, it is most often present only in the underlying till. Neutral pH values prevail in the upper profile but become mildly alkaline in the lower portion of the overlay and moderately alkaline in the underlying till.

Whitney soils occur only on the western side of the county in low-relief areas of till. The lower portions of these areas were once inundated by waters that deposited a fluvial-lacustrine veneer of material on which the Whitney soil has now formed. The Whitney soils occupy a similar landscape position to that of Crandford. Whitney is the minor map unit component in various combinations with the Hughendon, Flagstaff, or Lethbridge soils.

This soil generally has a relatively high rating for all agricultural uses. Under irrigation, lateral water movement may occur along the interface between the two materials, which could result in seepage.

## 4.B.6
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APPENDIX A

# LONG-TERM IRRIGATION EFFECTS ON SOIL SALINITY IN SOUTHERN ALBERTA

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(Prepared for Canadian Water Resources Association
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# LONG-TERM IRRIGATION EFFECTS ON SOIL SALINITY IN SOUTHERN ALBERTA

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At present, 400 000 ha of land are under irrigation in 13 irrigation districts of southern Alberta (Alberta Agriculture, 1982). This area constitutes about 3 percent of Alberta's arable land, but provides 20 percent of Alberta's farm output (van Schaik, 1973).

The permanance and prosperity of irrigated agriculture in southern Alberta have been challenged by Maierhofer (1956) and Stanley/SLN Consultants Limited (1978). After inspecting the irrigated and potential irrigated lands in Alberta, Maierhofer (1956) concluded that the productivity of many of the irrigated lands could be sustained only if adequate subsurface drainage was provided. Some of the natural subsurface drainage problems were attributed to the slowly permeable soils that extend to considerable depth. More recently, Stanley/SLN Consulting Limited (1978) stated that irrigation in the Oldman River Basin district could not continue without artificial subsurface drainage.

Unfortunately, the effects of long-term irrigation on soil salinity within this region have not been thoroughly examined, though irrigation was introduced into Alberta at the turn of the century. Because of these challenges of Maierhofer (1956) and Stanley/SLN Consulting Limited (1978) it became necessary to evaluate the long-term irrigation effects on soil salinity in southern Alberta.

Much of the land currently irrigated and much of the area with potential for irrigation development land in Alberta is experiencing or will experience subsurface drainage problems. Most of these drainage problems are attributable to shallow soils overlaying slowly permeable substrata, generally till. However, some soils with till near the surface (150 cm or less) have been irrigated for as much as 50 y. This till has low water transmissivity, which impedes drainage, and it is generally saline. Also in some of the irrigated soils of southern Alberta the water table frequently is within 150 cm from the soil surface. These soils have not salinized as extensively as expected (Rapp and van Schaik, 1972). Marshall and Palmer (1938) found that the total soluble salt content of irrigated soil at three sites near Tilley, Alberta, was reduced after 20 years of irrigation.

More recently Sommerfeldt and Oosterveld (1977) determined the changes in salinity over a 4-y period at eight locations in an irrigation district of Alberta. These lands had been irrigated for over 2 decades. The tills had hydraulic conductivities of 0.3

cm h(-1), and the soil over the till had hydraulic conductivities of 1 to 15 cm h(-1). These hydraulic conductivities are reflected in the rates of both rise and recession of the water table. Water levels above the till receded rapidly (10 - 15 cm d(-1)). Whereas the rate of recession in the till seldom exceeded 2 cm d(-1). When the water table was above the till abrupt rises were observed with minor water input events. When the water table was in the till, the rises were slow and small, and inputs had no effect on the water table level. Water tables at shallow depths were most common in the spring, when the snow was melting, the soil was thawing, precipitation was high and evapotranspiration was low. There was a correlation between the salinity of the subsoil and that of the ground water. With till at depths of 150 cm and greater, the EC and SAR appeared to be stable. When the till was within 60 cm of the surface the EC and SAR both increased over the 4-y period. With till between 60 and 120 cm depth the tendency was for the land to salinize, but at a slower rate than that for the till within 60 cm of the surface.

In a study to determine water and salt movement in a saline-sodic soil in southern Alberta, having till at 51 cm from the surface, Sommerfeldt and Chang (1980) found the average profile intake rate to be 3.76 cm d(-1). The Btj layer was identified as a factor limiting vertical flow. The till was structured and fracture lines were evident throughout the till to a depth of 180 cm. They concluded that the internal drainage of this soil was sufficient to accommodate water movement under normal conditions, and that the buildup of the water table and salinization of the soil were probably due to lateral flow from canal seepage and irrigation mismanagement. Sadler (1966) and Chang et al. (1985) reported that most of the waterlogging and salinization of the irrigated land in Alberta is due to seepage from canals.

Fracture lines and structuring in the till has been noted by Hendry (1982) also. He identified two fracture sets. Both sets of fractures produced secondary permeabilities which masked the low hydraulic conductivity of the till matrix. He concluded that these fractures probably explain the reason why this land has remained irrigable for over 60 years, as they provided conduits through which the infiltrating water could be transmitted to the groundwater regime.

In an 8-y study, Krogman and Hobbs (1972) reported a favorable salt balance in the root zone of a Brown Chernozemic soil regardless of the irrigation treatment used when irrigating to field capacity after 25, 50, or 75 percent of the available water was depleted.

Chang et al. (1982) determined the amount of water leached through two soil profiles (leaching fraction). The method required data on long term changes in the salinity status of the soil profile, and is based on the principle that water moving through gypsum-rich soils becomes saturated with gypsum. In the two soils studied, a clay and a clay loam, the average total soluble salt content decreased logarithmically since 1917, to a depth of 180 cm (fig. 1). The average Ca content decreased linearly at rates of 0.091 and 0.097 meq(100 g)(-1) for the clay (fig. 2) and clay loam soil, respectively. Based on these data a leaching fraction of 0.16 was achieved, through normal irrigation practices used at these two sites.

A salinity survey was carried out in the Taber Irrigation District (TID), The Western Division of the St. Mary River Irrigation District (WSMRID), and the Lethbridge Irrigation District (LNID) (Chang et al., 1985). The area of these districts comprise about 35 percent of the total irrigated lands in Alberta (Alberta Agriculture, 1982). A system was devised for random sampling. A total of at least 26 quarter-sections (71 ha per district) of land were selected for sampling within each district. A stratified randomized sampling design (Cochran, 1953) was used for sampling within each quarter-section of land to utilize relevant information and judgement on distribution of salinity within that parcel of land.

Soil samples were taken at 0-15, 15-45, 45-90, 90-120, and 120-150 cm depths for analyses. The legal description of the land, distance from water supply ditches, slope of land, occurrence and depth to till, and water table depth at each site were recorded.

The soil textures varied among the three irrigation districts. Generally the soils were coarsest in the TID and finest in the WSMRID. The average distances from irrigation supply ditches varied from 141 to 166 m.

The salinity level of the soil at 0-120 cm depth ranged from 0.5 to 15 dS m(-1) but most samples had a salinity level in the 0 to 2 dS m(-1) range (table 1). Thirty-three percent of the quarter-sections sampled in the TID had mean salinity levels greater than 2 dS m(-1) while for the WSMRID and LNID the corresponding percentages were only 12 and 13 percent, respectively. The average percentage of non-saline soil (EC $<$ 2 dS m(-1) of the total surveyed land in each district was 81 percent for the TID and 90 percent for both the WSMRID and LNID. However, yields of most crops grown in Alberta are not affected by soil with an EC $<$ 4 dS m(-1). If we chose an EC $<$ 4 dS m(-1) as non-saline, the percentage of non-saline soil became 91 percent for the TID, 94 percent for the LNID and 96 percent for the WSMRID. The highly salinized land (EC $>$ 8 dS m(-1) comprised less than 2 percent of total land surveyed in the three districts (table 1). Salinity tended to decrease with distance from the irrigation supply ditches.

**Table 1. Distribution and level of salinity at 0-to 120-cm depth in three irrigation districts in southern Alberta**

| District | No. qtrs. | EC ± SE (dS/m) | No. quarter-section with mean EC in range | | | % total land area with EC in range | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | 0-2 | 2-4 | 4-8 | 0-2 | 2-4 | 4-8 | > 8 |
| TID | 33 | 1.76 ± 0.14 | 22 | 11 | 0 | 80.9 | 10.2 | 7.5 | 1.4 |
| WSMRID | 26 | 1.31 ± 0.14 | 23 | 2 | 1 | 89.6 | 5.3 | 4.2 | 0.9 |
| LNID | 30 | 1.41 ± 0.15 | 26 | 3 | 1 | 89.7 | 4.0 | 5.8 | 0.5 |

The effects of long-term irrigation were determined by Chang and Oosterveld (1981) at 13 selected sites within four major irrigation districts of Alberta. Of these sites, 10 had been under irrigation for over 60 years and the other three had been under irrigation for 25 years. Soil textures ranged from sandy loam to clay. The total soluble salt content in all the soil profiles were either reduced, as illustrated in table 2, or unchanged after being irrigated for long term, except one. At this one site the EC was below 1 dS m(-1), which is non-saline. The magnitude of reduction in soluble salts of the other soil profiles was related to the original salt content and ranged from 0 to 82 percent of the original salt content. The SAR decreased in the subsoil at all sites. It is evident that these soils had not become salinized through long-term irrigation.

In summation it appears that long-term irrigation in Alberta is not as detrimental on the land as indicated (Maierhofer, 1956; Stanley/SLN Consulting Limited, 1978), and that extensive artificial subsurface drainage is not necessary for sustained irrigation. The major problem is from canal seepage. The soil has capacity to accommodate the irrigation water, when applied judiciously. The tills are fractured and structured to provide slow drainage for excess waters. Because of the climate of this region, the irrigation requirements in the growing season are not as great as in some hotter and drier climatic regions; the growing season is short followed by a long period for drainage to lower the water table that may have built up during the irrigation season. Under normal irrigation there is evidence of sufficient leaching to generally maintain a good salt balance in the soil. Some of this leaching can be attributed to precipitation, which has a desirable distribution. The mean

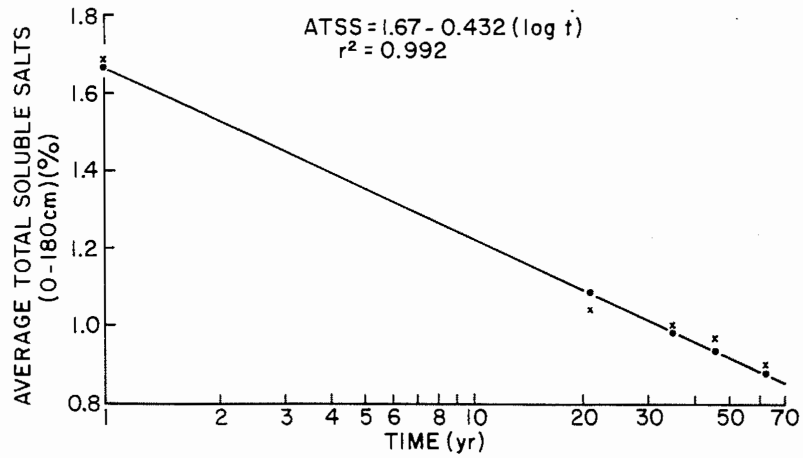


Fig. 1. Average total soluble salts of Tilley 1 at various times from 1917 to 1978 (×, observed; •, predicted).

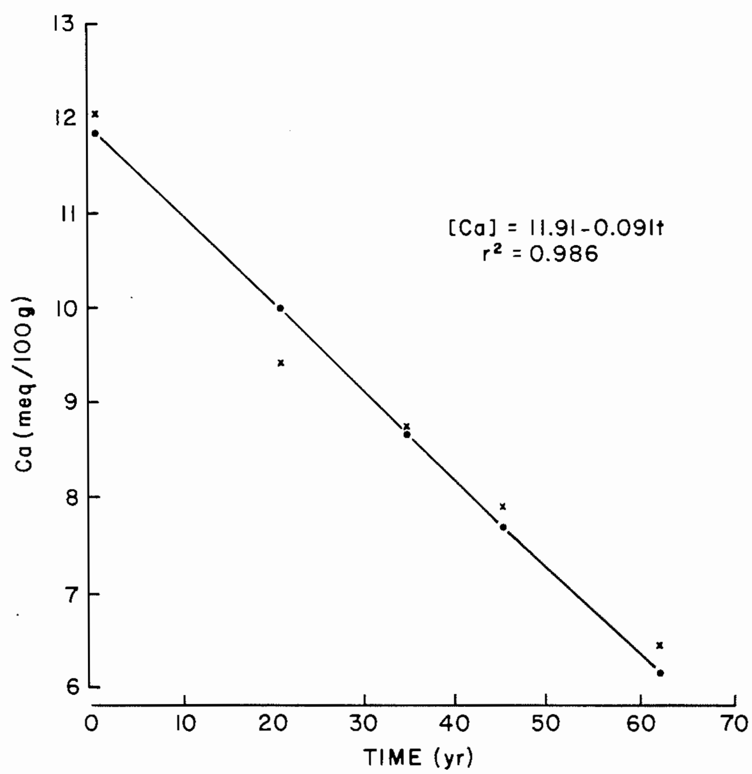


Fig. 2. Average Ca content of Tilley 1 at various times from 1917 to 1978 (×, observed; •, predicted).

**Table 2. Electric conductivity (EC) and sodium adsorption ratio (SAR) of saturation extracts of soil at various depths from sites at Hays (H), Tempest (TEM) and Lethbridge (LRS) --- (average of five samples)**

| Depth (cm) | H-1 | | H-2 | | H-3 | | TEM-1 | | LRS-1 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1952 | 1978 | 1952 | 1978 | 1952 | 1978 | Benchmark | 1978 | Benchmark | 1978 |
| | | | | | EC (mS/cm) | | | | | |
| 0- 15 | 0.68 | 1.04±0.12 | 0.47 | 0.85±0.05 | 0.46 | 1.03±0.04 | 0.44±0.01 | 0.62±0.05 | 0.72±0.05 | 0.79±0.04 |
| 15- 30 | 0.46 | 0.79±0.07 | 0.84 | 0.48±0.02 | 0.34 | 0.69±0.04 | 0.37±0.01 | 0.49±0.03 | 0.55±0.03 | 0.71±0.03 |
| 30- 60 | 0.47 | 0.68±0.05 | 0.61 | 0.42±0.01 | 0.40 | 0.95±0.11 | 0.38±0.02 | 0.44±0.01 | 0.41±0.03 | 0.62±0.02 |
| 60- 90 | 1.08 | 1.59±0.73 | 0.51 | 0.38±0.01 | 0.46 | 1.09±0.12 | 0.40±0.01 | 0.55±0.02 | 0.50±0.03 | 0.68±0.04 |
| 90-135 | 6.92 | 1.73±0.39 | 0.48 | 0.55±0.06 | 0.85 | 1.54±0.25 | 0.56±0.05 | 0.86±0.15 | 1.16±0.37* | 0.90±0.11* |
| 135-180 | 9.86 | 3.05±0.72 | 0.69 | 0.65±0.07 | 5.82 | 3.10±0.22 | 1.23±0.39 | 1.34±0.37 | ---- ** | ---- |
| 180-240 | ---- | ---- | ---- | ---- | ---- | ---- | 4.18±0.89 | 2.57±0.38 | ---- | ---- |
| Avg | 4.55 | 1.73 | 0.59 | 0.54 | 1.88 | 1.64 | 1.18 | 1.03 | 0.67 | 0.74 |
| | | | | | SAR ([meq.L-1]0.5) | | | | | |
| 0- 15 | 0.04 | 0.73 | ---- | 0.54 | ---- | 0.88 | 0.40 | 0.42 | 0.29 | 0.54 |
| 15- 30 | 0.52 | 0.77 | ---- | 0.71 | ---- | 1.35 | 0.44 | 0.50 | 0.30 | 0.61 |
| 30- 60 | 0.16 | 1.24 | 0.65 | 0.98 | ---- | 1.84 | 0.48 | 0.89 | 0.39 | 0.86 |
| 60- 90 | 1.74 | 1.45 | 0.22 | 1.27 | ---- | 2.34 | 0.80 | 1.14 | 0.68 | 1.51 |
| 90-135 | 6.02 | 4.61 | 2.24 | 2.25 | 0.48 | 1.99 | 3.17 | 1.27 | 1.98 | 1.75 |
| 135-180 | 10.53 | 3.41 | 2.08 | 2.09 | 2.08 | 1.51 | 3.08 | 1.60 | ---- | ---- |
| 180-240 | ---- | ---- | ---- | ---- | ---- | ---- | 3.32 | 1.69 | ---- | ---- |

* Sampled to 120 cm.
** Not available

annual precipitation is 405 mm, of which 70 percent falls from April 1 to September 30 (Hobbs, 1977), with peak precipitation in the months of May and June, a period when the soil could contain considerable moisture from fall, winter and early spring precipitation. With the extra May-June precipitation the soil can become saturated and leaching occurs. This along with the excess waters that percolate through the soil during normal irrigation is sufficient to provide the leaching required to maintain a desirable salt balance in the soil. Even with moderate applications of irrigation water there is evidence that some of the water penetrates deeper than anticipated (Chang and Sommerfeldt, 1982).

These factors coupled with excellent quality irrigation water are desirable for permanency of irrigation in Alberta. The quality of the waters of the Oldman River and its tributaries has been reported by Lutwick and Chang (1964) as being better than a C2 - S1 rating (USDA Salinity Lab. standards). Bowser et al. (1963) report the water quality of the St. Mary reservoir as being high quality with an EC of less than 0.3 dS m(-1) and an SAR of less than 1.0, and that there appears to be very small salt pick-up via the canals and reservoirs. Sommerfeldt (unpublished data) found the average water qualities in two irrigation systems, considerable distance down stream from their mountain sources had average Ecs of 0.37 and 0.52 dS m(-1) and the SARs were 0.88 and 1.52 respectively. The greatest threat to waterlogging and salinization of the land in the irrigation districts is seepage from the canals.

The soils within the irrigation districts of Alberta are generally permeable, some more so than others. Limited seepage is expected from all the earthen canals. When seepage exceeds the drainage capacity of the soil a water table builds up. Under these conditions measures such as lining of the canals, relocation of the canals to less permeable soils or drainage to intercept the seepage water is required to prevent further damage and to reclaim the damaged land.

The conclusions from these studies are that long-term irrigation in Alberta has not been a major contributor to soil waterlogging and salinization. Rather, canal seepage is the major contributor. Measures to control canal seepage are recommended. With the elimination of the seepage problems the needs for extensive artificial drainage for continued irrigation, as recommended by Maierhofer (1956) and Stanley/SLN Consultants Limited (1978) will not be necessary for continued irrigation in Alberta.

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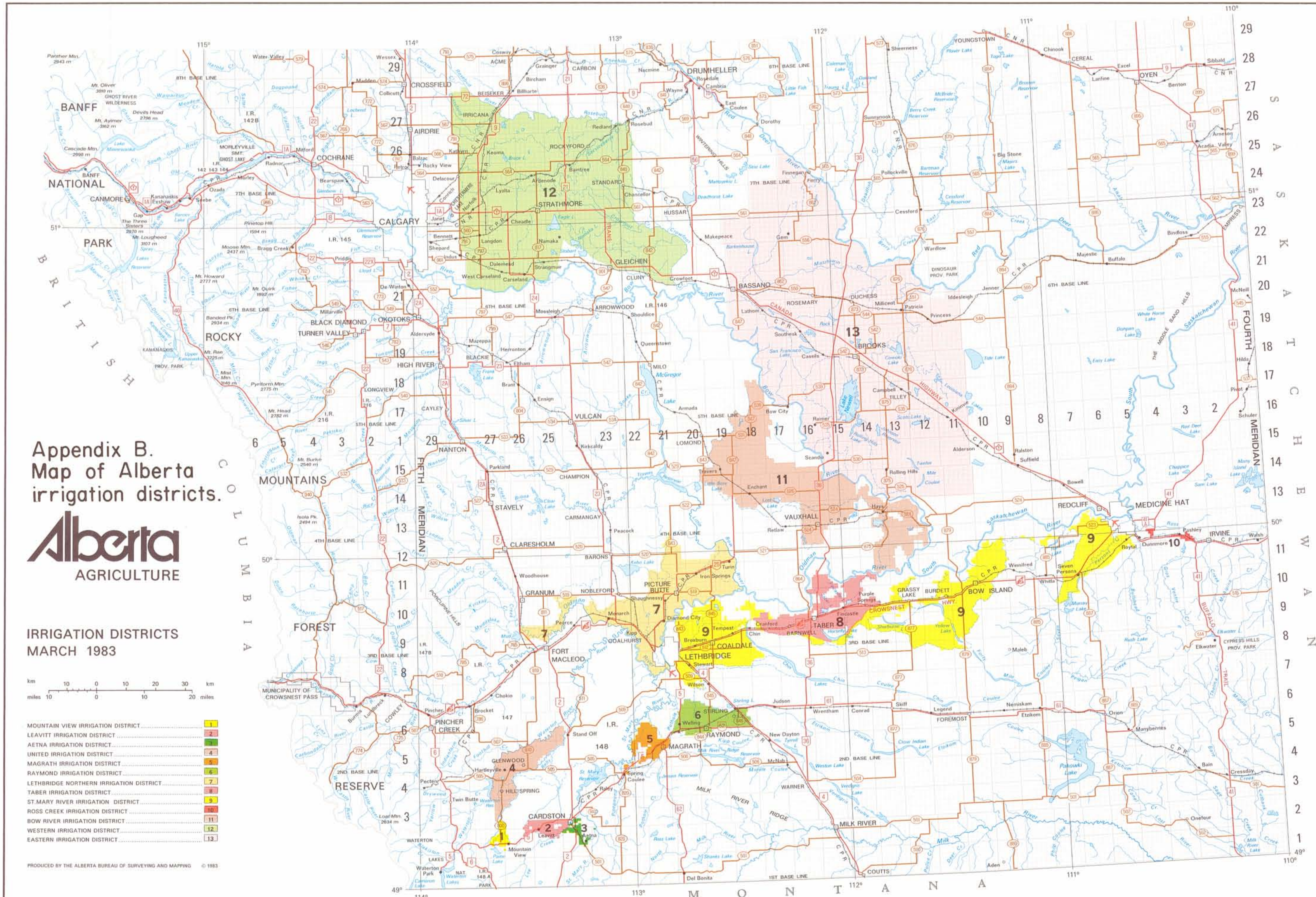

Appendix B.
Map of Alberta irrigation districts.
Alberta
AGRICULTURE
IRRIGATION DISTRICTS
MARCH 1983
MOUNTAIN VIEW IRRIGATION DISTRICT 1
LEAVITT IRRIGATION DISTRICT 2
AETNA IRRIGATION DISTRICT 3
UNITED IRRIGATION DISTRICT 4
MAGRATH IRRIGATION DISTRICT 5
RAYMOND IRRIGATION DISTRICT 6
LETHBRIDGE NORTHERN IRRIGATION DISTRICT 7
TABER IRRIGATION DISTRICT 8
ST.MARY RIVER IRRIGATION DISTRICT 9
ROSS CREEK IRRIGATION DISTRICT 10
BOW RIVER IRRIGATION DISTRICT 11
WESTERN IRRIGATION DISTRICT 12
EASTERN IRRIGATION DISTRICT 13
PRODUCED BY THE ALBERTA BUREAU OF SURVEYING AND MAPPING © 1983
BRITISH COLUMBIA
SASKATCHEWAN
MONTANA
FIFTH MERIDIAN
FOURTH MERIDIAN
CALGARY
LETHBRIDGE
MEDICINE HAT

CHAPTER 4.C.

# COMPARISON OF IRRIGATED LANDS IN ALBERTA, CANADA

# AND

# POTENTIALLY IRRIGATED LANDS IN CENTRAL SOUTH DAKOTA

by

U.S. BUREAU OF RECLAMATION
MB LAND CLASSIFICATION BRANCH

1987

## CONTENTS



## TABLES

## 4.C.1
## INTRODUCTION

Irrigated lands referred to are in southern Alberta, near Lethbridge. Central South Dakota lands are located in Beadle, Faulk, Hand, Hughes, Hyde, Spink and Sully Counties.

## 4.C.2
## TOPOGRAPHY

In Alberta many till lands have nearly level to slightly undulating slopes (0 to 3%) which have been gravity irrigated for many years. Some have been converted to sprinkler-type irrigation in the last 20 years. In the CENDAK Project a few acres would have this type of topography suitable for gravity irrigation. Most of the CENDAK lands have rolling to undulating complex (3 to 10%) slopes which are suitable for sprinkler irrigation. Presently more acres in Alberta unsuitable for gravity irrigation are now sprinkler irrigated and have rolling to undulating gradient; therefore, the topography as regards sprinkler irrigation is very similar between Alberta and CENDAK.

Alberta's irrigated lands have very few shallow closed depressions (potholes), but some areas of CENDAK have as many as 2 to 4 potholes that are 5 to 10 acres in size per section (640 acres) of land. Small to large, deep depressions, are of only minor extent in Alberta or CENDAK.

## 4.C.3
## CLIMATE

Climatic factors, which are very important for soil development, appear to be similar except more favorable for crop selection in CENDAK due to warmer night-time temperatures during the growing season. Higher natural precipitation in the CENDAK area has contributed to more developed soils with darker A & B horizons in association with higher organic matter in A horizons. During winter months, South Dakota has more snowfall and no chinook winds. In Alberta, winter chinooks are associated with freezing and thawing of surface soils during the winter and early spring.

## 4.C.4
## SOILS

Table 1 shows a comparison of major soil characteristics for till soils in Alberta and South Dakota. Table 2 indicates the average thickness of the different soil horizons. Some A horizons in South Dakota are slightly finer textured (clay loam vs silt loam) than in Alberta; otherwise, A horizons have corresponding

Table 1. Morphology of glacial till soils - central South Dakota and Alberta, Canada

| Soil Series | Texture A Horizons | Texture B Horizons | Texture C Horizons | Structure A Horizons | Structure B Horizons | Structure C Horizons | Color (Dry) A Horizons | Color (Dry) B Horizons | Color (Dry) C Horizons | Estimated Permeability Ranges * A Horizons | Estimated Permeability Ranges * B Horizons | Estimated Permeability Ranges * C Horizons |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SOUTH DAKOTA | | | | | | | | | | | | |
| Beadle | Clay Loam | Clay | Clay Loam | Prismatic, Subangular Blocky | Prismatic, Subangular Blocky | Massive | Dark Grayish Brown | Dark Grayish Brown | Light Brownish Gray | .25 to .10 | .15 to .08 | .15 to .02 |
| Bonilla | Loam | Loam | Clay Loam | Granular, Subangular Blocky | Prismatic, Subangular Blocky | Massive | Dark Grayish Brown | Dark Grayish Brown | Pale Yellow | .25 to .10 | .15 to .08 | .15 to .02 |
| Bowbells | Loam | Clay Loam | Clay Loam | Granular, Subangular Blocky | Prismatic, Subangular Blocky | Massive | Dark Gray | Dark Grayish Brown | Light Brownish Gray | .25 to .10 | .15 to .08 | .15 to .02 |
| Eakin | Silt Loam | Silty Clay Loam | Silty Clay Loam | Granular, Subangular Blocky | Prismatic, Subangular Blocky | Prismatic, Massive | Dark Grayish Brown | Dark Grayish Brown | Light Brownish Gray | .25 to .10 | .15 to .08 | .15 to .02 |
| Hand | Loam | Loam, Clay Loam | Clay Loam | Granular | Prismatic, Subangular Blocky | Massive | Dark Grayish Brown | Grayish Brown, Light Gray | Light Brownish Gray | .25 to .10 | .15 to .08 | .15 to .02 |
| Houdek | Loam | Clay Loam | Clay Loam | Granular | Prismatic, Subangular Blocky | Subangular Blocky | Dark Gray | Dark Grayish Brown | Light Brownish Gray | .25 to .10 | .15 to .08 | .15 to .02 |
| Prosper | Loam | Clay Loam | Clay Loam | Granular, Subangular Blocky | Prismatic, Subangular Blocky | Massive | Dark Gray | Dark Gray, Grayish Brown | Pale Yellow | .25 to .10 | .15 to .08 | .15 to .02 |
| Williams | Loam | Clay Loam | Clay Loam | Granular | Prismatic, Subangular Blocky | Massive | Dark Grayish Brown | Dark Grayish Brown, Brown | Pale Yellow | .25 to .10 | .15 to .08 | .15 to .02 |
| ALBERTA | | | | | | | | | | | | |
| Cecil | Loam | Loam, Clay Loam | Loam, Clay Loam | Granular, Platy | Subangular Blocky | Subangular Blocky, Massive | Brown, Grayish Brown | Dark Brown, Brown | Brown, Pale Yellow | 0.3 to 1.5 | 0.5 to 1.5 | 0.1 to 0.7 |
| Chin | Silt Loam | Silt Loam | Silt Loam | Granular | Prismatic, Subangular Blocky | Massive | Dark Brown, Brown | Yellowish Brown | Yellowish Brown, Olive Brown ** | 0.3 to 1.5 | 0.5 to 1.5 | 0.1 to 0.7 |
| Cranford | Loam | Loam, Silt Loam | Loam, Clay Loam | Granular, Subangular Blocky | Subangular Blocky | Subangular Blocky | Brown | Dark Brown, Yellowish Brown | Pale Brown, Brown | 2.0 | 1.0 | 0.7 |
| Hemaruka | Loam | Clay Loam, Clay | Clay Loam, Clay | Granular, Platy | Columnar, Angular Blocky | Subangular Blocky, Angular Blocky | Dark Brown, Grayish Brown | Dark Brown, Brown | Dark Grayish Brown | 1.0 to 4.0 | 1.0 to 3.0 | 1.0 to 3.0 |
| Hughendon | Loam | Loam, Clay Loam | Loam, Clay Loam | | Prismatic, Subangular Blocky | Blocky, Massive | Dark Brown | Dark Grayish Brown | Pale Brown | 2.0 | 1.0 | 1.0 to 1.5 |
| Lethbridge | Silt Loam | Silt Loam | Silt Loam | Granular | Prismatic, Subangular Blocky | Massive | Very Dark Brown | Yellowish Brown | Yellowish Brown, Olive Brown ** | 2.0 | 1.0 | 0.2 to 0.5 |
| Maleb | Loam | | | | | | Brown | Dark Grayish Brown | Yellowish Brown **, Pale Brown ** | 2.0 | 1.0 | 1.0 to 1.5 |
| Tilley | Silt Loam | Silty Clay Loam | Silt Loam | Granular, Subangular Blocky | Prismatic, Subangular Blocky | Massive | Grayish Brown | Dark Brown ** | Yellowish Brown **, Pale Brown ** | 0.5 to 2.0 | 0.1 to 2.0 | 0.2 to 1.0 |
| Wardlow | Silt Loam | Silty Clay Loam | Silty Clay Loam | Granular, Platy | Columnar, Subangular Blocky | Subangular Blocky, Massive | Grayish Brown | Dark Brown, Brown | Light Gray, Very Pale Brown | 1.0 to 4.0 | 0.02 to 0.5 | 0.05 to 0.8 |
| Whitney | Loam, Silt Loam | Silt Loam | Silty Clay Loam, Clay Loam | Granular, Subangular Blocky | Prismatic, Subangular Blocky | | Dark Grayish Brown | Dark Brown, Yellowish Brown | Yellowish Brown | 2.0 | 1.0 | 0.7 |

* Inches per hour
** Moist Color

Table 2. Average thickness of horizons - glacial till soils, central South Dakota and Alberta, Canada

| Soil Series | A Horizons (inches) | B Horizons (inches) | C Horizons (inches) |
|---|---|---|---|
| Beadle | 7 | 23 | 24+ |
| Bonilla | 9 | 20 | 31+ |
| Bowbells | 11 | 16 | 33+ |
| Eakin | 7 | 15 | 38+ |
| Hand | 9 | 20 | 31+ |
| Houdek | 7 | 22 | 31+ |
| Prosper | 10 | 24 | 26+ |
| Williams | 7 | 23 | 30+ |
| Cecil | 8 | 4 | 28+ |
| Chin | 5 | 8 | 43+ |
| Cranford | 4 | 9 | 7+ |
| Henaruka | 3 | 7 | 21+ |
| Hughendon | 4-6 | 6-8 | 10+ (estimate) |
| Lethbridge | 5 | 8 | 43+ |
| Maleb | N/A* | N/A* | N/A* |
| Tilley | 9 | 8 | 21+ |
| Wardlow | 4 | 8 | 98+ |
| Whitney | 4-6 | 6 | 12+ |

* Not Available
Till is considered part of the C Horizon.

textures. B horizons are very comparable except B horizons are approximately 12 inches thicker in South Dakota. Some C horizons in Alberta are slightly lighter textured (loam or silt loam vs clay loam); otherwise, C horizons are comparable, including till textures to a depth of 10 feet.

Soil structure in the A, B and C horizons are similar with granular, prismatic, subangular blocky and massive, being common to both Alberta and South Dakota soils.

All lands evaluated in both Alberta and CENDAK are underlain by till at depths less than 5 feet and in numerous situations at depths of 3 feet. Many of the soils in Alberta are considered shallow lacustrine deposits over till, while CENDAK soils are developed from till material or loess deposits over till. Technically the main concern is that they are glaciated lands both in Alberta and CENDAK, underlain by till, which in the past was of questionable suitability for sustained irrigation.

Soil colors, thickness of horizons, organic matter content, development of B horizons, soil textures etc., vary slightly between Alberta and CENDAK, but these factors are not of major concern for irrigation. Salinity throughout the soil profile and to a depth of 10 feet appears to be very comparable under rangeland, dryland or present irrigated conditions, although the present ground water used for private irrigation in the CENDAK area is of a much poorer quality than irrigation water directly diverted from streams in Alberta.

Alberta has some sodium (Solonetz Soils) lands which are presently being brought under irrigation on a trial basis. Sodium soils do not occur in the CENDAK project or are of a very limited extent.

Considering all other comparison, it is believed that till soils to a depth of at least 10 feet are slightly more desirable for sprinkler irrigation in the CENDAK area than in Alberta. This statement is based on the till in the CENDAK area being more ablated (reworked), having slightly less uniform clay content and lower bulk densities, and being more favorable to movement of air, water and roots than till in the Alberta area.

## 4.C.4.1
## Permeability (Hydraulic Conductivity)

Table 1 indicates estimated permeability ranges for the different soil horizons. All ranges are listed the same for A, B and C horizons. It is not advisable to try and show various rates for these genesis and morphology related till soils. A horizon and upper part of B horizon ranges of hydraulic conductivity could be considerably higher than shown on table 1 because of crops grown and different levels of management. C horizon rates are to a 10-foot depth in the weathered (oxidized) tills. In both Canada and South Dakota till is usually encountered at an average depth of 3 feet in the soil profile or directly below the Bca or Cca horizon.

Estimated ranges of permeability in table 1 for South Dakota were determined by evaluating four different sources of data, (1) in-place permeability tests and pump-in test results from the Bureau's report on Eastern South Dakota Basins supporting data dated 1971 - Missouri-Oahe Projects Office, Huron, South Dakota, (2) disturbed permeability tests analyzed at the Bureau Soil and Water Laboratory at Bismarck, North Dakota, for the 1982 Bureau reconnaissance land classification survey for the CENDAK Project, (3) results of undisturbed soil cores analyzed in the Bureau Soil Laboratory at Huron, South Dakota, and (4) published soil surveys for CENDAK counties by the USDA-SCS in cooperation with South Dakota Agricultural Experiment Station.

## 4.C.4.2
## Surface Cover (Stoniness or Rockiness)

In Alberta very few (if any) of the irrigated lands have glacial erratic boulders on the surface or in the soil profile. Some scattered tracts of land in the CENDAK area have a surface cover of granitic cobble or boulders, but where this feature is present, the problem is slight to moderate from a tillage standpoint.

# CHAPTER 5.A.

# HYDROGEOLOGY OF THE CENDAK AREA, SOUTH DAKOTA

by

SOUTH DAKOTA
DEPARTMENT OF WATER AND NATURAL RESOURCES
DIVISION OF GEOLOGICAL SURVEY

1987

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## 5.A.1
## INTRODUCTION

### 5.A.1.1
### Purpose

The purpose of this section of the comparison report is to define the hydrogeologic system of the CENDAK area. This will be accomplished by summarizing existing geologic and hydrologic data and incorporating current research by the South Dakota Geological Survey, United States Bureau of Reclamation, South Dakota State University, and others. These data will be evaluated and interpreted relative to water movement in the sediments of the CENDAK area.

Once the hydrogeologic evaluation is completed, a comparison will be provided (in sec. 5.C.) of hydrogeologic conditions existing in the CENDAK area to those existing in an extensive irrigated area in southern Alberta, Canada (see sec. 5.B.).

### 5.A.1.2
### Problem

It has long been known from soils infiltration studies and monitoring of shallow water levels in till soils that a significant but unquantified amount of precipitation water infiltrating the soil penetrates below the root zone (deep percolation). Until recently, conceptual hydrologic models attributed dissipation of substantial portions of this deep percolation water to:

1. downward movement to an aquifer system (as recharge) and subsequent discharge through a regional aquifer flow system,

2. lateral flow within the till and subsequent discharge through a local or regional flow system, or

3. a combination of both mechanisms.

In what is now the CENDAK area, Harding and others (1954) proposed that natural deep percolation water moved vertically downward through till where it reached a regional aquifer system that is now called the Tulare aquifer (Howells and Stephens, 1968) and flowed laterally to eventually be discharged into the James River. They (Harding and others, 1954) concluded that a regional flow system did exist and that it accounted for dissipation of a substantial portion of the deep percolation waters. However, they also concluded that due to the low hydraulic conductivity of the unweathered till overlying the aquifer system, the till could not transmit substantial additional increments of deep percolation water into the aquifer.

Koch (1980) described the Tulare aquifer in Hand and Hyde Counties as "... a complex system of interconnected sand and gravel layers which are separated by till." Recognizing the complexity of the aquifer systems Koch stated, "The boundaries of these aquifers and the hydrologic relationships between them can be determined only after detailed investigations have been made throughout the area." Thus, while recognizing the complexity and lack of understanding of the aquifer system, he depicted the flow system as a single interconnected system when preparing a potentiometric map (Koch, 1980, fig. 10) of the Tulare aquifer.

There is little doubt that part of the widespread "Tulare aquifer" system as defined by Hedges and others (1985) functions as suggested by Harding and others (1954) and Koch (1980). However, until recently the magnitude of water movement through unweathered till was unquantified. In much of Hand and Hyde Counties in particular, it is now doubtful that there is any significant water movement through unweathered till. This doubt was first voiced for till lands in South Dakota in general, and the CENDAK area specifically, by Barari (1983) and later by Barari and Hedges (1985) when it was suggested that vertical water movement through unweathered till may be insignificant or nonexistent. This concept has enormous implications when considering the technical practicality and environmental aspects for drainage of irrigated lands, not to mention aquifer recharge potential, as well as other environmental issues which may be affected.

If vertical water movement through unweathered till under natural conditions is insignificant or nonexistent in some areas, and if man-induced conditions (such as drainage wells) cannot substantially increase this rate of movement, then the drainage-well concept of draining excess irrigation water will not work for much of the CENDAK area. In addition, if lateral flow cannot dissipate this volume of water, as also suggested by Barari (1983) and Iles and others (in prep.), then some other mechanism must be responsible for the dissipation of water percolating below the root zone. The possibility that an alternative mechanism does exist is suggested when examining presently irrigated till soils in the United States and Canada. These areas have little or no artificial drainage and have not experienced prohibitive salt or water-logging problems over a 20- to 75-year period. Barari (1983) suggested that the primary alternative mechanisms are upward movement by capillary action (including evapotranspiration) and direct evaporation through fractures in the weathered till.

The specific questions that need to be addressed to provide answers to the issues raised in the previous discussion are:

1. If water percolating below the root zone is dissipated by regional aquifer flow, then,

   a. what is the degree and magnitude of hydraulic continuity between the till and aquifers, and

b. what are the areal extent and degree of physical and hydraulic continuity between the sand and gravel lenses of the "Tulare aquifer," particularly in Hand and Hyde Counties?

2. If other mechanisms are responsible for dissipation (in part or wholly) of water percolating below the root zone, then,

   a. what are these mechansims, and

   b. what are the magnitudes of water dissipated by these mechanisms?

## 5.A.2
## GEOLOGY

### 5.A.2.1
### Bedrock

Bedrock underlying the CENDAK area ranges in age from Cretaceous to Precambrian (table 1). The predominantly marine sedimentary rocks were deposited on the southeast flank of the Williston Basin, a large structural basin dipping to the northwest into North Dakota, Montana and Canada. Within the CENDAK area, the rocks dip to the northwest about 10 feet per mile, following the slope of the Precambrian basement rocks. Only upper Cretaceous bedrock subcrops beneath the glacial drift. Lithologies of all the bedrock units within the CENDAK area are described in table 1.

General information on occurrence and thickness of bedrock units was taken from many sources (Christensen, 1977; Duchossois, in prep.; Gries, 1981; Hedges, 1968; Hedges and others, 1985; Helgerson and Duchossois, in prep.; Schoon, 1971; and Robert Schoon, South Dakota Geological Survey, personal communication, 1986).

#### 5.A.2.1.1
#### Pre-Cretaceous Rocks

Pre-Cretaceous rock units range in age from Precambrian to Permian and are, in ascending order, undifferentiated igneous and metamorphic rocks, Sioux Quartzite, Winnipeg Formation, Red River Formation, sandstones of Devonian age, Madison Group, and Minnelusa Group. These rocks all thicken and dip to the northwest reflecting structural control of the Williston Basin. Because details of occurrence of these rocks are not germane for the purposes of this report, only brief, representative, lithologic descriptions of each rock unit are presented in table 1 and will not be repeated here.

## 5.A.2.1.2
## Cretaceous Rocks

Cretaceous rocks in the CENDAK area are all marine sedimentary rocks deposited in the continental interior seaway of North America (Caldwell, 1975). They generally dip to the northwest reflecting control of the Williston Basin. However, local structural and tectonic controls affected their thickness and distribution, particularly with respect to the Inyan Kara Group and the Dakota Formation, which are the lower sandstone units.

The Cretaceous rocks underlying the CENDAK area are, in ascending order, the Inyan Kara Group, Skull Creek Shale, Dakota Formation, Graneros Shale, Greenhorn Limestone, Carlile Shale, Niobrara Formation, and Pierre Shale. The Carlile Shale, Niobrara Formation, and Pierre Shale will be discussed in more detail because they are the rocks which directly underlie the glacial deposits mantling the CENDAK area. Detailed information on geologic and hydrologic characteristics of the other Cretaceous rocks can be obtained from references already cited. A general description of their occurrence and water-bearing characteristics can be found in table 1.

### 5.A.2.1.2.1
### CARLILE SHALE

The Carlile Shale is a light- to dark gray or black plastic-like shale. Concretions and lenses of sandstone may be present. The Codell Sandstone Member occurs at or near the top of the Carlile throughout much of the south central part of eastern South Dakota (Hedges and others, 1985), but is present in only a small portion of the CENDAK area in central Beadle County (Hedges, 1968). A sand with an average thickness of 13 feet has also been tentatively correlated with the Codell in Hughes County (Duchossois, in prep.). The Carlile underlies the entire CENDAK area and a range of thickness by county is shown in table 1. The Carlile directly underlies glacial drift in the deep, narrow bedrock channel in northern Beadle and southern Spink Counties (fig. 1).

### 5.A.2.1.2.2
### NIOBRARA FORMATION

The Niobrara Formation consists of speckled marl, chalk, and some shale. Foraminifera are abundant in the marl and give it the speckled appearance. The entire unit is generally calcareous. The Niobrara Formation underlies the entire CENDAK area except for the deep narrow bedrock channel in northern Beadle and southern Spink Counties where it has been completely eroded exposing the underlying Carlile Shale (fig. 1). The Niobrara Formation underlies and is in contact with glacial drift in central Beadle County, Spink County, and eastern Hand County (fig. 1). Throughout the remainder of the CENDAK area the Niobrara Formation is overlain by Pierre Shale.

Table 1. Age, lithology, water-bearing characteristics, occurrence, and thickness of bedrock units in the CENDAK area.

| Age (period) | Rock Unit | Dominant Lithology | Water-Bearing Characteristics | | Beadle | Faulk | Hand | Hyde | Hughes | Spink | Sully |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Occurrence and thickness (in feet) of rock units within the CENDAK area listed by County * | | | | | | |
| CRETACEOUS | Pierre Shale | Shale | Poorly permeable. May yield small amounts of mineralized water to wells from the upper weathered layer, if present. | CRETACEOUS CONFINING LAYER | 0-600 | >700 | 0-710 | | 60-690 | P | X |
| CRETACEOUS | Niobrara Formation | Chalk, light to dark gray, speckled, microfossiliferous. | Poorly permeable. May yield small amounts of mineralized water to wells. | | 0-110 | 200± | 65-155 | | 100-205- | P | X |
| CRETACEOUS | Carlile Shale | Shale, medium to dark gray, plastic, ironstone concretions and stringers of fine-grained sandstone | Impermeable | | 160-270 | 220± | 140-320 | | 270-340 | X | X |
| CRETACEOUS | Greenhorn Limestone | Limestone and shale, white to light gray, fossiliferous | Poorly permeable. May yield small amounts of mineralized water to wells. | | 20-110 | 110± | 74-120 | | 90-110 | X | X |
| CRETACEOUS | Graneros Shale | Shale, dark gray fissile to blocky, ironstone concretions | Impermeable | | 180-280 | 220± | 194-305 | | 210-320 | X | X |
| CRETACEOUS | Dakota Formation | Sandstone, white, fine to coarse-grained quartz and shale | Permeable, may supply flowing wells | | 0-550 | 60-360 | 203-315 | | 315-355 | X | X |
| CRETACEOUS | Skull Creek Shale | Shale, dark gray, glauconitic siltstone near middle part | Impermeable | | 0-50 | 110± | 26-125 | | 85-160 | P | X |
| CRETACEOUS | Inyan Kara Group | Sandstone, white, fine to coarse grained quartz | Permeable, may supply flowing wells | | 0-<100 | 140-360 | 80-240 | | 140-310 | P | X |
| JURASSIC | none | | | | | | | | | | |
| TRIASSIC | none | | | | | | | | | | |
| PERMIAN and PENNSYLVANIAN | Minnelusa Group | Sandstone, white to red, may be clayey; Limestone and/or dolomite, white to brown to gray to black, may be silty or contain shale; and Shale, green to red, plastic, may contain sands | Permeable, may supply flowing wells | | A | P | P | P | X | A | X |
| MISSISSIPPIAN | Madison Group | Limestone, white to light tan to medium brown to gray | Unknown, probable aquifer | | A | P | A | P | P | A | P |
| DEVONIAN | Devonian Sands | Sand | Unknown, probable aquifer | | A | P | A | P | P | A | P |
| SILURIAN | none | | | | | | | | | | |
| ORDOVICIAN | Red River Formation | Limestone, light colored in part dolomitized | Unknown, probable aquifer | | A | P | P | P | P | A | P |
| | Winnipeg Formation | Fine-grained quartz sandstone at base, green, splintery to subwaxy shale with small vitreous black phosphate nodules interbedded with siltstone at top | Unknown | | A | P | P | P | P | A | P |
| CAMBRIAN | none | | | | | | | | | | |
| PRECAMBRIAN | Sioux Quartzite | Orthoquartzite, silica-cemented sandstone, pale maroon to red | Impermeable except locally along fractures | | P | A | ? | ? | ? | A | A |
| | Igneous Rocks | Granite | Impermeable except locally along fractures | | X | X | X | X | X | X | X |

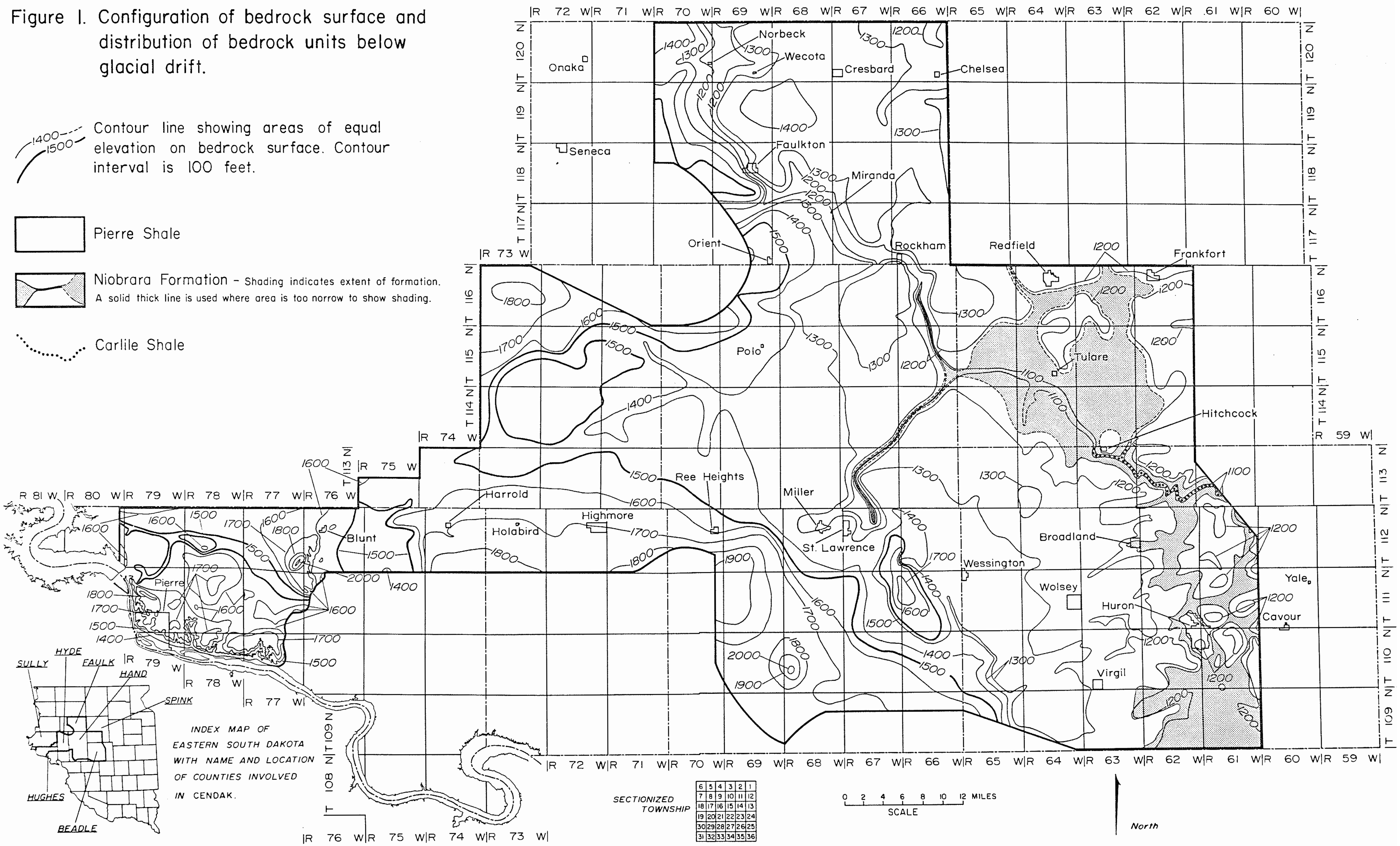
* Indicated thicknesses are within the County and not necessarily the CENDAK area.

Thicknesses are given where known, otherwise general occurrence is given as shown below.

- X: the indicated rock unit is present everywhere in the indicated county within the CENDAK area
- A: the indicated rock unit is absent everywhere in the indicated county within the CENDAK area
- P: the indicated rock unit is absent in a portion of the indicated county within the CENDAK area
- ±: approximate average thickness

Descriptions of dominant lithology taken from Schoon (1974).
Descriptions of water-bearing characteristics modified from Hamilton (1982).
Information on occurrence and thickness of rock units taken taken from Christensen(1977), Gries (1981), Hamilton (1982), Hedges (1968), Hedges and others (1985), Schoon (1971), and Duchossois and Schoon (1986, personal communications, South Dakota Geological Survey).

Figure 1. Configuration of bedrock surface and distribution of bedrock units below glacial drift.



### 5.A.2.1.2.3
### PIERRE SHALE

The Pierre Shale consists of light- to dark-gray to black shale, containing marly zones and chalky beds. Thin limestone beds, concretions, and bentonite may also be present. The Pierre Shale was subdivided into eight members by Crandall (1958), but will be discussed as a single unit in this report. The Pierre Shale underlies most of the CENDAK area except for limited areas in Beadle and Spink Counties, and extreme eastern Hand County where the Pierre Shale has been removed by erosion (fig. 1). The Pierre Shale is exposed at the land surface only in Hughes County and represents about 0.5 percent of the CENDAK area. Thickness of the Pierre Shale throughout the CENDAK area varies from 0 to about 900 feet and is illustrated on figure 2. This map was constructed by superimposing the bedrock topographic map (fig. 1) over a generalized contour map of the top of the Niobrara Formation and generating data of Pierre Shale thickness from difference in elevation of contour lines on the two maps. Thus, this map should be used only as a guide to general thickness distribution.

The upper surface of the Pierre Shale was subjected to long periods of weathering prior to being covered with glacial drift. Weathering and other processes such as glacial unloading have generally produced a highly fractured upper surface (Bredehoeft and others, 1983).

### 5.A.2.1.3
### Bedrock Topography

Topography of the bedrock surface within the CENDAK area is illustrated on figure 1. The topography is thought to be fairly representative of major pre-glacial drainage patterns in the area of the Coteau du Missouri even though significant modification of preexisting drainage undoubtedly occurred as ice advanced over the James Basin area. Regional pre-glacial drainage was to the north (Christensen, 1977; and Hedges, 1968), although a major southeasterly trending drainageway is seen to traverse portions of Faulk, Hand, Spink, and Beadle Counties (fig. 1). This portion of the pre-glacial drainage network is a remnant of the ancient Grand River drainageway (Christensen, 1977; and Duchossois, 1985). The existing bedrock topography had a major influence on the distribution and thickness of glacial drift.

## 5.A.2.2
## Origin and Age of Glacial Drift

When mapping the Pleistocene geology of eastern South Dakota, Flint (1955) used a four-fold subdivision for the Wisconsin Stage glaciation. These are from oldest to youngest, Iowan, Tazewell, Cary and Mankato substages. Each of these represented a major deglaciation and readvance of ice within the Wisconsin Stage. From more recent evidence based on regional correlations supported by radiocarbon dating of materials from below and within Wisconsin glacial drift, Lemke and others (1965) redefined the stratigraphy of Wisconsin drift in South Dakota. They simply numbered the Wisconsin advances from oldest to youngest (1 to 4 in South Dakota) and suggested that advance No. 1 occurred before about 22,000 years before present, or during the later part of the early Wisconsin stage and that the other advances postdated 22,000 years before present.

Hedges (1968) inferred the presence of early Wisconsin and pre-Wisconsin drift in Beadle County. Duchossois (in prep.) has also identified a buried till in Hughes County that could be early or pre-Wisconsin in age. However, neither of these inferred ages have been verified. Other extensive test drilling and geologic mapping in the CENDAK area has failed to verify the existence of more than one Wisconsin drift sheet or the presence of any pre-Wisconsin drifts (Helgerson and Duchossois, in prep.; Christensen, 1977; Duchossois, in prep.). North of the CENDAK area, in the James Basin and on the Missouri Coteau, extensive data have failed to provide evidence of more than one Wisconsin drift sheet (Leap, 1986; Koch, 1975; Christensen, 1977; Hedges, 1972; and Hedges, 1987). A preponderance of data therefore shows that the presence of pre-late Wisconsin drift in the CENDAK area is unlikely, or, if significant amounts are present, its upper weathered surface has been removed and is thus currently indistinguishable from late Wisconsin drift.

Regional ice flow directions for the late Wisconsin glaciation on a portion of the North American Continent are illustrated on figure 3 and show that the source area of glacial drift in the CENDAK area is to the north. Rock types along the flow path of the ice from Canada to southern South Dakota include predominantly Precambrian granitic rocks and Paleozoic limestones and dolomites in Canada and marine Cretaceous rocks in Canada, North Dakota, and South Dakota. The latter type was the dominant source for drift materials throughout approximately the last half of the flow path. The Cretaceous rocks over which the ice flowed contain an abundance of fine-grained materials (shales) and account for the high clay content of till generally found throughout most of South Dakota and in much of the CENDAK area (Flint, 1955).

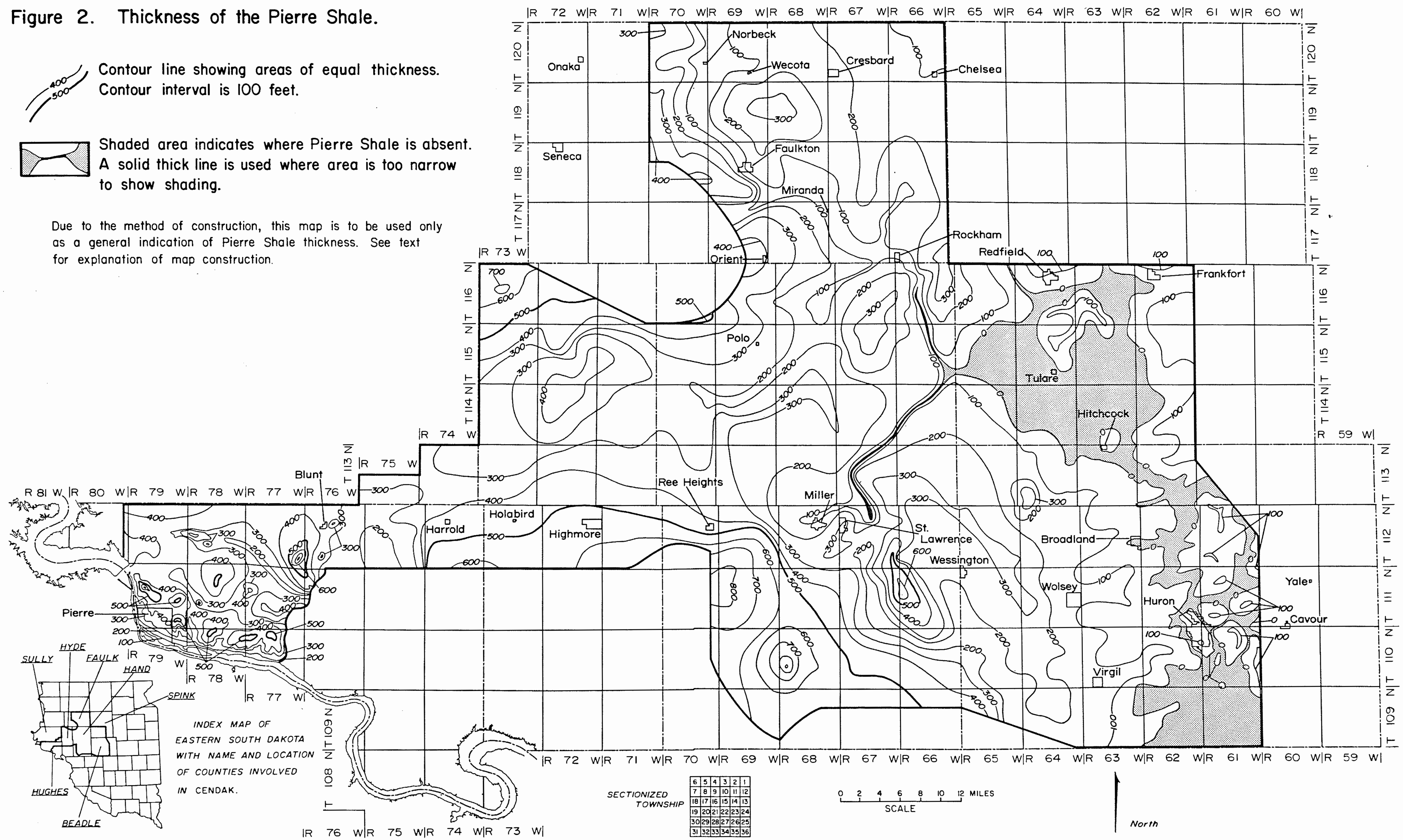
Ice of the James Lobe which was responsible for deposition of late Wisconsin age drift within the CENDAK area may have appeared as much as 22,000 years before present in South Dakota (Lemke and others, 1965). The time of cessation of active ice deposition is unknown, however, Hedges (in prep.) shows active ice in Aurora County about 25 miles south of the CENDAK area at 12,500 years before present. By inference, at least part of the CENDAK area would also have contained active ice at that time. Stagnant ice undoubtedly remained in many portions of the CENDAK area after retreat of the active ice and continued to shape landforms and deposit glacial drift as it melted. The length of time this

Figure 2. Thickness of the Pierre Shale.

Contour line showing areas of equal thickness. Contour interval is 100 feet.

Shaded area indicates where Pierre Shale is absent. A solid thick line is used where area is too narrow to show shading.

Due to the method of construction, this map is to be used only as a general indication of Pierre Shale thickness. See text for explanation of map construction.



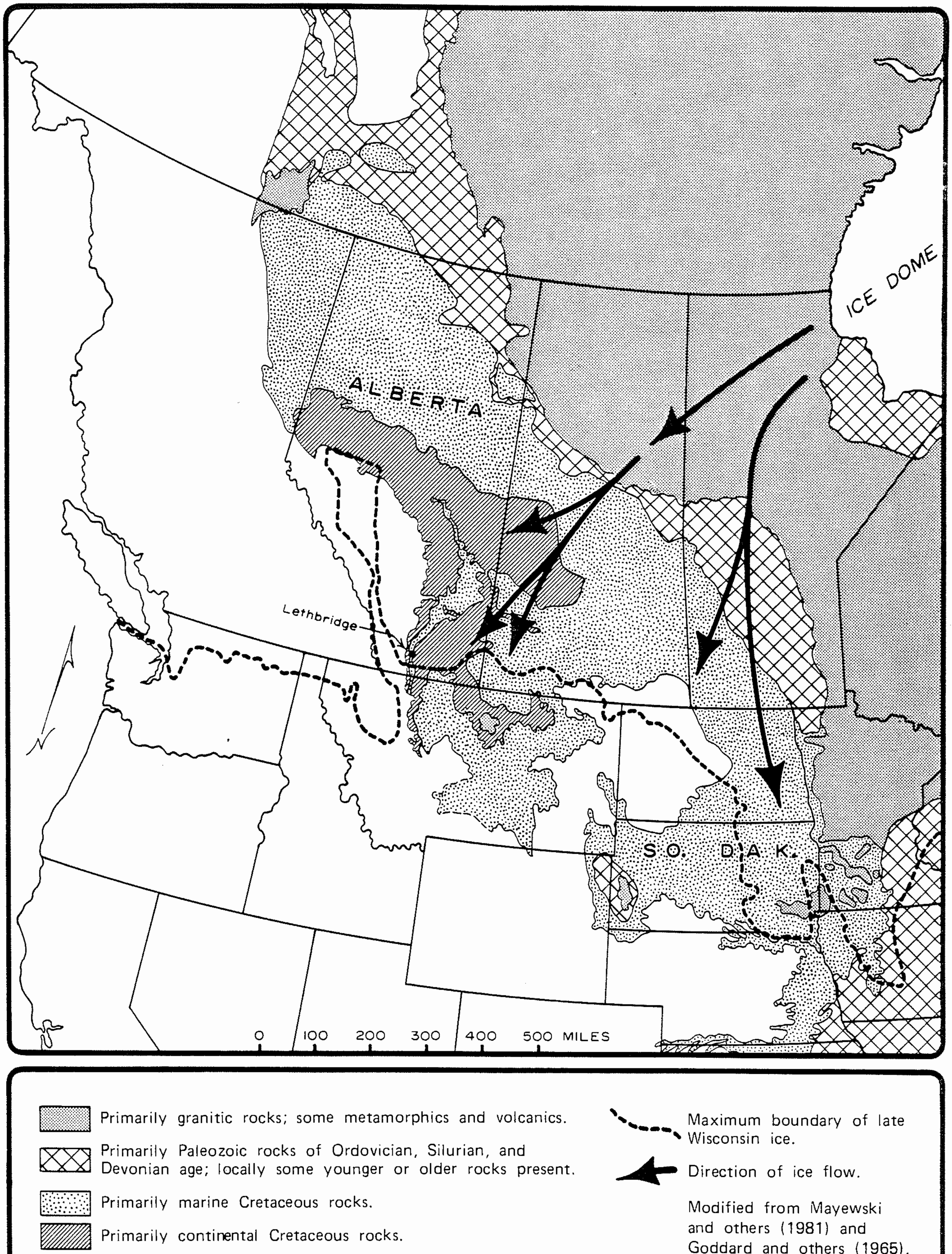



Figure 3. Distribution of major rock types, flow direction of late Wisconsin ice, and maximum extent of late Wisconsin drift in part of North America.

process occurred in the CENDAK area is unknown, however, Christensen (1977) reports stagnant ice conditions on the Missouri Coteau at 9,220 years before present. It is possible that similar conditions existed in part of the CENDAK area.

The preexisting bedrock topography was influential in channeling the James Lobe ice in a general southerly direction through eastern South Dakota. Late Wisconsin ice first entered the CENDAK area from the north along a bedrock low which is nearly coincident with the present James Basin. The ice eventually pushed westward from this bedrock low up onto the Coteau du Missouri, a bedrock high, and terminated near the present position of the Missouri River. The valleys of the major preglacial east-flowing streams in the CENDAK area (fig. 1) provided control for westward flowing sublobes of ice. The thickest deposits of glacial drift (fig. 4) are aligned over these valleys. Most portions of the preglacial valleys also were incorporated in the meltwater drainage system and often contain substantial amounts of outwash sediments. Numerous stillstands of the ice occurred during deglaciation as evidenced by recessional moraines (Lemke and others, 1965). If an earlier glaciation occurred in the CENDAK area, evidence of it was either masked or destroyed by the late Wisconsin ice advance, although evidence of pre-Wisconsin glaciation is present just south of the CENDAK area in Jerauld County (Hedges, in prep.b).

Glacial drift can be subdivided into two major lithologic groups, till and outwash. Other associated types of deposits generally included with glacial drift are glacial lake deposits, outwash-alluvium, loess and eolain sand. These deposits will be described in greater detail. Figure 4 is a generalized map showing thickness of glacial drift and associated deposits in the CENDAK area.

## 5.A.2.2.1
## Till

Till as a geologic term defines genetic origin in that it describes a method of deposition. Till is a sediment that was deposited directly under, from within or from the top of a glacier primarily without the benefit of the winnowing and sorting actions by running water. Within this context, the texture of till is generally described as a heterogeneous mixture of all materials picked up and transported in a glacier. In this same context, the texture of till is generally described as a heterogeneous mixture of clay, silt, sand, gravel, and boulder-sized materials, the proportions of which at any given location will depend on many factors associated with glacial flow and deposition. Primary factors determining the ultimate textural parameters of any till are: (1) material over which the glacier moves, (2) distance of travel before deposition as till, and (3) the amount and type of material already present in the ice.

Till within the CENDAK area was derived from ice of the James Lobe during late Wisconsin time (Lemke and others, 1965). Ice initially advanced into the South Dakota area along a topographic low on the bedrock surface which is essentially coincident with the present James Basin. The general character of the till was controlled by the sediments over which the last late Wisconsin ice was flowing. In this portion of the James Basin, those sediments consisted predominantly of Pierre Shale with some Niobrara Formation, till deposited during an eariler(?) advance, and lacustrine deposits.

The sub-crop extent of the Pierre Shale and Niobrara Formation is shown on figure 1. The presence and age, and extent of any preexisting till is unknown, however, most till predating the last ice advance is probably typical clayey till. The presence of a glacial lake predating Lake Dakota which could be a source of lacustrine sediments was first suggested by Flint (1955). Later, Hedges (1968) described thick lacustrine deposits in northern Beadle County, the presence of which confirms Flint's (1955) postulate. Also many test-hole samples from Spink, Beadle, and Hand Counties describe till which apparently is composed predominantly of reworked lacustrine sediments (Jensen, 1986). Furthermore, several test-holes in Beadle County (113-64-4d) drilled for an aquifer test (unpublished) encountered about 60 feet of till which contained only several feet of typical clayey till. The remainder of the till had a high content of reworked sandy, silty lacustrine deposits. These occurrences strongly imply the existence of a substantial lacustrine deposit in the northern James Basin which served as a source of lacustrine sediments incorporated in the till of the last ice advance.

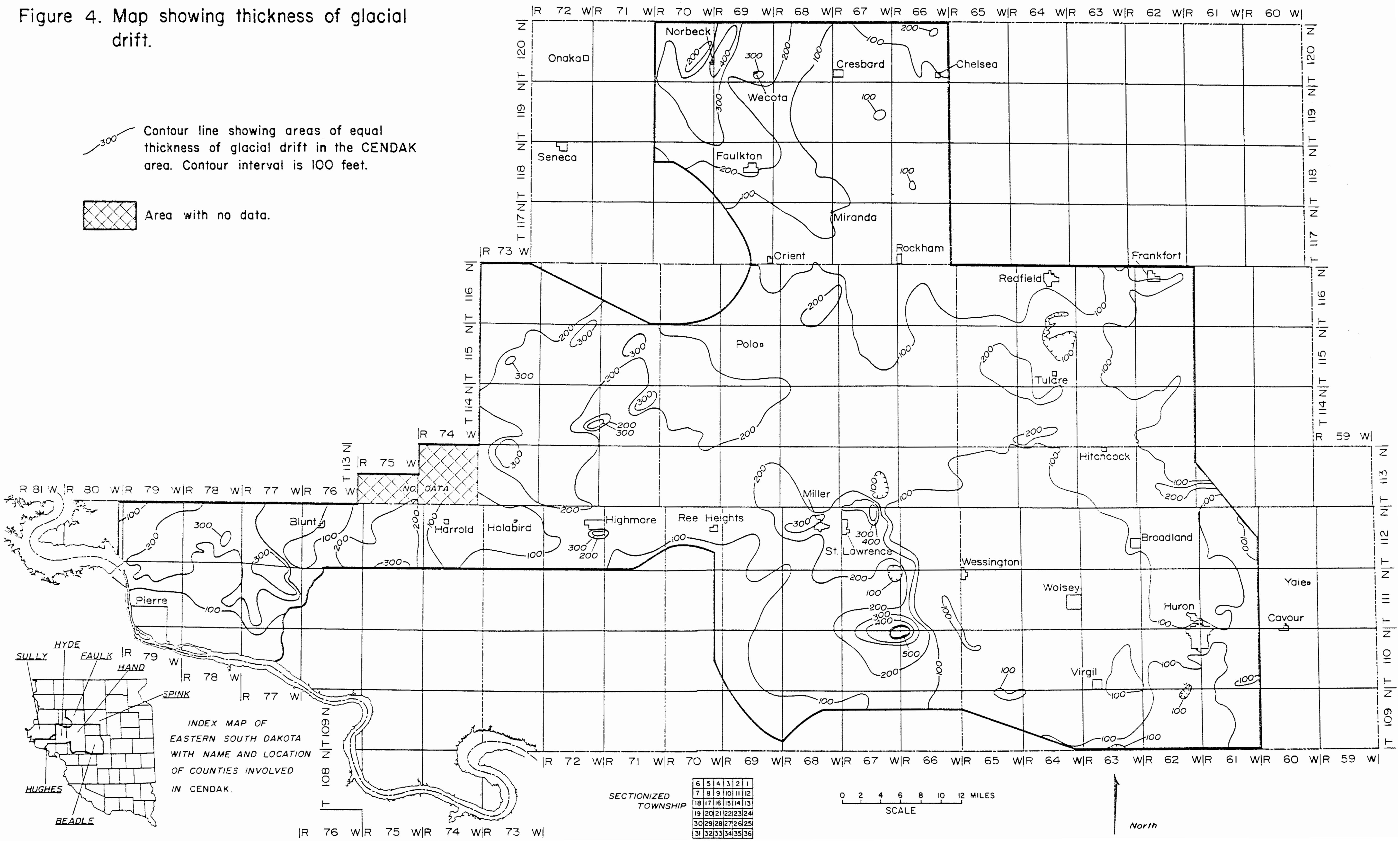
### 5.A.2.2.1.1
### DISTRIBUTION AND GEOMORPHOLOGY

Plate 1 is a generalized map illustrating the surface geology of the CENDAK area. More detailed maps are available for Beadle (Hedges, 1968), Hand and Hyde (Helgerson and Duchossois, in prep.), Hughes (Duchossois, in prep.), and Faulk Counties (Christensen, 1977); and these should be used for detailed investigative work. In addition, a geologic map interpreted and compiled from a soils map (Westin and others, 1954) was prepared for Spink County. Till is the most predominant surficial geologic unit and covers about 82 percent of the CENDAK area.

The till surface exhibits many various types of glacial geomorphic landforms which are, along with climate, major factors contributing to topography, drainage, and soil development. The till surface in the CENDAK area has been divided into two major geomorphic types, ground moraine and hummocky moraine.

Ground moraine is relatively flat, with local relief generally less than 20 feet. Sloughs and potholes generally are not as numerous as in hummocky moraine. Ground moraine is present in a

Figure 4. Map showing thickness of glacial drift.



strip several miles wide along the James River in northern Beadle and southern Spink Counties, a small area in southwestern Beadle and southeastern Hand Counties, and a north-south trending strip in central Faulk County and northern Hand County (pl. 1).

Hummocky moraine includes end moraine, and low and high relief stagnation moraine. Relief on hummocky moraine may vary from about 20 to over 100 feet. Slopes are steeper and potholes and sloughs are generally more numerous than in ground moraine. Hummocky moraine comprises the remainder of the till surface in the CENDAK area that is not ground moraine.

### 5.A.2.2.1.2 PHYSICAL CHARACTERISTICS

#### 5.A.2.2.1.2.1 Weathering

Interpretation of the depth of weathering was based on examination of individual test-hole logs and the characteristic color change from hues of yellow and brown (weathered) to gray (unweathered). The range of depth of weathering in till is illustrated in figure 5. In general, this map shows that the maximum depth of weathering gradually increases from about 35 feet in the east to over 90 feet in depth in the western part of the CENDAK area. It should be pointed out and emphasized that although the possible maximum depth of weathering increases westward, locally the depth of weathering may still be within the 15 to 35 feet range. Because many factors may contribute to the depth of weathering in till, the local and regional variations in depth of weathering of till in the CENDAK area cannot be explained at this time. Wherever saturated buried outwash (see section 5.A.2.2.2.3 for a discussion on buried outwash) is present at shallow depths, generally less than 35 feet, the overlying till is often completely weathered.

#### 5.A.2.2.1.2.2 Chemical Composition

Data on chemical composition of till are very limited in the CENDAK area. Fine (1982) lists values for specific electrical conductance, sodium-adsorption-ratio, and chloride content but lists only mean values for three tills representing three substages (Flint, 1955) of Wisconsin stage glaciation without providing locations for his 40 individual sample locations. The tills referred to in Fine's report occur in Hughes, Hyde, and Hand Counties and represent late Wisconsin till as defined in this report. A total of 76 samples were analyzed by Fine (1982) and mean values for three depth intervals (2-4, 4-6 and >6 meters) within the three tills in his report ranged from 2.95 to 5.02 mmhos/cm for specific electrical conductance, 2.60 to 7.60 for sodium-adsorption-ratio, and 1.26 to 3.56 meq/L for chloride content in saturated extracts. More recent data from till samples collected by the South Dakota Geological Survey and analyzed by the U.S. Bureau of Reclamation are presented in table 2.

**Table 2. Chemical data from till**

| | Sample Number | | | |
|---|---|---|---|---|
| | 62Q-3 | 62Q-4 | 62Q-5 | 62Q-6 |
| Mineralogy | Percentages | | | |
| Clay minerals: | | | | |
| Smectite (1) | 15 | 10-15 | 15-20 | 15 |
| Illite/micas (2) | 10 | 10-15 | 10 | 10 |
| Kaolinite | 5 | 5-10 | 5-10 | 5 |
| Calcite | 2- 3 | 2- 3 | 2- 3 | 2- 3 |
| Dolomite | 10 | 10 | 10-15 | 5-10 |
| Quartz | 35 | 30 | 30 | 30-35 |
| Feldspars | 5-10 | 10 | 5-10 | 10 |
| Gypsum (3) | 2- 3 | <1 | <1 | 3- 4 |
| Pyrite | 0 | 2- 3 | <1 | 1- 2 |
| Iron oxides (4) | 2- 3 | <1 | 2- 3 | 2- 3 |
| Chlorite | <1 | 2- 3 | <1 | <1 |
| Minor (5) | 10 | 10 | 10 | 10 |

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

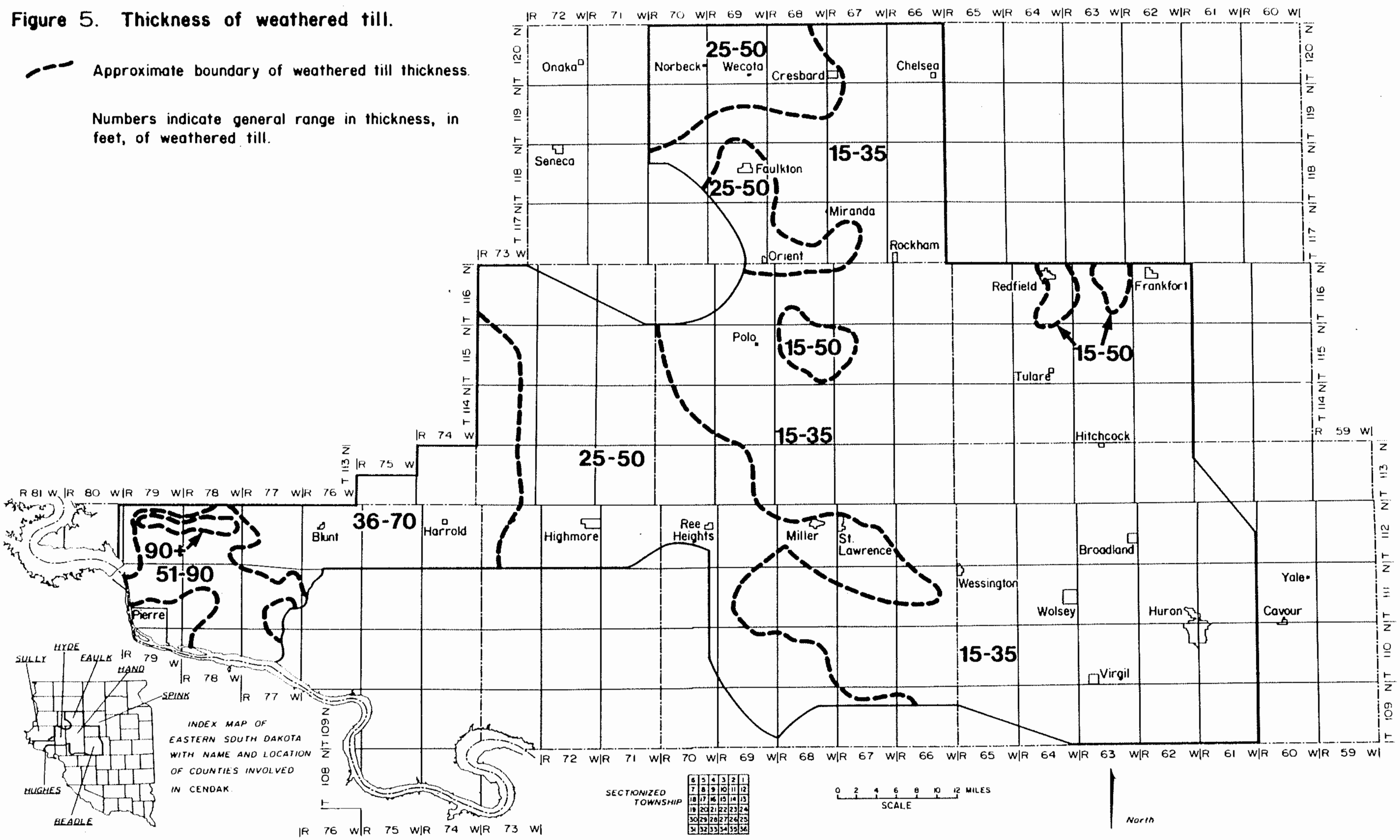
(1) Chiefly calcium montmorillonite, includes minor amounts of mixed and interlayered varieties.
(2) Chiefly illite, includes trace amounts of biotite and muscovite.
(3) During oven drying the mineral was converted to bassanite (plaster of paris - $CaSO_4 \times 0.5 H_2O$).
(4) Chiefly amorphous iron oxides, includes trace amounts of hematite, magnetite, and ilmenite.
(5) 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.

Sample locations and depths:
62Q-3: 113N-67W-20CCCC -- 17.5 to 20 feet.
62Q-4: 113N-67W-20CCCC -- 47.5 to 50 feet.
62Q-5: 116N-68W-29DCDC -- 17.5 to 20 feet.
62Q-6: 116N-68W-29DCDC -- 47.5 to 50 feet.

Figure 5. Thickness of weathered till.

Approximate boundary of weathered till thickness.

Numbers indicate general range in thickness, in feet, of weathered till.



5.A.2.2.1.2.3
Textural and Structural Properties

Texture of the till within the CENDAK area varies from a clayey till with some silt, sand, gravel, and boulders to a sandy silt with only minor amounts of other constituents. The clayey till has a higher proportion of local bedrock types (shale and marl) and reworked till of earlier ice advances(?) which also are probably of the clayey type. Unweathered portions of this type of till typically are very dense, massive in structure, and are dark gray to black.

The sandy, silty till has a high content of reworked lacustrine deposits. Unweathered till derived from these sediments is friable, may exhibit original lacustrine type bedding, and is light- to medium-gray in color. At any given location the till may be composed of both extremes as well as any combination of the two. The relative proportion of any textural constituent is the basis for describing a till as clayey, silty, sandy, etc.

Regionally, the till in the James Basin portion of the CENDAK area, particularly in much of Beadle and Spink Counites, and eastern Hand and Faulk Counties, may contain more fine sand and silt than till in the rest of the CENDAK area. This is probably due to incorporation into the till of large amounts of lacustrine sediments.

While detailed descriptions of till samples are generally lacking in the CENDAK area, a description of the four samples shown on table 2 are provided below and the physical properties of four samples are listed in table 3. The descriptions are from the U.S. Bureau of Reclamation, Engineering and Research Center, Soils Mechanics Section, Denver, Colorado, and are based on soil trimmings of core samples. The samples are believed to be generally representative of clayey till in the CENDAK area. In general, the till consists of a clay matrix with varying amounts of silt, sand, gravel, and boulders.

Descriptions of till samples:

**Sample 62Q-3 - 113N-67W-20C:** 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 1/4 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-4 - 113N-67W-20C:** Greenish 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 62Q-5 - 116N-68W-29D:** Grayish orange to pale yellowish brown; 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 1/2 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-6 - 116N-68W-29D:** 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.

Table 3. Soil property data from till

| | Unified Soil Classification | | | | Atterberg Limits | | |
|---|---|---|---|---|---|---|---|
| Sample Number | Group Symbol | % Gravel | % Sand | % Fines | Liquid Limit (%) | Plasticity Index (%) | Specific Gravity |
| 62Q-3 | CL | 4 | 31 | 65 | 35 | 17 | 2.66 |
| 62Q-4 | CL | 5 | 33 | 62 | 33 | 17 | 2.66 |
| 62Q-5 | CL | 2 | 31 | 67 | 34 | 17 | 2.68 |
| 62Q-6 | CL | 2 | 34 | 64 | 34 | 16 | 2.66 |

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

CL: clay loam

## 5.A.2.2.2
## Outwash

### 5.A.2.2.2.1
### ORIGIN AND AGE

Outwash was derived from detrital materials carried by the ice which once covered the CENDAK area. Deposition of the outwash was accomplished by meltwaters which generally removed finer grained materials while depositing sand and gravel. Volume, velocity, and direction of meltwaters changed often during glaciation as evidenced by variations in grain size and degree of sorting of the outwash.

Deposition occurred throughout glaciation by proglacial streams issuing from the advancing ice, by meltwater streams issuing from retreating ice, by subglacial streams, and by superglacial streams. Because outwash has generally been reworked at least once by these processes, it is usually difficult or impossible to distinguish one outwash from another on the basis of composition.

Age of the outwash is late Wisconsin and it probably spans a range of several hundred to several thousand years coincident with the ice which occupied the area.

### 5.A.2.2.2.2
### DISTRIBUTION AND THICKNESS OF SURFICIAL OUTWASH

Small patches of outwash, several acres to tens of acres in size, and generally less than 10 feet thick, occur randomly throughout the till terrain. Many of these are present but were either too small to include on the geologic map or were too small to have been identified in the mapping process. Detailed soils maps often are an aid in identifying the small patches of surficial outwash. Lithology of these outwash bodies is highly variable.

Numerous stream channels and meltwater channels in the CENDAK area may contain outwash sand and gravel overlain by finer-grained alluvial material. The thickness and presence of either sediment is highly variable but combined thicknesses may reach 50 feet. In general, only the major stream or meltwater channels contain significant amounts of either material; however, all major channels do not necessarily contain significant amounts of either outwash or alluvium. Because of their high variability in thickness and occurrence together, these two deposits have been discussed together and are presented as outwash-alluvium on plate 1. These combined sediments occur over about 10 percent of the CENDAK area.

Larger areas of surficial outwash are present in the CENDAK area, particularly in Beadle and Spink Counties (pl. 1). Outwash in these areas was generally deposited outside meltwater channels at periods when the meltwater channel could not contain all the meltwater. In general, these deposits are less than 20 feet thick although greater thicknesses are encountered. This type of surficial outwash covers about 4 percent of the land surface in the CENDAK area, most of this being present in Spink and Beadle Counties.

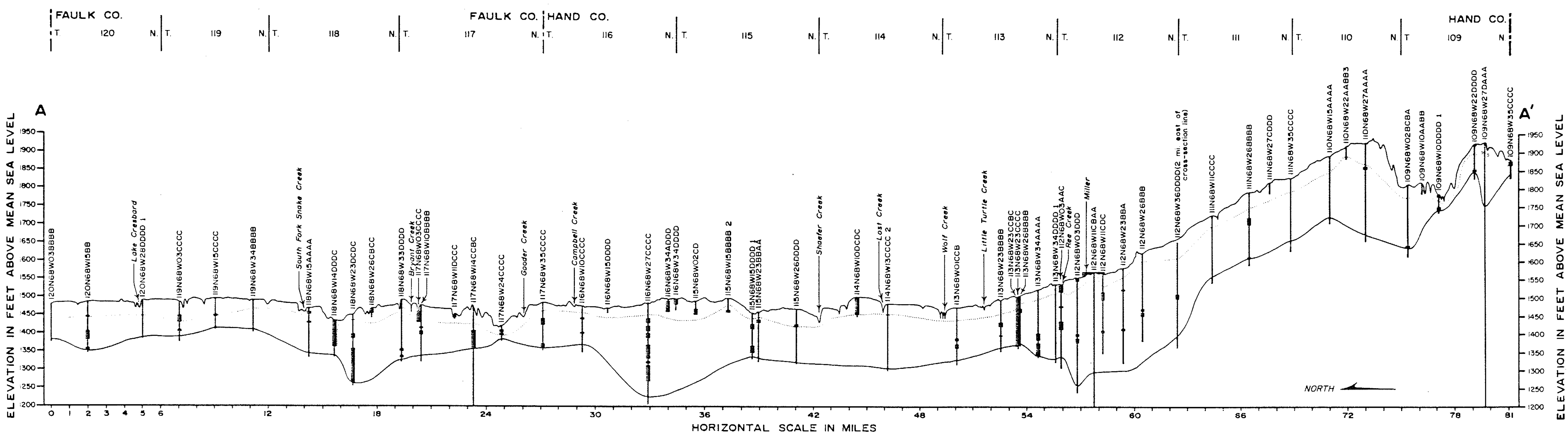
5.A.2.2.2.3
DISTRIBUTION AND THICKNESS OF BURIED OUTWASH

Buried outwash as used in this report refers to any outwash body, which in its general extent, is buried by as little as a few feet of till or any other sediment of significantly lower permeability, such as silty, clayey, glacial-lake deposits. A major exception to this definition is outwash confined to a stream valley that may be overlain by more than 10 feet of fine-grained alluvium (areas of outwash-alluvium on plate 1). Outwash occurring in this situation is included as outwash-alluvium which was previously discussed.

Buried outwash in the CENDAK area occurs in three general stratigraphic positions: (1) restricted to basal portions of pre-glacial(?) stream valleys and in contact with or close to bedrock, (2) lenses of varying thickness and continuity within the till, and (3) broader areas of nearly continuous buried outwash close to, or in contact with bedrock, but which are not necessarily part of the pre-glacial drainage system.

Buried outwash confined to basal portions of pre-glacial stream channels is found along the courses of the pre-glacial Grand, Bad and Cheyenne River systems (fig. 1) primarily in the Missouri Coteau portion of the CENDAK area. In Hughes County, and possibly elsewhere in the study area, this "outwash" may in fact consist, totally or in part, of non-glacial sand and/or gravel sediments (Duchossois, in prep.). These basal deposits in general are more laterally continuous as compared to the lenses within the till. Lenses within the till may be in contact with this outwash, in which case they are difficult or impossible to differentiate. Thickness of these deposits is variable but may be more than 100 feet thick.

Outwash lenses within the till are extremely variable in thickness and lateral continuity, especially in Hyde and Hand Counties (Helgerson and Duchossois, in prep.) as indicated by the hydrogeologic cross sections (figs. 6 and 7). They may be in contact with underlying outwash in pre-glacial channels; they may be in contact with surficial outwash or outwash-alluvium overlying them; they may be in contact with the broader areas of nearly continuous buried outwash which are found primarily in the eastern portion of the study area; and they may or may not be in contact laterally with other lenses found at the same stratigraphic altitude.



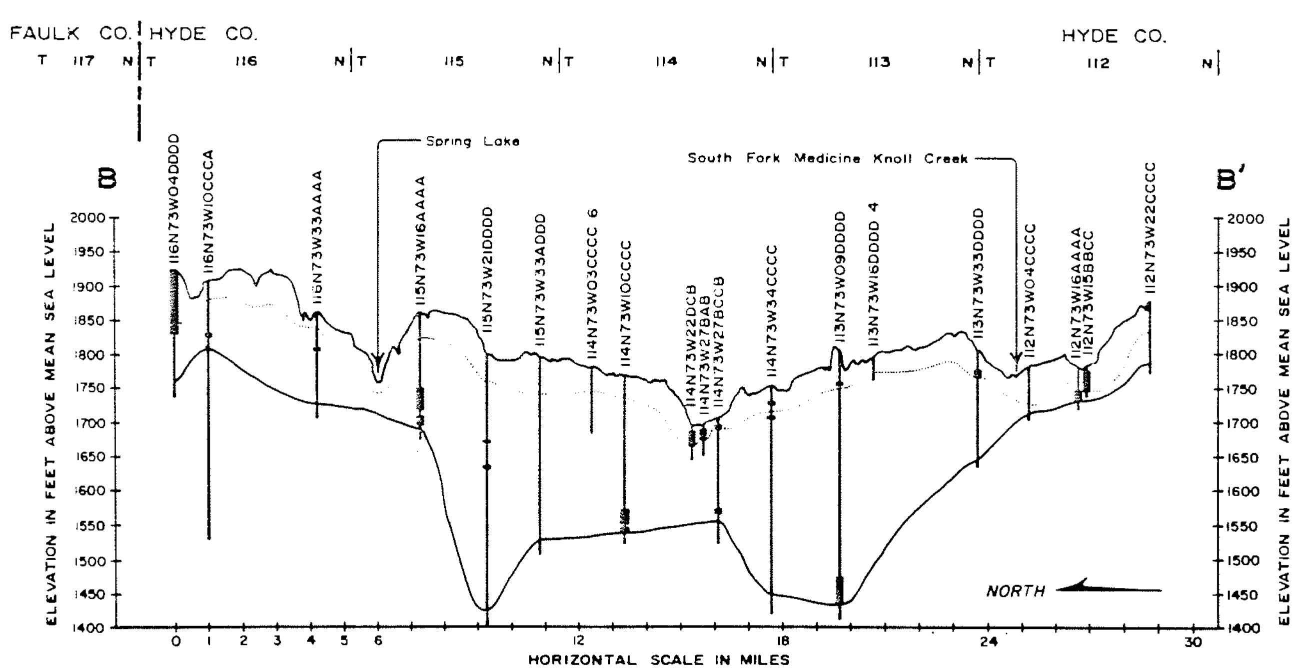




Figure 6. North-south geologic cross sections A-A' and B-B'.

drill hole | outwash — Drill hole showing vertical distribution of outwash and non-outwash sediments, mostly till.

Indicates depth of surficial oxidized zone

115N68W15DDDD 1 — Drill hole location format: Legal location 115N67W24ABCD 2 is the same as SE¼, SW¼, NW¼, NE¼, section 24, T. 115 N., R. 67 W. (A=NE, B=NW, C=SW, D=SE). The number "2" following "ABCD" is an identifier for one of multiple logs at the same location.

Vertical exaggeration = 105.6

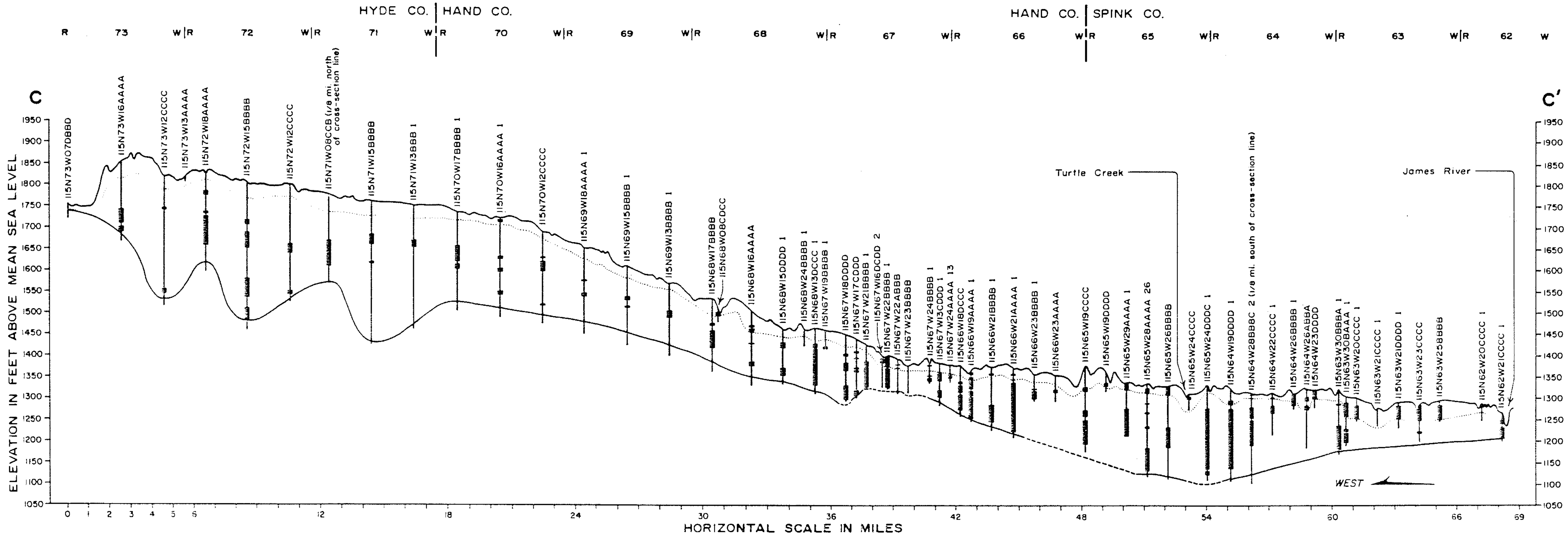



Figure 7. East–west geologic cross section C-C'.

drill hole — outwash: Drill hole showing vertical distribution of outwash and non-outwash sediments, mostly till.

Indicates depth of surficial oxidized zone.

115N68W15DDDD 1 — Drill hole location format: Legal location 115N67W24ABCD 2 is the same as SE¼, SW¼, NW¼, NE¼, section 24, T. 115 N., R. 67 W. (A=NE, B=NW, C=SW, D=SE). The number "2" following "ABCD" is an identifier for one of multiple logs at the same location.

Vertical exaggeration = 105.6

The broader areas of nearly continuous buried outwash are found primarily in the eastern part of the study area in Spink and Beadle Counties. Much of this outwash is along or near the courses of the inferred pre-glacial Grand and Bad-Cheyenne River systems; however, it may or may not be composed of sediments associated with those drainage systems. As mentioned earlier, primarily within the James Basin portion of the study area where these deposits occur, subsequent glacial activity may have substantially altered the pre-glacial drainage patterns and associated deposits. Thicknesses of these deposits are variable but ranges of 20 to 40 feet are common (fig. 7).

In the broader areas of buried outwash in Beadle and Spink Counties, the material overlying the outwash, generally till, may in places be less than 10 feet thick. Thus, the "buried" outwash may directly underlie the soil in some locations. In other locations, shallow depressions or drainageways may leave the "buried" outwash exposed at the land surface. If a "surficial" outwash is also present at these locations, it is very difficult or impossible to distinguish between them.

### 5.A.2.2.3
### Glacial-Lake Deposits

Glacial-lake deposits cover about 4 percent of the CENDAK area and are primarily associated with Glacial Lake Dakota (Todd, 1885) a large glacial lake that covered parts of northern Beadle County, large areas of Spink and Brown Counties, smaller portions of Day and Marshall Counties and extended northward into North Dakota (fig. 1, Chapter 3A). Glacial Lake Dakota formed in a shallow depression behind low end moraine ridges arcuately crossing the James Basin in southern Spink and northern Beadle Counties.

Glacial lake sediments in the CENDAK area occur primarily in south central Spink County (pl. 1). These sediments generally range in texture from silty sand to silty clay and are up to 35 feet thick in the study area (Westin and others, 1954). Because detailed geologic mapping has not been undertaken for Spink County, old beach lines and deltas associated with Lake Dakota have not been identified. These features undoubtedly would contain sand and/or gravel deposits if they exist in the area. Two small areas of several square miles each in north central Beadle County contain thin (generally less than 15 feet thick) silts to fine gravel deposits that Hedges (1968) attributed to an early southeast embayment of Lake Dakota.

### 5.A.2.2.4
### Loess

Loess is defined as windblown (eolian) material which consists of predominantly silty texture, although minor amounts of clay and/or fine sand may be present. As a geologic unit, loess usually is not mapped unless it is at least 5 feet thick and occurs as a nearly continous blanket masking the underlying material. No loess has been mapped in the CENDAK area although patchy areas of identifiable loess are present in western Hughes County (Duchossois, in prep.). Also, most of the CENDAK area probably has at least several inches of loess incorporated into the topsoil that was developed from some other parent material.

### 5.A.2.2.5
### Eolian Sand

Eolian sand is composed predominantly of sand particles which have been transported and deposited by the wind. This material covers about 0.5 percent of the CENDAK area in north-central Beadle County southwest of Hitchcock and to the north in Spink County (pl. 1). The eolian sand is generally located to the east of surficial outwash deposits, a probable source area. A thin mantle of sand with a maximum thickness of about 5 feet is present in Beadle County (Hedges, 1968). To the north in Spink County, the eolian sand exhibits dune topography and therefore is probably greater than 5 feet thick.

## 5.A.3
## HYDROLOGY

### 5.A.3.1
### Bedrock

Insufficient data preclude a detailed discussion of the hydrology of all bedrock units with the exception of the Dakota Formation. Also, as mentioned in the geology section of this report, a detailed knowledge and discussion is not required for the objectives of this report. Generalized water-bearing characteristics for each bedrock unit are described on table 1.

Water-quality data for major bedrock aquifer units will be presented only for the Dakota Formation, which is present throughout the CENDAK area. This is because water which may potentially be moving from major bedrock aquifer units into the glacial drift or vice versa would have to pass through the Dakota Formation and should be reflected by the quality of water therein.

#### 5.A.3.1.1
#### Pre-Cretaceous Rocks

All pre-Cretaceous aquifer units are under confined conditions, however, the Minnelusa Group is the only one of these known to produce flowing wells in the CENDAK area (table 1). Throughout much of the area the Minnelusa Group may be hydrologically connected to the overlying Inyan Kara Group and also to underlying bedrock aquifer units where they are present. Thus, the origin of the potentiometric head observed in the Minnelusa-Inyan Kara is uncertain. This is why Koch (1980) discussed the water-bearing characteristics of the Inyan Kara Group and older units together. Figure 8 shows where flowing wells from bedrock units older than the Dakota can be found in the CENDAK area. Water-quality data for the pre-Inyan Kara aquifer units are generally absent.

### 5.A.3.1.2
### Cretaceous

The Inyan Kara Group is under confined conditions and, as just pointed out, hydraulic connection with the underlying Minnelusa Group undoubtedly exists throughout much of the CENDAK area. In contrast, hydraulic connection with the overlying Dakota Formation exists only along the eastern edge of the CENDAK area where the Skull Creek Shale (confining layer) is absent (fig. 8).

The potentiometric surface of the Inyan Kara Group and/or older aquifer units is known to be above land surface over much of the CENDAK area (fig. 8). Where good hydraulic continuity exist between the Inyan Kara Group and the underlying and overlying units, it is not possible to distinguish which unit may be the major contributor to flowing-well conditions.

### 5.A.3.1.3
### Dakota Formation

The Dakota Formation is present throughout the CENDAK area and is under confined conditions. It is a distinct hydrologic unit except along the eastern portion of the area where it cannot be differentiated from the underlying Inyan Kara Group. Although the Dakota Formation is considered as one hydrologic unit on a regional scale, it may actually consist of many distinct layers on a local scale because of interbedded shale and silty layers within the sand and sandstone. It is the major bedrock aquifer in the CENDAK area.

The potentiometric surface of the Dakota Formation is above land surface in much of the eastern portion of the CENDAK area (fig. 8). Even in the "no-flow area," the potentiometric surface of water in the Dakota Formation, and possibly other units, is above the bedrock surface at most locations. Thus, there is a potential for upward movement of ground water from the bedrock units into glacial drift.

The Dakota Formation contains water which has a total-dissolved solids average of 2,101 milligrams per liter (mg/L), using data presented in appendix A. Primary constituents of the water are sulfate, sodium, chloride, and calcium (table 4). Dakota

Formation water is distinctly different chemically from water in overlying glacial sediments, as will be illustrated later.

**Table 4. Average water quality of the Dakota Formation**

| Parameter | Number of Analyses | Average | Standard Deviation |
|---|---|---|---|
| Specific Conductance | 43 | 2,742 | 327 |
| Total Dissolved solids | 60 | 2,101 | 298 |
| Hardness | 60 | 594 | 429 |
| Calcium | 60 | 167 | 129 |
| Magnesium | 60 | 42 | 28 |
| Sodium | 58 | 429 | 186 |
| Potassium | 54 | 18 | 7 |
| Iron | 25 | 1.2 | 1.2 |
| Manganese | 2 | 0.4 | 0.2 |
| Chloride | 60 | 196 | 145 |
| Fluoride | 56 | 2.4 | 0.6 |
| Nitrogen, NO3-N | 1 | 0 | 0 |
| Sulfate | 59 | 1,004 | 298 |

All averages are presented in milligrams per liter except for specific conductance which is in micromhos per centimeter.

## 5.A.3.1.4 Cretaceous Confining Layer

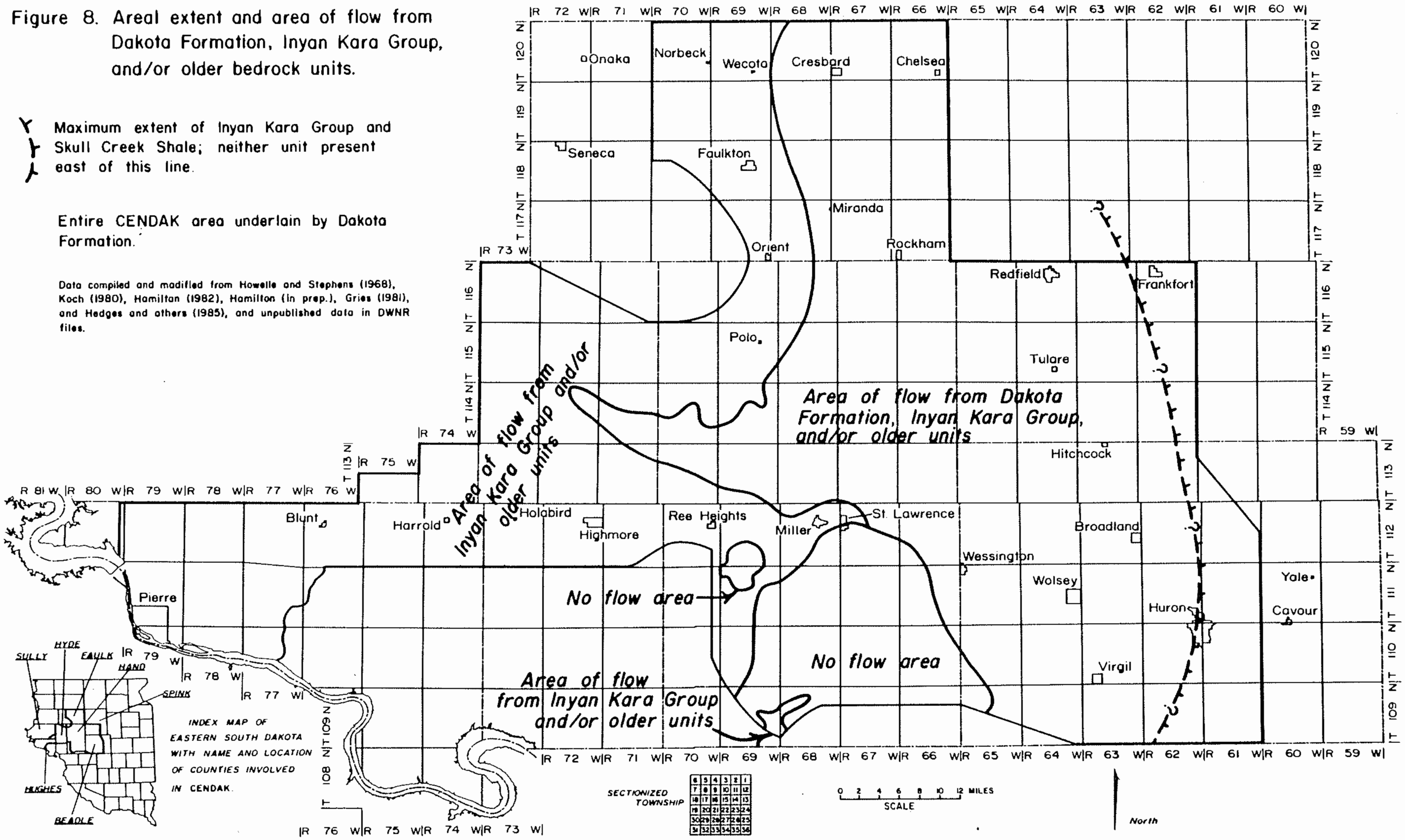
The importance of the Cretaceous confining layer is that it generally isolates water in bedrock-aquifer units from that in the glacial drift. This is in spite of the general upward hydraulic potential for ground-water movement (i.e., flowing-well conditions) from bedrock into glacial drift.

Figure 8. Areal extent and area of flow from Dakota Formation, Inyan Kara Group, and/or older bedrock units.

Maximum extent of Inyan Kara Group and Skull Creek Shale; neither unit present east of this line.

Entire CENDAK area underlain by Dakota Formation.

Data compiled and modified from Howells and Stephens (1968), Koch (1980), Hamilton (1982), Hamilton (in prep.), Gries (1981), and Hedges and others (1985), and unpublished data in DWNR files.



The concept of the Cretaceous confining layer is taken from Bredehoeft and others (1983) and consists of all bedrock units above the Dakota Formation in the CENDAK area. The following quote about the confining layer is taken from the above reference:

> "Although predominated by shale, the Cretaceous shale confining layer contains several minor aquifers, most important of which are the Niobrara Formation (predominantly chalk) and the Greenhorn Limestone."

The quote contains two important items; first, the predominant lithologic type of the confining layer is shale and secondly, the confining layer contains minor aquifers. Shales comprising the confining layer are the Graneros, Carlile, and Pierre (table 1). Minor aquifers in the confining layer in the CENDAK area are the Codell Sandstone within the Carlile Shale and the Niobrara Formation which directly overlies the Carlile. The Greenhorn Limestone mentioned by Bredehoeft and others (1983) may be utilized as an aquifer in the CENDAK area in only a few instances.

Were it not for the fact that a deep bedrock valley exists in Beadle and Spink Counties in the CENDAK area (fig. 1), the Cretaceous-confining layer could be presented here in terms of the Pierre Shale only. However, because the Niobrara Formation, and most likely the Codell Sandstone, subcrop beneath glacial drift in this valley, the confining layer must be considered on a larger vertical scale. The Pierre Shale, however, is the unit of primary importance because of its presence directly beneath the glacial drift throughout much of the CENDAK area.

### 5.A.3.1.4.1
### HYDRAULIC CONDUCTIVITY OF THE PIERRE SHALE

Hydraulic conductivity of the Pierre Shale has been determined at two sites in central South Dakota utilizing modified slug tests and laboratory tests. Values were determined for vertical hydraulic conductivity of the Pierre Shale and were found to range from 1.7E-10 to 1.9E-12 centimeters per second (cm/sec.) (Bredehoeft and others, 1983). The value of 1.7E-10 is read as the quantity 1.7 times 10 to the minus tenth power. The actual hydraulic conductivity of the shale may be lower than presented values, as stated in their report, due to possible error in experimental measurements. They also found that hydraulic conductivity decreased with depth. Although specific data on hydraulic conductivity are not available for other shale units in the Cretaceous-confining layer, they are assumed to be generally comparable to the Pierre Shale.

Bredehoeft and others (1983) concluded that the hydraulic conductivities presented are representative of intact shale between fractures and that leakage on a regional scale, as determined through ground-water modeling, could occur through fractures in the bedrock units involved. This leads to the interpretation that although the presented hydraulic conductivities are very low, ground-water flow may still occur through the shale. However, their study neither validated nor invalidated the possibility of flow through the Cretaceous confining layer.

Little data are available on water levels within the Pierre Shale. One report does, however, give some insight to occurrence of water in the Pierre. Nichols and Collins (1986) conducted studies about 48 kilometers west of Hughes County which is in reasonable proximity to the CENDAK area. They present data which show that although the Pierre Shale is saturated, free water does not occur at depth within the shale. Two fracture zones were documented between 70 and 92 meters at one location with each zone having a typical thickness of about 5 meters. The following is a quote from their report:

> "Although the zones are highly fractured, the recovered fragmented shale lacked free water in fracture spaces and contained no evidence of chemical alteration . . . ".

Findings of this type cast doubt on the conclusion of Bredehoeft and others (1983) that there is significant movement of water through fractures in spite of very low hydraulic conductivities recorded in the Pierre Shale. Lack of free water at depth within the shale combined with very low hydraulic conductivities indicate that there may be no measurable water level or potentiometric surface associated with the unit where it is buried beneath glacial drift.

## 5.A.3.2 Glacial Drift

### 5.A.3.2.1 Till

This section discusses past and current research being conducted on the hydrogeology and hydrochemistry of glacial till deposits in the CENDAK area. Data discussed were obtained over the time period of the 1950's to present.

Till deposits consist of two units, a weathered (oxidized) unit and an unweathered (unoxidized) unit. The weathered unit overlies the unweathered unit and is generally 15 to 35 feet thick. Hydraulic conductivity values of the weathered unit are generally three to four orders of magnitude greater than those of the unweathered unit. This is attributed to fractures and macropores present in the weathered unit (Prudic, 1982).

5.A.3.2.1.1.
INSTRUMENTATION AND DATA ACQUISITION

The South Dakota Geological Survey has installed a network of 86 piezometers completed in either weathered or unweathered till at 22 sites throughout the CENDAK area (fig. 9). The word "piezometer" as used in this report refers to any drill hole with casing installed for the purpose of obtaining hydraulic, chemical, and lithologic data from till. The piezometers are installed at 22 different sites, with three to six piezometers at each site. Installation of the piezometers at different depths allows hydraulic pressures and water quality to be determined at various depth intervals. Generally, the piezometers used to measure water levels are not sampled for water quality because to do so would disturb the continuity of water-level readings. An additional set of piezometers is usually installed for the sole purpose of water-quality sampling.

Water levels in these piezometers are measured to the nearest hundredth of a foot. Water-level data are used to monitor gradients and response to recharge events.

Water samples were obtained from piezometers using a point-source teflon bailer. The bailer is an open-ended hollow cylinder with a check valve on both ends. As the bailer is lowered into the piezometer by the poly-rope attached to it, water moves through the bailer. When the bailer is stopped and pulled up, both check valves close and the water sample trapped in the bailer is representative of the maximum depth attained.

Two types of water intake areas were used by the South Dakota Geological Survey during piezometer construction: <u>screened intake</u> and <u>cored intake</u>.

Construction of a screened-intake piezometer is as follows:

1. Auger 4-inch diameter hole to desired depth.
2. Insert 2-inch diameter schedule 80 PVC casing, with 2-foot long slotted screen (0.012 or 0.018 slot size) in auger hole.
3. Add filter pack (medium-grained, primarily quartz sand) in annulus around casing to cover the screen.
4. Add granular bentonite to within 2 feet of land surface.
5. Fill remainder of the annulus with till cuttings.

Figure 10 depicts the construction method for a screened-intake piezometer.

Construction of a cored-intake piezometer is as follows:

1. Auger 4-inch diameter hole to desired depth.
2. Insert 2-inch diameter schedule 80 PVC casing (with sharpened end of casing covered by a thin plastic cap) into auger hole.

3. Push casing approximately 3 inches into bottom of hole (thereby cutting through thin plastic cap and allowing hydraulic connection with the sediment).
4. Obtain a 12-inch long core of bottom-hole sediment through inside of casing with a 1.5-inch diameter thin-wall sampler (Shelby tube).
5. Pump bentonite slurry into annulus from bottom up to within 2 feet of land surface.
6. Fill the rest of the annulus with till cuttings.

Figure 11 depicts the construction method for a cored-intake piezometer.

Major deviations (for example, different piezometer-intake dimensions) from the general construction procedures outlined above will be indicated in the log for that particular piezometer. Appendix B contains the logs for the till piezometers at the 22 sites in the CENDAK area. Cowman (in prep.) discusses the advantages and disadvantages of various piezometer construction methods.

5.A.3.2.1.2
WEATHERED TILL

Weathered till is characterized by its yellow-brown color. Visual inspection of core samples of weathered till obtained by the South Dakota Geological Survey were found to exhibit fractures and macropores filled with salts, such as gypsum and calcite (Cowman, South Dakota Geological Survey, personal communication, 1986). Weathered till contains a primary (intergranular) permeability and a secondary (fracture) permeability (Hendry, 1982). The results of these two types of permeability are discussed under the hydraulic conductivity section of this report.

<u>5.A.3.2.1.2.1</u>
<u>Water Levels</u>

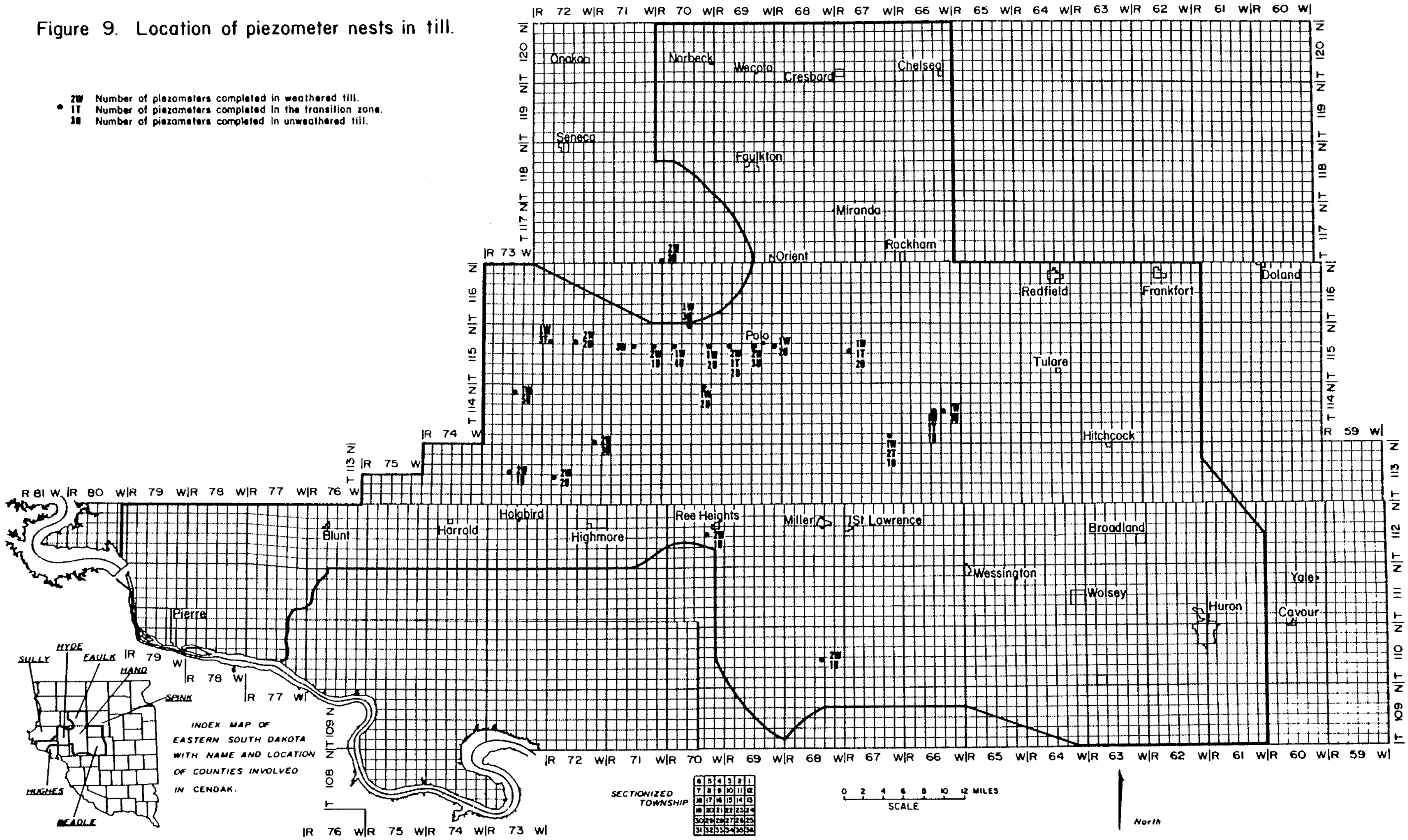
Periodic water-level readings were used by the South Dakota Geological Survey to construct water-level hydrographs and calculate vertical hydraulic gradients. The next two sections of this report discuss those data.

5.A.3.2.1.2.1.1
Hydrographs

Appendix C contains water-level hydrographs for the piezometers at the 22 sites in the CENDAK area. The inset on each hydrograph depicts the location of the piezometer intake. It can be seen from the hydrographs that water levels in piezometers completed in the weathered till unit fluctuate at various times of the year. The rise in water level is due to recharge via spring

Figure 9. Location of piezometer nests in till.

- 2W Number of piezometers completed in weathered till.
- 1T Number of piezometers completed in the transition zone.
- 3U Number of piezometers completed in unweathered till.



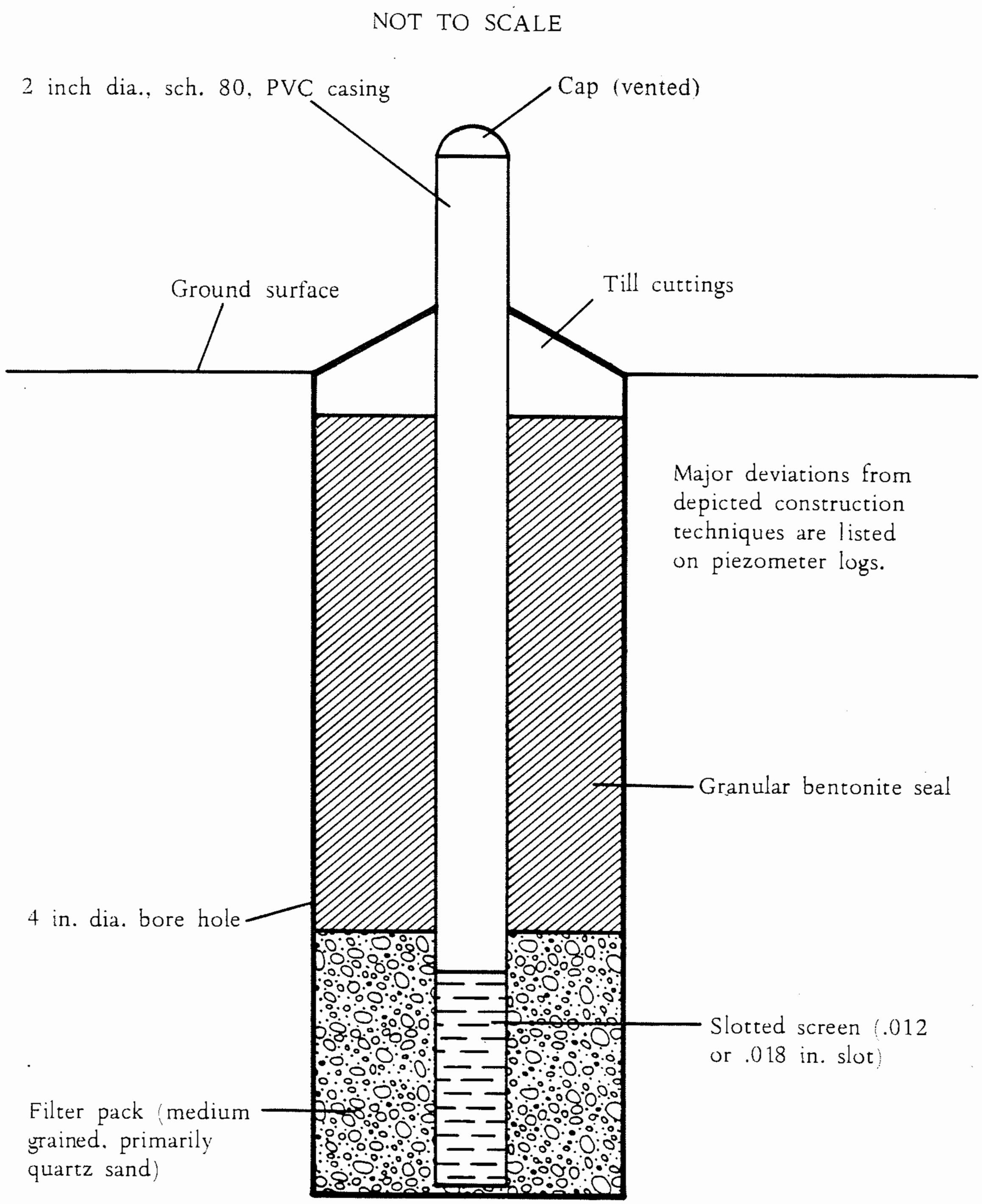



Figure 10. Screened intake piezometer construction.

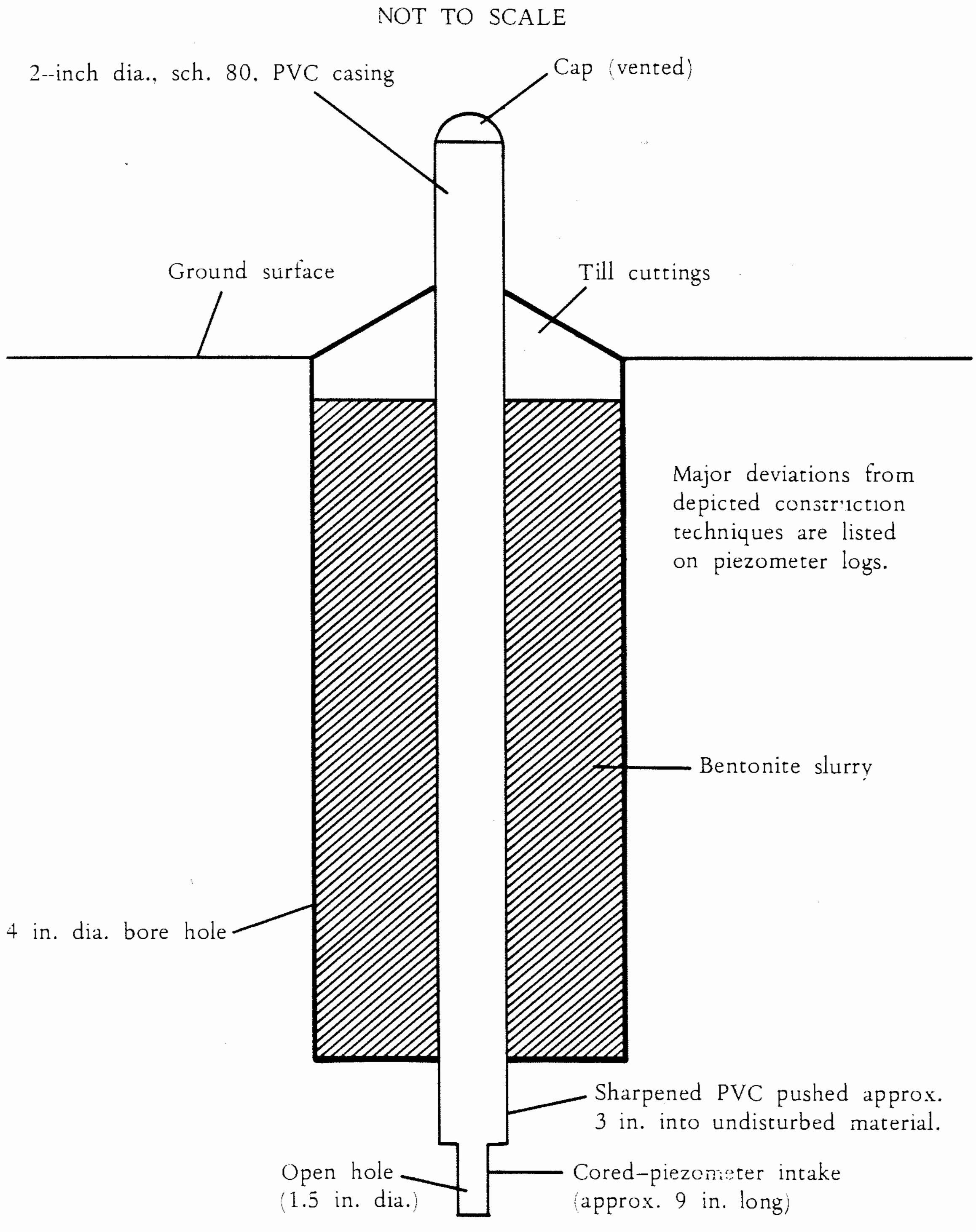



Figure 11. Cored intake piezometer construction.

thaw and precipitation. The rapid response of these piezometers indicates that a relatively high vertical permeability exists. According to Hendry (1982), such a rapid response is due to the secondary permeability resulting from the fracture system present within the weathered till.

5.A.3.2.1.2.1.2
Vertical Hydraulic Gradients

Table 5 summarizes the vertical hydraulic gradients existing in the weathered till during the period of October 4, 1983, to May 20, 1986. The downward gradients existing in weathered till (average = 0.065) are much smaller than the gradients existing in unweathered till (average = 0.652). This may be attributed to the large differences found in the hydraulic conductivity between the two units. Gradients within the weathered till tend to fluctuate on an annual basis as well as with individual recharge events. Gradient reversals are often seen in the weathered till at various times during the year. Appendix D contains a complete set of data on hydraulic gradients in the till.

**Table 5. Statistical summary of water-table measurements and vertical hydraulic gradients in weathered till.**

| | Vertical Gradients | Water Table * |
|---|---|---|
| number of observations: | 297 | 296 |
| average: | 0.065 | 5.68 feet |
| std. dev.: | 0.252 | 3.40 feet |
| minimum: | -0.928 | -0.83 feet |
| maximum: | 1.196 | 15.48 feet |
| reversals: | 142 | ------ |

* Numbers in feet represent water-table depth below land surface.

5.A.3.2.1.2.1.3
Water Table in Weathered Till

Table 5 also contains a statistical summary of the water-table levels in weathered till in the CENDAK area from the period of October 4, 1983, to May 20, 1986. Appendix C contains complete data of water-table fluctuations during the same time period. Each of the 22 till piezometer nest sites in the CENDAK area contains at least one shallow piezometer completed at a depth of 15 feet or less. It is the shallowest piezometer at each piezometer nest that is used to monitor the water table.

The water table ranged from 0.83 feet above to 15.48 feet below land surface and averaged 5.68 feet below land surface. The standard deviation was 3.40 feet. The small standard deviation and the relatively small water-table fluctuations show that the regional water table remains fairly uniform except for some seasonal fluctuations and response to recharge events. Cravens (1985) made two general observations about the water table in Hand and Hyde Counties:

1. In general, the water table rises and falls uniformly with time throughout the study area.

2. The water table generally reflects the surface topography, although its relief is usually less than the topographic relief.

5.A.3.2.1.2.2
Hydraulic Conductivity

Many hydraulic conductivity tests have been performed on weathered till in the CENDAK area. Means of testing was by both in situ and laboratory methods. This section describes and reports the hydraulic conductivity test methods and results for weathered till.

5.A.3.2.1.2.2.1
In Situ Tests

Single piezometer response tests were conducted by Cravens (1985) in weathered till of Hand and Hyde Counties. These tests were conducted by withdrawing a slug of water from the piezometer and then measuring the recovery rate. The method Cravens used to analyze the data was that presented by Hvorslev (1951). Table 6 contains a statistical summary of Cravens' results. The location of each individual test along with the results are listed in appendix E. The geometric mean hydraulic conductivity derived using piezometers completed in weathered till was 9.4E-06 centimeters per second (Cravens, 1985). The range of values was from 4.4E-07 to 2.0E-04 cm/s.

Table 6. Statistical summary of hydraulic conductivities of weathered till using in situ test results.

| Investigator | Number of tests | Geometric Mean Hydraulic Conductivity * | Log Standard Deviation | Range * |
|---|---|---|---|---|
| Cravens (1985); (Hvorslev method) | 31 | 9.4E-06 | 0.73 | 4.4E-07 to 2.0E-04 |
| Bender and Carlson (1984); (Luthin and Kirkham method) | 5 | 1.5E-07 | 0.29 | 5.3E-08 to 3.1E-07 |
| Bender and others (1983); ring-permeameter test) | 4 | 1.9E-04 | 0.36 | 4.9E-05 to 4.3E-04 |
| U.S. Bureau of Reclamation (1960); auger-hole test) | 6 | 1.1E-04 | 0.19 | 7.2E-05 to 2.2E-04 |
| Strube Fossen (1986) and Jewell (1986); (lysimeter test, constant-head | 28 (vertical hydraulic conductivity) | 5.0E-05 | 0.45 | 1.1E-05 to 1.1E-03 |
| test, ring-permeameter test, shallow-well pump in test) | 32 (horizontal hydraulic conductivity) | 1.7E-05 | 1.9 | 1.4E-06 to 1.2E-04 |

* Results in cm/s

Bender and Carlson (1984) also conducted in situ hydraulic conductivity tests in weathered till using three piezometers completed at a depth of approximately 16 feet and two piezometers completed at a depth of approximately 15 feet. Their tests consisted of installing a 2-inch diameter piezometer in the weathered unit and then applying irrigation water to the area in which the piezometers were installed. The water level recovery rates were then recorded and the hydraulic conductivity was calculated using the method set forth by Luthin and Kirkham (1949). Based on two water-level measurements in each piezometer, the hydraulic conductivity of the five piezometers was determined. A summary of the results are reported in table 6. The location of each individual test along with the results are listed in appendix E. The geometric mean hydraulic conductivity of the five piezometers tested was 1.5E-07 cm/s. The range of values was from 5.3E-08 to 3.1E-07 cm/s.

Bender and others (1983) conducted ring-infiltration tests at four sites. A summary of the infiltration rates are given in table 6. The location of each individual test along with the results are listed in appendix E. The geometric mean infiltration rate was 1.9E-04 cm/s. The range of values was from 4.9E-05 to 4.3E-04 cm/s.

The U.S. Bureau of Reclamation conducted auger-hole tests in weathered till during the OAHE project studies in the 1950's (U.S. Bureau of Reclamation, 1960). The tests consisted of augering a hole into weathered till and then withdrawing from or adding to the hole a slug of water. Of the tests that were conducted in or very near the CENDAK project area, the geometric mean hydraulic conductivity was 1.1E-04 cm/s. The range of values was from 7.2E-05 to 2.2E-04 cm/s. Table 6 contains a summary of the test results. The location of each individual test along with the results are listed in appendix E.

Hydraulic conductivity values for weathered till were also obtained by the Bureau of Reclamation at lysimeter sites constructed in the CENDAK area (Strube Fossen, 1986; Jewell, 1986). The lysimeter sites were constructed by forming a 9.5 foot square soil monolith with 8-foot deep trenches on all sides. An impermeable wall was then inserted from the bottom to the top of the trenches. The bottom half of the wall consisted of a 4-foot high concrete seal extending the entire width of the trench. The upper half of the wall consisted of a 30-mil PVC membrane extending into the concrete layer to provide a consistent impermeable unit. Compacted backfill was placed between the PVC membrane and the outer trench wall to ensure a tight seal between the soil monolith and the impermeable wall.

A hydraulic monitoring system was then installed inside the soil monolith. The system consisted of a neutron moisture probe access tube, two tensiometers, and three transiometers. A transiometer (Trooien, 1985) is the union of a soil tensiometer and a pressure transducer. The transiometer has the advantage of being capable of measuring both negative hydraulic potentials (unsaturated zone) and positive hydraulic potentials (saturated zone). This capability is essential for the shallow hydraulic conductivity tests conducted at the lysimeter sites because both saturated and unsaturated conditions are sometimes encountered.

Water was then applied to the lysimeter plots on a schedule that would closely simulate steady flow rates. From the quantity of water moving through the monolith and the vertical gradients measured with the transiometers, a vertical hydraulic conductivity value was obtained. However, the soil profile from the surface to the 6-foot depth was not saturated, so these hydraulic conductivity values are less than hydraulic conductivity values for saturated conditions. Table 6 contains a summary of the values obtained from the lysimeter testing. The location of each individual test along with the results are listed in appendix E. Data from two of the lysimeter test sites (D. Faulstich and H. Faulstich sites) are not reported in table 6 or appendix E. Test results from these sites were not used in any of the calculations because the testing at these sites occurred in material other than till (that is, lacustrine material and sand lenses).

In addition to the lysimeter testing mentioned above, two other types of vertical testing were conducted at the lysimeter sites. These were a ring-permeameter test and a constant-head test. A ring-permeameter test generally consists of driving a hollow cylinder vertically into the soil so that it fills with the sediment to be tested. Then water is applied and the infiltration rate is measured. A complete description of a ring-permeameter test is given in the Bureau of Reclamation's Drainage Manual (U.S. Bureau of Reclamation, 1978). A constant-head test was conducted at the lysimeter sites by maintaining a constant water level above the surface of the soil monolith with and monitoring instrument response within the profile. The water level was then brought up to a level above the surface of the soil monolith and held constant. The pressure head at the 8-foot deep transiometer in the lysimeter plot and the constant head water level were then used to determine the vertical gradient across the lysimeter. The amount of flow through the lysimeter was recorded. From the flow data and the gradient data, the hydraulic conductivity was calculated using Darcy's law (Jewell, U.S. Bureau of Reclamation, personal communication, 1986).

The summary in table 6 includes all three types of vertical hydraulic conductivity testing at the lysimeter sites. The geometric mean vertical hydraulic conductivity obtained at the sites using all three types of tests is 5.0E-05 cm/s. The range of vertical hydraulic conductivity values at the lysimeter sites was from 1.1E-05 to 1.1E-03 cm/s.

Values for horizontal hydraulic conductivities were also obtained near the lysimeter sites via conventional pump-in tests (Strube Fossen, 1986; Jewell, 1986). In general, a pump-in test consists of completing a piezometer in the interval to be tested and maintaining a constant head in the piezometer by pumping in water. The amount of water flowing laterally out of the piezometer under the constant head can then be measured. A complete description of a conventional pump-in test can be found in the Bureau of Reclamation's Drainage Manual (U.S. Bureau of Reclamation, 1978). A summary of the horizontal hydraulic conductivity values obtained from the lysimeter sites are reported in table 6. The location of each individual test along with the results are listed in appendix E. The geometric mean horizontal hydraulic conductivity is 1.7E-05 cm/s. The range of horizontal hydraulic conductivity values at the lysimeter sites was from 1.2E-04 to 1.4E-06 cm/s. Data from two of the lysimeter test sites (D. Faulstich and H. Faulstich sites) are not reported in table 6 or appendix E. These sites were also not used in any of the calculations because the testing at these sites occurred in material other than till (that is, lacustrine material and sand lenses).

5.A.3.2.1.2.2.2
Laboratory Tests

Bender and others (1983) obtained partially disturbed weathered till core samples for laboratory analysis. The samples were obtained by augering a bore hole to the desired depth and then sampling with a split-spoon sampler containing brass liners. The brass liners were then removed from the split-spoon sampler and transported to the laboratory. Laboratory hydraulic conductivity samples were then obtained by placing the intact sample and liner in a constant-head permeameter. Because of ambiguities in the bore-hole logs, it was not clear whether the sample was of weathered or unweathered till. Thus, the results reported in table 7 are only on those samples which could be positively identified as being weathered till. The geometric mean hydraulic conductivity is 2.8E-07 cm/s. The range of values was from 6.3E-10 to 5.8E-04 cm/s.

**Table 7. Statistical summary of hydraulic conductivities in weathered till using laboratory results.**

| Investigator | Number of tests | Geometric Mean Hydraulic Conductivity * | Log Standard Deviation | Range * |
|---|---|---|---|---|
| Bender and others (1983); (constant-head permeameter) | 73 | 2.8E-07 | 1.7 | 6.3E-10 to 5.8E-04 |
| U.S. Bureau of Reclamation (1960) | 2 | 3.4E-08 | 0.09 | 2.9E-08 to 3.9E-08 |

* Results in cm/s

Laboratory tests on weathered till samples were also conducted by the Bureau of Reclamation in the 1950's for the OAHE project (U.S. Bureau of Reclamation, 1960). Of the tests that were conducted in or very near the CENDAK project area, the geometric mean hydraulic conductivity was 3.4E-08 cm/s (table 7). The values ranged from 2.9E-08 to 3.9E-08 cm/s. The location of each individual test along with the results are listed in appendix E.

Laboratory hydraulic conductivity tests were also conducted on 10 till samples from Spink and Hand Counties in South Dakota by Norris (1962). Unfortunately, Norris does not provide locations, depths, or till zone classification for his samples. Therefore, it is assumed that the samples came from both weathered and unweathered till zones. The wide range of hydraulic conductivity values obtained by Norris reinforces this assumption. The average hydraulic conductivity from the 10 samples tested by Norris is 6.9E-07 cm/s. The log standard deviation is 0.92. The range of hydraulic conductivity values obtained by Norris is 1.4E-08 to 2.4E-05 cm/s.

From the available data of values for horizontal hydraulic conductivities and vertical hydraulic conductivities in weathered till, it appears that there is no substantial difference between the two. If the relatively higher hydraulic conductivity of weathered till, compared with unweathered till (section 5.A.3.2.1.3.2) can be attributed to fracture flow (Hendry, 1982), then from hydraulic conductivity data it appears that the fractures do not preferentially enhance vertical flow over horizontal flow or vice-versa.

In the topography and surface drainage section of this report (Chapter 3.A), an average regional topographic slope of 8 feet per mile is reported for the CENDAK area. Because the water table in weathered till remains shallow across the study area (section 5.A.3.2.1.2.1.3), the regional topographic slope can be used to approximate the regional horizontal hydraulic gradient. In a report on ground-water movement through till in eastern South Dakota, Iles and others (in prep.) reported that under the prevailing horizontal gradients and hydraulic conductivities in weathered till, lateral flow cannot be the major component of dissipation of recharge water to the till. The horizontal hydraulic conductivities Iles used in his report are similar to those measured by Strube Fossen (1986) and Jewell (1986) in the CENDAK area. The hydraulic gradient in weathered till used by Iles is over 5 times larger than the regional gradient in the CENDAK area. Therefore, on a regional basis, lateral ground-water flow through weathered till is probably of little significance in the CENDAK area. It is reasonable to assume, however, that on a local scale there are instances in which lateral flow is more significant in the weathered till due to locally higher horizontal gradients. Although actual values for the magnitude of lateral flow in weathered till are not available, studies are forthcoming which will quantify the lateral flow component.

5.A.3.2.1.2.3
Water Chemistry

5.A.3.2.1.2.3.1
Major Ions

Extensive water sampling has been done in weathered till in the CENDAK area for major ion analysis. The South Dakota Geological Survey collected 33 water samples from piezometers developed in weathered till and conducted extensive chemical analyses on them. Appendix A contains complete analyses from these samples. Values discussed in the following paragraphs pertain to results from those analyses. A statistical summary of water quality analyses from weathered till is reported in table 8.

Table 8. Statistical summary of water-quality analyses from weathered till.

| Parameter | Mean | Standard Deviation | Range |
|---|---|---|---|
| Specific Conductance | 5289 | 2919 | 729 to 10,300 |
| Total Dissolved Solids | 5199 | 3351 | 536 to 13,420 |
| Sodium | 562 | 448 | 11 to 1,540 |
| Calcium | 375 | 156 | 55 to 612 |
| Magnesium | 412 | 358 | 39 to 1,765 |
| Potassium | 16.7 | 8.1 | 2.8 to 29.0 |
| Sulfate | 3039 | 2196 | 132 to 9,380 |
| Bicarbonate | 516 | 117 | 222 to 751 |
| Carbonate | 0 | 0 | 0 to 0 |
| Chloride | 235 | 373 | 3 to 1,500 |
| Fluoride | 0.38 | 0.32 | 0.03 to 1.58 |
| Nitrate-Nitrogen | 3.1 | 7.1 | 0.1 to 35.5 |
| Iron | 0.10 | 0.21 | 0.03 to 1.22 |
| Manganese | 0.96 | 2.04 | 0.03 to 10.48 |
| Hardness | 2633 | 1702 | 385 to 8,642 |
| Total Alkalinity | 424 | 95.6 | 182 to 616 |

Specific conductance reported in umhos/cm @ 25 deg. C., all other parameters are reported in mg/L. Number of analyses is 33. Table was generated using data in appendix A.

The major cation in weathered till is sodium, with an average concentration of 562 milligrams per liter (mg/L). The major anion is sulfate, with an average concentration of 3,039 mg/L. Other cations with high concentrations are calcium and magnesium. Other anions with high concentrations are bicarbonate and chloride. The average total dissolved solids (TDS) value for weathered till in the CENDAK area is 5,199 mg/L.

Figure 12 illustrates the water quality of weathered till utilizing a Stiff diagram and a trilinear diagram. The data used were from the average concentrations reported in table 8. This water can be classified as a type III glacial water in the manner of the standards put forth by Freeze and Cherry (1979, p. 284). A type III water is characterzied by TDS values in the range of 1,000 to 10,000 mg/L; sodium, magnesium, calcium, bicarbonate, and sulfate occur in major concentrations; sulfate is the dominant anion.

The excessively poor water quality in weathered till is further evidence against significant lateral flow in this hydraulic unit. A continual sequence of recharge to the till followed by lateral movement of recharge water after it reaches the water table and final discharge to a topographic low point such as a stream or valley would preclude a substantial buildup of salts in the waters of the weathered till. To the contrary, water from weathered till exhibits substantially high salt concentration.

5.A.3.2.1.2.3.2
Isotope Analyses

Two weathered till piezometers at two separate sites were sampled for isotope analysis. Tritium, carbon-14, oxygen-18, and deuterium isotope analyses were conducted on these samples. The results of the tritium and carbon-14 analyses are discussed in more detail in the following sections. The results of the stable isotope (oxygen-18 and deuterium) analyses were inconclusive. This is probably due to the small number of samples, thus, discussion of stable isotope is deferred until additional analyses are available.

5.A.3.2.1.2.3.2.1

TRITIUM

Tritium is a radioactive isotope of hydrogen which is created in the atmosphere when neutrons produced by cosmic-ray action collide with nitrogen-14. The reaction is similar to the creation of carbon-14, but takes place at different energy levels:

N-14 + neutron --> C-12 + tritium

Tritium combines with oxygen and another hydrogen atom to form a water molecule and enters the hydrologic cycle this way. Tritium has a half-life of 12.3 years.

Prior to 1953 atmospheric tritium levels were about 5-20 tritium units (TU), plus or minus depending on geographic location

(Payne, 1972). One tritium unit correlates with one tritium atom in 10(18) hydrogen atoms. Beginning in 1953, large amounts of man-made tritium entered the atmosphere due to thermonuclear bomb testing. As a result, waters that have entered ground-water regimes after 1953 contain tritium concentrations well over 10 TU.

Waters from two piezometers completed in weathered till in the CENDAK area were sampled for tritium analysis. In both samples, tritium concentrations were well above 10 TU.

5.A.3.2.1.2.3.2.2
CARBON-14

Carbon-14 is a radioactive isotope created in the atmosphere as a result of a reaction between neutrons produced by cosmic-ray action and nitrogen-14:

N-14 + neutron --> C-14 + H

Carbon-14 combines with oxygen to form carbon dioxide and in this manner enters the structure of natural substances. Carbon-14 is unstable and decays via beta emission to nitrogen-14. The half life of carbon-14 is 5,730 years. Since the atmosphere has a constant ratio of C-14 to C-12 (C-12 is the stable form of carbon), the measurement of this ratio allows the calculation of the amount of time a substance has been out of contact with the atmosphere. Organic carbon is generally lighter than inorganic carbon which indicates therefore fractionation occurs during photosynthesis. To obtain the greatest precision from radiocarbon dating, a correction for this fractionation must be made. This is accomplished by measuring the ratio of C-13 to C-12 in the sample. In hydrologic systems, the ratio of C-14 to C-12 allows calculation of the time elapsed since a ground water has been removed from atmospheric contact; that is, the time since recharge to a confined aquifer has occurred.

Carbon-14 samples were obtained by filling a 100-liter stainless-steel funnel with well water. Aeration was kept to a minimum during this process. A sodium hydroxide solution was added to the sample to raise the pH and deprotonate the bicarbonate. Then a barium chloride solution was added to effectively precipitate barium carbonate from the sample. The precipitate was collected and sealed in a two liter polyethylene bottle and shipped to a contractor for analysis of the carbonate-carbon.

Errors associated with this method of sampling and analysis may include contact with the atmosphere during sampling and precipitation. Introduction of modern carbon into the sample would cause an apparently younger age to be determined. If old carbon in the sediment is exchanged with young carbon in the water, an apparently older age will be determined.

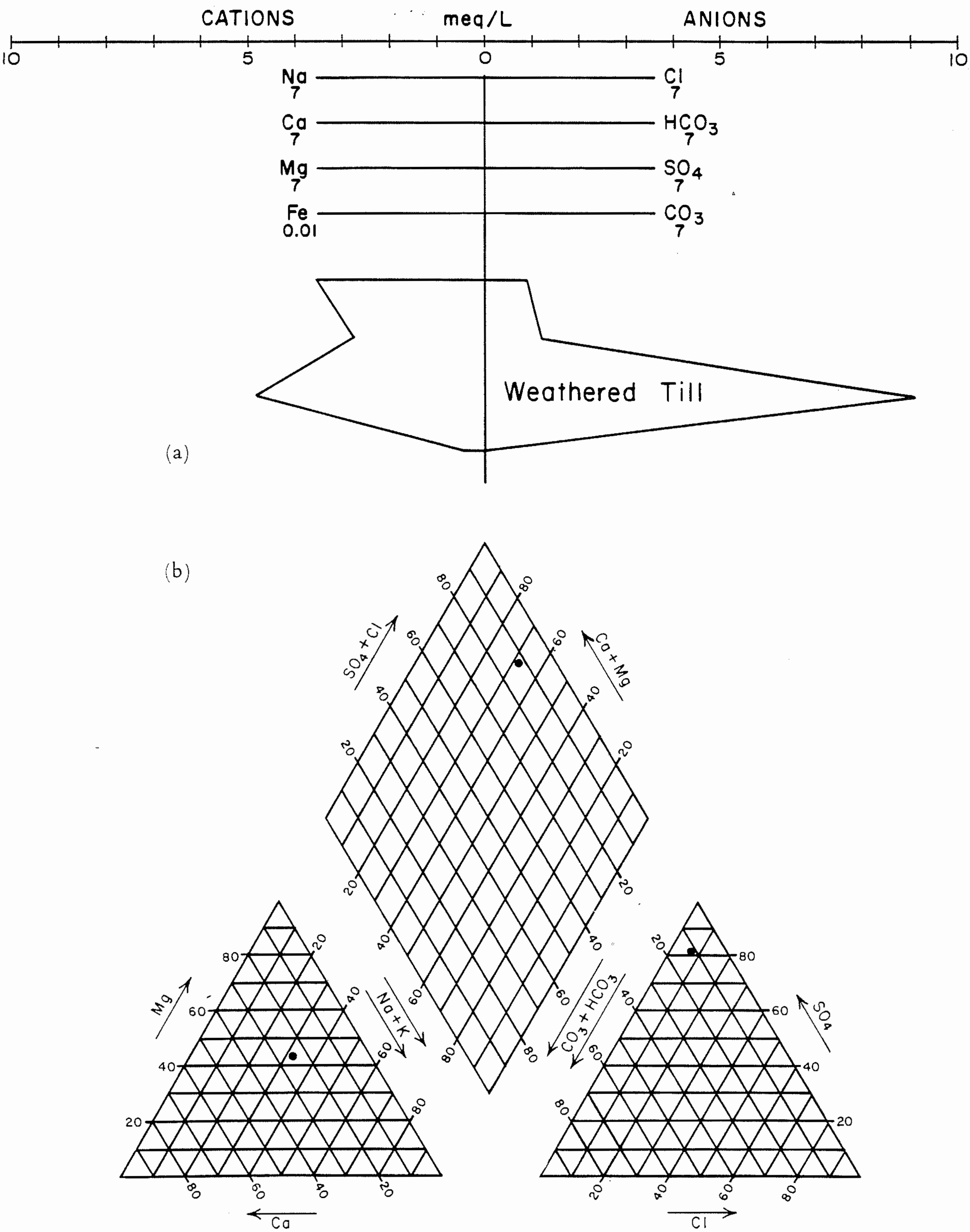



Figure 12. Water quality of weathered till. (a) Stiff diagram (b) trilinear diagram

One weathered till piezometer in the CENDAK area was sampled for carbon-14 analysis. The result shows that the water in the weathered till at this site is of recent age. This indicates that the weathered till is receiving recharge from modern-day precipitation.

5.A.3.2.1.3
UNWEATHERED TILL

Unweathered till is characterized by its gray color and dense clayey material containing numerous pebbles and boulders. Fractures were not observed by visual inspection of core samples (Cowman, South Dakota Geological Survey, personal communication, 1985). As with weathered till, unweathered till waters consist of a certain chemical makeup and quality. These chemical properties are discussed in section 5.A.3.2.1.3.3 of this report. In contrast to the weathered till, unweathered till is characterized by only one type of permeability, that being intergranular permeability (Hendry, 1982). The intergranular permeability is discussed in section 5.A.3.2.1.3.2 of this report.

5.A.3.2.1.3.1
Water Levels

Section 5.A.3.2.1.1 of this report gives a summary of the purpose for installing vertically nested piezometers in till. It also discusses the method used for monitoring water-level changes in the piezometers. The procedures used for piezometer construction and installation are also found in section 5.A.3.2.1.1. The following section discusses data obtained from the water-level recordings in piezometers completed in unweathered till.

5.A.3.2.1.3.1.1
Hydrographs

Appendix C contains water-level hydrographs for the piezometers at the 22 sites in the CENDAK area. The inset on each hydrograph depicts the location of the piezometer intake. The water level recovery curves for unweathered till piezometers are typical of sediment with low permeability. It can be seen from the hydrographs that piezometers completed in unweathered till rarely deviate from the smooth recovery curve shape and thus are not showing response to rapid recharge events such as spring thaw and precipitation. To the contrary, water levels in piezometers completed in the weathered unit fluctuate rapidly at various times of the year in response to rapid recharge from precipitation and spring thaw. The difference in characteristic water level behavior between the weathered-till piezometers and the unweathered-till piezometers indicates that the two units differ drastically in hydraulic properties. This difference correlates with the proposed insignificant hydraulic connection between the weathered and unweathered units (Barari and Hedges, 1985).

5.A.3.2.1.3.1.2
Vertical Hydraulic Gradients

Table 9 is a summary of vertical hydraulic gradients existing in unweathered till during the period of October 4, 1984, to May 20, 1986. Downward gradients in the unweathered till (average = 0.652) are much larger than gradients existing in the weathered till (average = 0.065). This may be attributed to the large differences in hydraulic conductivities between the two units.

Because of the time lag between installation of a piezometer in unweathered till and the time when water pressure in the piezometer equals that of the surrounding medium, many of the water levels used to calculate gradients in unweathered till are not equilibrium water levels. However, because the data in appendix C indicate that overall there is no trend in the changes in the magnitude of the gradients in the unweathered till as water levels approach equilibrium, the values reported in table 9 and appendix D should be fairly representative of vertical gradients in unweathered till. This time lag phenomenon is not observed in weathered till to the degree it is observed in unweathered till because of the higher hydraulic conductivities present in the weathered till.

**Table 9. Statistical summary of vertical hydraulic gradients in unweathered till.**

| | |
|---|---|
| number of observations | 234 |
| average | 0.652 |
| standard deviation | 1.00 |
| minimum | -2.00 |
| maximum | 4.64 |
| gradient reversals | 48 |

5.A.3.2.1.3.2
Hydraulic Conductivity

Many hydraulic conductivity tests have been performed on unweathered till in the CENDAK area utilizing in situ and laboratory methods. This section describes and reports the hydraulic conductivity test methods and results for unweathered till.

5.A.3.2.1.3.2.1
In Situ Tests

In situ hydraulic conductivity tests in unweathered till in the CENDAK area were conducted by Cowman (in prep.). The tests were a form of slug test sometimes referred to as a "bail-down test." The testing procedure consisted of measuring water level recovery rates as the water levels recovered from some point below the static-water level. The water level recovery data were then used to calculate a hydraulic conductivity for each piezometer. The methods of data analysis used were those presented by Luthin and Kirkham (1949) and Hvorslev (1951). Table 10 contains a summary of the results of in situ hydraulic conductivity tests performed on unweathered till in the CENDAK area by Cowman (in prep.). The location of each individual test along with the results are listed in appendix E. The geometric mean hydraulic conductivity of piezometers in the CENDAK area was 1.6E-08 cm/s. The range of hydraulic conductivity values was 6.2E-09 cm/s to 4.8E-08 cm/s.

**Table 10. Statistical summary of hydraulic conductivities in unweathered till using in situ test results.**

| Investigator | Number of tests | Geometric Mean Hydraulic Conductivity * | Log Standard Deviation | Range * |
|---|---|---|---|---|
| Cowman (in prep); (Hvorslev method; Luthin and Kirkham method) | 11 | 1.6E-08 | 0.25 | 6.2E-09 to 4.8E-08 |
| Cravens (1985); (Hvorslev method) | 35 | 5.5E-07 | 0.63 | 5.8E-08 to 2.9E-05 |

* Results in cm/s

Cravens (1985) conducted single piezometer response tests in unweathered till in Hand and Hyde Counties. These tests were conducted by withdrawing a slug of water from the piezometer and then measuring the water level recovery rate. The method used by

Cravens to analyze his data was that of Hvorslev (1951). Table 10 contains a summary of the results of in situ tests conducted by Cravens in unweathered till. The locations of each individual test along with the results are listed in appendix E. The geometric mean hydraulic conductivity values using piezometers completed in the unweathered till was 5.5E-07 cm/s. Cravens' values ranged from 5.8E-08 to 2.9E-05 cm/s. The mean value for unweathered till that Cravens calculated is far greater than the mean values calculated in the other studies discussed in this report. This may be attributable to the fact that most of Cravens' piezometers were in the top portion of the unweathered till unit. Tests conducted in the deeper unweathered till piezometers in the CENDAK area by Cowman (in prep.) showed lower hydraulic conductivity values. In a study on till in New York, Prudic (1982) obtained data that indicate that the hydraulic conductivity of the till decreases with depth due to overburden pressure.

During the 1950's, several aquifer tests were conducted in the CENDAK area by the U.S. Bureau of Reclamation to determine the feasibility of draining irrigated agricultural lands by pumping the underlying aquifer. During the 1950's, analytical techniques to analyze pumping test data were more limited than present-day techniques. With the advancement in analytical techniques since the time these tests were conducted, it became apparent that a reanalysis of the data should be made. Johnson (1985) conducted this reanalysis using the data that were available. The techniques Johnson used to reanalyze the data were to (1) plot time-drawdown data on log-log paper as time divided by the radius squared versus drawdown and included data from all observation wells completed in the pumped interval on a single plot, (2) visually evaluate the plots as to type of response, and (3) attempt a quantitative evaluation using appropriate type curves. Of the 16 test sites that were reanalyzed, Johnson classified four as showing artesian response, six as showing water-table response, and six as showing leaky-artesian response. According to Johnson, the artesian response classification indicates that pumping of the aquifer at this site would not affect the level of the shallow water table. Also, according to Johnson, a water-table response classification indicates that pumping the aquifer at this site will not increase the vertical hydraulic gradient between the till and the aquifer because a maximum vertical hydraulic gradient already exists at water table aquifer sites. According to Johnson, the goal of pump drainage is to stress the aquifer enough to significantly increase the vertical hydraulic gradient between the till and the underlying aquifer. If unweathered till was permeable enough to allow significant vertical movement, no shallow water table should exist at these sites. However, the low permeability of the unweathered till allows it to act as a barrier, allowing a shallow water table to exist in the overlying weathered till.

A leaky artesian response indicates that the aquifer being pumped is receiving recharge from another unit. Any unit that is acting to recharge the aquifer being pumped could be one of, or a combination of, many units. These possible units would include an underlying aquifer, an overlying aquifer, or the overlying till. Johnson states that:

> "The ultimate test of the concept, therefore, is lowering of the shallow (root zone depth) water table during the conduct of the underlying aquifer test. None of the aquifer test data sets available which indicate leaky artesian response contain unquestionable shallow ground-water data to support the concept of agricultural drainage by pumping of the underlying aquifer."

The conclusions drawn by Johnson from his reanalyses are stated in his report as follows:

1. Because of the theoretically better interpretative methods available, the reanalyses have provided better values for aquifer characteristics (transmissivity, storativity, and if applicable, leakance).

2. The reanalyses have not demonstrated that agricultural drainage by pumping the underlying aquifer is possible at any location within the CENDAK area.

3. Areas showing artesian response should be excluded from further study at the present time.

4. Drainage conditions will not be improved by pumping in areas where water levels in the aquifer are below basal till. (Note that Johnson is referring to basal till as the till unit directly overlying the aquifer.) Methods other than aquifer tests will be needed to evaluate agricultural drainage by natural flow to the underlying aquifer in these areas.

5. Because of incomplete data sets, areas showing leaky artesian response cannot be placed in either a drainable or undrainable category. These areas can only be considered candidates for further study by additional, properly designed and executed aquifer tests or by other means.

Testing of the hydraulic conductivity of unweathered till in the CENDAK area by a pumping test in the underlying glacial aquifer has recently been completed. A detailed description of this test is provided in a U.S. Bureau of Reclamation (1986) report. The decision to conduct pumping test(s) in order to evaluate the hydraulic conductivity of unweathered till was made before the establishment of the CENDAK Drainage Steering Committee. It was postulated that monitoring of the drawdown, or lack thereof, of water levels in the till unit after reducing the hydraulic pressure in the aquifer by pumping could be used to determine the hydraulic conductivity of the till and the feasibility of lowering the shallow water table by aquifer pumping. The Steering Committee developed several criteria which would have to be met before a site for the pumping test could be finalized. In general, the criteria were:

1. The site must contain a weathered till unit underlain by an unweathered till unit.

2. The unweathered till must be of significant thickness (at least 30 feet) and devoid of significant sand lenses.

3. The underlying outwash must be of sufficient areal extent and thickness to allow a significant pumping rate (at least 100 gallons per minute).

4. The site must be in the CENDAK project area.

5. The site should be on land signed up for the CENDAK project to maximize cooperation efforts.

6. The site should be easily accessible and should contain an outlet for discharge water from the aquifer pumping test.

Published data were used as a guide to locate those areas that best suited the project requirements. During the summer and fall of 1985, extensive exploration drilling in Hand and Hyde Counties was conducted by the South Dakota Geological Survey and Materi Exploration, a subcontractor of the J. M. Montgomery consulting firm, to find a site which met all of the criteria. After drilling over 30 test holes, no site in Hand and Hyde Counties was found that could meet the project requirements.

After discussing this problem, the CENDAK Drainage Steering Committee decided that other sites outside of Hand and Hyde Counties, but still within the CENDAK project boundaries, would be explored. Also, if necessary, relaxation of some of the criteria set earlier for site selection would be considered. With this in mind, existing geologic data from the SDGS and additional exploration drilling by Materi Exploration confirmed a site for testing in northwestern Beadle County. This site contained a weathered sediment unit underlain by a sufficient thickness of unweathered sediment. Preliminary aquifer transmissivity testing by Materi Exploration indicated that the aquifer would produce a sufficient quantity of water. One problem that existed was that the unweathered sediment contained several sand lenses and was more silty in the lower part than the tills generally encountered throughout Hand and Hyde Counties. However, a dense clayey till was encountered at a depth of about 20 to 30 feet. That was judged adequate for testing purposes.

Piezometers were installed in the various overburden units and observation wells were completed in the aquifer by Materi Exploration. Water levels in most of these piezometers recovered to within 10 feet of the land surface (which is about the same as the potentiometric surface of the aquifer) within a few weeks (D. Jewell, U.S. Bureau of Reclamation, personal communication, 1986). These water level recovery rates were much more rapid than water level recovery rates in nearly all other cases where the piezometers are installed in unweathered till (for example: Cowman, in prep.). The rapid recovery rate of piezometers installed in the lower part of the unweathered sediment indicated that the sediment at this site may be more permeable than is typical of much of the CENDAK area.

The production well was pumped for 30 days at an initial rate of 300 gallons per minute and later reduced to 235 gallons per minute. Recovery in the piezometers and observation wells was monitored for 5 days. Data analyis showed that the Tulare aquifer at this site has a transmissivity of 11,900 gallons per day per foot. The drawdown data from the piezometers and observation wells were analyzed to determine how much, if any, water movement occurred through the overlying till. The conclusions and recommendations in the report are reported below:

1. The area underlain by aquifers capable of producing significant yields from individual wells, within the designated "aquifer lands" of the CENDAK Project, appears to be significantly less than anticipated, based on the exploratory drilling for this investigation.

2. Glacial aquifers have limited areal extent because of their mode of deposition. Such boundary conditions cause additional drawdown in potential water-supply and/or drainage wells and result in reduced well yields on a long-term basis.

3. The 30-day pumping test of a Tulare aquifer well on the Marshall Farm produced measurable drawdown in all the piezometers installed at various depths below the water table. However, the magnitude of change at the water table was minimal.

4. Analyses of data from the test showed that vertical permeabilities range from 1.9 x 10(-4) to 1.9 x 10(-2) gpd/ft2 (about 9.0E-09 cm/sec and about 9.0E-07 cm/sec, respectively), which are near the low end of values quoted in the literature.

5. Calculated "apparent specific yield" values also are low, reflecting the extremely slow rate of drainage of the clay till.

6. Based on all of the above, drainage of agricultural lands in the CENDAK Project by pumping from glacial aquifers is not considered to be technically feasible.

5.A.3.2.1.3.2.2
Laboratory Tests

Bender and others (1983) obtained unweathered till core samples for laboratory analysis. The samples were obtained by augering a bore hole to the desired depth and then sampling with a split-spoon sampler containing brass liners. The brass liners were then removed from the split-spoon sampler and transported to the laboratory. Laboratory hydraulic conductivity values were then obtained by placing the sample and liner in a constant-head permeameter. Table 11 contains a summary of the laboratory hydraulic conductivity results. The location of each individual test along with the results are listed in appendix E. Some of the tests reported by Bender and others (1983) are not clearly identified as to whether they were conducted in weathered or unweathered till. In some cases, ambiguity in the bore-hole logs made it impossible to determine from which zone the samples were obtained. Data reported here are only those which were discernible in the report of Bender and others (1983) as being from unweathered till. The geometric mean hydraulic conductivity of the values obtained by Bender and others (1983) is 2.1E-08 cm/s. The range of values was from 7.1E-10 to 1.4E-06 cm/s.

Table 11. Statistical summary of hydraulic conductivities in unweathered till using laboratory test results.

| Investigator | Number of tests | Geometric Mean Hydraulic Conductivity * | Log Standard Deviation | Range * |
|---|---|---|---|---|
| Bender and others (1983); (constant-head permeameter) | 34 | 2.1E-07 | 0.81 | 7.1E-10 to 1.4E-06 |
| Faris (1986); (flow-pump test) | 3 (vertical hydraulic conductivity) | 3.8E-09 | 0.18 | 2.4E-09 to 5.0E-09 |
| Faris (1986); (flow-pump test) | 1 (horizontal hydraulic conductivity) | 1.2E-08 | ------- | ------- |

* Results in cm/s

Laboratory tests on two unweathered till cores were conducted by the U.S. Bureau of Reclamation Engineering and Research Center to determine the vertical and horizontal hydraulic conductivities (Faris, 1986). The samples were obtained by the South Dakota Geological Survey with a hollow-stem auger drilling rig and a core barrel. The core barrel contained 2.5-foot long acrylic liners. Upon augering to the desired depth, the core barrel was inserted into the hollow auger and the sample obtained. The sampling system yielded 2.5-foot long by 5.5-inch diameter undisturbed samples which were shipped to the Bureau's laboratory in Denver, Colorado. Specimens from both samples were tested in horizontal and vertical orientators using the lab's high pressure permeability testing equipment. This method involves placing a specimen from the sample in a triaxial chamber and applying a back pressure. The flow rate is then measured as a change in water volume in a small diameter tube. The hydraulic gradient is controlled, thus the flow rate is the dependent variable. After being tested for 3 days at the maximum applicable gradient of 12 (detection limit 9.6E-08 cm/s), no flow was detected in any of the specimens and the tests were terminated (Faris, U.S. Bureau of Reclamation, personal communication, 1986).

In light of the values reported from in situ testing, this was expected. The laboratory then contacted the University of Colorado to inquire about the feasibility of using the University's flow pump permeability method (Schiffman and Fairless, 1984). This method involves pushing or pulling water through the sample specimen with a piston (or syringe). Flow rate is controlled so that the gradient is the dependent variable. That is, for a given hydraulic conductivity, a gradient will develop to meet the induced flow rates. This gradient is then measured. It was determined that this method would meet the requirements and so the samples were tested. One sample was taken from a depth of 47.5 to 50.0 feet below ground at 113N-67W-20C. The geometric mean vertical hydraulic conductivity from this sample was 4.8E-09 cm/s. Another sample was obtained from a depth of 47.5 to 50.0 feet below ground at 116N-68W-29D. The vertical hydraulic conductivity for this sample was 2.4E-09 cm/s. It should be noted that the latter sample was not classified purely as unweathered till, but as a transition zone sample which had characteristics of both weathered and unweathered till. It had a brownish-gray color and could be considered partially weathered. Fracturing is either absent or fractures were not encountered in the transition zone as shown by the extremely low hydraulic conductivities obtained for this sample. Table 11 contains a summary of the data from the flow pump permeability testing. The locations of each individual test along with the results are listed in appendix E.

Laboratory hydraulic conductivity tests were also conducted on 10 till samples from Spink and Hand Counties in South Dakota by Norris (1962). Unfortunately, Norris does not provide locations, depths, or till zone classification for his samples. Therefore, it is assumed that the samples came from both the weathered and unweathered till zones. The wide range of hydraulic conductivity values obtained by Norris justifies this assumption. The geometric mean hydraulic conductivity from the 10 samples tested by

Norris is 6.9E-07 cm/s. The log standard deviation is 0.92 cm/s. The range of hydraulic conductivity values obtained by Norris is 1.4E-08 to 2.4E-05 cm/s. In his study, Norris also reported values from till hydraulic conductivity tests in Ohio and Illinois. From the comparison of the range of values he obtained, Norris noted that:

> "The close grouping of most of the permeability values suggests that, with judgment, they can be extrapolated over large distances and applied with reasonable confidence in estimating the rate of percolation through glacial till to underlying aquifers."

With the data presented in this and previous sections, a theoretical flow velocity through the till was calculated using a one dimensional vertical flow model in Todd (1980, pp. 81-83), which takes into account the water table in the weathered till unit. A vertical Darcy velocity of 0.16 inches per year is obtained using this model. This is the amount of water theoretically reaching an underlying aquifer system. In actuality, the flow velocity may be less than the value calculated. This arises from the concept of a nonlinear behavior of Darcy's Law in low-permeable materials under low-hydraulic gradient (Swartzendruber, 1962). The values used in the above flow model are:

1. Thickness of weathered till = 25 feet (Cravens, 1985, p. 47).

2. Thickness of unweathered till = 75 feet (approximate value).

3. Hydraulic conductivity of weathered till = 2.1E-06 cm/s (average of Bender and others, 1983; Bender and Carlson, 1984; Cravens, 1985; Strube Fossen, 1986; Jewell, 1986; U.S. Bureau of Reclamation, 1960).

4. Hydraulic conductivity of unweathered till = 2.2E-08 cm/s (average of Bender and others, 1983; Cowman, in prep.; Faris, 1986; USBR, 1986).

5. Depth to water table = 5 feet.

6. Depth to potentiometric surface of aquifer = 50 feet (approximate value).

Once again it is noted that these theoretical Darcy flow velocities must be interpreted with caution. The actual flow velocity may be different than the calculated flow velocity.

In a report on the movement of ground water in an area of eastern South Dakota, Holly (in prep.) found that ground-water withdrawal from an outwash aquifer by two rural water systems has resulted in continuous decline of the potentiometric surface in that aquifer for a number of years. Based on ground-water withdrawal rates and the continuous decline of the potentiometric surface, Holly determined that a recharge rate of less than 0.10 inches per year is occurring through the till overlying the outwash. It is noted that this conclusion was calculated independent of hydraulic conductivity data in unweathered till, and thus should be free of any errors associated with the measurement of hydraulic conductivity values and vertical gradients in unweathered till.

## 5.A.3.2.1.3.3 Water Chemistry

### 5.A.3.2.1.3.3.1 Major Ions

Extensive water sampling has been done in the unweathered till zone in the CENDAK area for major ion analysis. During the summer of 1984, the SDGS collected 32 water samples from piezometers completed in unweathered till. Extensive chemical analyses were conducted on these samples. The complete analyses from these samples are given in appendix A. The values discussed in the following paragraphs pertain to the results from those analyses. A statistical summary of water-quality analyses from unweathered till is reported in table 12. Comparison of water-quality data from weathered till and unweathered till, tables 8 and 12, shows that unweathered-till waters have lower concentrations of dissolved ions than weathered-till waters. This is in accordance with the observation by Barari and Hedges (1985) that the salt content of weathered-till waters is much greater than the salt content of unweathered-till waters.

**Table 12. Statistical summary of water-quality analyses from unweathered till.**

| Parameter | Mean | Std. Dev. | Range | | |
|---|---|---|---|---|---|
| Specific Conductance | 3982 | 1951 | 1,260 | to | 9,040 |
| Total Dissolved Solids | 3601 | 1987 | 608 | to | 7,910 |
| Sodium | 487 | 338 | 18 | to | 1,205 |
| Calcium | 344 | 157 | 53 | to | 602 |
| Magnesium | 183 | 136 | 17 | to | 535 |
| Potassium | 17.3 | 6.0 | 7.2 | to | 30.0 |
| Sulfate | 1909 | 1262 | 185 | to | 5,030 |
| Bicarbonate | 607 | 153 | 296 | to | 925 |

Table 12 -- continued.

| Parameter | Mean | Std. Dev. | Range | | |
|---|---|---|---|---|---|
| Carbonate | 0 | 0 | 0 | to | 0 |
| Chloride | 182 | 340 | 3 | to | 1,380 |
| Fluoride | 0.24 | 0.14 | 0.04 | to | 0.67 |
| Nitrate-Nitrogen | 0.7 | 1.1 | 0.1 | to | 4.9 |
| Iron | 0.33 | 0.61 | 0.03 | to | 2.84 |
| Manganese | 2.05 | 1.52 | 0.03 | to | 6.50 |
| Hardness | 1643 | 870 | 202 | to | 3,364 |
| Total Alkalinity | 498 | 126 | 243 | to | 759 |

Specific conductance reported in umhos/cm @ 25 deg. C., all other parameters are reported in mg/L. Number of analyses is 32. Table was generated using data in appendix A.

The major cation in the unweathered till is sodium, with an average concentration of 487 mg/L. The major anion in the unweathered till is sulfate, with an average concentration of 1,909 mg/L. Other cations in high concentrations are calcium and magnesium. Other anions with high concentrations are bicarbonate and chloride. The average total dissolved solids value for unweathered till in the CENDAK area is 3,601 mg/L. This value is much lower than the average TDS value of weathered till (5,199 mg/L, table 8).

Figure 13 illustrates the water quality of unweathered till (data from table 12) utilizing a Stiff diagram and a trilinear diagram. This water is classified as a type III glacial water in the manner of the standards put forth by Freeze and Cherry (1979, p. 284).

Water in weathered till contains more dissolved solids than water in unweathered till. In a ground water flow system, water moving continuously along a flow path undergoes major-ion evolution (Freeze and Cherry, 1979, p. 24). This is the result of chemical equilibrium processes taking place between the water and sediment. One result of major-ion evolution is an increase in TDS with movement along the flow path. In a classic paper based on over 10,000 chemical analyses of water well samples from Australia, Chebotarev (1955) characterized water flow in a large sedimentary basin into three main zones. The upper zone is characterized by active ground water in a recharge area, with a low TDS value. The intermediate zone has less active ground-water circulation, total dissolved solids is relatively higher in this

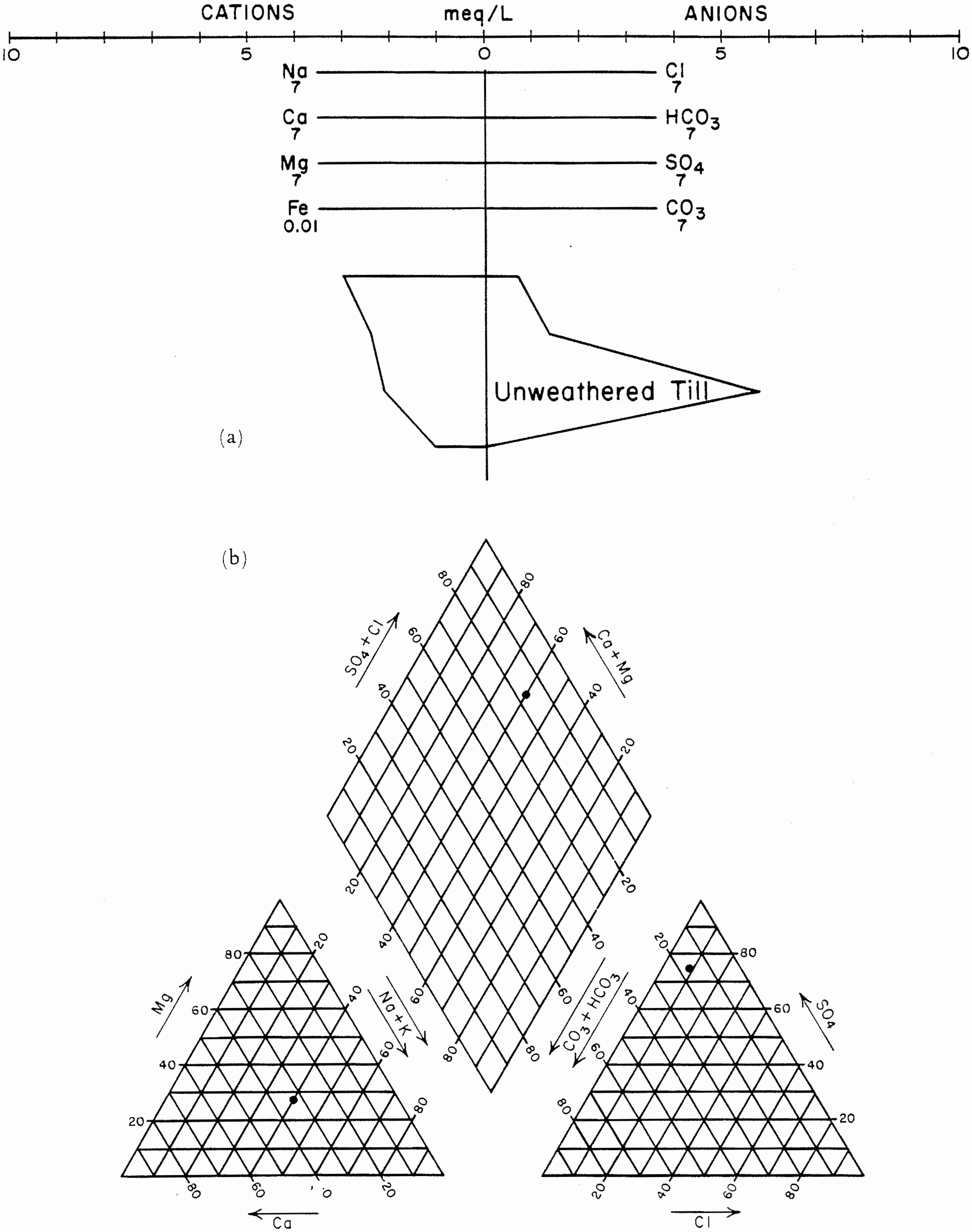



Figure 13. Water quality of unweathered till. (a) Stiff diagram (b) trilinear diagram

zone than the upper zone. The lower zone has very little ground-water movement and has the highest total dissolved solids values. This typical sedimentary basin has downward ground-water movement. In light of the earlier statement that a decrease in TDS is observed in going from the weathered till to the unweathered till, it can be inferred that downward ground-water flow through unweathered till in the CENDAK area is insignificant as evidenced by the lack of major-ion evolution.

5.A.3.2.1.3.3.2
Isotope Analyses

During the summer of 1986, six unweathered till piezometers at two separate sites were sampled for isotope analysis. Tritium, carbon-14, oxygen-18, and deuterium isotope analyses were conducted on these samples. The results of the tritium and carbon-14 analyses are discussed in more detail in the following sections. The results of the stable isotope (oxygen-18 and deuterium) analyses were inconclusive. This is probably due to the small number of samples. Thus, discussion of stable isotope analyses is deferred until additional analyses are available.

5.A.3.2.1.3.3.2.1
TRITIUM

Section 5.A.3.2.1.2.3.2.1 contains a brief discussion on tritium in the hydrologic cycle. The point is again stated here that recharge waters younger than 1953 have tritium concentrations well over 10 tritium units (TU).

Waters from six piezometers completed in unweathered till in the CENDAK area were sampled for tritium analysis. The four deepest piezometers showed tritium concentrations under 10 TU. The two shallowest piezometers show tritium concentrations greater than 10 TU (17.3 TU and 15.0 TU). The latter two piezometers are completed within 15 feet of the weathered till zone. Their proximity to the weathered till zone may account for some modern water reaching the piezometer intake.

5.A.3.2.1.3.3.2.2
CARBON-14

Six unweathered till piezometers in the CENDAK area were sampled for carbon-14 analysis. With the exception of one well, results from the deep unweathered till wells indicate old water approximately the same age as the sediment. This indicates that most of the water in the unweathered till was emplaced in the till during deposition by the glaciers and that no significant water movement has occurred since that time. The deep well showing recent water is in contrast to all other deep till wells in this area and other areas of eastern South Dakota that have been sampled for isotope analysis. In addition, results from the unweathered till well above the well in question show significantly older water. Because of this anomaly, this site will be sampled again.

## 5.A.3.2.2
## Outwash Aquifers

Outwash, as described in the "Geology" section of this report, is divided into two major types: buried and surficial. Buried and surficial are terms generally used when discussing large scale or regional occurrence of outwash aquifers. This subdivision will not always stand the test of detailed site specific examination because of the presence of transition zones from one type to the other within and between outwash bodies. Confined conditions usually prevail in buried outwash and unconfined conditions usually prevail in surficial outwash, but the reverse does occur locally and regionally as will be demonstrated later. The above statements are offered because glacial hydrogeology does not often lend itself to absolute categorization. However, for the sake of discussion, the categories of buried and surficial will be used.

### 5.A.3.2.2.1
### SURFICIAL-OUTWASH AQUIFERS

#### 5.A.3.2.2.1.1
#### Occurrence

The major surficial outwash bodies that may be aquifers within the CENDAK area are found associated with stream valleys or former meltwater channels. On the geologic map (pl. 1), these areas are identified as outwash-alluvium (O-A) or outwash (O). The geologic units outwash and alluvium are connected physically and hydraulically and therefore are discussed as a single hydrologic unit. In those portions of a valley where alluvium is a minor portion of the deposit, the alluvium is ignored and the deposit is referenced as outwash (O) only. In the areas of surficial outwash an aquifer may or may not be present depending upon:

1. presence and thickness of aquifer material (sand and/or gravel), and

2. whether and/or how often and how long the sand and gravel is saturated.

Aquifers in the surficial outwash or outwash-alluvium are generally under unconfined conditions. Where the surficial outwash overlies and is in contact with a confined aquifer (such as in a stream valley), the two function as an unconfined aquifer. The possibility of this occurring is illustrated on cross section

C-C' (fig. 7) where "buried" sand and gravel is present at or near valleys.

In Beadle and Spink Counties more extensive areas of surface outwash are present adjacent to and generally in contact with outwash-alluvium (pl. 1). The outwash in these areas are thin (generally less than 20 feet) and are not important sources of water. Thus, there is very little data available for these areas.

### 5.A.3.2.2.1.2 Water Levels

In the CENDAK area there are about 30 observation wells completed in surficial aquifers. About two-thirds of these are in Hand County (app. F, and fig. 14) and are generally spaced too far apart to construct meaningful water-level maps. Thus, only general statements can be made about water levels in surficial aquifers.

Most of the observation wells in surficial aquifers in the CENDAK area are located in stream valleys and are completed in outwash-alluvium. The aquifer material is at or near the land surface and the water table is generally less than 20 feet deep. Thus, these aquifers respond very quickly to precipitation and flood events. Recorded water-level fluctuations in individual wells range from 1.7 feet to 12.6 feet for the length of record.

### 5.A.3.2.2.1.3 Recharge-Discharge

Recharge to surficial outwash occurs from the infiltration of precipitation, flooding, and lateral inflow from adjacent outwash areas. Estimates of recharge rates by Hedges and others (1985) ranged from 2.0 to 3.2 inches per year for surficial outwash and outwash-alluvium in the CENDAK area. Factors affecting the rate of recharge to surficial outwash and outwash-alluvium include amount and intensity of precipitation, surface topography, local geology, and type and thickness of overburden.

Discharge from surficial aquifers by pumping is thought to be minimal. Therefore, most discharge is by natural lateral outflow, evaporation, and transpiration. Discharge downwards to buried aquifers could be significant where hydrogeologic conditions are favorable.

### 5.A.3.2.2.1.4 Water Chemistry

The Division of Water Rights, Department of Water and Natural Resources, controls 28 observation wells in the CENDAK area which are completed in surficial outwash (fig. 14). While these wells are located throughout the CENDAK area, about two-thirds of them are concentrated in Hand County. Water-quality data from these wells were used to compile the general statistical representations in table 13 and figure 15. Figure 16 shows the location of these wells and total dissolved solids vlues of water samples.

**Table 13. Statistical summary of water-quality analyses from surficial outwash.**

| Parameter | Number of Samples | Mean | Standard Deviation | Range |
|---|---|---|---|---|
| Specific Conductance | 28 | 1665 | 1162 | 420 to 5,200 |
| Total Dissolved Solids | 28 | 1223 | 1016 | 276 to 4,308 |
| Hardness | 28 | 473 | 366 | 82 to 1,344 |
| Calcium | 28 | 108 | 95 | 16 to 360 |
| Magnesium | 28 | 50 | 37 | 9 to 165 |
| Sodium | 28 | 199 | 210 | 12 to 860 |
| Potassium | 28 | 14 | 9 | 3 to 48 |
| Bicarbonate | 27 | 326 | 169 | 83 to 710 |
| Carbonate | 20 | 2 | 10 | 0 to 43 |
| Sulfate | 28 | 456 | 542 | 5 to 2,325 |
| Chloride | 28 | 135 | 175 | 4 to 725 |
| Fluoride | 0 | 0 | ---- | --- to --- |
| Nitrate-Nitrogen | 27 | 5 | 21.4 | 0.0 to 112 |
| Iron | 26 | 0.45 | 0.75 | 0.00 to 3.75 |
| Manganese | 0 | --- | ---- | --- to --- |
| Total Alkalinity | 27 | 273 | 153 | 68 to 726 |

Specific conductance reported in umhos/cm @ 25 deg. C., all other parameters are reported in mg/L.

5.A.3.2.2.1.4.1
Major Ions

Appendix A contains the water-quality analyses from wells completed in surficial outwash in the CENDAK area and may contain analyses in addition to those used to compile statistical data.

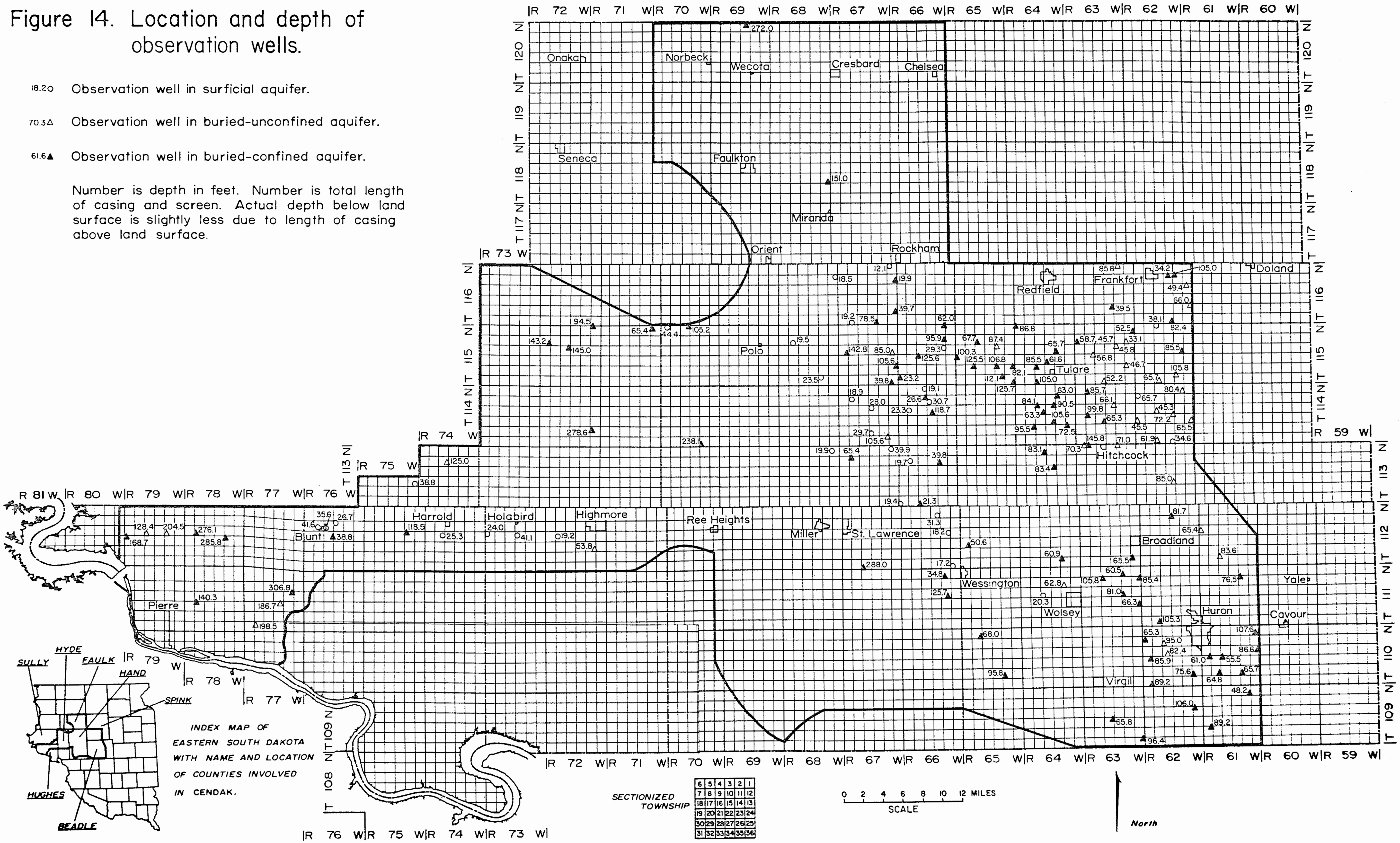
## Figure 14. Location and depth of observation wells.

18.2○ Observation well in surficial aquifer.

70.3△ Observation well in buried-unconfined aquifer.

61.6▲ Observation well in buried-confined aquifer.

Number is depth in feet. Number is total length of casing and screen. Actual depth below land surface is slightly less due to length of casing above land surface.



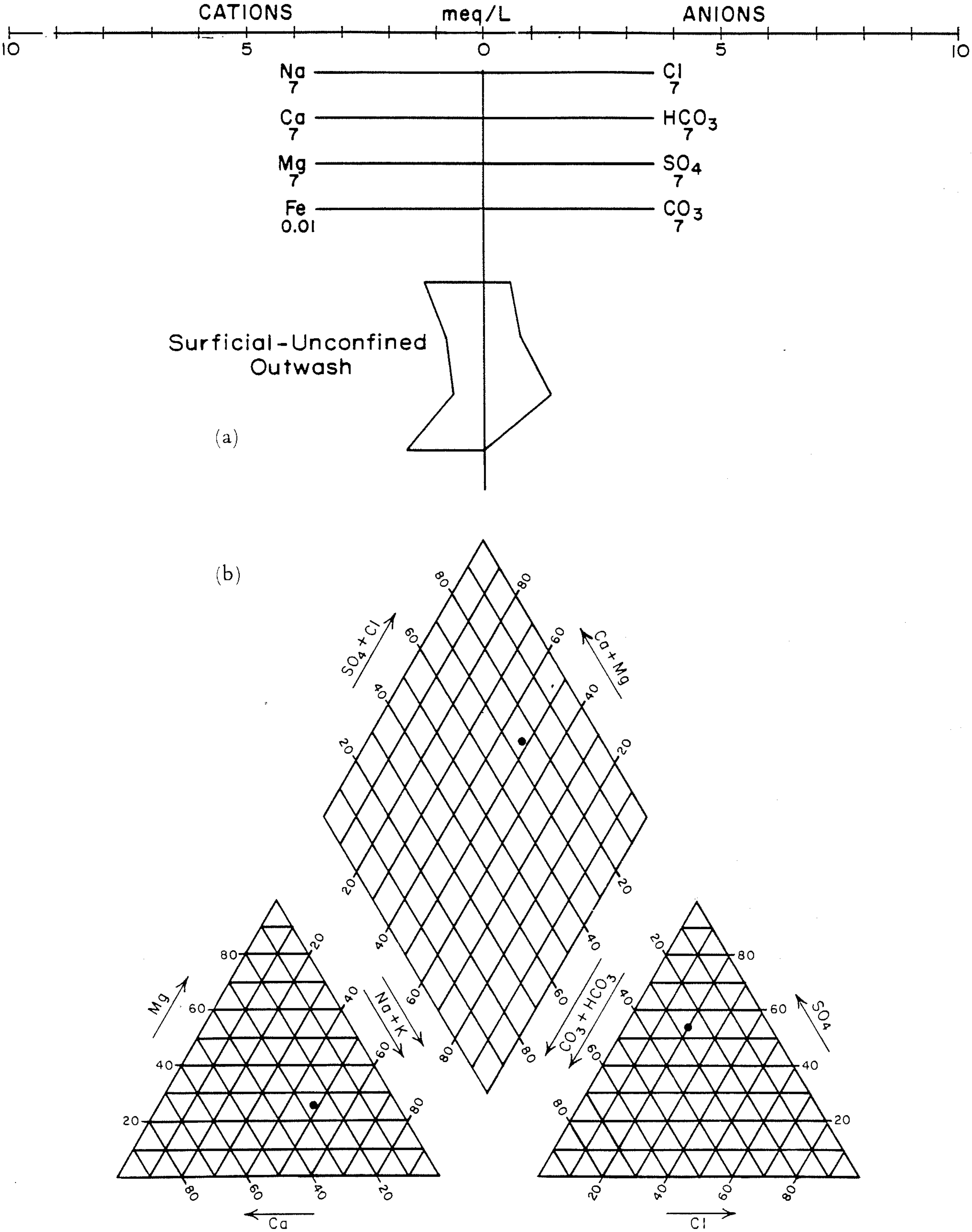



Figure 15. Water quality of surficial–unconfined outwash. (a) Stiff diagram (b) trilinear diagram

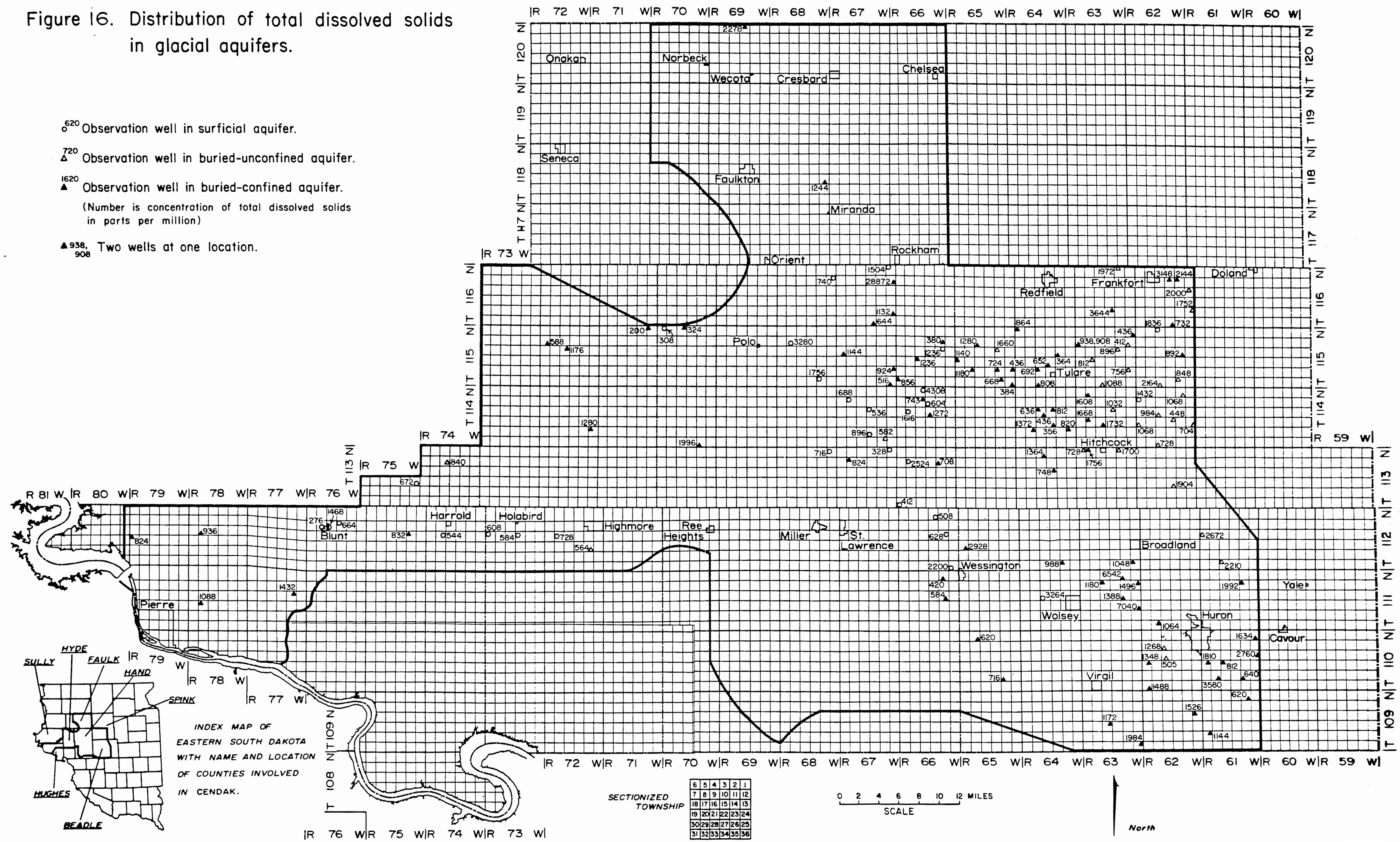



Figure 16. Distribution of total dissolved solids in glacial aquifers.

Only wells which could be classified as buried or surficial and as confined or unconfined were used in the statistical compilation. Chemical analyses from appendix A were used to construct figure 15 and compile table 13 which shows general chemical quality and provides a statistical summary of water chemistry from surficial deposits in the CENDAK area, respectively.

The dominant cations in the surficial outwash are sodium and calcium with mean concentrations of 199 mg/L and 108 mg/L, respectively. The dominant anions are sulfate and bicarbonate with mean concentrations of 456 mg/L and 326 mg/L, respectively. The mean total dissolved solids value is 1,223 mg/L. These chemical characteristics allow water from the surficial outwash to be classified as a type III water in the manner set forth by Freeze and Cherry (1979, p. 284).

5.A.3.2.2.2
BURIED OUTWASH AQUIFERS

5.A.3.2.2.2.1
Occurrence

Hedges and others (1985) compiled aquifer data for eastern South Dakota and developed a system for classifying and naming aquifers. This was done primarily to show regional interrelationships of aquifers and aquifer systems and to develop an aquifer-framework system for data base implementation. In the CENDAK area, this compilation was based primarily on the following work:

1. Beadle County - Howells and Stephens, 1968

2. McPherson, Edmunds, and Faulk Counties - Hamilton, 1982

3. Hand and Hyde Counties - Koch, 1980

4. Hughes County - Hamilton, in preparation

5. Spink County - unpublished studies performed by the Division of Geological Survey and Division of Water Rights, Department of Water and Natural Resources, for the water rights permitting process, and

6. Portions of Hand, Beadle, and Spink Counties - Kuiper, 1984.

The map showing distribution of buried aquifers in the CENDAK area (fig. 17) is adapted from Hedges and others (1985) and is derived from all of these previously mentioned sources with only minor modification where recent local data may have warranted change.

In section 5.A.2.2.2.3, it was stated that buried outwash aquifers occur in three general stratigraphic positions:

1. a basal outwash confined to basal portions of preglacial stream valleys and in contact with or close to bedrock,

2. outwash occurring as lenses of varying thickness within till, and

3. broader areas of nearly continuous buried outwash in contact with or close to bedrock but not necessarily part of the preglacial drainage system. In the CENDAK area those portions located between the unconfined buried aquifers to the east and the outwash lenses to the west are a transition zone that may locally have either characteristic.

The areal distribution of these within the CENDAK area are shown on (fig. 17). For ease of discussion these will be referred to as:

1. basal-outwash aquifers,

2. outwash-lens aquifers, and,

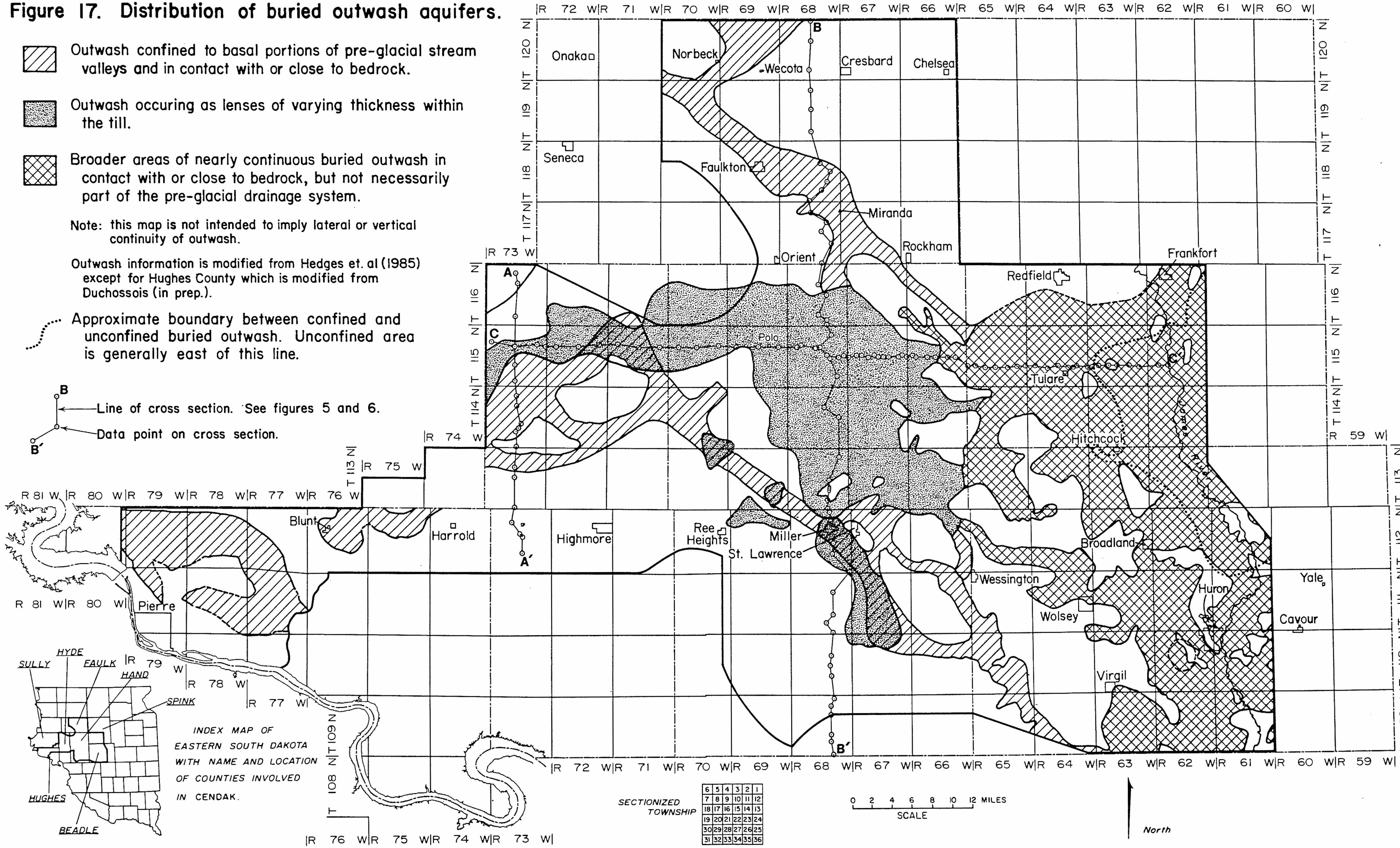
3. broad buried outwash aquifers.

In general, all of these aquifers are "buried" in the sense that they are covered with till throughout most of their extent. Examination of cross section C-C', (fig. 7) shows the till cover generally thickening from about 10 feet in the east to more than 200 feet in the western portions. Locally these aquifers are not "buried" where they are exposed in valleys or where they are in contact with a surficial outwash. Examples of this occurring are illustrated on the cross-sections (figs. 6 and 7).

In discussing the hydrology, Koch (1980) concluded that the outwash-lens aquifers (Tulare aquifer) in Hand and Hyde Counties were mostly interconnected. On the other hand, while discussing the geology, Helgerson and Duschossois (in prep.) concluded the outwash lenses were mostly isolated from each other. This difference in interpretation is understandable when examining the cross-sections (figs. 6 and 7). Because this difference in interpretation of physical continuity of outwash lenses has not been satisfactorily resolved, there has been no attempt to laterally correlate outwash lenses from one test hole to another on the cross sections.

While documentation of lateral continuity, or lack thereof, cannot be accomplished from test-hole data only, more recent hydrologic data indicates that the outwash-lens aquifers, particularly in Hand and Hyde Counties, are mostly isolated from each other physically and hydrologically. These data will be summarized in Chapter 5.A.4 of this report.

Figure 17. Distribution of buried outwash aquifers.



## 5.A.3.2.2.2.2
## Water Levels

There are about 111 observation wells completed in the buried outwash in the CENDAK area (fig. 14 and app. F). Of these, about 25 are completed in unconfined portions of the outwash and the remainder in the confined portions. Depth to water from land surface in the unconfined portions of the outwash ranges from 6 to 76 feet and maximum water level fluctuations range from 1.3 to 22.3 feet, however, the general ranges are 15 to 50 feet and 5 to 10 feet, respectively.

Most wells in the buried outwash which exhibit unconfined conditions are located in Beadle and Spink Counties (fig. 14 and app. F) and are adjacent to or within a few miles of the James River. These portions of the buried outwash owe their unconfined condition to downcutting of the James River, evapotranspiration, and pumping. Examination of the eastern portion of cross section C-C' (fig. 7) shows buried outwash at a higher elevation than the James River flood plain, thus allowing an avenue of discharge from the outwash. Hedges (1968) reports exposures of dry, buried cemented outwash in the valley wall of the James River in Beadle County, thus attesting to former ground-water discharge in that area. Kuiper (1984) attributes substantial discharge from the buried outwash through evapotranspiration in portions of southern Spink and northern Beadle Counties. Pumping has undoubtedly contributed to the decline in water levels leading to unconfined conditions, although Kuiper (1984) states that much of the pumped water would be lost to evaporation if not pumped. The amount of decline caused by each process and the point in time at which this buried outwash probably changed from confined to unconfined conditions is unknown. However, in and near the Huron City well field, periodic pumping by the City since the 1930's has caused a sufficient decline in water levels to change the aquifer from confined to unconfined conditions (see water-level records for observation well BD-60F located at 110-62-16dccc, Jensen, 1986).

Depths to water in buried-confined aquifers range from 5 to 202 feet below the land surface. In Beadle, Spink, and Hand Counties the maximum recorded depths are generally less than 60 feet. The greater depths to water are found in Hyde, Faulk, and Hughes Counties where drift thicknesses are generally greater, particularly along the courses of the pre-diversion channels. The maximum range in water-level fluctuation within individual wells is 1.3 to 55.1 feet, but the general range is 10 to 20 feet.

No attempt has been made to provide water-level maps for this report because lateral and vertical hydrologic continuity between many of the outwash "lenses" have not been established. In fact, most recent evidence would suggest many of the outwash lenses are not hydraulically connected. This evidence is detailed throughout the hydrogeology section (5.A.3) of this report and will be summarized later. A series of nested observation wells with intake zones in the outwash found at various depths would be very beneficial in providing data to help define the hydrologic continuity. An example of how beneficial this type of data could be is shown in the following example. At location 115N-67W-18DDDD in northern Hand County, two outwash units were penetrated at depths of 65 to 82 and 115 to 151 feet. Water levels in these outwash units were recorded as 36 feet and 96 feet below land surface, respectively. This example shows a lack of or very limited hydrologic continuity at this location. It is expected that a series of nested observation well sets would show similar occurrences throughout much of the CENDAK area.

#### 5.A.3.2.2.2.3
#### Recharge-Discharge

Recharge to the buried outwash units can occur from infiltrating precipitation and lateral and vertical inflow from other outwash units and bedrock aquifers. Recharge from precipitation via vertical inflow may occur in areas where the buried outwash has a direct hydraulic connection to an overlying surface outwash. Recharge may also occur where other deposits of sufficient permeability overlie the buried outwash, such as in the eastern portion of the broad buried outwash area denoted as being water table on figure 17. In this area, thin weathered till overlies the outwash and piezometers indicate a rapid response to precipitation. However, where deeply buried outwash is enclosed within unweathered till, recharge from surface infiltration is believed to be insignificant.

Estimates of recharge rates to buried outwash were calculated using various methods by Hedges and others (1985). Values reported ranged from 0.15 to 0.60 inch per year. However, it should be noted that these values included unconfined portions of the outwash. Therefore, these values are probably higher than recharge rates where the aquifer is totally confined.

In a numerical model study of the broad buried outwash area (fig. 17) in Spink County and northern Beadle County, Kuiper (1984) used a recharge value of 0.8 inch per year for the model calibration. It should be pointed out that in a large portion of the model study area, the buried outwash is unconfined and the recharge value is an assumed value including both the confined and unconfined portions, thus, it provided only a maximum value and does not define a minimum value or a value to be associated with the confined portion overlain by unweathered till.

In the preceding discussion of water levels in the buried outwash, it was noted that only periodic pumping from the Huron City well field has caused a water-level decline of as much as 20 feet. This pumping and subsequent water-level decline has been sufficient to change the aquifer from confined to unconfined conditions. Examination of the distribution of buried aquifers (fig. 17) shows significant occurrence of the aquifer to be present up gradient to the west: thus there is a potential source for lateral recharge if there were adequate hydraulic continuity. The slow rate of recovery in water levels in the well field area indicates a lack of significant lateral or vertical continuity. Thus, relatively impermeable material, presumably till, must be effectively blocking recharge to the aquifer.

Discharge from the buried outwash is by pumping, vertical or lateral outflow, evaporation, and evapotranspiration. Total discharge from pumping is unknown but it must be significant because many irrigation, stock and domestic, and municipal wells derive their water from the buried outwash aquifer. Lateral outflow from the entire system is reported as very small (Kuiper, 1984); too small in fact to be measurable as base-flow gain in the James River. Vertical discharge in the confined portions is probably insignificant due to the low hydraulic conductivity of the confining layers. In the unconfined portions, downward discharge is insignificant due to the low hydraulic conductivity of the underlying material. Kuiper (1984) attributes significant discharge to evapotranspiration under natural conditions, presumably in the eastern portion of the area where the aquifers are unconfined. According to Kuiper (1984), much of the water pumped for irrigation purposes would be lost to evapotranspiration under natural nonpumping conditions.

#### 5.A.3.2.2.2.4 Transmissivity and Storativity

Most of the aquifer tests used to obtain transmissivity and storativity values were obtained during the early 1950's when the U.S. Bureau of Reclamation was conducting studies to determine the feasibility of draining irrigated lands by pumping the underlying outwash. These values have been reported for outwashes in Beadle, Hand, and Spink Counties in the CENDAK area and are shown in table 14. The majority of values in this table were reported by Johnson (1985) in a report on the reanalysis of aquifer tests. The reanalyses were done using mathematical methods that have been developed since the tests and initial analyses were performed. The values obtained from Howells and Stephens (1968) and Koch (1980) have not been reanalyzed and are the original values reported by the U.S. Bureau of Reclamation.

Transmissivity is defined as the rate water is transmitted through a vertical section of unit width under a unit hydraulic gradient. Common U.S. units are gallons per day per foot (gpd/ft).

Storativity is the volume of water that an aquifer will absorb or expel from storage per unit surface area per unit change in hydraulic head. Values for storativity are indicative of whether an outwash is under unconfined or confined conditions and typically range from 0.01 to 0.30 and .00001 to .001, respectively.

By definition, all of the test sites reported in table 14 are contained within buried outwash. At those sites where till is not the surface deposit, the buried outwash is close to, or in contact with, the surface deposit and the production well is probably completed primarily in the "buried aquifer." Thus, there are no known aquifer tests in the CENDAK area in which the production test well was completed in only surficial outwash.

Values for transmissivity range from 3,000 to 695,000 gpd/ft (table 14). At three sites more than one aquifer test was performed using different discharge rates and it was found that calculated transmissivity values varied significantly with the various pumping rates (table 14). Reasons for the variations are not known.

Examination of the storativity values listed in table 14 indicates that 10 of the tests were indicative of unconfined conditions. Some of these occur outside the area of unconfined buried outwash shown on figure 17. These may be local areas where unconfined conditions happen to exist, or it may be due to change from confined to unconfined conditions during the test.

Separate tests within a 1 square mile area revealed both confined and unconfined conditions present in the buried aquifer at three different locations.

**Table 14. Transmissivity and storativity values from aquifer tests conducted in the CENDAK area of South Dakota.**

| LOCATION | DATA SOURCE* | DISCHARGE RATE (gpm) | SURFACE GEOLOGY** | TRANSMISSIVITY (gpd/ft) | STORATIVITY |
|---|---|---|---|---|---|
| Beadle County | | | | | |
| 109N-63W-34acab | 1 | ----- | O-A | 425,000 | ------ |
| 110N-61W-06-acdd2 | 1 | ----- | O-A | 29,000 | .00035 |
| 113N-62W-05ddbb1 | 1 | ----- | T | 175,000 | ------ |
| 113N-62W-18bcad1 | 2 | 150 | T | 24,000 | .0003 |
| 113N-62W-22abba | 2 | 300 | T | 58,000 | .0003 |
| | 2 | 600 | T | 82,000 | .00005 |
| 113N-62W-34cc | 2 | 62 | T | 25,000 | .0002-.0007 |

Table 14 -- continued.

| LOCATION | DATA SOURCE* | DISCHARGE RATE (gpm) | SURFACE GEOLOGY** | TRANSMIS-SIVITY (gpd/ft) | STORA-TIVITY |
|---|---|---|---|---|---|
| 113N-62W-34cdcc2 | 1 | ----- | T | 50,000 | .0044 |
| 113N-62W-36dccd | 2 | 62 | T | 25,000 | .096 |
| 113N-62W-36dcdb1 | 1 | ----- | T | 48,000 | .00039 |
| HAND COUNTY | | | | | |
| 115N-66W-18dccc | 2 | 300 | T | 58,000 (max) | .0005-.01 (assumed) |
| 115N-66W-20dabd | 3 | 150 | T | 26,000 | .15 |
| 115N-66W-20dabd3 | 3 | 830 | T | 65,000 | .00038 |
| 115N-66W-20daca | 2 | 300 | T | 54,000 | .21 |
| | 2 | 150 | T | 19,000 | .18 |
| | 2 | 300 | T | 12,000 | .12 |
| 115N-66W-20dadb4 | 3 | 300 | T | 26,000 | .28 |
| 115N-67W-19cabb | 2 | 200 | T | 24,000 | .02 |
| 115N-67W-19cabb2 | 3 | 100 | T | 55,000 | .00016 |
| 115N-67W-19cabb3 | 3 | 400 | T | 55,000 | .00016 |
| 115N-68W-23bbab | 2 | 25 | T | 3,000 | .0004 |
| SPINK COUNTY | | | | | |
| 114N-63W-14dccc | 2 | 150 | T | 86,000 | .14 |
| 114N-63W-17dddd | 2 | 104 | Es | 22,000-24,000 | .0002-.0007 |
| 114N-63W-24cbaa1 | 1 | ----- | T | 695,000 | ------ |
| 114N-63W-26acaa1 | 1 | ----- | T | 250,000 | ------ |
| 114N-64W-04cdcd | 2 | 125 | O | 40,000 | .0005 |

Table 14 -- continued.

| LOCATION | DATA SOURCE* | DISCHARGE RATE (gpm) | SURFACE GEOLOGY** | TRANSMIS-SIVITY (gpd/ft) | STORA-TIVITY |
|---|---|---|---|---|---|
| 114N-64W-09cadd | 2 | 300 | O | 58,000 | .00024 |
| | 2 | 1,000 | O | 82,000 | .00024 |
| 114N-64W-20aaaa | 2 | 150 | T | 86,000 | .14 |
| 114N-64W-22ddd | 4 | 503 | T | 50,000 | .0003 |
| 115N-63W-27dbdc | 2 | 40 | Ls | 26,000 | .10 |
| 115N-64W-19dddd | 2 | 110 | T | 22,000 | .004 |
| 115N-65W-28aaaa | 2 | 300 | T | 36,000 | .0015 |

* 1: Howells and Stephens (1968)
2: Johnson (1985)
3: Koch (1980)
4: Unpublished data, South Dakota Geological Survey files.

** O-A = Outwash alluvium
T = Till
Es = Eolian sand
Ls = Lacustrine sediments

## 5.A.3.2.2.2.5 Water Chemistry

The Division of Water Rights, Department of Water and Natural Resources, controls 111 observation wells in the CENDAK area (fig. 14) which are completed in buried outwash. These wells are further classified as being completed in buried unconfined outwash (27 wells) or buried confined (84 wells) outwash as defined in this report. Water quality data from these wells were used to compile the general statistical representations on tables 15 and 16 and figures 18 and 19. Figure 16 shows the locations of these wells and the total dissolved solids values of water samples taken from these wells.

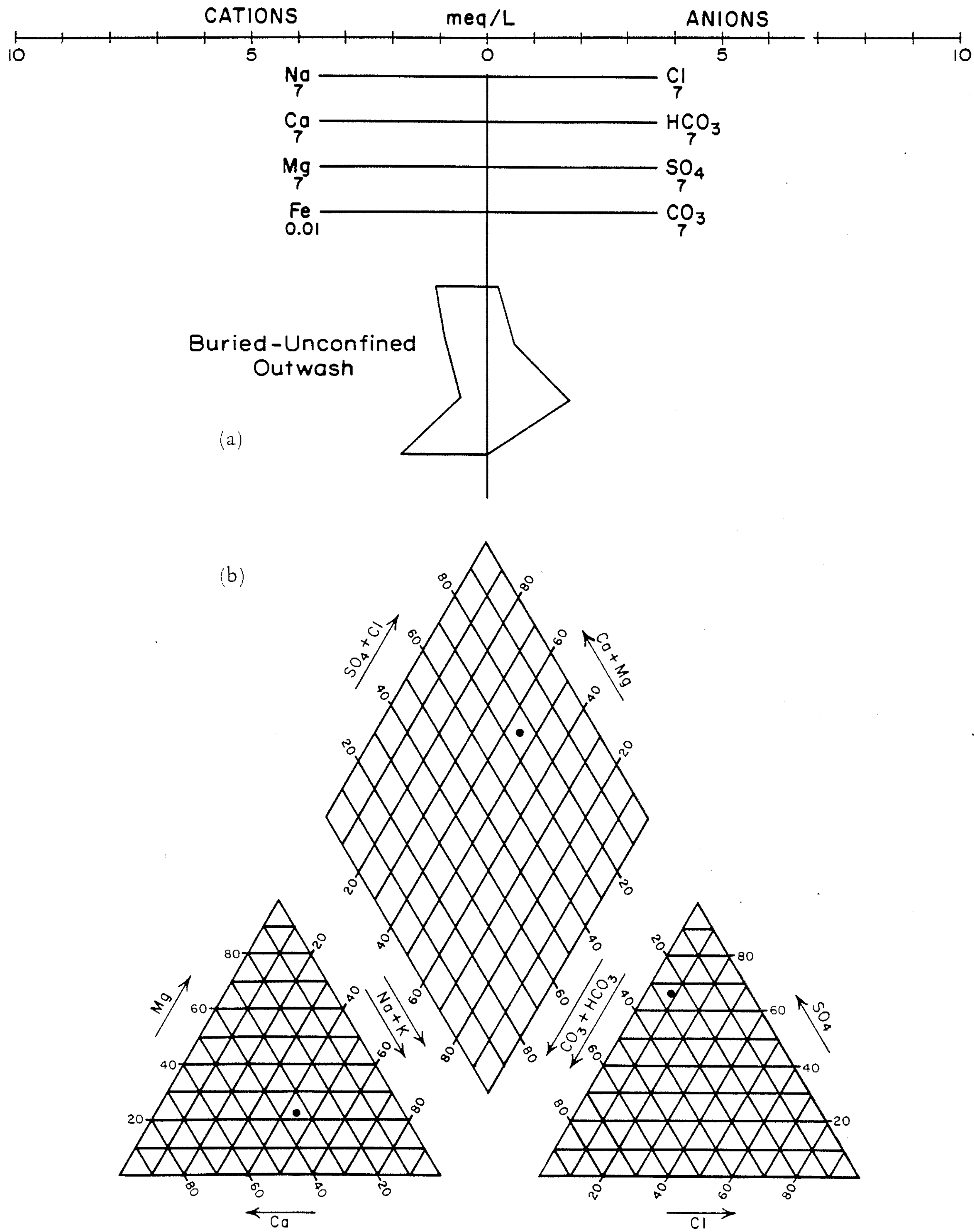



Figure 18. Water quality of buried–unconfined outwash. (a) Stiff diagram (b) trilinear diagram

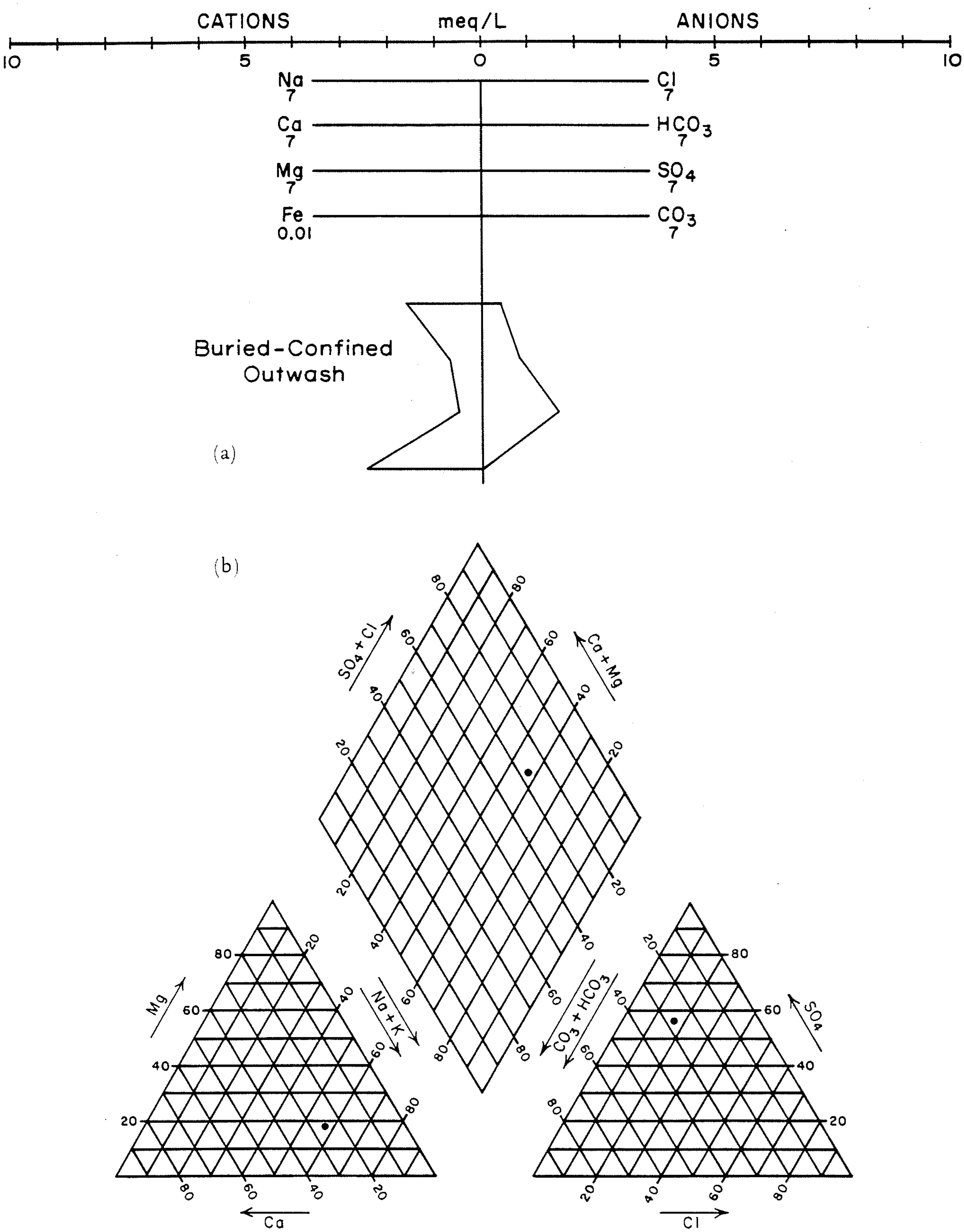



Figure 19. Water quality of buried–confined outwash. (a) Stiff diagram (b) trilinear diagram

5.A.3.2.2.2.5.1
Major Ions

Appendix A contains the water-quality analyses from wells completed in buried outwash in the CENDAK area. This appendix contains water-quality analyses in addition to those used to compile statistical data. Only wells which could be classified as buried or surficial and as confined or unconfined were used to compile water-quality statistics. Chemical analyses from appendix A were used to compile tables 15 and 16 which are statisical summaries of analyses from buried unconfined and buried confined outwash, respectively. In tables 15 and 16, it is apparent that the chemistry of the waters in buried unconfined outwash and buried confined outwash differ only slightly. A t-test conducted on the mean total dissolved solids values for the buried unconfined and buried confined units confirmed that no significant difference existed between the two units at the 95 percent confidence level.

The dominant cations in the buried unconfined outwash are sodium and calcium with concentrations of 171 mg/L and 125 mg/L, respectively. The dominant anions are sulfate and bicarbonate with concentrations of 571 mg/L and 267 mg/L, respectively. The mean total dissolved solids concentration is 1,214 mg/L.

The dominant cation in the buried confined outwash is sodium with a concentration of 253 mg/L. The dominant anions are sulfate and bicarbonate with concentrations of 529 mg/L and 341 mg/L, respectively. The mean total dissolved solids values is 1,291 mg/L.

Both buried unconfined and buried confined outwash waters can be classified as a <u>type III</u> water in the manner set forth by Freeze and Cherry (1979, p. 284).

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**Table 15. Statistical summary of water-quality analyses from buried-unconfined outwash.**

| Parameter | Number of Samples | Mean | Standard Deviation | Range |
|---|---|---|---|---|
| Specific Conductance | 27 | 1561 | 624 | 650 to 2,600 |
| Total Dissolved Solids | 27 | 1214 | 626 | 412 to 2,672 |
| Hardness | 27 | 529 | 362 | 48 to 1,400 |
| Calcium | 27 | 125 | 95 | 11 to 360 |

Table 15 -- continued.

| Parameter | Number of Samples | Mean | Standard Deviation | Range | | |
|---|---|---|---|---|---|---|
| Magnesium | 27 | 52 | 35 | 5 | to | 145 |
| Sodium | 27 | 171 | 123 | 21 | to | 401 |
| Potassium | 26 | 14 | 5 | 5 | to | 29 |
| Bicarbonate | 26 | 267 | 139 | 29 | to | 627 |
| Carbonate | 24 | 2 | 6 | 0 | to | 20 |
| Sulfate | 27 | 571 | 365 | 94 | to | 1,435 |
| Chloride | 27 | 59 | 53 | 4 | to | 190 |
| Fluoride | 3 | 0.7 | 0.7 | 0.2 | to | 1.5 |
| Nitrate-Nitrogen | 25 | 0.9 | 0.8 | 0.0 | to | 2.9 |
| Iron | 27 | 0.51 | 0.56 | 0.00 | to | 2.24 |
| Manganese | 1 | 0.04 | --- | 0.04 | to | 0.04 |
| Total Alkalinity | 27 | 232 | 120 | 56 | to | 514 |

--------------------

Specific conductance reported in umhos/cm @ 25 deg. C., all other parameters are reported in mg/L.

**Table 16. Statistical summary of water-quality analyses from buried-confined outwash.**

| Parameter | Number of Samples | Mean | Standard Deviation | Range | | |
|---|---|---|---|---|---|---|
| Specific Conductance | 84 | 1733 | 1138 | 380 | to | 6,990 |
| Total Dissolved Solids | 84 | 1291 | 1111 | 200 | to | 7,040 |
| Hardness | 84 | 422 | 523 | 48 | to | 2,900 |
| Calcium | 84 | 95 | 110 | 10 | to | 536 |
| Magnesium | 84 | 45 | 74 | 2 | to | 490 |
| Sodium | 84 | 253 | 213 | 11 | to | 1,100 |
| Potassium | 84 | 15 | 6 | 4 | to | 27 |
| Bicarbonate | 81 | 341 | 173 | 88 | to | 881 |
| Carbonate | 75 | 6 | 12 | 0 | to | 67 |
| Sulfate | 84 | 529 | 698 | 19 | to | 4,600 |
| Chloride | 84 | 106 | 172 | 1 | to | 1,120 |

Table 16 -- continued.

| Parameter | Number of Samples | Mean | Standard Deviation | Range | | |
|---|---|---|---|---|---|---|
| Fluoride | 1 | 0.3 | --- | 0.30 | to | 0.30 |
| Nitrate-Nitrogen | 80 | 0.9 | 0.9 | 0.0 | to | 3.2 |
| Iron | 81 | 0.68 | 2.06 | 0.00 | to | 15.00 |
| Manganese | 1 | 0.12 | --- | 0.12 | to | 0.12 |
| Total Alkalinity | 80 | 291 | 155 | 72 | to | 736 |

Specific conductance reported in umhos/cm @ 25 deg. C., all other parameters are reported in mg/L.

It is apparent that the buried outwash water chemistry (tables 15 and 16) does not reflect the overlying unweathered till water chemistry (table 12). A t-test conducted on the mean total dissolved solids values in unweathered till and buried confined outwash confirms that a significant difference exists between these two units at the 95 percent confidence level. In light of the buried outwash water chemistry, the stratigraphic relationship between weathered till, unweathered till, and buried outwash and the water quality flow model of Chebotarev (1955) discussed in section 5.A.3.2.1.3.3, it appears that a downward flow of water through this sequence of hydraulic units is insignificant or nonexistent. This further substantiates the concept of a poor hydraulic connection between unweathered till and the underlying outwash as proposed by Barari and Hedges (1985). Figure 20 contains stiff diagrams for weathered till, unweathered till, and the three outwash classes. It shows a distinct difference in water chemistry between till and the outwash units.

The limited hydraulic continuity between the till and the outwash is even better demonstrated when specific examples are used. The South Dakota Geological Survey has installed a nest (CK-HD-2) of till piezometers at location 115N-67W-18DDDD. An observation well (HD-78B) completed in the buried outwash and controlled by the Division of Water Rights, South Dakota Department of Water and Natural Resources, is also present at this location. In general, the stratigraphy consists of weathered till from 0 to 27 feet, unweathered till from 27 to 118 feet (containing a sand layer from 65 to 82 feet) and gravel from 118 to 151 feet. Well HD-78B is developed in the 118- to 151-foot gravel layer. The potentiometric surface of the gravel layer fluctuates around the 100-foot level, plus or minus 15 feet, and the water table in the till is about 10 feet below the general land surface. Thus, the hydraulic potential at this site is downward. Table 17 summarizes the water chemistry of weathered and unweathered till and the outwash. It is evident from the chemistry that major differences occur between till zones and the aquifer. This large hydrochemical difference indicates that there is not significant ground-water movement from the till units to the outwash. If a good hydraulic connection were present, the water quality of the outwash should reflect the water quality of the till. Just by examining the TDS values (7,135 mg/L for weathered till, 5,660 mg/L for unweathered till, and 1,144 mg/L for the outwash), it can be inferred that there are three separate hydraulic units.

**Table 17. Site-specific vertical comparison of water quality in till units and outwash.**

LOCATION: 115N-67W-18DDDD

| Parameter | Weathered Till | Unweathered Till | Buried Outwash |
|---|---|---|---|
| Total Dissolved Solids | 7,135 | 5,660 | 1,114 |
| Calcium | 438 | 589 | 57 |
| Magnesium | 660 | 220 | 37 |
| Sodium | 578 | 780 | 277 |
| Sulfate | 4,450 | 3,205 | 374 |
| Bicarbonate | 495 | 296 | 459 |
| Chloride | 125 | 445 | 68 |
| Iron | <0.05 | <0.05 | 0.11 |
| Manganese | <0.05 | 1.03 | ----- |

LOCATION: 115N-70W-14AAAA (till) and 115N-70W-14BBAD (outwash)

| Parameter | Weathered Till | Unweathered Till | Buried Outwash |
|---|---|---|---|
| Total Dissolved Solids | 3,130 | 1,168 | 492 |
| Calcium | 367 | 60 | 38 |
| Magnesium | 244 | 25 | 10 |
| Sodium | 210 | 335 | 119 |
| Sulfate | 1,750 | 372 | 90 |
| Bicarbonate | 645 | 677 | 335 |
| Chloride | 40 | 16 | 8 |
| Iron | <0.05 | <0.05 | 0.33 |
| Manganese | 0.06 | 0.04 | 0.27 |

All values are reported in mg/L.

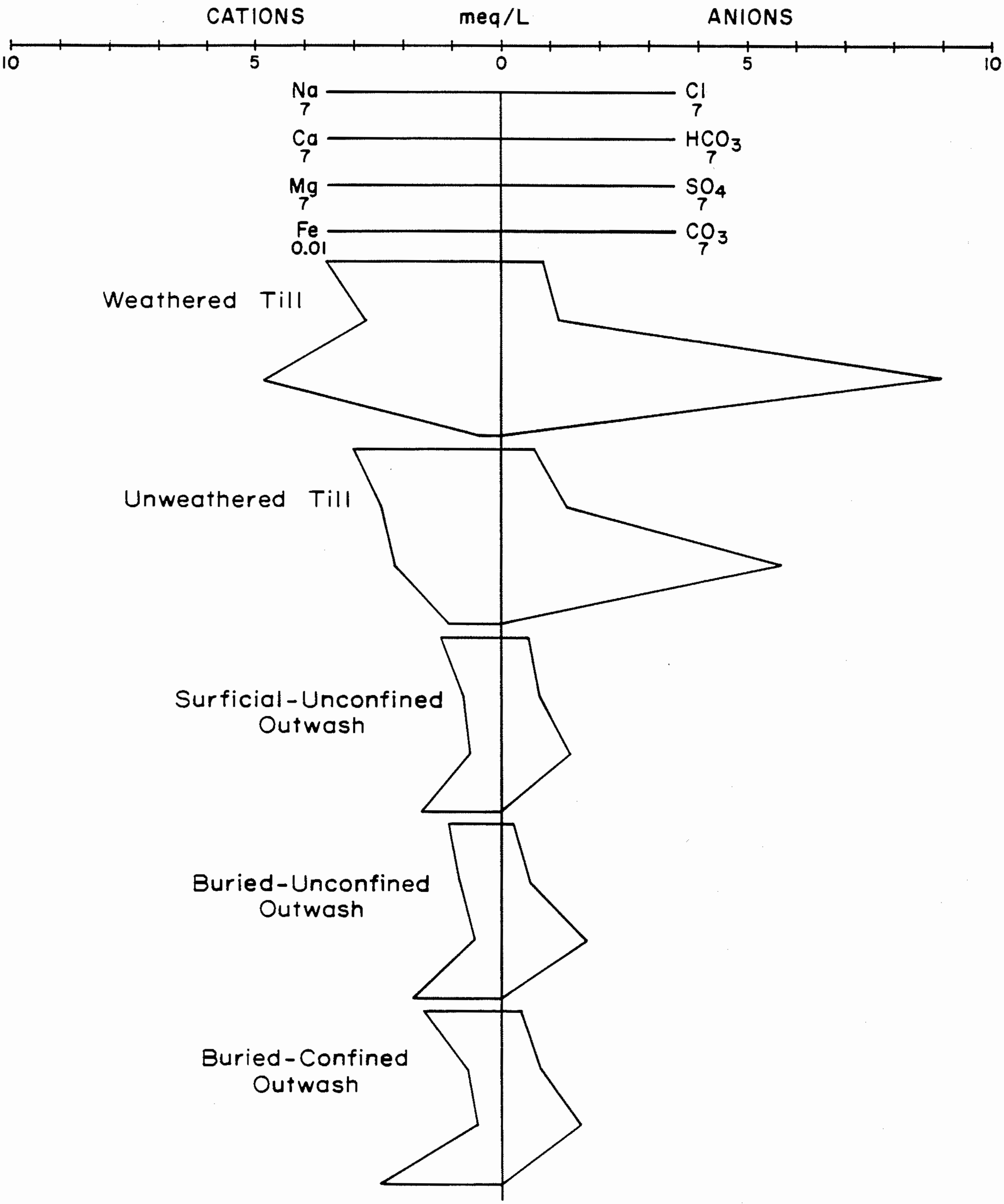


Figure 20. Stiff diagrams of till and outwash units.

Table 18 -- continued.

| Parameter | Well A | Well B | Well C |
|---|---|---|---|
| Total Dissolved Solids | 492 | 1,650 | 2,040 |
| Calcium | 38 | 163 | 196 |
| Magnesium | 10 | 71 | 55 |
| Sodium | 119 | 268 | 365 |
| Sulfate | 90 | 525 | 1,074 |
| Bicarbonate | 335 | 690 | 500 |
| Chloride | 8 | 78 | 27 |
| Iron | 0.33 | 0.06 | 2.35 |
| Manganese | 0.27 | 0.36 | 0.67 |

All values are reported in mg/L.

5.A.3.2.2.2.5.2
Isotope Analysis-age Dating

Four private wells completed in buried outwash were sampled in 1984 and various isotope analyses were performed. The following sections discuss the results of these analyses.

5.A.3.2.2.2.5.2.1
CARBON-14

Table 19 lists the locations and ages of the four water/barium carbonate samples from buried outwash. The age values are corrected for fractionation as explained above in section 5.A.3.2.1.2.3.2.2. of this report.

**Table 19. Locations and results of isotope analyses from buried outwash samples.**

| Location | Sample No. | Well Depth (ft.) | Age* | 0-18* | Deuterium* |
|---|---|---|---|---|---|
| 115-70-14BBAD | A | 90 | 4,890 | -14.98 | -107.1 |
| 115-70-08CDDC | B | 116 | 11,500 | -18.86 | -134.6 |
| 115-70-07CCAD | C | 105 | 26,500 | -18.90 | -138.4 |
| 115-72-31DBDA | D | 130 | - 720 | -11.97 | - 87.3 |

* Age is reported in years before present; 0-18 and deuterium are reported in delta per mille with respect to the standard mean ocean water.

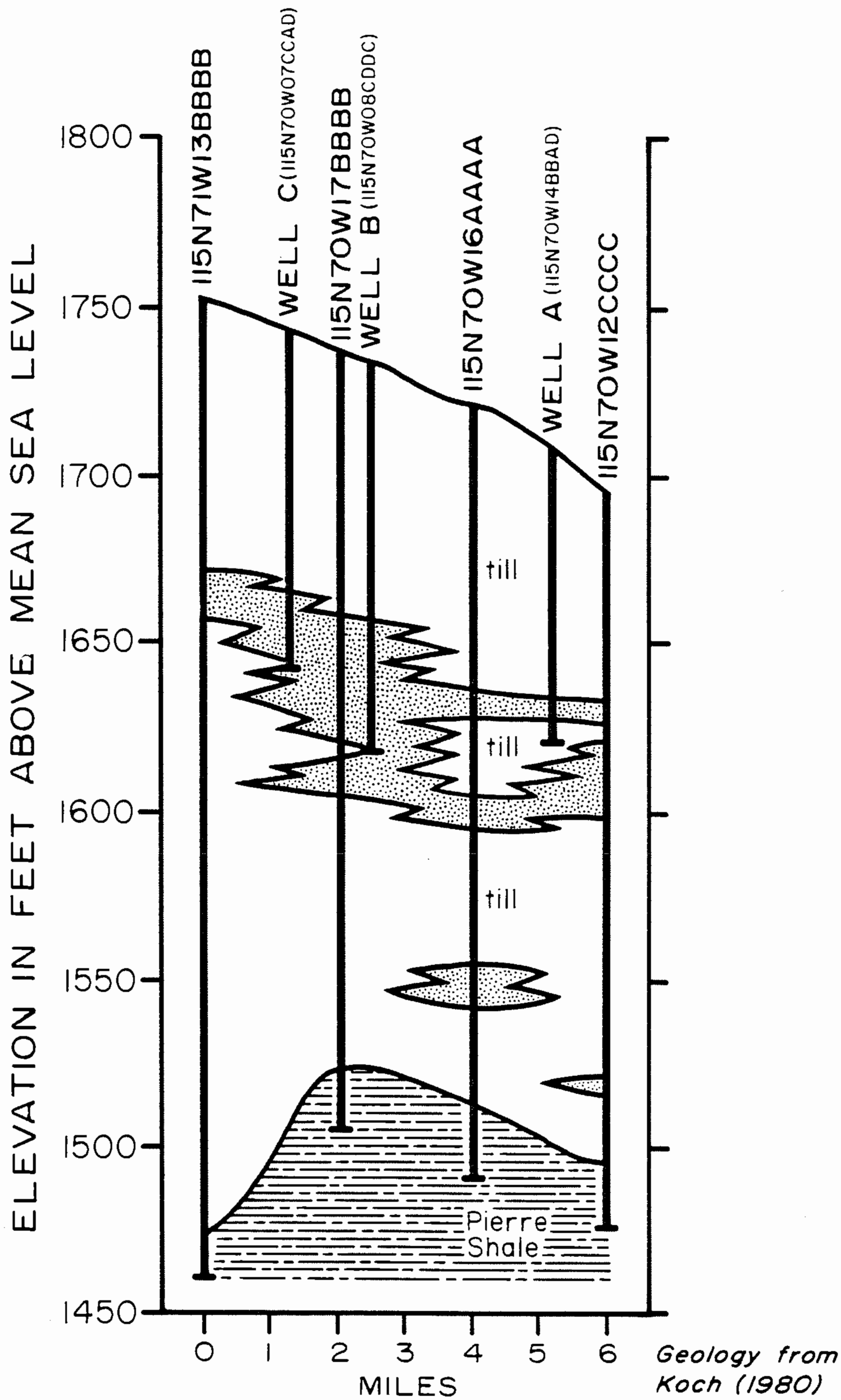


Figure 21. Geologic cross section showing locations of private wells A, B, and C.

It is apparent from the ages of samples A, B, and C that waters in the buried outwash are not of recent origin. The waters are of an age that would correlate with glacial age waters. Therefore, contemporary recharge to this outwash through the overlying till or any other medium, is interpreted to be insignificant or nonexistent. The exception to this interpretation is sample D which shows recent water (the negative value for age is due to uncertainty ranges in the analytical method). According to the well owner, the sampled well had been installed only 3 months prior to sampling. Thus, water in the aquifer at this site may have been contaminated with recent water introduced during the well drilling-development process and this probably accounts for the recent age of this water sample.

The locations of isotope samples A, B, and C (see table 19 for locations) are shown on the Koch (1980) cross-section in figure 21. The hydraulic gradient in the outwash depicted by Koch is toward the east (Koch, 1980). Figure 21 indicates that, for the most part, the buried outwash in this area is a laterally continuous hydraulic unit. However, the large age differences between samples A, B, and C over such a small horizontal distance (4 miles) indicate that there is minimal lateral hydraulic connection in this area of the outwash. It could be argued that the exchange of old carbon in the sediment for young carbon in the water caused significant error in the analyses. However, if this were the case, then the water should increase in age down gradient, because as the water moves along the flow path, it dissolves more old carbon. Contrary to this scenario, the samples decrease in age down gradient. Therefore, the carbon-14 results indicate there is minimal lateral hydraulic connection in the outwash contained within the till in this area. This interpretation of lateral discontinuity is consistent with previous conclusions given in this report based on general water chemistry and water levels.

## 5.A.3.2.2.2.5.2.2 OXYGEN-18 AND DEUTERIUM

Isotopic fractionation is a natural process which results in the change in the isotope content of a substance due to evaporation, condensation, freezing, melting, chemical reactions, and biological processes. Condensation and isotopic fractionation are temperature dependent and so the isotopic composition of atmospheric precipitation is also temperature dependent. A correlation of unaltered water samples worldwide shows a linear relationship of deuterium to oxygen-18. The equation defining this line is known as the meteoric water line (Craig, 1961). Due to local climatic conditions, the coefficients in the meteoric water line equation will vary by locale. The degree of variation, however, is generally slight. Water bodies which have undergone extensive evaporation will plot below the meteoric water line. This is because enrichment of oxygen-18 is greater relative to enrichment of deuterium during evaporation. Figure 22 shows the results of four isotope analyses from buried outwash water samples in the

CENDAK area plotted on a deuterium versus oxygen-18 graph. The four samples all fall very close to the meteoric water line indicating no significant evaporation has taken place. The type of graph in figure 22 is also good for comparing the climatic conditions under which the ground waters originated. This is because waters which originated in cooler climates (for instance, connate glacial waters) will fall further down along the meteoric line than waters originating in warmer climates (for instance, recent precipitation).

## 5.A.3.2.3
## Glacial-Lake Deposits

Glacial-lake deposits in the CENDAK area comprise the lake plain that resulted from glacial Lake Dakota. Surficial sediments in the lake plain consist mainly of silt with clay and fine sand. The thickness of this deposit in the CENDAK area varies from less than 10 feet to greater than 50 feet with the maximum thickness found to be 64.5 feet (Hopkins and Petri, 1962).

Hydrogeologic data are available only from the early 1950's when tests were performed to determine the drainability of the lands with respect to proposed irrigation. Results of the tests are discussed in Harding and others (1954). In that report, the accuracy of test results was questioned because of variability in results found using different testing methods. Permeability of the sediments was found to vary as described in the following quote from Harding and others (1954):

> "For the lake plain soils the available permeability determinations include the following: 0.26 inch per hour for field infiltration tests; a mean of about 0.34 inch per hour for the pump-in, pump-out, lateral, piezometer tests; 0.12 inch per hour for the 30 by 40 heavily irrigated plot on the Redfield farm; and 0.20 inch per hour for pump tests 12 and 13. From a consideration of the procedures and conditions under which these tests were made it is concluded that the values obtained by the infiltration, pump-in, pump-out, lateral, and piezometer methods are the most applicable for use in drainage considerations in the lake plains silts. This average value of permeability as determined from the above figures is 0.30 inch per hour."

This average permeability is equivalent to 2.12E-04 cm/sec.

Harding and others (1954) also present data on the specific yield of lake-plain sediments. Tests were conducted on soils ranging from 4 to 10 feet in depth and the mean value for specific yield was found to be 3.12 percent. However, Harding and others (1954) used a value of 3.25 percent in their calculations regarding artificial drainage requirements for the soil. An explanation for the difference in these values was not given.

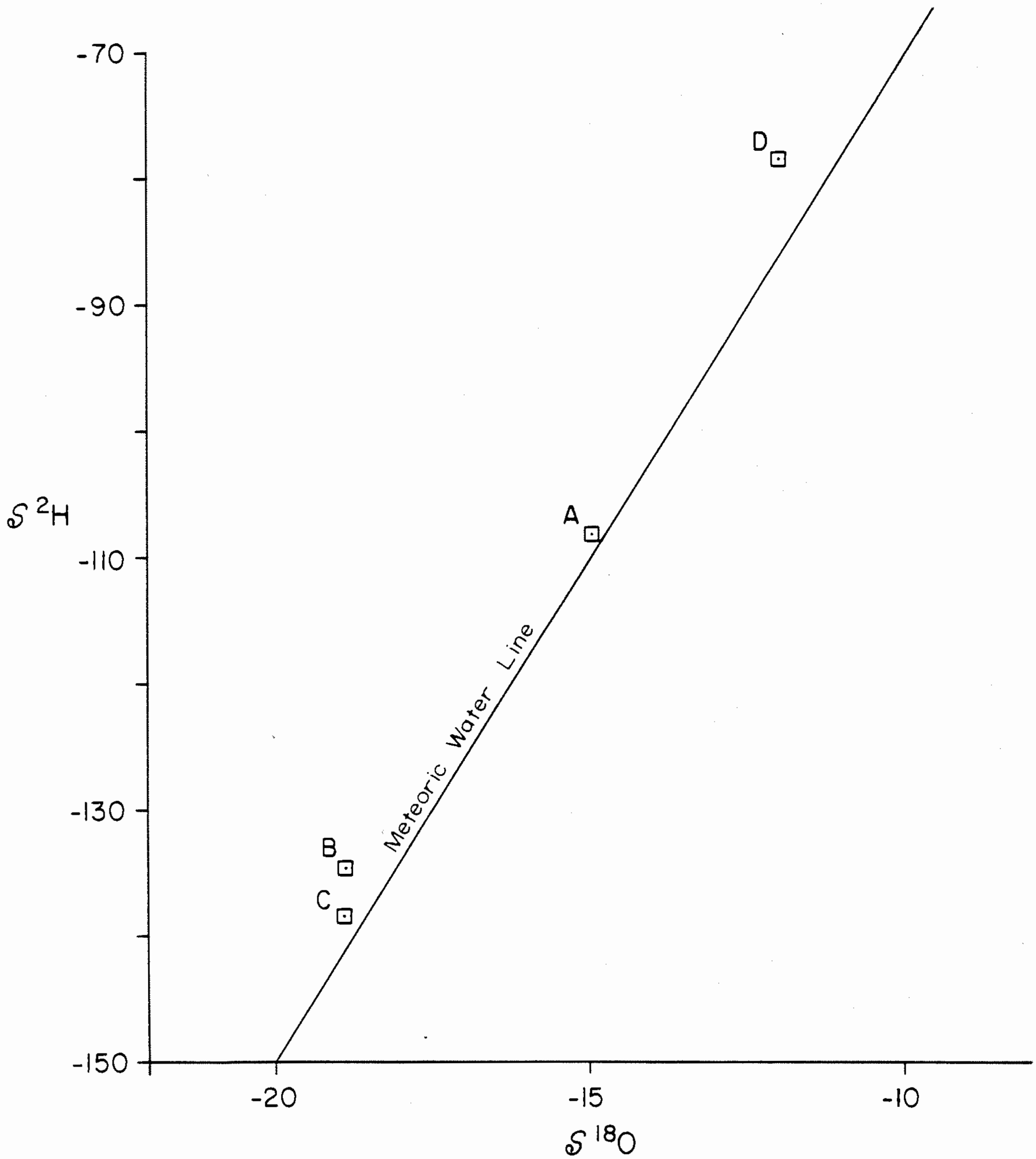


Figure 22. Graph of deuterium versus oxygen-18 for buried outwash isotope samples.

Specific yield will vary within the CENDAK area but the above mentioned values are probably representative.

### 5.A.3.2.4
### Loess and Eolian Sand

The occurrence of loess as a geologic unit in the CENDAK area is too insignificant for mapping purposes. Eolian sand is a mappable unit but its relatively limited extent and thickness has not been considered important in past hydrologic studies. Thus, there is no hydrologic data available for either of these units. Due to their coarser textures, soils derived from these materials would have significantly higher water intake rates than clayey till derived soils.

## 5.A.4
## SUMMARY OF GROUND-WATER MOVEMENT IN THE CENDAK AREA

Ground-water movement in the CENDAK area is controlled by the physical characteristics of the bedrock units and glacial drift. The combined lower Cretaceous and pre-Cretaceous bedrock aquifer units provide an upward potential for water movement that results in flowing well conditions throughout most of the CENDAK area. Thus, on a regional scale the bedrock aquifer units cannot serve as a discharge conduit for precipitation water entering the ground-water flow system in the CENDAK area.

Water movement within glacial drift is controlled by the physical characteristics of the major drift deposits, till and outwash. Till contains an upper weathered unit with a geometric mean hydraulic conductivity of 2.1E-06 cm/s and where the till is thick enough, there is an underlying unweathered till unit with a geometric mean hydraulic conductivity of 2.2E-08 cm/s. The till also varies lithologically in response to the character of the source material. In the eastern portion of the CENDAK area particularly, the till may contain significant amounts of reworked lacustrine derived silts and fine sands which, when concentrated, will cause zones in the till to have higher hydraulic conductivity values than the typical clayey tills.

Fluctuations of water levels below the root zone in the upper weathered till show a rapid response to precipitation. The mechanism for dissipation of the water that penetrates below the root zone and enters the ground-water system as recharge is not quantified or even well understood. The low hydraulic conductivity of unweathered till strongly indicates that downward movement through it would be minimal. Using the geometric mean hydraulic conductivity value for the till and the water tables and potentiometric surfaces that were measured in the CENDAK area, a flow rate of 0.10 to 0.16 inches per year can be calculated. In reality, flow rates may be even less than this value based on several lines of supporting evidence discussed in the following paragraphs.

Tritium values reported from various depths in weathered and unweathered till indicate virtually no penetration of modern (post 1953) waters into the unweathered till. Comparing total dissolved solid concentrations, water in weathered till contains significantly higher quantities of chemical constituents than water in the unweathered till. Where outwash aquifers are present under unweathered till, water from the aquifers contains significantly less chemical constituents (average total dissolved solids) than either water from weathered or unweathered till. If a significant amount of water is moving downwards through the till, then progressively poorer quality water should be present in the unweathered till and outwash aquifers.

If significant downward movement occurs through unweathered till, water levels in till over aquifers should be lower than in areas where aquifers are not present. In reality, there is no difference in water levels between aquifer and non-aquifer lands. In areas where outwash aquifers are absent, downward movement of significant amounts of water cannot occur because of the upward hydraulic potential between bedrock aquifers and glacial drift, and because the low hydraulic conductivity of the bedrock and unweathered till would preclude significant lateral movement through a regional flow system. Additionally, C-14 dates on ground water from the outwash indicates that it was emplaced during the last episode of glaciation which occurred about 11,000 to 22,000 years before present. If significant amounts of contemporary recharge water were able to penetrate the unweathered till, much or all of the connate aquifer water emplaced at time of deposition of the till would be replaced by more recent water.

A recent (1986) sophisticated pumping test and data analysis yielded hydraulic conductivity values for dense unweathered clayey till that confirm values of other in situ and laboratory methods.

Thus, the current state of research indicates that downward movement of water through unweathered till throughout much of the CENDAK area can account for, at best, only relatively small quantities of water.

Although weathered till may have hydraulic conductivites several orders of magnitude higher than unweathered till, lateral flow through this medium does not appear to account for dissipation of a significant amount of recharge water on a regional basis. The relatively flat topography and lack of deeply incised streams in the CENDAK area provide the potential for only very low horizontal hydraulic gradients for regional flow. The combination of low horizontal hydraulic gradients and calculated hydraulic conductivities of weathered till do not provide adequate flow rates to dissipate significant recharge water. Although local lateral flow could be greater than regional lateral flow due to local conditions, this apparently does not occur to a great extent. If significant local lateral flow did occur, then weathered till should be flushed of its water containing high concentrations of chemical constitutents and large areas of saline seeps should be present. These are not known to be common features in the CENDAK area.

All data previously discussed and summarized strongly indicate that recharge water penetrating below the root zone cannot be dissipated by downward movement through unweathered till or by local or regional lateral flow through weathered and unweathered till. Thus, evaporation and/or transpiration must account for dissipation of more water from below the root zone than was assumed in previous water-budget calculations by other investigators. The precise mechanisms responsible for this phenomenon has not been documented and quantified at the present time. However, most water chemistry data concerning weathered till is consistent with this concept. Additional research is planned or is in progress which should allow more precise quantification of upward movement of water from the water table in weathered till.

## 5.A.5
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# APPENDIX A

## Water-quality analyses from glacial till, surficial outwash, buried outwash and the Dakota Formation in the CENDAK area

This appendix contains those analyses referenced in the text plus additional ones. All results are reported in milligrams per liter (mg/L), except specific conductance, which is reported in micromhos per centimeter (umhos/cm) at 25 degrees Celsius. A blank space in the parameter value column shows that no analysis was performed for that parameter. A "0" indicates that an analysis was performed but the constituent was not present. The "+" symbol denotes analysis by the United States Geological Survey (USGS); an "*" symbol denotes analysis by the South Dakota Geological Survey (SDGS); and no denotation indicates that the analysis was conducted by the South Dakota Water Resources Research Institute Water Quality Laboratory. Both the USGS and the SDGS give nitrate values as nitrate-nitrogen + nitrite-nitrogen, while the Water Resources Research Institute Laboratory gives nitrate values as nitrate-nitrogen only.

+ Analyses from U.S. Geological Survey (USGS)
* Analyses from South Dakota Geological Survey (SDGS)

| LOCATION T. R. sec. | DEPTH OF WELL (ft) | SPECIFIC CONDUCTANCE (umhos/cm) | TOTAL DISSOLVED SOLIDS (mg/L as CaCO3) | HARDNESS (mg/L) | TOTAL ALKALINITY (mg/L) | BICARBONATE (mg/L) | CALCIUM (mg/L) | MAGNESIUM (mg/L) | SODIUM (mg/L) | POTASSIUM (mg/L) | IRON (mg/L) | MANGANESE (mg/L) | CHLORIDE (mg/L) | FLUORIDE (mg/L) | NO3-N (mg/L) | SULFATE (mg/L) | CARBONATE (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
| BEADLE COUNTY | | | | | | | | | | | | | | | | | |
| SURFICIAL OUTWASH | | | | | | | | | | | | | | | | | |
| 111N64W16CCCC2 | 20.3 | 3400 | 3264 | 1216 | 380 | 464 | 312 | 106 | 540 | 12 | 0.39 | ---- | 125 | ---- | 0.04 | 1725 | 0 |
| HAND COUNTY | | | | | | | | | | | | | | | | | |
| SURFICIAL OUTWASH | | | | | | | | | | | | | | | | | |
| 112N66W 3DDDC1 | 31.3 | 750 | 508 | 240 | 128 | 156 | 55 | 25 | 60 | 8 | 0.20 | ---- | 25 | ---- | 0.24 | 204 | 0 |
| 112N66W14ADDA | 18.2 | 950 | 628 | 279 | 156 | 190 | 59 | 32 | 88 | 9 | 0.02 | ---- | 29 | ---- | 0.00 | 292 | 0 |
| 112N66W36CCCC2 | 17.2 | 2699 | 2200 | 761 | 424 | 517 | 158 | 89 | 523 | 11 | 6.10 | ---- | 30 | ---- | 0.63 | 1240 | -- |
| 113N66W 8BCCB | 19.7 | 2777 | 2524 | 1344 | 388 | 473 | 360 | 108 | 309 | 22 | 0.72 | ---- | 190 | ---- | 0.33 | 1128 | -- |
| 113N66W31CCCC3 | 19.4 | 650 | 412 | 297 | 176 | 215 | 48 | 43 | 20 | 4 | 0.01 | ---- | 21 | ---- | 0.04 | 122 | 0 |

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 113N67W 1BBCC2 | 39.9 | 550 | 328 | 231 | 148 | 181 | 43 | 30 | 19 | 12 | 0.01 | ---- | 22 | ---- | 0.02 | 124 | 0 |
| 113N68W 1BCCC | 19.9 | 1100 | 716 | 403 | 160 | 195 | 74 | 53 | 55 | 8 | 0.02 | ---- | 54 | ---- | 0.11 | 315 | 0 |
| 114N66W 4ADDD | 19.1 | 5200 | 4308 | 1072 | 380 | 464 | 157 | 165 | 860 | 48 | 0.05 | ---- | 250 | ---- | 0.03 | 2325 | 0 |
| 114N66W10CCBB | 30.7 | 950 | 604 | 334 | 209 | 255 | 58 | 46 | 70 | 12 | 0.00 | ---- | 90 | ---- | 0.02 | 194 | 0 |
| 114N66W17BCCB | 23.3 | 2169 | 1616 | 917 | 278 | 339 | 250 | 71 | 194 | 7 | 0.33 | ---- | 148 | ---- | 0.85 | 750 | -- |
| 114N67W 8BBCC | 18.9 | 1000 | 688 | 324 | 140 | 171 | 77 | 32 | 87 | 15 | 0.06 | ---- | 50 | ---- | 0.31 | 315 | 0 |
| 114N67W15BBBB | 28.0 | 985 | 536 | 379 | 280 | 342 | 84 | 41 | 81 | 6 | 0.89 | ---- | 26 | ---- | 0.60 | 195 | -- |
| 114N67W27CCCB | 29.7 | 1499 | 896 | 565 | 352 | 429 | 147 | 48 | 133 | 9 | 0.56 | ---- | 69 | ---- | 0.44 | 405 | -- |
| 115N66W14AADD | 29.3 | 2025 | 1236 | 392 | 564 | 688 | 114 | 26 | 314 | 16 | 3.75 | ---- | 112 | ---- | 4.10 | 367 | -- |
| 115N68W 8CDCC | 19.5 | 3877 | 3280 | 1293 | 198 | 242 | 328 | 115 | 500 | 11 | 0.03 | ---- | 330 | ---- | 112.00 | 1325 | -- |
| 115N68W35BBBB | 23.5 | 2250 | 1756 | 229 | 291 | 355 | 29 | 38 | 100 | 19 | 0.09 | ---- | 210 | ---- | 0.60 | 610 | 0 |
| + 115N70W 6AAAA | 44.4 | 456 | 308 | 270 | --- | --- | 80 | 17 | 14 | 6 | 0.40 | ---- | 4 | ---- | ------ | 17 | -- |
| 116N67W 1BBBB | 12.1 | 2467 | 1504 | 637 | 514 | 627 | 120 | 82 | 316 | 11 | 1.00 | ---- | 205 | ---- | 1.76 | 500 | -- |
| 116N68W12AAAD | 18.5 | 1200 | 740 | 292 | 228 | 278 | 51 | 40 | 146 | 15 | 0.05 | ---- | 38 | ---- | 0.04 | 340 | 0 |

HYDE COUNTY

SURFICIAL OUTWASH

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 112N72W17BCCB2 | 19.2 | 900 | 728 | 240 | 302 | 369 | 55 | 25 | 135 | 19 | 0.12 | ---- | 23 | ---- | 0.66 | 240 | 0 |
| 112N73W15BBCC | 41.1 | 800 | 584 | 151 | 234 | 286 | 29 | 19 | 115 | 18 | 0.20 | ---- | 32 | ---- | 2.22 | 128 | 0 |
| 112N73W18BBBB | 24.0 | 850 | 608 | 89 | 340 | 415 | 16 | 12 | 202 | 13 | 0.14 | ---- | 6 | ---- | 1.10 | 160 | 0 |

HUGHES COUNTY

SURFICIAL OUTWASH

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 112N74W17ADAA | 25.3 | 800 | 544 | 290 | 324 | 395 | 80 | 22 | 67 | 9 | 1.26 | ---- | 20 | ---- | 1.00 | 77 | 0 |
| 112N76W 8DBCC | 41.6 | 420 | 276 | 170 | 82 | 100 | 45 | 13 | 12 | 3 | 0.54 | ---- | 16 | ---- | 2.00 | 87 | 0 |
| 112N76W 9CBAA | 35.6 | 1650 | 1468 | 678 | 68 | 83 | 184 | 53 | 55 | 8 | ------ | ---- | 405 | ---- | 0.00 | 178 | 0 |
| 112N76W10BBBB | 26.7 | 1200 | 664 | 275 | 140 | 171 | 44 | 40 | 96 | 8 | ------ | ---- | 21 | ---- | 0.16 | 280 | 0 |

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **SPINK COUNTY** | | | | | | | | | | | | | | | | | |
| **SURFICIAL OUTWASH** | | | | | | | | | | | | | | | | | |
| 114N62W 7BBBB | 65.7 | 2300 | 1432 | 543 | 192 | 234 | 87 | 79 | 256 | 36 | 0.33 | ---- | 525 | ---- | 1.45 | 200 | 0 |
| 115N62W 4BBBB | 38.1 | 3100 | 1836 | 82 | 726 | 710 | 18 | 9 | 670 | 19 | 0.37 | ---- | 725 | ---- | 3.80 | 5 | 43 |
| **SULLY COUNTY** | | | | | | | | | | | | | | | | | |
| **SURFICIAL OUTWASH** | | | | | | | | | | | | | | | | | |
| 113N75W24DCCD | 38.8 | 1000 | 672 | 305 | 162 | 198 | 58 | 39 | 82 | 8 | 0.16 | ---- | 37 | ---- | 0.00 | 290 | 0 |
| **BEADLE COUNTY** | | | | | | | | | | | | | | | | | |
| **BURIED OUTWASH** | | | | | | | | | | | | | | | | | |
| 109N61W 2DDDD | 48.2 | 900 | 620 | 280 | 112 | 137 | 61 | 31 | 71 | 8 | 0.36 | ---- | 32 | ---- | 0.57 | 267 | 0 |
| 109N61W30AAAA | 89.2 | 1400 | 1144 | 476 | 336 | 410 | 128 | 38 | 182 | 15 | 0.43 | ---- | 20 | ---- | 0.00 | 500 | 0 |
| 109N62W13BBBB | 106.0 | 2250 | 1526 | 80 | 520 | 454 | 22 | 6 | 176 | 11 | 0.75 | ---- | 57 | ---- | 1.38 | 574 | 44 |
| 109N63W21AAAA2 | 65.8 | 1550 | 1172 | 437 | 84 | 102 | 96 | 48 | 149 | 14 | 1.72 | ---- | 51 | ---- | 1.41 | 620 | 0 |
| 109N63W36AAAA | 96.4 | 2000 | 1984 | 746 | 292 | 356 | 208 | 55 | 317 | 20 | 0.29 | ---- | 113 | ---- | 0.00 | 1025 | 0 |
| 110N61W 1DCCC | 107.6 | 2300 | 1634 | 113 | 228 | 239 | 27 | 11 | 550 | 10 | 0.52 | ---- | 555 | ---- | 2.58 | 412 | 10 |
| 110N61W13ADDD | 86.6 | 3500 | 2760 | 528 | 132 | 161 | 144 | 41 | 690 | 16 | 0.07 | ---- | 200 | ---- | 2.75 | 1450 | 0 |
| + 110N61W19AAAA | 61.0 | 3100 | 1810 | 150 | --- | 477 | 38 | 14 | 500 | 13 | 10.00 | ---- | 670 | ---- | ---- | 150 | 0 |
| 110N61W21BBBC | 55.5 | 1100 | 812 | 397 | 80 | 98 | 80 | 48 | 76 | 8 | 0.55 | ---- | 50 | ---- | 0.66 | 391 | 0 |
| 110N61W26CCCC | 65.7 | 800 | 640 | 360 | 268 | 327 | 88 | 34 | 87 | 4 | 0.22 | ---- | 41 | ---- | 0.00 | 190 | 0 |
| + 110N61W29DDDD | 64.8 | 4020 | 3580 | 1200 | --- | 881 | 400 | 62 | 410 | 27 | ----- | ---- | 58 | ---- | ---- | 1700 | 0 |
| 110N62W 9CCCC2 | 95.0 | 1950 | 1268 | 109 | 404 | 376 | 24 | 12 | 380 | 14 | 1.12 | ---- | 49 | 1.52 | ---- | 510 | 20 |
| 110N62W16DCCC | 82.4 | 816 | 505 | 48 | 56 | 29 | 11 | 5 | 138 | 16 | 0.02 | 0.04 | 36 | 0.50 | 0.20 | 245 | 19 |
| 110N62W19AAAA2 | 85.9 | 2000 | 1348 | 355 | 356 | 434 | 124 | 11 | 287 | 16 | 0.09 | ---- | 58 | ---- | 0.03 | 560 | 0 |
| 110N62W31DDDD2 | 89.2 | 1950 | 1488 | 111 | 72 | 88 | 38 | 4 | 470 | 6 | 0.18 | ---- | 332 | ---- | 0.04 | 530 | 0 |
| 110N65W 5DDDD | 68.0 | 950 | 620 | 138 | 244 | 220 | 34 | 13 | 144 | 10 | 0.35 | ---- | 16 | ---- | 1.98 | 230 | 19 |
| 110N65W26CCCC | 95.8 | 1050 | 716 | 177 | 196 | 220 | 38 | 20 | 154 | 10 | 3.92 | ---- | 24 | ---- | 2.45 | 315 | 5 |
| 111N61W11BBBB1 | 76.5 | 2303 | 1992 | 1119 | 74 | 90 | 392 | 34 | 180 | 26 | 0.07 | ---- | 32 | ---- | 0.02 | 1340 | 0 |
| 111N62W32ADAA2 | 105.3 | 1800 | 1064 | 213 | 492 | 542 | 62 | 14 | 291 | 12 | 0.12 | ---- | 18 | ---- | 0.04 | 344 | 14 |
| 111N63W 2CCCC | 60.5 | 6218 | 6542 | 2835 | 148 | --- | 380 | 458 | 896 | 11 | 15.00 | ---- | 87 | ---- | 0.13 | 3555 | -- |
| 111N63W 9BBBB | 105.8 | 1800 | 1180 | 447 | 386 | 471 | 128 | 31 | 207 | 10 | 0.15 | ---- | 23 | ---- | 0.02 | 459 | 0 |
| 111N63W12AAAA | 85.4 | 2350 | 1496 | 390 | 632 | 771 | 90 | 40 | 397 | 11 | 0.12 | ---- | 130 | ---- | 0.03 | 462 | 0 |
| 111N63W14CCCC | 81.0 | 1700 | 1388 | 538 | 476 | 581 | 148 | 41 | 284 | 14 | 0.30 | ---- | 92 | ---- | 0.03 | 530 | -- |

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| + | 111N63W24DDDD | 66.3 | 6990 | 7040 | 2900 | --- | 262 | 360 | 490 | 1100 | 27 | 0.08 | ---- | 160 | ---- | ---- | 4600 | 0 |
| | 112N61W18CBBB2 | 65.4 | 2500 | 2672 | 1376 | 514 | 627 | 312 | 145 | 301 | 21 | 0.15 | ---- | 8 | ---- | 0.02 | 1435 | 0 |
| + | 112N61W33BBBB | 83.6 | 2230 | 2210 | 1400 | 404 | --- | 360 | 110 | 140 | -- | 0.11 | ---- | 11 | 0.16 | ---- | 1100 | -- |
| | 112N63W36BBBB | 65.5 | 1700 | 1048 | 132 | 252 | 259 | 20 | 20 | 330 | 15 | 0.62 | ---- | 168 | ---- | 1.60 | 344 | 12 |
| | 112N64W35BBBB | 60.9 | 1437 | 988 | 579 | 324 | 395 | 138 | 57 | 112 | 8 | 1.28 | ---- | 31 | ---- | 1.70 | 435 | -- |
| | 112N65W19DDDD | 50.6 | 3400 | 2928 | 976 | 456 | 556 | 320 | 43 | 570 | 22 | 0.22 | ---- | 130 | ---- | 0.03 | 1600 | 0 |
| | 113N62W22DDDD | 85.0 | 2300 | 1904 | 779 | 392 | 473 | 203 | 66 | 346 | 16 | 0.16 | ---- | 190 | ---- | 0.02 | 862 | 0 |
| | 113N63W 2BBBB | 71.0 | 1950 | 1700 | 915 | 68 | 83 | 264 | 62 | 107 | 12 | 2.24 | ---- | 35 | ---- | 0.26 | 1000 | 0 |
| | 113N63W 5BBBB | 145.8 | 2400 | 1756 | 557 | 358 | 437 | 152 | 43 | 351 | 18 | 0.08 | ---- | 75 | ---- | 0.02 | 850 | 0 |
| | 113N63W 6AAAA1 | 70.3 | 1078 | 728 | 338 | 356 | 434 | 86 | 30 | 125 | 12 | 0.46 | ---- | 15 | ---- | 0.65 | 205 | -- |
| | 113N64W 4DDDD | 83.1 | 2200 | 1364 | 209 | 528 | 586 | 54 | 18 | 414 | 11 | 0.09 | ---- | 132 | ---- | 0.04 | 462 | 14 |
| | 113N64W15AAAA | 83.4 | 1200 | 748 | 162 | 384 | 469 | 45 | 12 | 217 | 8 | 0.23 | ---- | 17 | ---- | 0.02 | 180 | 0 |
| | **FAULK COUNTY** | | | | | | | | | | | | | | | | | |
| | **BURIED OUTWASH** | | | | | | | | | | | | | | | | | |
| | 118N68W24DCDD2 | 151.0 | 2300 | 1244 | 93 | 556 | 503 | 14 | 14 | 500 | 13 | 1.29 | ---- | 452 | ---- | 1.58 | 76 | 43 |
| | 120N69W 3ABBB | 272.0 | 4300 | 2278 | 120 | 392 | 381 | 30 | 11 | 830 | 19 | 4.08 | ---- | 1120 | ---- | 3.20 | 85 | 24 |
| | **HAND COUNTY** | | | | | | | | | | | | | | | | | |
| | **BURIED OUTWASH** | | | | | | | | | | | | | | | | | |
| | 111N66W 2CDCC | 34.8 | 700 | 420 | 207 | 160 | 195 | 45 | 23 | 71 | 12 | 0.07 | ---- | 3 | ---- | 0.52 | 180 | 0 |
| | 111N66W14DCCC | 125.7 | 900 | 584 | 122 | 204 | 249 | 29 | 12 | 149 | 12 | 0.20 | ---- | 14 | ---- | 0.84 | 215 | 0 |
| | 113N66W11CBCC | 39.8 | 1100 | 708 | 288 | 182 | 222 | 56 | 36 | 108 | 14 | 0.00 | ---- | 42 | ---- | 0.42 | 312 | 0 |
| | 113N67W 8BBBB | 65.4 | 1300 | 824 | 205 | 220 | 268 | 41 | 25 | 206 | 20 | 0.03 | ---- | 60 | ---- | 1.12 | 340 | 0 |
| | 114N66W 9AADD | 26.6 | 1150 | 743 | 431 | 170 | 207 | 85 | 53 | 104 | 13 | 0.03 | ---- | 47 | ---- | 0.47 | 382 | 0 |
| | 114N66W15CDDD1 | 118.7 | 2000 | 1272 | 94 | 318 | 349 | 16 | 13 | 400 | 26 | 0.03 | ---- | 160 | ---- | 1.52 | 500 | 10 |
| * | 114N67W35AAAA | 105.6 | 908 | 582 | 190 | 123 | 150 | 30 | 28 | 141 | 9 | 0.07 | 0.17 | 130 | 0.07 | (0.20 | 180 | 0 |
| | 114N70W35CCCC | 238.1 | 3100 | 1996 | 86 | 736 | 761 | 18 | 10 | 790 | 21 | 0.30 | ---- | 520 | ---- | 2.82 | 270 | 34 |
| | 115N66W11DAAA2 | 95.9 | 560 | 380 | 119 | 220 | 268 | 28 | 12 | 69 | 14 | 0.03 | ---- | 6 | ---- | 0.62 | 59 | 0 |
| | 115N66W21BBBB2 | 125.6 | 1950 | 1236 | 91 | 464 | 469 | 20 | 10 | 392 | 23 | 0.05 | ---- | 160 | ---- | 0.16 | 357 | 24 |
| | 115N66W31BCBB | 23.2 | 1350 | 856 | 539 | 158 | 193 | 112 | 63 | 52 | 12 | 0.02 | ---- | 90 | ---- | 0.03 | 360 | 0 |
| | 115N67W18DDDD | 142.8 | 1591 | 1144 | 295 | 376 | 459 | 57 | 37 | 277 | 16 | 0.11 | ---- | 68 | ---- | 1.75 | 374 | -- |
| | 115N67W25AAAA | 105.6 | 1400 | 924 | 61 | 496 | 547 | 13 | 7 | 314 | 16 | 0.15 | ---- | 7 | ---- | 1.47 | 208 | 14 |
| | 115N67W36CDDC | 39.8 | 850 | 516 | 219 | 212 | 259 | 40 | 29 | 96 | 20 | 0.00 | ---- | 23 | ---- | 1.19 | 178 | 0 |

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| + 115N70W 4AAAA1 | 105.2 | 448 | 324 | 260 | --- | --- | 64 | 24 | 16 | 5 | 0.00 | ---- | 10 | ---- | ------ | 19 | -- |
| 116N67W12DADD | 19.9 | 24594 | 28872 | 7925 | 380 | 464 | 667 | 1520 | 6700 | 38 | 74.00 | ---- | 4100 | ---- | 0.05 | 16500 | -- |
| 116N67W25DDDD | 39.7 | 1700 | 1132 | 273 | 218 | 266 | 58 | 31 | 264 | 21 | 0.08 | ---- | 95 | ---- | 1.18 | 531 | 0 |
| 116N67W34DDDD | 78.5 | 850 | 644 | 369 | 184 | 225 | 52 | 58 | 55 | 12 | 0.05 | ---- | 6 | ---- | 0.53 | 315 | 0 |
| **HYDE COUNTY** | | | | | | | | | | | | | | | | | |
| **BURIED OUTWASH** | | | | | | | | | | | | | | | | | |
| 112N72W23DDDD | 53.8 | 950 | 564 | 106 | 268 | 288 | 31 | 7 | 143 | 12 | 0.19 | ---- | 36 | ---- | 1.48 | 94 | 10 |
| 114N72W25BBBB1 | 278.6 | 2150 | 1280 | 83 | 580 | 669 | 20 | 8 | 440 | 25 | 0.30 | ---- | 255 | ---- | 1.09 | 196 | 10 |
| 115N71W 1BBCC | 65.4 | 380 | 200 | 155 | 150 | 183 | 29 | 20 | 11 | 7 | 0.11 | ---- | 5 | ---- | 0.20 | 38 | 0 |
| * 115N72W 7DDDD | 143.2 | 788 | 588 | 194 | 389 | 474 | 53 | 15 | 139 | 5 | 0.36 | 0.12 | <2 | 0.30 | <0.20 | 88 | 0 |
| 115N72W16AAAA | 145.0 | 1442 | 1176 | 460 | 300 | 366 | 96 | 53 | 195 | 12 | 1.64 | ---- | 4 | ---- | 0.95 | 484 | -- |
| **HUGHES COUNTY** | | | | | | | | | | | | | | | | | |
| **BURIED OUTWASH** | | | | | | | | | | | | | | | | | |
| 111N77W14AAAA | 306.8 | 2250 | 1432 | 48 | 690 | 569 | 16 | 2 | 560 | 10 | ------ | ---- | 360 | ---- | 3.04 | 124 | 67 |
| 111N78W20BBBA | 140.3 | 1850 | 1088 | 72 | 444 | 473 | 24 | 3 | 400 | 7 | ------ | ---- | 270 | ---- | 0.95 | 138 | 17 |
| 112N75W14BBBB2 | 118.5 | 950 | 832 | 531 | 180 | 220 | 140 | 44 | 47 | 8 | 0.06 | ---- | 28 | ---- | 0.44 | 390 | 0 |
| 112N78W17CCCC | 276.1 | 1400 | 936 | 185 | 504 | 576 | 28 | 28 | 266 | 20 | 0.05 | ---- | 12 | ---- | 0.00 | 278 | 10 |
| 112N79W19BBBB | 168.7 | 1250 | 824 | 160 | 464 | 547 | 31 | 20 | 235 | 21 | 0.15 | ---- | 10 | ---- | 0.00 | 208 | 5 |
| **SPINK COUNTY** | | | | | | | | | | | | | | | | | |
| **BURIED OUTWASH** | | | | | | | | | | | | | | | | | |
| 114N62W 2DDDD | 80.4 | 1550 | 1068 | 224 | 258 | 315 | 42 | 29 | 254 | 14 | 0.26 | ---- | 38 | ---- | 2.53 | 445 | 0 |
| 114N62W16CCCC | 45.3 | 1650 | 984 | 675 | 132 | 161 | 160 | 67 | 73 | 15 | 0.72 | ---- | 120 | ---- | 1.00 | 520 | 0 |
| 114N62W19CCCC | 45.5 | 1500 | 1068 | 686 | 160 | 195 | 151 | 75 | 56 | 20 | 0.98 | ---- | 30 | ---- | 1.00 | 600 | 0 |
| 114N62W22AAAA | 72.2 | 650 | 448 | 181 | 156 | 190 | 51 | 13 | 74 | 6 | 0.26 | ---- | 27 | ---- | 0.70 | 135 | 0 |
| 114N62W24DDDD | 65.5 | 1050 | 704 | 301 | 128 | 156 | 76 | 27 | 100 | 10 | 0.13 | ---- | 32 | ---- | 1.04 | 325 | 0 |
| 114N62W33CCCC | 61.9 | 1000 | 728 | 397 | 135 | 165 | 88 | 43 | 59 | 12 | 0.68 | ---- | 36 | ---- | 0.50 | 325 | 0 |
| 114N63W 5CCCC | 85.7 | 2300 | 1608 | 300 | 244 | 298 | 64 | 34 | 390 | 27 | 0.08 | ---- | 165 | ---- | 2.60 | 680 | 0 |
| 114N63W15AAAA | 66.1 | 1300 | 1032 | 584 | 140 | 171 | 115 | 72 | 51 | 16 | 0.66 | ---- | 10 | ---- | 1.09 | 500 | 0 |
| 114N63W20BBBB | 99.8 | 1950 | 1668 | 948 | 112 | 137 | 195 | 112 | 70 | 17 | 0.69 | ---- | 6 | ---- | 1.87 | 1000 | 0 |
| 114N63W21DDDD2 | 65.3 | 2050 | 1732 | 834 | 142 | 173 | 169 | 100 | 142 | 24 | 0.45 | ---- | 9 | ---- | 2.05 | 950 | 0 |

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 114N64W15AAAA | 90.5 | 950 | 812 | 249 | 212 | 259 | 52 | 29 | 134 | 18 | 0.51 | ---- | 26 | ---- | 1.08 | 312 | 0 |
| 114N64W16BBBB | 84.1 | 1000 | 636 | 236 | 170 | 207 | 40 | 33 | 96 | 18 | 0.12 | ---- | 22 | ---- | 1.10 | 262 | 0 |
| 114N64W16DDDD | 63.3 | 750 | 436 | 211 | 148 | 181 | 35 | 30 | 56 | 17 | 0.00 | ---- | 10 | ---- | 0.00 | 175 | 0 |
| 114N64W22DDDD | 105.6 | 650 | 356 | 169 | 88 | 107 | 28 | 24 | 37 | 10 | 0.19 | ---- | 9 | ---- | 0.65 | 135 | 0 |
| 114N64W25BBBB1 | 72.5 | 1100 | 820 | 460 | 222 | 271 | 115 | 42 | 41 | 17 | 0.21 | ---- | 4 | ---- | 0.84 | 355 | 0 |
| 114N64W29AAAD | 95.5 | 1750 | 1372 | 559 | 119 | 145 | 133 | 55 | 175 | 22 | 0.06 | ---- | 15 | ---- | 1.14 | 738 | 0 |
| 115N62W14DDDD | 85.5 | 1500 | 892 | 106 | 448 | 469 | 11 | 19 | 293 | 21 | 0.00 | ---- | 12 | ---- | 1.60 | 300 | 19 |
| 115N62W33CDDD | 65.7 | 2600 | 2164 | 739 | 216 | 264 | 85 | 128 | 335 | 20 | 0.18 | ---- | 40 | ---- | 2.88 | 1200 | 0 |
| 115N62W35BBBB | 105.8 | 1280 | 848 | 505 | 412 | 503 | 133 | 42 | 126 | 8 | 1.56 | ---- | 28 | ---- | 0.53 | 317 | -- |
| 115N63W 1DDDD | 52.5 | 700 | 436 | 91 | 326 | 320 | 15 | 13 | 133 | 16 | 0.24 | ---- | 3 | ---- | 1.47 | 61 | 19 |
| 115N63W 7CCDC1 | 58.7 | 1150 | 938 | 492 | 294 | --- | 108 | 54 | 360 | 14 | 1.56 | ---- | 41 | ---- | 0.28 | 334 | -- |
| 115N63W 7CCDC2 | 45.7 | 1250 | 908 | 617 | 172 | 210 | 153 | 57 | 38 | 8 | 0.02 | ---- | 38 | ---- | 0.00 | 434 | 0 |
| 115N63W12CCCC | 33.1 | 650 | 412 | 307 | 220 | 268 | 72 | 31 | 21 | 5 | 0.02 | ---- | 4 | ---- | 0.23 | 112 | 0 |
| 115N63W14BBBC | 45.8 | 1250 | 896 | 243 | 188 | 229 | 56 | 25 | 191 | 11 | 0.00 | ---- | 42 | ---- | 0.64 | 402 | 0 |
| 115N63W20AAAA | 56.8 | 1050 | 812 | 505 | 168 | 205 | 118 | 51 | 38 | 8 | 0.56 | ---- | 14 | ---- | 0.86 | 400 | 0 |
| 115N63W25BBBB | 46.7 | 950 | 756 | 371 | 136 | 166 | 81 | 41 | 84 | 14 | 0.00 | ---- | 120 | ---- | 0.35 | 275 | 0 |
| 115N63W33DDDD2 | 52.2 | 1450 | 1088 | 489 | 198 | 242 | 92 | 63 | 135 | 20 | 0.42 | ---- | 110 | ---- | 1.53 | 445 | 0 |
| 115N64W 6BBBB | 86.8 | 1250 | 864 | 119 | 277 | 309 | 13 | 21 | 226 | 20 | 0.00 | ---- | 215 | ---- | 1.46 | 116 | 7 |
| 115N64W14CCCB | 65.7 | 600 | 364 | 255 | 170 | 207 | 61 | 25 | 32 | 8 | 0.41 | ---- | 6 | ---- | 0.26 | 144 | 0 |
| 115N64W22CCCC1 | 61.6 | 950 | 652 | 325 | 158 | 193 | 51 | 48 | 94 | 12 | 0.00 | ---- | 10 | ---- | 1.27 | 325 | 0 |
| 115N64W28BBBC2 | 85.5 | 1000 | 692 | 347 | 192 | 234 | 55 | 51 | 61 | 16 | 0.11 | ---- | 21 | ---- | 0.02 | 285 | 0 |
| 115N64W33CCCC | 105.0 | 950 | 808 | 372 | 174 | 212 | 65 | 51 | 94 | 17 | 0.04 | ---- | 72 | ---- | 1.45 | 285 | 0 |
| 115N65W 9CCCC | 67.7 | 1850 | 1280 | 95 | 430 | 476 | 10 | 17 | 385 | 18 | 0.00 | ---- | 145 | ---- | 1.48 | 385 | 12 |
| 115N65W14BBBB | 87.4 | 2150 | 1660 | 263 | 270 | 329 | 56 | 30 | 401 | 19 | 0.03 | ---- | 162 | ---- | 1.10 | 655 | 0 |
| 115N65W19BBCC | 100.3 | 1700 | 1140 | 108 | 444 | 503 | 30 | 8 | 352 | 15 | 0.29 | ---- | 120 | ---- | 1.00 | 277 | 10 |
| 115N65W25AAAD1 | 82.1 | 700 | 436 | 210 | 196 | 239 | 28 | 34 | 59 | 22 | 0.05 | ---- | 26 | ---- | 0.94 | 100 | 0 |
| 115N65W26BBBB | 106.8 | 1100 | 724 | 189 | 310 | 378 | 26 | 30 | 163 | 16 | 0.15 | ---- | 64 | ---- | 1.24 | 204 | 0 |
| 115N65W29AAAA1 | 125.5 | 1700 | 1180 | 112 | 446 | 525 | 25 | 12 | 337 | 15 | 0.04 | ---- | 140 | ---- | 1.16 | 262 | 5 |
| 115N65W35ABAB | 112.1 | 850 | 668 | 289 | 172 | 210 | 101 | 9 | 75 | 14 | 0.27 | ---- | 32 | ---- | 0.00 | 237 | -- |
| 115N65W36DDDD | 125.7 | 590 | 384 | 202 | 152 | 185 | 53 | 17 | 32 | 12 | 0.08 | ---- | 4 | ---- | 0.00 | 124 | 0 |
| 116N62W10ABBB | 34.2 | 3400 | 3148 | 1861 | 216 | 264 | 536 | 127 | 213 | 27 | 0.06 | ---- | 308 | ---- | 0.49 | 1675 | 0 |
| 116N62W11BBBB | 105.0 | 2600 | 2144 | 895 | 312 | 381 | 256 | 62 | 245 | 18 | 0.25 | ---- | 71 | ---- | 0.14 | 1000 | 0 |
| 116N62W13BAAA2 | 49.4 | 2500 | 2000 | 688 | 344 | 420 | 180 | 58 | 364 | 13 | 0.44 | ---- | 95 | ---- | 0.00 | 975 | 0 |
| 116N62W25AAAA | 66.0 | 2400 | 1752 | 411 | 250 | 305 | 97 | 41 | 382 | 29 | 0.52 | ---- | 145 | ---- | 2.60 | 812 | 0 |
| 116N62W34DDDD | 82.4 | 1182 | 732 | 293 | 388 | 473 | 68 | 30 | 160 | 11 | 1.41 | ---- | 42 | ---- | 1.13 | 212 | -- |
| 116N63W 2BABA2 | 85.8 | 2250 | 1972 | 1197 | 92 | 112 | 344 | 82 | 83 | 19 | 0.17 | ---- | 128 | ---- | 1.14 | 1100 | 0 |
| 116N63W27AADA | 39.5 | 3700 | 3644 | 2109 | 136 | 166 | 480 | 221 | 193 | 27 | 0.52 | ---- | 54 | ---- | 0.59 | 2250 | 0 |

SULLY COUNTY

BURIED OUTWASH

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 113N74W 9DAAA | 125.0 | 1150 | 840 | 437 | 200 | 244 | 96 | 48 | 114 | 14 | 1.62 | ---- | 34 | ---- | 0.01 | 425 | 0 |

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | BEADLE COUNTY | | | | | | | | | | |
| | | | | | | | DAKOTA FORMATION | | | | | | | | | | |
| + 109N61W 6BAAC | ----- | 2760 | 2050 | 580 | --- | --- | 160 | 40 | 410 | 19 | ---- | ---- | 130 | 2.7 | ---- | 1100 | -- |
| + 109N62W 4AAAD2 | ----- | 2830 | 2240 | 930 | --- | --- | 260 | 66 | 320 | 19 | ---- | ---- | 210 | 2.4 | ---- | 1100 | -- |
| + 109N62W17DDAA2 | ----- | 2000 | 1330 | 380 | --- | --- | 28 | 75 | 280 | 50 | ---- | ---- | 110 | ---- | ---- | 470 | -- |
| + 110N62W 1DBAB | ----- | 2700 | 2030 | 580 | --- | --- | 160 | 41 | 410 | 21 | 0.19 | ---- | 130 | 2.4 | ---- | 1100 | -- |
| + 110N62W 7BDBC | ----- | 2730 | 2060 | 620 | --- | --- | 170 | 49 | 410 | 18 | ---- | ---- | 140 | 1.7 | ---- | 1100 | -- |
| + 110N62W 9B | ----- | 2350 | 2390 | 1300 | --- | --- | 400 | 67 | 160 | 23 | 0.00 | ---- | 140 | ---- | ---- | ---- | -- |
| + 110N64W 2BAAA | ----- | 2690 | 2050 | 660 | --- | --- | 180 | 53 | 360 | 18 | ---- | ---- | 130 | 1.8 | ---- | 1100 | -- |
| + 110N64W32AADD | ----- | 2780 | 2260 | 980 | --- | --- | 280 | 68 | 300 | 18 | ---- | ---- | 160 | 2.3 | ---- | 1200 | -- |
| + 110N65W16DCDC2 | ----- | 2740 | 2040 | 580 | --- | --- | 160 | 41 | 400 | 16 | ---- | ---- | 130 | 1.9 | ---- | 1200 | -- |
| + 111N61W12DADD | ----- | 2860 | 2040 | 230 | --- | --- | 59 | 20 | 550 | 14 | ---- | ---- | 91 | 2.4 | ---- | 1100 | -- |
| + 111N63W24CDCD | ----- | 2690 | 2080 | 750 | --- | --- | 210 | 53 | 350 | 19 | ---- | ---- | 130 | 2.1 | ---- | 1100 | -- |
| + 111N64W24BBCD | ----- | 2400 | 2250 | 1100 | --- | --- | 310 | 72 | 210 | 20 | 1.70 | ---- | 120 | 2.6 | ---- | 1200 | -- |
| + 111N64W24BBCD2 | ----- | 2400 | 2240 | 1100 | --- | --- | 310 | 71 | 210 | 21 | 0.60 | ---- | 120 | 2.6 | ---- | 1300 | -- |
| + 111N64W24BBCD3 | ----- | 2380 | 2240 | 1100 | --- | --- | 310 | 71 | 210 | 20 | 1.70 | ---- | 120 | 2.5 | ---- | 1200 | -- |
| + 111N64W24BBCD4 | ----- | 2810 | 2050 | 500 | --- | --- | 140 | 39 | 460 | 17 | ---- | ---- | 160 | 2.6 | ---- | 1100 | -- |
| + 111N64W24BBCD5 | ----- | ---- | 2270 | 1100 | --- | --- | 310 | 77 | 200 | 21 | 1.80 | ---- | 130 | 2.3 | ---- | 1300 | -- |
| + 111N65W 1CCCD | ----- | 2950 | 2230 | 770 | --- | --- | 220 | 55 | 380 | 17 | ---- | ---- | 230 | 2.6 | ---- | 1100 | -- |
| + 111N65W 6BBBC | ----- | ---- | 2170 | 940 | --- | --- | 260 | 73 | --- | -- | ---- | ---- | 30 | 3.0 | ---- | 1200 | -- |
| + 111N65W 6BCAC | ----- | ---- | 2210 | 830 | --- | --- | 240 | 56 | 350 | 17 | 1.60 | ---- | 150 | 2.7 | ---- | 1200 | -- |
| + 111N65W31BBBC | ----- | 3370 | 2260 | 170 | --- | --- | 45 | 14 | 720 | 11 | ---- | ---- | 330 | 2.2 | ---- | 990 | -- |
| + 112N61W14CDCD | ----- | 2760 | 2190 | 820 | --- | --- | 230 | 58 | 330 | 19 | ---- | ---- | 120 | 1.7 | ---- | 1200 | -- |
| + 112N61W14CDCD2 | ----- | 2950 | 1970 | 50 | --- | --- | 16 | 2 | 650 | 9 | ---- | ---- | 180 | 1.9 | ---- | 980 | -- |
| + 112N62W14DADD | ----- | 2690 | 2130 | 730 | --- | --- | 200 | 59 | 350 | 23 | ---- | ---- | 94 | 2.0 | ---- | 1200 | -- |
| + 112N63W24CAAB | ----- | 2650 | 2250 | 1100 | --- | --- | 330 | 76 | 180 | 23 | 0.04 | ---- | 120 | 2.5 | ---- | 1200 | -- |
| + 112N63W24CAAB2 | ----- | ---- | 2220 | 1100 | --- | --- | 330 | 78 | 190 | 23 | 5.80 | ---- | 120 | 2.6 | ---- | 1300 | -- |
| + 113N63W 4BADD | ----- | 2460 | 2230 | 1100 | --- | --- | 330 | 77 | 170 | 23 | 1.40 | ---- | 97 | 2.3 | ---- | 1300 | -- |
| + 113N63W 4BADD2 | ----- | ---- | 2290 | 1300 | --- | --- | 370 | 83 | --- | -- | 1.80 | ---- | 99 | 2.7 | ---- | 1300 | -- |
| + 113N63W31CCBB2 | ----- | 2630 | 2160 | 980 | --- | --- | 280 | 71 | 250 | 23 | ---- | ---- | 110 | 2.0 | ---- | 1200 | -- |
| + 113N65W 4BDCA | ----- | 2510 | 2210 | 1300 | --- | --- | 370 | 85 | 150 | 22 | ---- | ---- | 98 | 2.7 | ---- | 1300 | -- |
| + 113N65W16DDCD | ----- | 2570 | 2240 | 1300 | --- | --- | 460 | 27 | 170 | 21 | ---- | ---- | 100 | 2.9 | ---- | 1300 | -- |
| | | | | | | | FAULK COUNTY | | | | | | | | | | |
| | | | | | | | DAKOTA FORMATION | | | | | | | | | | |
| + 117N66W31ACDD | ------ | 2810 | 1960 | 23 | --- | --- | 6 | 2 | 690 | 8 | ------ | ---- | 330 | 3.1 | ---- | 580 | -- |
| + 117N66W31DBC | ------ | ---- | 2070 | 23 | --- | --- | 6 | 2 | 700 | 9 | 0.80 | ---- | 330 | 3.4 | ---- | 600 | -- |
| + 117N66W36CDDD | ------ | ---- | 1890 | 54 | --- | --- | 5 | 10 | 660 | 6 | <0.02 | ---- | 260 | 4.0 | ---- | 620 | -- |
| + 118N67W16DBCC | ------ | 3190 | 2020 | 73 | --- | --- | 18 | 7 | 710 | 12 | ------ | ---- | 410 | 2.7 | ---- | 520 | -- |
| + 118N68W23BCBB1 | 1524.0 | 2310 | 2110 | 1200 | --- | --- | 340 | 78 | 130 | 31 | ------ | ---- | 47 | 2.6 | ---- | 1300 | -- |

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| + 118N69W15BCCD | 1600.0 | 2330 | 2180 | 1300 | --- | --- | 370 | 86 | 120 | 26 | ------ | ---- | 49 | 2.9 | ---- | 1300 | -- |
| + 119N66W11ABAA | ------ | 2700 | 1780 | 250 | --- | --- | 69 | 20 | 480 | 22 | ------ | ---- | 260 | 2.0 | ---- | 740 | -- |
| HAND COUNTY | | | | | | | | | | | | | | | | | |
| DAKOTA FORMATION | | | | | | | | | | | | | | | | | |
| + 111N66W34BCB2 | ----- | 3630 | 2440 | 510 | --- | --- | 120 | 52 | 610 | 18 | ------ | ---- | 530 | 2.0 | ---- | 920 | -- |
| + 112N68W10ACCB | ----- | ---- | 2080 | 530 | --- | --- | 140 | 44 | 430 | 19 | 0.60 | ---- | 88 | 1.8 | ---- | 1100 | -- |
| + 112N68W10DCD | ----- | 2600 | 2160 | 740 | --- | --- | 200 | 56 | 350 | 19 | 1.50 | ---- | 88 | 2.1 | ---- | 1100 | -- |
| + 113N66W25DADA2 | ----- | 2540 | 2270 | 1400 | --- | --- | 390 | 93 | 170 | 22 | 2.00 | ---- | 110 | 0.3 | ---- | 1300 | -- |
| + 113N69W 6DDBD | ----- | 2410 | 1630 | 240 | --- | --- | 62 | 20 | 440 | 14 | 0.03 | ---- | 190 | 2.3 | ---- | 730 | -- |
| + 116N67W31DDDB | ----- | 2560 | 1690 | 180 | --- | --- | 31 | 25 | 520 | 12 | ------ | ---- | 270 | 2.4 | ---- | 610 | -- |
| HYDE COUNTY | | | | | | | | | | | | | | | | | |
| DAKOTA FORMATION | | | | | | | | | | | | | | | | | |
| + 114N72W19CDD | ----- | 2520 | 1580 | 140 | --- | --- | 37 | 12 | 490 | 14 | ------ | ---- | 350 | 2.0 | ---- | 450 | -- |
| HUGHES COUNTY | | | | | | | | | | | | | | | | | |
| DAKOTA FORMATION | | | | | | | | | | | | | | | | | |
| + 111N78W15BDAD | 1400 | 3610 | 3610 | 460 | --- | --- | 110 | 43 | 590 | 23 | ------ | ---- | 830 | 2.5 | ---- | 290 | -- |
| + 112N74W 4DC | ---- | 3020 | 1720 | 51 | --- | --- | 12 | 5 | 610 | 12 | ------ | ---- | 510 | 4.5 | 0.00 | 250 | -- |
| + 112N74W 8DAAA | ---- | ---- | 1270 | 390 | --- | --- | 130 | 15 | 460 | -- | 2.60 | ---- | 360 | ---- | ---- | 300 | -- |
| + 112N74W21CBBB | ---- | ---- | 1760 | 110 | --- | --- | 20 | 15 | 750 | -- | 1.00 | ---- | 660 | ---- | ---- | 270 | -- |
| SPINK COUNTY | | | | | | | | | | | | | | | | | |
| DAKOTA FORMATION | | | | | | | | | | | | | | | | | |
| + 114N64W22BB | ----- | 3140 | 2230 | 240 | --- | --- | 66 | 18 | 640 | 22 | ------ | ---- | 190 | 2.8 | ---- | 1200 | -- |
| + 115N62W18CB | ----- | 2930 | 1980 | 110 | --- | --- | 28 | 9 | 630 | 20 | ------ | ---- | 210 | 3.2 | ---- | 930 | -- |

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| + 115N64W27DDAB | ----- | ---- | 2140 | 420 | --- | --- | 120 | 30 | 520 | 17 | 1.20 | ---- | 130 | 2.0 | ---- | 1200 | -- |
| + 115N64W27DDAC | ----- | 2860 | 2110 | 360 | --- | --- | 100 | 27 | 510 | 17 | 0.90 | ---- | 140 | 1.8 | ---- | 1100 | -- |
| + 115N65W 4ADDC | ----- | 2780 | 2210 | 810 | --- | --- | 230 | 58 | 320 | 22 | ------ | 0.67 | 100 | 1.4 | ---- | 1200 | -- |
| + 116N62W 5 | ----- | ---- | 2060 | 120 | --- | --- | 32 | 9 | 630 | 13 | 0.40 | ---- | 200 | 1.8 | ---- | 960 | -- |
| + 116N62W 5DDCC | ----- | 3110 | 2100 | 100 | --- | --- | 27 | 8 | 650 | 12 | ------ | 0.20 | 190 | 1.9 | ---- | 1000 | -- |
| + 116N62W 8AA | ----- | ---- | 2090 | 90 | --- | --- | 24 | 8 | 660 | 17 | 1.40 | ---- | 210 | 2.3 | ---- | 1000 | -- |
| + 116N64W 3BC | ----- | ---- | 2080 | 150 | --- | --- | 53 | 4 | 480 | -- | 0.24 | ---- | 150 | 2.8 | ---- | 1000 | -- |
| + 116N64W 9AAAC | ----- | ---- | 2220 | 110 | --- | --- | 33 | 7 | 700 | 11 | 1.40 | ---- | 200 | 3.0 | ---- | 1100 | -- |
| + 116N64W10BBBD | ----- | ---- | 2120 | 150 | --- | --- | 39 | 12 | 660 | 13 | 0.40 | ---- | 200 | 2.4 | ---- | 1000 | -- |
| + 116N64W21AD | ----- | ---- | 2110 | 310 | --- | --- | 76 | 28 | 460 | -- | ------ | ---- | 160 | 2.8 | ---- | 1100 | -- |

HAND COUNTY

WEATHERED TILL WELLS

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| * 110N68W22AABB1 | 13 | 1150 | 738 | 520 | 428 | 522 | 55 | 93 | 54 | 3.5 | <0.05 | <0.05 | 6 | 1.58 | 0.90 | 1836 | 0 |
| * 110N68W22AABB2 | 23 | 3840 | 4405 | 2701 | 536 | 653 | 475 | 368 | 183 | 18.6 | 0.28 | 5.42 | 5 | 0.33 | ≤0.20 | 2440 | 0 |
| * 112N70W14CCCC1 | 13 | 8640 | 10135 | 5095 | 434 | 529 | 434 | 974 | 1020 | 12.4 | <0.05 | 0.40 | 790 | 0.08 | 3.70 | 5400 | 0 |
| * 112N70W14CCCC2 | 23 | 10300 | 10730 | 5111 | 473 | 577 | 485 | 947 | 1235 | 27.0 | <0.05 | 1.77 | 1500 | 0.23 | 0.30 | 5107 | 0 |
| * 114N66W14CCCC | 13 | 9411 | 7775 | 3440 | 366 | 446 | 510 | 526 | 1140 | 21.0 | <0.05 | 0.16 | 1310 | 0.46 | 1.40 | 3810 | 0 |
| * 114N66W15CDDD | 15 | 1994 | 1685 | 1071 | 326 | 397 | 152 | 168 | 66 | 5.5 | <0.05 | <0.05 | 9 | 0.73 | 1.20 | 815 | 0 |
| * 114N67W35AAAA | 13 | 8030 | 9365 | 4881 | 334 | 407 | 530 | 864 | 905 | 18.1 | <0.57 | 0.57 | 400 | 0.34 | <0.20 | 6060 | 0 |
| * 114N70W 2BBBB | 23 | 1070 | 653 | 385 | 432 | 527 | 90 | 39 | 81 | 7.1 | ≤0.05 | <0.05 | 3 | 0.24 | <0.20 | 134 | 0 |
| * 115N67W18DDDD | 16 | 6550 | 7135 | 3812 | 406 | 495 | 438 | 660 | 578 | 18.0 | <0.05 | <0.05 | 125 | 0.37 | 1.60 | 4450 | 0 |
| * 115N69W15BBBB1 | 20 | 8220 | 7135 | 3080 | 390 | 475 | 508 | 440 | 1013 | 25.0 | 0.20 | ≤0.05 | 870 | 0.13 | 8.90 | 3450 | 0 |
| * 115N69W15BBBB2 | 28 | 6690 | 5465 | 2496 | 348 | 424 | 528 | 286 | 739 | 24.6 | <0.05 | 3.80 | 630 | 0.03 | 1.30 | 2550 | 0 |
| * 115N69W18AAAA1 | 13 | 3220 | 2970 | 1995 | 182 | 222 | 522 | 168 | 77 | 11.3 | <0.05 | ≤0.05 | 7 | 0.28 | ≤0.20 | 1990 | 0 |
| * 115N69W18AAAA2 | 18 | 2890 | 2735 | 2014 | 229 | 279 | 612 | 118 | 110 | 12.5 | <0.05 | <0.05 | 8 | 0.19 | <0.20 | 1800 | 0 |
| * 115N70W14AAAA | 18 | 3490 | 3130 | 1921 | 529 | 645 | 367 | 244 | 210 | 9.0 | <0.05 | 0.06 | 40 | 0.23 | 1.70 | 1750 | 0 |
| * 115N70W17BBBB | 13 | 2250 | 1690 | 1103 | 552 | 673 | 163 | 169 | 110 | 5.1 | <0.05 | 0.36 | 21 | 0.27 | 2.00 | 690 | 0 |

HYDE COUNTY

WEATHERED TILL WELLS

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| * 113N72W20BBBB1 | 13 | 2083 | 1555 | 1045 | 520 | 634 | 143 | 167 | 123 | 2.8 | 0.26 | 0.24 | 14 | 0.46 | <0.20 | 761 | 0 |
| * 113N72W20BBBB2 | 23 | 2447 | 1975 | 1352 | 510 | 622 | 261 | 170 | 79 | 7.1 | 0.32 | 2.16 | 9 | 0.26 | <0.20 | 1020 | 0 |
| * 113N73W16DDDD1 | 13 | 1250 | 888 | 570 | 403 | 491 | 111 | 71 | 51 | 14.2 | 0.09 | 0.78 | 4 | 0.57 | <0.20 | 307 | 0 |
| * 113N73W16DDDD2 | 23 | 3690 | 3800 | 2194 | 459 | 560 | 435 | 269 | 204 | 23.0 | 0.06 | 10.48 | 5 | 0.22 | <0.20 | 2050 | 0 |
| * 114N72W36CCCC1 | 13 | 9913 | 9360 | 3875 | 341 | 416 | 414 | 690 | 1540 | 22.0 | 0.08 | 0.17 | 395 | 0.30 | 35.50 | 6620 | 0 |
| * 114N72W36CCCC2 | 28 | 7152 | 6445 | 2784 | 558 | 680 | 424 | 419 | 963 | 25.4 | <0.05 | 0.21 | 227 | 0.17 | 23.00 | 3850 | 0 |
| * 114N73W 3CCCC | 13 | 8474 | 13420 | 8642 | 389 | 474 | 550 | 1765 | 605 | 27.0 | <0.05 | 0.15 | 71 | 1.29 | 2.10 | 9380 | 0 |
| * 115N71W13BBBB1 | 18 | 6537 | 6840 | 3592 | 616 | 751 | 416 | 620 | 745 | 13.6 | <0.05 | 0.11 | 113 | 0.32 | 6.40 | 4250 | 0 |

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| * 115N71W13BBBB2 | 33 | 4545 | 3990 | 1907 | 421 | 513 | 467 | 180 | 469 | 17.2 | 0.06 | 0.32 | 78 | 0.37 | <0.20 | 2250 | 0 |
| * 115N71W15BBBB1 | 18 | 8783 | 6785 | 2609 | 352 | 429 | 405 | 388 | 1090 | 22.6 | <0.05 | 0.46 | 295 | 0.42 | 2.10 | 4280 | 0 |
| * 115N71W15BBBB2 | 28 | 6274 | 4845 | 2004 | 518 | 631 | 443 | 218 | 712 | 21.2 | <0.05 | <0.05 | 180 | 0.28 | ≤0.20 | 2750 | 0 |
| * 115N71W15BBBB3 | 48 | 5019 | 4540 | 1959 | 528 | 644 | 473 | 189 | 646 | 20.8 | <0.05 | 1.21 | 180 | 0.22 | <0.20 | 2600 | 0 |
| * 115N72W 7DDDD | 13 | 729 | 536 | 438 | 330 | 402 | 111 | 39 | 11 | 4.0 | <0.05 | <0.05 | 4 | 0.33 | 0.80 | 132 | 0 |
| * 115N72W10CCCC1 | 15 | 6777 | 7332 | 3810 | 320 | 390 | 388 | 690 | 633 | 14.4 | <0.05 | <0.05 | 5 | 0.42 | 0.72 | 4810 | 0 |
| * 115N72W10CCCC2 | 28 | 7240 | 7255 | 3573 | 501 | 611 | 400 | 625 | 925 | 28.0 | <0.05 | <0.05 | 10 | 0.36 | 0.48 | 5380 | 0 |
| HAND COUNTY | | | | | | | | | | | | | | | | | |
| TRANSITION ZONE WELLS | | | | | | | | | | | | | | | | | |
| * 114N66W15CDDD | 18 | 1162 | 885 | 548 | 308 | 375 | 142 | 47 | 44 | 9.7 | 0.77 | 1.05 | 4 | 0.24 | <0.20 | 340 | 0 |
| * 114N67W35AAAA1 | 18 | 4651 | 3355 | 1750 | 381 | 464 | 404 | 180 | 291 | 15.0 | 0.18 | 4.17 | 430 | 0.24 | <0.20 | 1210 | 0 |
| * 114N67W35AAAA2 | 26 | 5144 | 4590 | 2619 | 359 | 438 | 622 | 258 | 316 | 19.1 | <0.05 | 2.87 | 368 | 0.28 | <0.20 | 2320 | 0 |
| * 115N67W18DDDD | 23 | 5106 | 4795 | 2477 | 388 | 473 | 522 | 285 | 500 | 20.7 | 0.07 | 0.69 | 429 | 0.16 | <0.20 | 2690 | 0 |
| * 115N69W13BBBB | 18 | 1510 | 940 | 682 | 452 | 551 | 156 | 71 | 56 | 10.9 | 0.07 | 0.70 | 38 | 0.25 | <0.20 | 323 | 0 |
| * 115N69W18AAAA | 28 | 3110 | 2715 | 1804 | 407 | 496 | 500 | 135 | 77 | 14.9 | <0.05 | 4.71 | 3 | 0.19 | <0.20 | 1470 | 0 |
| HYDE COUNTY | | | | | | | | | | | | | | | | | |
| TRANSITION ZONE WELLS | | | | | | | | | | | | | | | | | |
| * 115N72W 7DDDD | 18 | 618 | 428 | 350 | 306 | 373 | 89 | 31 | 16 | 5.6 | <0.05 | 0.37 | <2 | 0.26 | <0.20 | 94 | 0 |
| HAND COUNTY | | | | | | | | | | | | | | | | | |
| UNWEATHERED TILL WELLS | | | | | | | | | | | | | | | | | |
| * 110N68W22AABB | 33 | 5000 | 4605 | 2596 | 669 | 816 | 522 | 314 | 342 | 24.2 | 0.36 | 3.27 | 7 | 0.14 | <0.20 | 2560 | 0 |
| * 112N70W14CCCC | 33 | 9040 | 7410 | 2935 | 547 | 667 | 585 | 358 | 1205 | 30.0 | 0.33 | 3.61 | 1380 | 0.04 | <0.20 | 3155 | 0 |
| * 114N66W14CCCC1 | 23 | 7220 | 6055 | 2223 | 473 | 577 | 473 | 253 | 1052 | 21.0 | 2.84 | 3.53 | 1100 | 0.24 | 0.50 | 2540 | 0 |
| * 114N66W14CCCC2 | 38 | 4660 | 4015 | 1344 | 491 | 599 | 332 | 125 | 780 | 22.5 | <0.05 | 1.97 | 810 | 0.24 | 1.80 | 1240 | 0 |
| * 114N66W14CCCC3 | 53 | 4038 | 2510 | 730 | 484 | 590 | 195 | 59 | 614 | 18.1 | 0.08 | <0.05 | 620 | 0.24 | ≤0.20 | 725 | 0 |
| * 114N66W15CDDD | 33 | 2829 | 2385 | 1163 | 364 | 444 | 215 | 152 | 232 | 11.8 | <0.05 | <0.05 | 15 | 0.35 | <0.20 | 1318 | 0 |
| * 114N67W35AAAA | 33 | 2489 | 1960 | 1248 | 351 | 428 | 330 | 103 | 132 | 12.9 | <0.05 | 2.53 | 186 | 0.12 | <0.20 | 972 | 0 |
| * 114N70W 2BBBB1 | 38 | 2140 | 1495 | 550 | 500 | 610 | 136 | 51 | 274 | 12.2 | <0.05 | <0.05 | 7 | 0.25 | <0.20 | 575 | 0 |
| * 114N70W 2BBBB2 | 53 | 3205 | 2380 | 783 | 467 | 569 | 208 | 64 | 442 | 16.3 | <0.05 | 1.36 | 12 | 0.15 | <0.20 | 1250 | 0 |
| * 115N67W18DDDD | 30 | 6244 | 5660 | 2377 | 243 | 296 | 589 | 220 | 780 | 27.5 | <0.05 | 1.30 | 445 | 0.11 | 2.80 | 3205 | 0 |

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| * 115N69W13BBBB1 | 28 | 1260 | 608 | 626 | 476 | 580 | 147 | 63 | 18 | 8.6 | <0.05 | 1.84 | 19 | 0.17 | <0.20 | 185 | 0 |
| * 115N69W13BBBB2 | 38 | 1380 | 933 | 663 | 576 | 702 | 165 | 61 | 46 | 10.6 | <0.05 | 1.82 | 3 | 0.18 | 1.20 | 225 | 0 |
| * 115N69W15BBBB | 38 | 5680 | 4645 | 1857 | 400 | 488 | 450 | 178 | 711 | 21.5 | ≤0.05 | 2.80 | 560 | 0.11 | <0.20 | 2200 | 0 |
| * 115N69W18AAAA1 | 32 | 3240 | 3360 | 1882 | 309 | 377 | 480 | 166 | 254 | 15.7 | <0.05 | 3.20 | 7 | 0.08 | 1.20 | 2150 | 0 |
| * 115N69W18AAAA2 | 38 | 3625 | 3280 | 1534 | 476 | 569 | 347 | 162 | 420 | 18.0 | <0.05 | 2.65 | 4 | 0.16 | 0.70 | 1980 | 0 |
| * 115N70W 4AAAA1 | 43 | 2641 | 2060 | 846 | 336 | 410 | 225 | 69 | 307 | 15.8 | <0.05 | 2.24 | 50 | 0.17 | 0.70 | 1100 | 0 |
| * 115N70W 4AAAA2 | 18 | 7028 | 7290 | 3364 | 390 | 475 | 465 | 535 | 838 | 21.0 | 1.33 | 5.32 | 137 | 0.49 | <0.20 | 4660 | 0 |
| * 115N70W 4AAAA3 | 28 | 5732 | 5020 | 1576 | 396 | 483 | 374 | 156 | 963 | 22.0 | <0.05 | 0.77 | 92 | 0.21 | 4.90 | 3140 | 0 |
| * 115N70W14AAAA1 | 28 | 2000 | 1273 | 303 | 561 | 684 | 67 | 33 | 348 | 8.6 | <0.05 | ≤0.05 | 14 | 0.20 | 0.30 | 458 | 0 |
| * 115N70W14AAAA2 | 38 | 1690 | 1063 | 202 | 549 | 669 | 53 | 17 | 322 | 8.5 | <0.05 | 0.06 | 17 | 0.30 | 0.50 | 285 | 0 |
| * 115N70W17BBBB1 | 18 | 2980 | 2480 | 1542 | 582 | 709 | 347 | 164 | 145 | 11.6 | 1.32 | 3.43 | 17 | 0.23 | <0.20 | 1140 | 0 |
| * 115N70W17BBBB2 | 28 | 1970 | 2823 | 1589 | 590 | 719 | 389 | 150 | 226 | 15.3 | <0.05 | 2.99 | 13 | 0.34 | <0.20 | 1470 | 0 |
| * 115N70W17BBBB3 | 53 | 2330 | 1678 | 594 | 484 | 590 | 157 | 49 | 342 | 12.2 | <0.05 | 1.10 | 22 | 0.45 | <0.20 | 708 | 0 |

---

HYDE COUNTY

UNWEATHERED TILL WELLS

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| * 113N72W20BBBB | 33 | 1467 | 1115 | 763 | 490 | 597 | 190 | 70 | 61 | 7.2 | ≤0.05 | 1.48 | 5 | 0.15 | <0.20 | 435 | 0 |
| * 113N73W16DDDD | 33 | 4220 | 4100 | 2500 | 759 | 925 | 602 | 242 | 196 | 21.6 | 0.97 | 6.50 | 9 | 0.14 | <0.20 | 2070 | 0 |
| * 114N72W36CCCC1 | 43 | 6776 | 6338 | 2455 | 730 | 890 | 505 | 290 | 1032 | 26.2 | <0.05 | 1.22 | 137 | 0.22 | 1.60 | 3770 | 0 |
| * 114N73W 3CCCC1 | 33 | 4203 | 4628 | 3039 | 628 | 766 | 518 | 424 | 191 | 17.8 | <0.05 | 2.82 | 3 | 0.17 | <0.20 | 2880 | 0 |
| * 114N73W 3CCCC2 | 23 | 4389 | 4655 | 2855 | 333 | 406 | 510 | 384 | 255 | 15.7 | <0.05 | 0.59 | 5 | 0.49 | 2.20 | 3080 | 0 |
| * 114N73W 3CCCC3 | 28 | 4415 | 4690 | 1863 | 410 | 500 | 370 | 228 | 704 | 17.2 | <0.05 | 0.60 | 4 | 0.67 | 2.80 | 3010 | 0 |
| * 115N71W13BBBB | 48 | 3520 | 2915 | 1070 | 516 | 629 | 272 | 95 | 525 | 14.0 | 0.98 | 1.22 | 41 | 0.33 | 0.40 | 1700 | 0 |
| * 115N72W 7DDDD1 | 28 | 830 | 582 | 353 | 319 | 389 | 92 | 30 | 62 | 7.6 | <0.05 | <0.05 | <2 | 0.23 | <0.20 | 184 | 0 |
| * 115N72W 7DDDD2 | 38 | 673 | 434 | 291 | 330 | 402 | 77 | 24 | 47 | 7.3 | <0.05 | <0.05 | ≤2 | 0.22 | <0.20 | 73 | 0 |
| * 115N72W10CCCC | 43 | 6704 | 7910 | 3198 | 706 | 861 | 448 | 505 | 1145 | 28.0 | 0.48 | 2.82 | 25 | 0.31 | <0.20 | 5030 | 0 |

# APPENDIX B

## Glacial till piezometer logs

Piezometer logs in this appendix contain information about the sediment encountered while drilling the borehole and information about construction of the piezometer. The legal location of each piezometer is given in the piezometer logs. The "OTHER WELL NAME" heading in the left-hand column of the piezometer log correlates with the "SITE" heading on the water-level hydrographs in appendix C.

COUNTY: HAND LOCATION: 115N-67W-18DDDD 4
LEGAL LOCATION: SE SE SE SE SEC. 18, T. 115 N., R. 67 W.
LATITUDE: 44.4557 LONGITUDE: 98.5537
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: C. SINGH DRILLER'S LOG:
GEOLOGIST: S. CRAVENS GEOLOGIST'S LOG: X
DATE DRILLED: 08-18-1983 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1448.00 T
TOTAL DRILL HOLE DEPTH: 23 TEST HOLE NUMBER: A2-83-239
WATER RIGHTS WELL: SDGS WELL NAME: A2-83-239
OTHER WELL NAME: CK-HD-2A
BASIN: JAMES AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: PVC, MFG. SCREEN LENGTH: 2.0
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1451.00 T
CASING STICK-UP: 2.50 TOTAL CASING AND SCREEN: 25.4
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160009
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

WASHED CONCRETE SAND AROUND SANDPOINT. SEALED WITH BENTONITE PELLETS. BACKFILLED TO SURFACE WITH BENTONITE.

| | | |
|---|---|---|
| 0 - | 1 | SILT, DARK-BROWN, CLAYEY; DRY (TOPSOIL) |
| 1 - | 23 | CLAY, BROWN, SILTY, SANDY, PEBBLY; MOIST, OXIDIZED (TILL) |

* * * *

COUNTY: HAND                                    LOCATION: 115N-67W-18DDDD 6
LEGAL LOCATION: SE SE SE SE SEC. 18, T. 115 N., R. 67 W.
LATITUDE: 44.4557                                    LONGITUDE: 98.5537
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: L. THOMAS                                    DRILLER'S LOG:
GEOLOGIST: S. CRAVENS                                    GEOLOGIST'S LOG: X
DATE DRILLED: 06-19-1984                    DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1448.00 T
TOTAL DRILL HOLE DEPTH: 16                    TEST HOLE NUMBER: A1-84-135
WATER RIGHTS WELL:                                    SDGS WELL NAME: A1-84-135
OTHER WELL NAME: CK-HD-2A2
BASIN: JAMES                    AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: PVC, MFG.                                    SCREEN LENGTH: 2.5
CASING TYPE: PVC                                    CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1450.00 T
CASING STICK-UP: 2.00                    TOTAL CASING AND SCREEN: 18.7
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160009
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL:                    SINGLE POINT RESISTIVITY:
NATURAL GAMMA:                                    EXTRA:
SAMPLES:

WASHED CONCRETE SAND AROUND SANDPOINT TO WITHIN ONE FOOT OF SURFACE. SEALED WITH BENTONITE AT GROUND SURFACE.

0 - 16 CLAY, BROWN, SILTY, SANDY, PEBBLY; MOIST, OXIDIZED (TILL)

* * * *

COUNTY: HAND LOCATION: 115N-67W-18DDDD 5
LEGAL LOCATION: SE SE SE SE SEC. 18, T. 115 N., R. 67 W.
LATITUDE: 44.4557 LONGITUDE: 98.5537
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: D. TOMHAVE DRILLER'S LOG:
GEOLOGIST: S. CRAVENS GEOLOGIST'S LOG: X
DATE DRILLED: 08-18-1983 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1448.00 T
TOTAL DRILL HOLE DEPTH: 38 TEST HOLE NUMBER: A1-83-199
WATER RIGHTS WELL: SDGS WELL NAME: A1-83-199
OTHER WELL NAME: CK-HD-2B
BASIN: JAMES AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: PVC, MFG. SCREEN LENGTH: 2.0
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1451.00 T
CASING STICK-UP: 2.50 TOTAL CASING AND SCREEN: 39.6
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160009
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

WASHED CONCRETE SAND AROUND SANDPOINT. SEALED WITH BENTONITE PELLETS. BACKFILLED TO SURFACE WITH BENTONITE.

| | | |
|---|---|---|
| 0 - | 2 | SILT, BROWN, CLAYEY; DRY, OXIDIZED (TOPSOIL) |
| 2 - | 19 | CLAY, BROWN, SILTY, SANDY, PEBBLY; MOIST, OXIDIZED (TILL) |
| 19 - | 38 | CLAY, GRAY, SILTY, SANDY, PEBBLY; MOIST, UNOXIDIZED, VERY MOIST AT 28 FEET (TILL) |

* * * *

COUNTY: HAND LOCATION: 115N-67W-18DDDD 7
LEGAL LOCATION: SE SE SE SE SEC. 18, T. 115 N., R. 67 W.
LATITUDE: 44.4557 LONGITUDE: 98.5537
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: L. THOMAS DRILLER'S LOG:
GEOLOGIST: S. CRAVENS GEOLOGIST'S LOG: X
DATE DRILLED: 06-19-1984 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1448.00 T
TOTAL DRILL HOLE DEPTH: 30 TEST HOLE NUMBER: A1-84-134
WATER RIGHTS WELL: SDGS WELL NAME: A1-84-134
OTHER WELL NAME: CK-HD-2B2
BASIN: JAMES AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: PVC, MFG. SCREEN LENGTH: 2.5
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1450.00 T
CASING STICK-UP: 2.00 TOTAL CASING AND SCREEN: 33.2
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160009
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

WASHED CONCRETE SAND AROUND SANDPOINT. SEALED WITH BENTONITE PELLETS. BACKFILLED TO SURFACE WITH BENTONITE.

| | | |
|---|---|---|
| 0 - | 22 | CLAY, BROWN, SILTY, SANDY, PEBBLY; MOIST, OXIDIZED (TILL) |
| 22 - | 30 | CLAY, GRAY, SILTY, SANDY, PEBBLY; MOIST, UNOXIDIZED (TILL) |

* * * *

COUNTY: HAND LOCATION: 115N-70W-04AAAA 2
LEGAL LOCATION: NE NE NE NE SEC. 04, T. 115 N., R. 70 W.
LATITUDE: 44.4832 LONGITUDE: 99.1506
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: M. YESKE DRILLER'S LOG:
GEOLOGIST: S. CRAVENS GEOLOGIST'S LOG: X
DATE DRILLED: 08-24-1983 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1789.00 T
TOTAL DRILL HOLE DEPTH: 18 TEST HOLE NUMBER: A2-83-252
WATER RIGHTS WELL: SDGS WELL NAME: A2-83-252
OTHER WELL NAME: CK-HD-5A
BASIN: JAMES AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: PVC, MFG. SCREEN LENGTH: 2.0
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1792.00 T
CASING STICK-UP: 2.50 TOTAL CASING AND SCREEN: 20.4
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160009
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

WASHED CONCRETE SAND AROUND SANDPOINT. SEALED WITH BENTONITE. BACKFILLED TO SURFACE WITH SAND AND BENTONITE.

| | | |
|---|---|---|
| 0 - | 8 | SILT, LIGHT-BROWN, CLAYEY, SANDY; DRY, OXIDIZED (TILL) |
| 8 - | 13 | CLAY, BROWN, VERY SILTY, SANDY, PEBBLY; MOIST, OXIDIZED (TILL) |
| 13 - | 18 | CLAY, GRAY, VERY SILTY, SANDY, PEBBLY; MOIST, UNOXIDIZED (TILL) |

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COUNTY: HAND LOCATION: 115N-70W-04AAAA 4
LEGAL LOCATION: NE NE NE NE SEC. 04, T. 115 N., R. 70 W.
LATITUDE: 44.4832 LONGITUDE: 99.1506
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: L. THOMAS DRILLER'S LOG: X
GEOLOGIST: S. CRAVENS GEOLOGIST'S LOG:
DATE DRILLED: 06-20-1984 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1789.00 T
TOTAL DRILL HOLE DEPTH: 13 TEST HOLE NUMBER: A1-84-141
WATER RIGHTS WELL: SDGS WELL NAME: A1-84-141
OTHER WELL NAME: CK-HD-5A2
BASIN: JAMES AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: PVC, MFG. SCREEN LENGTH: 2.0
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1791.50 T
CASING STICK-UP: 2.50 TOTAL CASING AND SCREEN: 15.2
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160009
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

WASHED CONCRETE SAND AROUND SANDPOINT TO WITHIN ONE FOOT OF SURFACE. SEALED WITH BENTONITE AT GROUND SURFACE.

0 - 13 CLAY, BROWN, SILTY, SANDY, PEBBLY; MOIST, OXIDIZED (TILL)

* * * *

COUNTY: HAND LOCATION: 115N-70W-04AAAA 3
LEGAL LOCATION: NE NE NE NE SEC. 04, T. 115 N., R. 70 W.
LATITUDE: 44.4832 LONGITUDE: 99.1506
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: T. STACK DRILLER'S LOG:
GEOLOGIST: S. CRAVENS GEOLOGIST'S LOG: X
DATE DRILLED: 08-24-1983 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1789.00 T
TOTAL DRILL HOLE DEPTH: 43 TEST HOLE NUMBER: A1-83-210
WATER RIGHTS WELL: SDGS WELL NAME: A1-83-210
OTHER WELL NAME: CK-HD-5B
BASIN: JAMES AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: PVC, MFG. SCREEN LENGTH: 2.0
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1792.00 T
CASING STICK-UP: 2.75 TOTAL CASING AND SCREEN: 45.7
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160009
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

WASHED CONCRETE SAND AROUND SANDPOINT. SEALED WITH BENTONITE. BACKFILLED TO SURFACE WITH SAND AND BENTONITE.

| | | |
|---|---|---|
| 0 - | 1 | SILT, DARK-BROWN, PEBBLY (TOPSOIL) |
| 1 - | 3 | SILT, LIGHT-BROWN, SANDY, PEBBLY |
| 3 - | 4 | GRAVEL, BROWN, MEDIUM, SANDY |
| 4 - | 17 | CLAY, LIGHT-BROWN, SANDY, PEBBLY; MOIST, OXIDIZED (TILL) |
| 17 - | 43 | CLAY, GRAY, SANDY, PEBBLY; MOIST, UNOXIDIZED, SATURATED AT 22 FEET (TILL) |

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COUNTY: HAND LOCATION: 115N-70W-04AAAA 5
LEGAL LOCATION: NE NE NE NE SEC. 04, T. 115 N., R. 70 W.
LATITUDE: 44.4832 LONGITUDE: 99.1506
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: L. THOMAS DRILLER'S LOG: X
GEOLOGIST: S. CRAVENS GEOLOGIST'S LOG:
DATE DRILLED: 06-20-1984 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1789.00 T
TOTAL DRILL HOLE DEPTH: 30 TEST HOLE NUMBER: A1-84-142
WATER RIGHTS WELL: SDGS WELL NAME: A1-84-142
OTHER WELL NAME: CK-HD-5B2
BASIN: JAMES AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: PVC, MFG. SCREEN LENGTH: 2.0
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1791.50 T
CASING STICK-UP: 2.50 TOTAL CASING AND SCREEN: 30.2
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160009
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

WASHED CONCRETE SAND AROUND SANDPOINT. SEALED WITH BENTONITE PELLETS. BACKFILLED TO SURFACE WITH BENTONITE.

| | | |
|---|---|---|
| 0 - | 19 | CLAY, BROWN, SILTY, SANDY, PEBBLY; MOIST, OXIDIZED (TILL) |
| 19 - | 28 | CLAY, GRAY, SILTY, SANDY, PEBBLY; MOIST, UNOXIDIZED (TILL) |

* * * *

COUNTY: HAND LOCATION: 114N-70W-02BBBB 2
LEGAL LOCATION: NW NW NW NW SEC. 02, T. 114 N., R. 70 W.
LATITUDE: 44.4317 LONGITUDE: 99.1355
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: K. THOMPSON DRILLER'S LOG:
GEOLOGIST: S. CRAVENS GEOLOGIST'S LOG: X
DATE DRILLED: 08-24-1983 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1630.00 T
TOTAL DRILL HOLE DEPTH: 23 TEST HOLE NUMBER: A1-83-212
WATER RIGHTS WELL: SDGS WELL NAME: A1-83-212
OTHER WELL NAME: CK-HD-6A
BASIN: JAMES AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: PVC, MFG. SCREEN LENGTH: 2.0
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1634.00 T
CASING STICK-UP: 4.00 TOTAL CASING AND SCREEN: 25.7
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160009
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

WASHED CONCRETE SAND AROUND SANDPOINT. SEALED AND BACKFILLED TO SURFACE WITH BENTONITE.

| | | |
|---|---|---|
| 0 - | 1 | SILT, DARK-GRAY, CLAYEY (TOPSOIL) |
| 1 - | 23 | CLAY, BROWN, SILTY, SANDY, PEBBLY; MOIST, OXIDIZED (TILL) |

* * * *

COUNTY: HAND LOCATION: 114N-70W-02BBBB 3
LEGAL LOCATION: NW NW NW NW SEC. 02, T. 114 N., R. 70 W.
LATITUDE: 44.4317 LONGITUDE: 99.1355
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: K. THOMPSON DRILLER'S LOG:
GEOLOGIST: S. CRAVENS GEOLOGIST'S LOG: X
DATE DRILLED: 08-24-1983 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1630.00 T
TOTAL DRILL HOLE DEPTH: 38 TEST HOLE NUMBER: A1-83-211
WATER RIGHTS WELL: SDGS WELL NAME: A1-83-211
OTHER WELL NAME: CK-HD-6B
BASIN: JAMES AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: PVC, MFG. SCREEN LENGTH: 2.0
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1633.00 T
CASING STICK-UP: 2.50 TOTAL CASING AND SCREEN: 39.7
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160009
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

WASHED CONCRETE SAND AROUND SANDPOINT. SEALED WITH BENTONITE. BACKFILLED TO SURFACE WITH SAND AND BENTONITE.

| | | |
|---|---|---|
| 0 - | 1 | SILT, DARK-BROWN (TOPSOIL) |
| 1 - | 21 | CLAY, DARK-BROWN, SILTY, SANDY, PEBBLY; MOIST, OXIDIZED (TILL) |
| 21 - | 26 | CLAY, GRAYISH-BROWN, SILTY, SANDY, PEBBLY; SLIGHTLY OXIDIZED (TILL) |
| 26 - | 38 | CLAY, DARK-GRAY, SILTY, SANDY, PEBBLY; MOIST, UNOXIDIZED (TILL) |

* * * *

COUNTY: HAND LOCATION: 114N-70W-02BBBB 4
LEGAL LOCATION: NW NW NW NW SEC. 02, T. 114 N., R. 70 W.
LATITUDE: 44.4317 LONGITUDE: 99.1355
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: C. SINGH DRILLER'S LOG:
GEOLOGIST: S. CRAVENS GEOLOGIST'S LOG: X
DATE DRILLED: 08-24-1983 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1630.00 T
TOTAL DRILL HOLE DEPTH: 53 TEST HOLE NUMBER: A2-83-253
WATER RIGHTS WELL: SDGS WELL NAME: A2-83-253
OTHER WELL NAME: CK-HD-6C
BASIN: JAMES AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: PVC, MFG. SCREEN LENGTH: 2.0
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1633.00 T
CASING STICK-UP: 2.50 TOTAL CASING AND SCREEN: 55.5
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160009
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

WASHED CONCRETE SAND AROUND SANDPOINT. SEALED AND BACKFILLED WITH BENTONITE.

| | | |
|---|---|---|
| 0 - | 1 | SILT, DARK-GRAY, CLAYEY; DRY (TOPSOIL) |
| 1 - | 26 | CLAY, BROWN, SILTY, SANDY, PEBBLY; MOIST, OXIDIZED, VERY MOIST AT 13 FEET (TILL) |
| 26 - | 53 | CLAY, GRAY, VERY SILTY, SANDY, PEBBLY; MOIST TO SATURATED, UNOXIDIZED (TILL) |

* * * *

COUNTY: HAND LOCATION: 114N-66W-15CDDD 4
LEGAL LOCATION: SE SE SE SW SEC. 15, T. 114 N., R. 66 W.
LATITUDE: 44.4041 LONGITUDE: 98.4523
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: M. YESKE DRILLER'S LOG:
GEOLOGIST: S. CRAVENS GEOLOGIST'S LOG: X
DATE DRILLED: 08-19-1983 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1388.00 T
TOTAL DRILL HOLE DEPTH: 18 TEST HOLE NUMBER: A2-83-241
WATER RIGHTS WELL: SDGS WELL NAME: A2-83-241
OTHER WELL NAME: CK-HD-7A
BASIN: JAMES AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: PVC, MFG. SCREEN LENGTH: 2.0
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1391.00 T
CASING STICK-UP: 2.60 TOTAL CASING AND SCREEN: 20.6
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160009
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

WASHED CONCRETE SAND AROUND SANDPOINT. SEALED WITH BENTONITE PELLETS. BACKFILLED TO SURFACE WITH BENTONITE.

| | | |
|---|---|---|
| 0 - | 1 | SILT, DARK-BROWN, CLAYEY; DRY (TOPSOIL) |
| 1 - | 18 | CLAY, BROWN, SILTY, SANDY, PEBBLY; MOIST, OXIDIZED, VERY SILTY FROM 6 TO 8 FEET, GRAYISH-BROWN AT 16 FEET (TILL) |

* * * *

COUNTY: HAND LOCATION: 114N-66W-15CDDD 6
LEGAL LOCATION: SE SE SE SW SEC. 15, T. 114 N., R. 66 W.
LATITUDE: 44.4041 LONGITUDE: 98.4523
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: L. THOMAS DRILLER'S LOG:
GEOLOGIST: S. CRAVENS GEOLOGIST'S LOG: X
DATE DRILLED: 06-19-1984 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1388.00 T
TOTAL DRILL HOLE DEPTH: 15 TEST HOLE NUMBER: A1-84-132
WATER RIGHTS WELL: SDGS WELL NAME: A1-84-132
OTHER WELL NAME: CK-HD-7A2
BASIN: JAMES AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: PVC, MFG. SCREEN LENGTH: 4.0
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1390.00 T
CASING STICK-UP: 2.00 TOTAL CASING AND SCREEN: 17.5
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160009
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

WASHED CONCRETE SAND AROUND SANDPOINT. SEALED WITH BENTONITE PELLETS. BACKFILLED TO SURFACE WITH BENTONITE.

0 - 15 CLAY, BROWN, SILTY, SANDY, PEBBLY; MOIST TO SATURATED, OXIDIZED (TILL)

* * * *

COUNTY: HAND LOCATION: 114N-66W-15CDDD 5
LEGAL LOCATION: SE SE SE SW SEC. 15, T. 114 N., R. 66 W.
LATITUDE: 44.4041 LONGITUDE: 98.4523
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: D. TOMHAVE DRILLER'S LOG:
GEOLOGIST: S. CRAVENS GEOLOGIST'S LOG: X
DATE DRILLED: 08-19-1983 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1388.00 T
TOTAL DRILL HOLE DEPTH: 33 TEST HOLE NUMBER: A1-83-201
WATER RIGHTS WELL: SDGS WELL NAME: A1-83-201
OTHER WELL NAME: CK-HD-7B
BASIN: JAMES AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: PVC, MFG. SCREEN LENGTH: 2.0
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1391.00 T
CASING STICK-UP: 2.50 TOTAL CASING AND SCREEN: 33.2
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160009
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

WASHED CONCRETE SAND AROUND SANDPOINT. SEALED WITH BENTONITE PELLETS. BACKFILLED TO SURFACE WITH BENTONITE.

| | | |
|---|---|---|
| 0 - | 2 | SILT, BROWNISH-BLACK, CLAYEY; DRY (TOPSOIL) |
| 2 - | 16 | CLAY, BROWN, SILTY, SANDY, PEBBLY; MOIST, OXIDIZED (TILL) |
| 16 - | 33 | CLAY, GRAY, SILTY, SANDY, PEBBLY; MOIST, UNOXIDIZED, VERY MOIST AT 20 FEET (TILL) |

* * * *

COUNTY: HAND LOCATION: 114N-67W-35AAAA 2
LEGAL LOCATION: NE NE NE NE SEC. 35, T. 114 N., R. 67 W.
LATITUDE: 44.3857 LONGITUDE: 98.5157
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: C. SINGH DRILLER'S LOG:
GEOLOGIST: S. CRAVENS GEOLOGIST'S LOG: X
DATE DRILLED: 08-18-1983 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1393.00 T
TOTAL DRILL HOLE DEPTH: 18 TEST HOLE NUMBER: A1-83-240
WATER RIGHTS WELL: SDGS WELL NAME: A2-83-240
OTHER WELL NAME: CK-HD-8A
BASIN: JAMES AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: PVC, MFG. SCREEN LENGTH: 2.0
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1396.00 T
CASING STICK-UP: 2.50 TOTAL CASING AND SCREEN: 21.0
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160009
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

WASHED CONCRETE SAND AROUND SANDPOINT. SEALED WITH BENTONITE PELLETS. BACKFILLED TO SURFACE WITH BENTONITE.

| | | |
|---|---|---|
| 0 - | 1 | SILT, BROWN, CLAYEY; DRY (TOPSOIL) |
| 1 - | 18 | CLAY, LIGHT-BROWN, SILTY, PEBBLY; DRY, OXIDIZED, MOIST AT 4 FEET, SANDY AFTER 8 FEET, GRAYISH-BROWN AT 16 FEET (TILL) |

* * * *

COUNTY: HAND LOCATION: 114N-67W-35AAAA 4
LEGAL LOCATION: NE NE NE NE SEC. 35, T. 114 N., R. 67 W.
LATITUDE: 44.3857 LONGITUDE: 98.5157
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: L. THOMAS DRILLER'S LOG:
GEOLOGIST: S. CRAVENS GEOLOGIST'S LOG: X
DATE DRILLED: 06-19-1984 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1393.00 T
TOTAL DRILL HOLE DEPTH: 13 TEST HOLE NUMBER: A1-84-131
WATER RIGHTS WELL: SDGS WELL NAME: A1-84-131
OTHER WELL NAME: CK-HD-8A2
BASIN: JAMES AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: PVC, MFG. SCREEN LENGTH: 4.0
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1395.50 T
CASING STICK-UP: 2.50 TOTAL CASING AND SCREEN: 15.8
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160009
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

WASHED CONCRETE SAND AROUND SANDPOINT. SEALED WITH BENTONITE PELLETS. BACKFILLED TO SURFACE WITH BENTONITE.

0 - 13 CLAY, BROWN, SILTY, SANDY, PEBBLY; MOIST, OXIDIZED (TILL)

* * * *

COUNTY: HAND LOCATION: 114N-67W-35AAAA 3
LEGAL LOCATION: NE NE NE NE SEC. 35, T. 114 N., R. 67 W.
LATITUDE: 44.3857 LONGITUDE: 98.5157
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: D. TOMHAVE DRILLER'S LOG:
GEOLOGIST: S. CRAVENS GEOLOGIST'S LOG: X
DATE DRILLED: 08-18-1983 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1393.00 T
TOTAL DRILL HOLE DEPTH: 33 TEST HOLE NUMBER: A1-83-200
WATER RIGHTS WELL: SDGS WELL NAME: A1-83-200
OTHER WELL NAME: CK-HD-8B
BASIN: JAMES AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: PVC, MFG. SCREEN LENGTH: 2.0
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1395.00 T
CASING STICK-UP: 2.40 TOTAL CASING AND SCREEN: 35.4
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160009
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

WASHED CONCRETE SAND AROUND SANDPOINT. SEALED WITH BENTONITE PELLETS. BACKFILLED TO SURFACE WITH BENTONITE.

| | | |
|---|---|---|
| 0 - | 2 | SILT, BROWN, CLAYEY; DRY, OXIDIZED |
| 2 - | 16 | CLAY, BROWN, SILTY, SANDY, PEBBLY; MOIST, OXIDIZED (TILL) |
| 16 - | 33 | CLAY, GRAY, SILTY, SANDY, PEBBLY; MOIST, UNOXIDIZED (TILL) |

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COUNTY: HAND LOCATION: 114N-67W-35AAAA 5
LEGAL LOCATION: NE NE NE NE SEC. 35, T. 114 N., R. 67 W.
LATITUDE: 44.3857 LONGITUDE: 98.5157
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: L. THOMAS DRILLER'S LOG:
GEOLOGIST: S. CRAVENS GEOLOGIST'S LOG: X
DATE DRILLED: 06-19-1984 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1393.00 T
TOTAL DRILL HOLE DEPTH: 26 TEST HOLE NUMBER: A1-84-130
WATER RIGHTS WELL: SDGS WELL NAME: A1-84-130
OTHER WELL NAME: CK-HD-8B2
BASIN: JAMES AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: PVC, MFG. SCREEN LENGTH: 2.5
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1395.80 T
CASING STICK-UP: 2.80 TOTAL CASING AND SCREEN: 26.0
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160009
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

WASHED CONCRETE SAND AROUND SANDPOINT. SEALED WITH TWO FEET OF BENTONITE. TEN FOOT ANNULUS ABOVE SEAL DUE TO BRIDGING.

0 - 26 CLAY, BROWN, SILTY, SANDY, PEBBLY; MOIST, OXIDIZED, SATURATED AT 20 FEET.

* * * *

COUNTY: HAND LOCATION: 114N-66W-14CCCC 4
LEGAL LOCATION: SW SW SW SW SEC. 14, T. 114 N., R. 66 W.
LATITUDE: 44.4040 LONGITUDE: 98.4446
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: C. SINGH DRILLER'S LOG:
GEOLOGIST: S. CRAVENS GEOLOGIST'S LOG: X
DATE DRILLED: 08-19-1983 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1379.00 T
TOTAL DRILL HOLE DEPTH: 23 TEST HOLE NUMBER: A2-83-242
WATER RIGHTS WELL: SDGS WELL NAME: A2-83-242
OTHER WELL NAME: CK-HD-9A
BASIN: JAMES AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: PVC, MFG. SCREEN LENGTH: 2.0
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1383.00 T
CASING STICK-UP: 4.50 TOTAL CASING AND SCREEN: 27.0
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160009
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

WASHED CONCRETE SAND AROUND SANDPOINT. SEALED WITH BENTONITE PELLETS. BACKFILLED TO SURFACE WITH BENTONITE.

| | | |
|---|---|---|
| 0 - | 4 | SILT, LIGHT-BROWN, CLAYEY; DRY, OXIDIZED (TOPSOIL) |
| 4 - | 18 | CLAY, BROWN, SILTY, SANDY, PEBBLY; MOIST, OXIDIZED (TILL) |
| 18 - | 23 | CLAY, GRAY, VERY SILTY, SANDY, PEBBLY; MOIST, UNOXIDIZED (TILL) |

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COUNTY: HAND LOCATION: 114N-66W-14CCCC 6
LEGAL LOCATION: SW SW SW SW SEC. 14, T. 114 N., R. 66 W.
LATITUDE: 44.4040 LONGITUDE: 99.4446
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: L. THOMAS DRILLER'S LOG:
GEOLOGIST: S. CRAVENS GEOLOGIST'S LOG: X
DATE DRILLED: 06-19-1984 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1379.00 T
TOTAL DRILL HOLE DEPTH: 13 TEST HOLE NUMBER: A1-84-133
WATER RIGHTS WELL: SDGS WELL NAME: A1-84-133
OTHER WELL NAME: CK-HD-9A2
BASIN: JAMES AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: PVC, MFG. SCREEN LENGTH: 4.0
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1383.20 T
CASING STICK-UP: 4.20 TOTAL CASING AND SCREEN: 17.2
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160009
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

WASHED CONCRETE SAND AROUND SANDPOINT. SEALED WITH BENTONITE PELLETS. BACKFILLED TO SURFACE WITH BENTONITE.

0 - 13 CLAY, BROWN, SILTY, SANDY, PEBBLY; MOIST, OXIDIZED (TILL)

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COUNTY: HAND LOCATION: 114N-66W-14CCCC 5
LEGAL LOCATION: SW SW SW SW SEC. 14, T. 114 N., R. 66 W.
LATITUDE: 44.4040 LONGITUDE: 98.4446
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: M. YESKE DRILLER'S LOG:
GEOLOGIST: S. CRAVENS GEOLOGIST'S LOG: X
DATE DRILLED: 08-19-1983 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1379.00 T
TOTAL DRILL HOLE DEPTH: 38 TEST HOLE NUMBER: A2-83-243
WATER RIGHTS WELL: SDGS WELL NAME: A2-83-243
OTHER WELL NAME: CK-HD-9B
BASIN: JAMES AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: PVC, MFG. SCREEN LENGTH: 2.0
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1383.00 T
CASING STICK-UP: 4.50 TOTAL CASING AND SCREEN: 42.0
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160009
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

WASHED CONCRETE SAND AROUND SANDPOINT. SEALED WITH BENTONITE PELLETS. BACKFILLED TO SURFACE WITH BENTONITE.

| | | |
|---|---|---|
| 0 - | 4 | SILT, LIGHT-BROWN, CLAYEY; DRY, OXIDIZED (TOPSOIL) |
| 4 - | 18 | CLAY, BROWN, VERY SILTY, SANDY, PEBBLY; MOIST, OXIDIZED (TILL) |
| 18 - | 38 | CLAY, GRAY, VERY SILTY, SANDY, PEBBLY; MOIST, UNOXIDIZED (TILL) |

* * * *

COUNTY: HAND LOCATION: 114N-66W-14CCCC 3
LEGAL LOCATION: SW SW SW SW SEC. 14, T. 114 N., R. 66 W.
LATITUDE: 44.4040 LONGITUDE: 98.4446
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: D. TOMHAVE DRILLER'S LOG:
GEOLOGIST: S. CRAVENS GEOLOGIST'S LOG: X
DATE DRILLED: 08-19-1983 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1379.00 T
TOTAL DRILL HOLE DEPTH: 53 TEST HOLE NUMBER: A1-83-202
WATER RIGHTS WELL: SDGS WELL NAME: A1-83-202
OTHER WELL NAME: CK-HD-9C
BASIN: JAMES AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: PVC, MFG. SCREEN LENGTH: 2.0
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1383.00 T
CASING STICK-UP: 4.50 TOTAL CASING AND SCREEN: 53.7
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160009
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

WASHED CONCRETE SAND AROUND SANDPOINT. SEALED WITH BENTONITE PELLETS. BACKFILLED TO SURFACE WITH BENTONITE.

| | | |
|---|---|---|
| 0 - | 2 | SILT, LIGHT-BROWN, CLAYEY; DRY, OXIDIZED (TOPSOIL) |
| 2 - | 18 | CLAY, BROWN, SILTY, SANDY, PEBBLY; MOIST, OXIDIZED (TILL) |
| 18 - | 53 | CLAY, GRAY, SILTY, SANDY, PEBBLY; MOIST, UNOXIDIZED, VERY MOIST AT 35 FEET (TILL) |

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COUNTY: HAND LOCATION: 115N-69W-13BBBB 2
LEGAL LOCATION: NW NW NW NW SEC. 13, T. 115 N., R. 69 W.
LATITUDE: 44.4645 LONGITUDE: 99.0518
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: D. TOMHAVE DRILLER'S LOG:
GEOLOGIST: S. CRAVENS GEOLOGIST'S LOG: X
DATE DRILLED: 08-17-1983 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1566.00 T
TOTAL DRILL HOLE DEPTH: 18 TEST HOLE NUMBER: A1-83-194
WATER RIGHTS WELL: SDGS WELL NAME: A1-83-194
OTHER WELL NAME: CK-HD-10A
BASIN: JAMES AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: PVC, MFG. SCREEN LENGTH: 2.0
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1569.00 T
CASING STICK-UP: 2.50 TOTAL CASING AND SCREEN: 20.5
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160009
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

WASHED CONCRETE SAND AROUND SANDPOINT. SEALED WITH BENTONITE PELLETS. BACKFILLED TO SURFACE WITH SAND AND BENTONITE.

| | | |
|---|---|---|
| 0 - | 4 | CLAY, GRAYISH-BLACK, SILTY, SANDY; MOIST (TOPSOIL) |
| 4 - | 18 | CLAY, BROWN, SILTY, SANDY, PEBBLY; MOIST, OXIDIZED, VERY MOIST AT 11 FEET (TILL) |

* * * *

COUNTY: HAND LOCATION: 115N-69W-13BBBB 3
LEGAL LOCATION: NW NW NW NW SEC. 13, T. 115 N., R. 69 W.
LATITUDE: 44.4645 LONGITUDE: 99.0518
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: M. YESKE DRILLER'S LOG:
GEOLOGIST: S. CRAVENS GEOLOGIST'S LOG: X
DATE DRILLED: 08-17-1983 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1566.00 T
TOTAL DRILL HOLE DEPTH: 28 TEST HOLE NUMBER: A2-83-235
WATER RIGHTS WELL: SDGS WELL NAME: A2-83-235
OTHER WELL NAME: CK-HD-10B
BASIN: JAMES AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: PVC, MFG. SCREEN LENGTH: 2.0
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1569.00 T
CASING STICK-UP: 2.50 TOTAL CASING AND SCREEN: 30.9
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160009
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

WASHED CONCRETE SAND AROUND SANDPOINT. SEALED WITH BENTONITE PELLETS. BACKFILLED TO SURFACE WITH SAND AND BENTONITE.

| | | |
|---|---|---|
| 0 - | 5 | CLAY, BROWNISH-BLACK, SILTY; MOIST (TOPSOIL) |
| 5 - | 16 | CLAY, YELLOWISH-BROWN, SILTY, SANDY, PEBBLY; MOIST, OXIDIZED, VERY MOIST AT 8 FEET (TILL) |
| 16 - | 28 | CLAY, BLUISH-GRAY, SILTY, SANDY, PEBBLY; VERY MOIST, UNOXIDIZED (TILL) |

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COUNTY: HAND LOCATION: 115N-69W-13BBBB 4
LEGAL LOCATION: NW NW NW NW SEC. 13, T. 115 N., R. 69 W.
LATITUDE: 44.4645 LONGITUDE: 99.0518
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: D. TOMHAVE DRILLER'S LOG:
GEOLOGIST: S. CRAVENS GEOLOGIST'S LOG: X
DATE DRILLED: 08-17-1983 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1566.00 T
TOTAL DRILL HOLE DEPTH: 38 TEST HOLE NUMBER: A1-83-193
WATER RIGHTS WELL: SDGS WELL NAME: A1-83-193
OTHER WELL NAME: CK-HD-10C
BASIN: JAMES AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: PVC, MFG. SCREEN LENGTH: 2.0
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1569.00 T
CASING STICK-UP: 2.50 TOTAL CASING AND SCREEN: 40.5
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160009
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

WASHED CONCRETE SAND AROUND SANDPOINT. SEALED WITH BENTONITE PELLETS. BACKFILLED TO SURFACE WITH SAND AND BENTONITE.

| | | |
|---|---|---|
| 0 - | 3 | CLAY, GRAYISH-BLACK, SILTY, SANDY; MOIST (TOPSOIL) |
| 3 - | 14 | CLAY, BROWN, SILTY, SANDY, PEBBLY; MOIST, OXIDIZED (TILL) |
| 14 - | 38 | CLAY, GRAY, SILTY, SANDY, PEBBLY; MOIST, UNOXIDIZED (TILL) |

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COUNTY: HAND LOCATION: 115N-69W-15BBBB 2
LEGAL LOCATION: NW NW NW NW SEC. 15, T. 115 N., R. 69 W.
LATITUDE: 44.4647 LONGITUDE: 99.0745
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: C. SINGH DRILLER'S LOG:
GEOLOGIST: S. CRAVENS GEOLOGIST'S LOG: X
DATE DRILLED: 08-17-1983 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1610.00 T
TOTAL DRILL HOLE DEPTH: 28 TEST HOLE NUMBER: A2-83-236
WATER RIGHTS WELL: SDGS WELL NAME: A2-83-236
OTHER WELL NAME: CK-HD-11A
BASIN: JAMES AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: PVC, MFG. SCREEN LENGTH: 2.0
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1613.00 T
CASING STICK-UP: 2.80 TOTAL CASING AND SCREEN: 30.3
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160009
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

WASHED CONCRETE SAND AROUND SANDPOINT. SEALED WITH BENTONITE PELLETS. BACKFILLED TO SURFACE WITH SAND AND BENTONITE.

| | | |
|---|---|---|
| 0 - | 1 | CLAY, DARK-BROWN, SILTY; MOIST, OXIDIZED (TOPSOIL) |
| 1 - | 28 | CLAY, BROWN, SILTY, SANDY, PEBBLY; MOIST, OXIDIZED, DARK-BROWN AT 13 FEET (TILL) |

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COUNTY: HAND LOCATION: 115N-69W-15BBBB 4
LEGAL LOCATION: NW NW NW NW SEC. 15, T. 115 N., R. 69 W.
LATITUDE: 44.4647 LONGITUDE: 99.0745
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: L. THOMAS DRILLER'S LOG:
GEOLOGIST: S. CRAVENS GEOLOGIST'S LOG: X
DATE DRILLED: 06-19-1984 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1610.00 T
TOTAL DRILL HOLE DEPTH: 20 TEST HOLE NUMBER: A1-84-136
WATER RIGHTS WELL: SDGS WELL NAME: A1-84-136
OTHER WELL NAME: CK-HD-11A2
BASIN: JAMES AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: PVC, MFG. SCREEN LENGTH: 2.5
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1612.50 T
CASING STICK-UP: 2.50 TOTAL CASING AND SCREEN: 23.1
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160009
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

WASHED CONCRETE SAND AROUND SANDPOINT. SAND BACKFILL TO WITHIN 10 FEET OF SURFACE. BENTONITE SEAL AND BACKFILL TO SURFACE.

0 - 20 CLAY, BROWN, SILTY, SANDY, PEBBLY; MOIST, OXIDIZED (TILL)

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COUNTY: HAND LOCATION: 115N-69W-15BBBB 3
LEGAL LOCATION: NW NW NW NW SEC. 15, T. 115 N., R. 69 W.
LATITUDE: 44.4647 LONGITUDE: 99.0745
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: D. TOMHAVE DRILLER'S LOG:
GEOLOGIST: S. CRAVENS GEOLOGIST'S LOG: X
DATE DRILLED: 08-17-1983 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1610.00 T
TOTAL DRILL HOLE DEPTH: 38 TEST HOLE NUMBER: A1-83-195
WATER RIGHTS WELL: SDGS WELL NAME: A1-83-195
OTHER WELL NAME: CK-HD-11B
BASIN: JAMES AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: PVC, MFG. SCREEN LENGTH: 2.0
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1613.00 T
CASING STICK-UP: 2.50 TOTAL CASING AND SCREEN: 40.5
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160009
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

WASHED CONCRETE SAND AROUND SANDPOINT. SEALED WITH BENTONITE PELLETS. BACKFILLED TO SURFACE WITH SAND AND BENTONITE.

| | | |
|---|---|---|
| 0 - | 30 | CLAY, DARK-BROWN, SILTY, SANDY, PEBBLY; MOIST, OXIDIZED (TILL) |
| 30 - | 38 | CLAY, GRAYISH-BROWN, SILTY, SANDY, PEBBLY; MOIST, SLIGHTLY OXIDIZED, BECOMES GRAY AND UNOXIDIZED AT 33 FEET (TILL) |

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COUNTY: HAND LOCATION: 115N-69W-15BBBB 6
LEGAL LOCATION: NW NW NW NW SEC. 15, T. 115 N., R. 69 W.
LATITUDE: 44.4647 LONGITUDE: 99.0745
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: L. THOMAS DRILLER'S LOG: X
GEOLOGIST: M. JARRETT GEOLOGIST'S LOG:
DATE DRILLED: 09-07-1984 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1610.00 T
TOTAL DRILL HOLE DEPTH: 37 TEST HOLE NUMBER: A2-84-203
WATER RIGHTS WELL: SDGS WELL NAME: A2-84-203
OTHER WELL NAME: CK-HD-11B2
BASIN: JAMES AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: SCREEN LENGTH:
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1612.00 T
CASING STICK-UP: 2.50 TOTAL CASING AND SCREEN: 40.0
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160009
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

SHELBIED. COMPARISON WELL WITH CK-HD-11B. NO SCREEN.

| | | |
|---|---|---|
| 0 - | 16 | CLAY, BROWN, VERY SILTY, SANDY, PEBBLY; MOIST, OXIDIZED (TILL) |
| 16 - | 18 | SAND, BROWN, VERY SILTY AND PEBBLY; SLIGHTLY SATURATED, OXIDIZED |
| 18 - | 26 | SAND, BROWN, CLAYEY; SATURATED, OXIDIZED |
| 26 - | 30 | CLAY, GRAY, VERY SILTY, SANDY, PEBBLY; SLIGHTLY SATURATED, UNOXIDIZED (TILL) |
| 30 - | 37 | CLAY, GRAY, SILTY, SANDY, PEBBLY; VERY MOIST, UNOXIDIZED (TILL) |

TULARE AQUIFER UNDERLIES TILL AT 72 TO 80 FEET DEPTH.

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COUNTY: HAND LOCATION: 115N-69W-15BBBB 5
LEGAL LOCATION: NW NW NW NW SEC. 15, T. 115 N., R. 69 W.
LATITUDE: 44.4647 LONGITUDE: 99.0745
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: L. THOMAS DRILLER'S LOG: X
GEOLOGIST: M. JARRETT GEOLOGIST'S LOG:
DATE DRILLED: 09-07-1984 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1610.00 T
TOTAL DRILL HOLE DEPTH: 67 TEST HOLE NUMBER: A2-84-202
WATER RIGHTS WELL: SDGS WELL NAME: A2-84-202
OTHER WELL NAME: CK-HD-11D
BASIN: JAMES AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: SCREEN LENGTH:
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1612.00 T
CASING STICK-UP: 2.50 TOTAL CASING AND SCREEN: 70.1
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160009
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

SHELBIED. NO SCREEN.

| | | |
|---|---|---|
| 0 - | 24 | CLAY, BROWN, SILTY, SANDY, PEBBLY; DRY, OXIDIZED (TILL) |
| 24 - | 67 | CLAY, GRAY, SILTY, SANDY, PEBBLY; DRY TO SLIGHTLY MOIST WITH DEPTH, UNOXIDIZED (TILL) |

NO CORE RETURNED; PROBABLY SAND. TULARE AQUIFER UNDERLIES TILL AT 72 TO 80 FEET DEPTH.

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COUNTY: HAND LOCATION: 115N-69W-18AAAA 4
LEGAL LOCATION: NE NE NE NE SEC. 18, T. 115 N., R. 69 W.
LATITUDE: 44.4647 LONGITUDE: 99.1014
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: K. THOMPSON DRILLER'S LOG:
GEOLOGIST: S. CRAVENS GEOLOGIST'S LOG: X
DATE DRILLED: 08-17-1983 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1649.00 T
TOTAL DRILL HOLE DEPTH: 18 TEST HOLE NUMBER: A1-83-197
WATER RIGHTS WELL: SDGS WELL NAME: A1-83-197
OTHER WELL NAME: CK-HD-12A
BASIN: JAMES AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: PVC, MFG. SCREEN LENGTH: 2.0
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1652.00 T
CASING STICK-UP: 2.50 TOTAL CASING AND SCREEN: 20.5
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160009
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

WASHED CONCRETE SAND AROUND SANDPOINT. SEALED WITH BENTONITE PELLETS. BACKFILLED TO SURFACE WITH BENTONITE.

0 - 18 CLAY, BROWN, SILTY, SANDY, PEBBLY; MOIST, OXIDIZED (TILL)

* * * *

COUNTY: HAND LOCATION: 115N-69W-18AAAA 5
LEGAL LOCATION: NE NE NE NE SEC. 18, T. 115 N., R. 69 W.
LATITUDE: 44.4647 LONGITUDE: 99.1014
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: L. THOMAS DRILLER'S LOG:
GEOLOGIST: S. CRAVENS GEOLOGIST'S LOG: X
DATE DRILLED: 06-19-1984 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1649.00 T
TOTAL DRILL HOLE DEPTH: 13 TEST HOLE NUMBER: A1-84-138
WATER RIGHTS WELL: SDGS WELL NAME: A1-84-138
OTHER WELL NAME: CK-HD-12A2
BASIN: JAMES AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: PVC, MFG. SCREEN LENGTH: 4.0
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1651.50 T
CASING STICK-UP: 2.50 TOTAL CASING AND SCREEN: 15.1
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160009
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

WASHED CONCRETE SAND AROUND SANDPOINT. BACKFILLED TO SURFACE WITH SAND. BENTONITE SEAL AT SURFACE.

0 - 13 CLAY, BROWN, SILTY, SANDY, PEBBLY; MOIST, OXIDIZED, SATURATED AT 9 FEET (TILL)

* * * *

COUNTY: HAND LOCATION: 115N-69W-18AAAA 2
LEGAL LOCATION: NE NE NE NE SEC. 18, T. 115 N., R. 69 W.
LATITUDE: 44.4647 LONGITUDE: 99.1014
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: M. YESKE DRILLER'S LOG:
GEOLOGIST: S. CRAVENS GEOLOGIST'S LOG: X
DATE DRILLED: 08-17-1983 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1649.00 T
TOTAL DRILL HOLE DEPTH: 28 TEST HOLE NUMBER: A2-83-237
WATER RIGHTS WELL: SDGS WELL NAME: A2-83-237
OTHER WELL NAME: CK-HD-12B
BASIN: JAMES AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: PVC, MFG. SCREEN LENGTH: 2.0
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1652.00 T
CASING STICK-UP: 2.80 TOTAL CASING AND SCREEN: 30.8
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160009
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

WASHED CONCRETE SAND AROUND SANDPOINT. SEALED WITH BENTONITE PELLETS. BACKFILLED TO SURFACE WITH SAND AND BENTONITE.

| | | |
|---|---|---|
| 0 - | 1 | CLAY, DARK-BROWN, PEBBLY; MOIST (TOPSOIL) |
| 1 - | 25 | CLAY, BROWN, SILTY, SANDY, PEBBLY; MOIST, OXIDIZED, VERY MOIST AT 16 FEET, TURNS DARK-BROWN AT 18 FEET (TILL) |
| 25 - | 28 | CLAY, GRAYISH-BROWN, VERY SILTY, SANDY, PEBBLY; VERY MOIST, SLIGHTLY OXIDIZED (TILL) |

* * * *

COUNTY: HAND LOCATION: 115N-69W-18AAAA 6
LEGAL LOCATION: NE NE NE NE SEC. 18, T. 115 N., R. 69 W.
LATITUDE: 44.4647 LONGITUDE: 99.1014
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: L. THOMAS DRILLER'S LOG:
GEOLOGIST: S. CRAVENS GEOLOGIST'S LOG: X
DATE DRILLED: 06-19-1984 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1649.00 T
TOTAL DRILL HOLE DEPTH: 32 TEST HOLE NUMBER: A1-84-137
WATER RIGHTS WELL: SDGS WELL NAME: A1-84-137
OTHER WELL NAME: CK-HD-12B2
BASIN: JAMES AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: PVC, MFG. SCREEN LENGTH: 2.0
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1651.25 T
CASING STICK-UP: 2.25 TOTAL CASING AND SCREEN: 34.5
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160009
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

WASHED CONCRETE SAND AROUND SANDPOINT. SEALED WITH BENTONITE PELLETS WITH UP TO TEN FOOT ANNULUS DUE TO BRIDGING. QUESTIONABLE AS TO THE DEPTH AT WHICH WELL IS SEALED.

| | | |
|---|---|---|
| 0 - | 24 | CLAY, BROWN, SILTY, SANDY, PEBBLY; MOIST, OXIDIZED (TILL) |
| 24 - | 32 | CLAY, GRAY, SILTY, SANDY, PEBBLY; MOIST, UNOXIDIZED (TILL) |

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COUNTY: HAND LOCATION: 115N-69W-18AAAA 3
LEGAL LOCATION: NE NE NE NE SEC. 18, T. 115 N., R. 69 W.
LATITUDE: 44.4647 LONGITUDE: 99.1014
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: D. TOMHAVE DRILLER'S LOG:
GEOLOGIST: S. CRAVENS GEOLOGIST'S LOG: X
DATE DRILLED: 08-17-1983 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1649.00 T
TOTAL DRILL HOLE DEPTH: 38 TEST HOLE NUMBER: A1-83-196
WATER RIGHTS WELL: SDGS WELL NAME: A1-83-196
OTHER WELL NAME: CK-HD-12C
BASIN: JAMES AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: PVC, MFG. SCREEN LENGTH: 2.0
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1652.00 T
CASING STICK-UP: 2.50 TOTAL CASING AND SCREEN: 40.3
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160009
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

WASHED CONCRETE SAND AROUND SANDPOINT. SEALED WITH BENTONITE PELLETS. BACKFILLED TO SURFACE WITH SAND AND BENTONITE.

| | | |
|---|---|---|
| 0 - | 26 | CLAY, BROWN, SILTY, SANDY, PEBBLY; MOIST, OXIDIZED (TILL) |
| 26 - | 30 | CLAY, GRAYISH-BROWN, SILTY, SANDY, PEBBLY; MOIST, SLIGHTLY OXIDIZED (TILL) |
| 30 - | 38 | CLAY, GRAY, SILTY, SANDY, PEBBLY; MOIST, UNOXIDIZED (TILL) |

* * * *

COUNTY: HAND LOCATION: 115N-70W-14AAAA 1
LEGAL LOCATION: NE NE NE NE SEC. 14, T. 115 N., R. 70 W.
LATITUDE: 44.4647 LONGITUDE: 99.1240
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: C. SINGH DRILLER'S LOG:
GEOLOGIST: S. CRAVENS GEOLOGIST'S LOG: X
DATE DRILLED: 08-17-1983 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1667.00 T
TOTAL DRILL HOLE DEPTH: 28 TEST HOLE NUMBER: A2-83-238
WATER RIGHTS WELL: SDGS WELL NAME: A2-83-238
OTHER WELL NAME: CK-HD-13A
BASIN: JAMES AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: PVC, MFG. SCREEN LENGTH: 2.0
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1670.00 T
CASING STICK-UP: 2.50 TOTAL CASING AND SCREEN: 30.8
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160009
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

WASHED CONCRETE SAND AROUND SANDPOINT. SEALED WITH BENTONITE PELLETS. BACKFILLED TO SURFACE WITH SAND AND BENTONITE.

| | | |
|---|---|---|
| 0 - | 1 | CLAY, DARK-BROWN, SILTY; MOIST (TOPSOIL) |
| 1 - | 24 | CLAY, BROWN, VERY SILTY, SANDY, PEBBLY; MOIST, OXIDIZED, SATURATED AT 22 FEET (TILL) |
| 24 - | 28 | CLAY, GRAY, SILTY, SANDY, PEBBLY; MOIST, UNOXIDIZED (TILL) |

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COUNTY: HAND LOCATION: 115N-70W-14AAAA 3
LEGAL LOCATION: NE NE NE NE SEC. 14, T. 115 N., R. 70 W.
LATITUDE: 44.4647 LONGITUDE: 99.1240
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: L. THOMAS DRILLER'S LOG:
GEOLOGIST: S. CRAVENS GEOLOGIST'S LOG: X
DATE DRILLED: 06-20-1984 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1667.00 T
TOTAL DRILL HOLE DEPTH: 18 TEST HOLE NUMBER: A1-84-139
WATER RIGHTS WELL: SDGS WELL NAME: A1-84-139
OTHER WELL NAME: CK-HD-13A2
BASIN: JAMES AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: PVC, MFG. SCREEN LENGTH: 4.0
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1669.50 T
CASING STICK-UP: 2.50 TOTAL CASING AND SCREEN: 20.3
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160009
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

WASHED CONCRETE SAND AROUND SANDPOINT. BACKFILLED WITH SAND TO 8 FEET. SEALED AT SURFACE WITH BENTONITE.

| | | |
|---|---|---|
| 0 - | 3 | CLAY, DARK-BRCWN, SILTY; MOIST, OXIDIZED |
| 3 - | 18 | CLAY, BROWN, SILTY, SANDY, PEBBLY; SATURATED AT 5 FEET, OXIDIZED |

* * * *

COUNTY: HAND LOCATION: 115N-70W-14AAAA 2
LEGAL LOCATION: NE NE NE NE SEC. 14, T. 115 N., R. 70 W.
LATITUDE: 44.4647 LONGITUDE: 99.1240
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: D. TOMHAVE DRILLER'S LOG:
GEOLOGIST: S. CRAVENS GEOLOGIST'S LOG: X
DATE DRILLED: 08-17-1983 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1667.00 T
TOTAL DRILL HOLE DEPTH: 38 TEST HOLE NUMBER: A1-83-198
WATER RIGHTS WELL: SDGS WELL NAME: A1-83-198
OTHER WELL NAME: CK-HD-13B
BASIN: JAMES AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: PVC, MFG. SCREEN LENGTH: 2.0
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1670.00 T
CASING STICK-UP: 2.50 TOTAL CASING AND SCREEN: 40.6
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160009
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

WASHED CONCRETE SAND AROUND SANDPOINT. SEALED WITH BENTONITE PELLETS. BACKFILLED TO SURFACE WITH SAND AND BENTONITE.

| | | |
|---|---|---|
| 0 - | 2 | SILT, BLACK, SANDY; DRY (TOPSOIL) |
| 2 - | 20 | CLAY, BROWN, SILTY, SANDY, PEBBLY; MOIST, OXIDIZED (TILL) |
| 20 - | 38 | CLAY, GRAY, SILTY, SANDY, PEBBLY; MOIST, UNOXIDIZED (TILL) |

* * * *

COUNTY: HAND LOCATION: 115N-70W-17BBBB 4
LEGAL LOCATION: NW NW NW NW SEC. 17, T. 115 N., R. 70 W.
LATITUDE: 44.4647 LONGITUDE: 99.1732
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: C. SINGH DRILLER'S LOG:
GEOLOGIST: S. CRAVENS GEOLOGIST'S LOG: X
DATE DRILLED: 08-24-1983 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1733.00 T
TOTAL DRILL HOLE DEPTH: 18 TEST HOLE NUMBER: A2-83-251
WATER RIGHTS WELL: SDGS WELL NAME: A2-83-251
OTHER WELL NAME: CK-HD-15A
BASIN: JAMES AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: PVC, MFG. SCREEN LENGTH: 2.0
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1736.00 T
CASING STICK-UP: 2.80 TOTAL CASING AND SCREEN: 20.6
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160009
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

WASHED CONCRETE SAND AROUND SANDPOINT. SEALED WITH BENTONITE. BACKFILLED TO SURFACE WITH SAND AND BENTONITE.

| | | |
|---|---|---|
| 0 - | 4 | SILT, DARK-BROWN, CLAYEY; MOIST (TOPSOIL) |
| 4 - | 16 | CLAY, BROWN, VERY SILTY, SANDY, PEBBLY; MOIST, OXIDIZED (TILL) |
| 16 - | 18 | CLAY, GRAY, SILTY, SANDY, PEBBLY; MOIST, UNOXIDIZED (TILL) |

* * * *

COUNTY: HAND LOCATION: 115N-70W-17BBBB 5
LEGAL LOCATION: NW NW NW NW SEC. 17, T. 115 N., R. 70 W.
LATITUDE: 44.4647 LONGITUDE: 99.1732
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: L. THOMAS DRILLER'S LOG:
GEOLOGIST: S. CRAVENS GEOLOGIST'S LOG: X
DATE DRILLED: 06-20-1984 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1733.00 T
TOTAL DRILL HOLE DEPTH: 13 TEST HOLE NUMBER: A1-84-140
WATER RIGHTS WELL: SDGS WELL NAME: A1-84-140
OTHER WELL NAME: CK-HD-15A2
BASIN: JAMES AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: PVC, MFG. SCREEN LENGTH: 2.0
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1735.30 T
CASING STICK-UP: 2.30 TOTAL CASING AND SCREEN: 15.4
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160009
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

WASHED CONCRETE SAND AROUND SANDPOINT. SEALED WITH BENTONITE TO SURFACE.

0 - 13 CLAY, BROWN, SILTY, SANDY, PEBBLY; MOIST, OXIDIZED (TILL)

* * * *

COUNTY: HAND LOCATION: 115N-70W-17BBBB 2
LEGAL LOCATION: NW NW NW NW SEC. 17, T. 115 N., R. 70 W.
LATITUDE: 44.4647 LONGITUDE: 99.1732
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: M. YESKE DRILLER'S LOG:
GEOLOGIST: S. CRAVENS GEOLOGIST'S LOG: X
DATE DRILLED: 08-24-1983 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1733.00 T
TOTAL DRILL HOLE DEPTH: 28 TEST HOLE NUMBER: A2-83-250
WATER RIGHTS WELL: SDGS WELL NAME: A2-83-250
OTHER WELL NAME: CK-HD-15B
BASIN: JAMES AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: PVC, MFG. SCREEN LENGTH: 2.0
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1735.00 T
CASING STICK-UP: 2.00 TOTAL CASING AND SCREEN: 30.3
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160009
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

WASHED CONCRETE SAND AROUND SANDPOINT. SEALED WITH BENTONITE. BACKFILLED TO SURFACE WITH SAND AND BENTONITE.

| | | |
|---|---|---|
| 0 - | 3 | SILT, DARK-BROWN, CLAYEY; MOIST, OXIDIZED (TOPSOIL) |
| 3 - | 16 | CLAY, BROWN, VERY SILTY, SANDY, PEBBLY; MOIST, OXIDIZED, VERY SANDY AT 10 FEET (TILL) |
| 16 - | 28 | CLAY, GRAY, SILTY, SANDY, PEBBLY; MOIST TO SATURATED, UNOXIDIZED (TILL) |

* * * *

COUNTY: HAND LOCATION: 115N-70W-17BBBB 3
LEGAL LOCATION: NW NW NW NW SEC. 17, T. 115 N., R. 70 W.
LATITUDE: 44.4647 LONGITUDE: 99.1732
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: K. THOMPSON DRILLER'S LOG:
GEOLOGIST: S. CRAVENS GEOLOGIST'S LOG: X
DATE DRILLED: 08-24-1983 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1733.00 T
TOTAL DRILL HOLE DEPTH: 53 TEST HOLE NUMBER: A1-83-209
WATER RIGHTS WELL: SDGS WELL NAME: A1-83-209
OTHER WELL NAME: CK-HD-15C
BASIN: JAMES AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: PVC, MFG. SCREEN LENGTH: 2.0
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1736.00 T
CASING STICK-UP: 2.50 TOTAL CASING AND SCREEN: 55.6
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160009
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

WASHED CONCRETE SAND AROUND SANDPOINT. SEALED WITH BENTONITE. BACKFILLED TO SURFACE WITH SAND AND BENTONITE.

| | | |
|---|---|---|
| 0 - | 3 | CLAY, BLACK, SILTY, SANDY (TOPSOIL) |
| 3 - | 16 | CLAY, BROWN, SILTY, SANDY, PEBBLY; MOIST, OXIDIZED (TILL) |
| 16 - | 53 | CLAY, GRAY, SILTY, SANDY, PEBBLY; MOIST, UNOXIDIZED, SATURATED AT 28 FEET (TILL) |

COUNTY: HAND LOCATION: 115N-70W-17BBBB 6
LEGAL LOCATION: NW NW NW NW SEC. 17, T. 115 N., R. 70 W.
LATITUDE: 44.4647 LONGITUDE: 99.1732
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: L. THOMAS DRILLER'S LOG: X
GEOLOGIST: M. JARRETT GEOLOGIST'S LOG:
DATE DRILLED: 09-07-1984 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1733.00 T
TOTAL DRILL HOLE DEPTH: 67 TEST HOLE NUMBER: A2-84-201
WATER RIGHTS WELL: SDGS WELL NAME: A2-84-201
OTHER WELL NAME: CK-HD-15D
BASIN: JAMES AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: SCREEN LENGTH:
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1735.00 T
CASING STICK-UP: 2.50 TOTAL CASING AND SCREEN: 70.3
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160009
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

SHELBIED. NO SCREEN.

| | | |
|---|---|---|
| 0 - | 19 | SAND, BROWN; OXIDIZED, SATURATED AT 6 TO 7 FEET |
| 19 - | 35 | CLAY, GRAY, SILTY, SANDY, PEBBLY; DRY, UNOXIDIZED (TILL) |
| 35 - | 51 | CLAY, GRAY, SILTY, SANDY, PEBBLY; SLIGHTLY SATURATED, UNOXIDIZED (TILL) |
| 51 - | 67 | CLAY, GRAY, SILTY, SANDY, PEBBLY; SLIGHTLY TO FULLY SATURATED, UNOXIDIZED (TILL) |

TULARE AQUIFER UNDERLIES TILL AT 78 TO 115 FEET DEPTH.

* * * *

COUNTY: HAND LOCATION: 110N-68W-22AABB 1
LEGAL LOCATION: NW NW NE NE SEC. 22, T. 110 N., R. 68 W.
LATITUDE: 44.1937 LONGITUDE: 98.5917
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: D. TOMHAVE DRILLER'S LOG:
GEOLOGIST: D. TOMHAVE GEOLOGIST'S LOG: X
DATE DRILLED: 10-19-1983 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1920.00 T
TOTAL DRILL HOLE DEPTH: 13 TEST HOLE NUMBER: A2-83-282
WATER RIGHTS WELL: SDGS WELL NAME: A2-83-282
OTHER WELL NAME: CK-HD-16A
BASIN: JAMES AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: PVC, MFG. SCREEN LENGTH: 2.5
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1923.00 T
CASING STICK-UP: 2.50 TOTAL CASING AND SCREEN: 15.5
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160009
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

WASHED CONCRETE SAND AROUND SANDPOINT. SEALED WITH BENTONITE PELLETS. BACKFILLED TO SURFACE WITH BENTONITE.

| | | |
|---|---|---|
| 0 - | 3 | CLAY, LIGHT-BROWN, SILTY, SANDY, PEBBLY; DRY, OXIDIZED, SOME COARSE PEBBLES (TILL) |
| 3 - | 13 | CLAY, BROWN, SILTY, SANDY, PEBBLY; MOIST, OXIDIZED (TILL) |

* * * *

COUNTY: HAND LOCATION: 110N-68W-22AABB 2
LEGAL LOCATION: NW NW NE NE SEC. 22, T. 110 N., R. 68 W.
LATITUDE: 44.1937 LONGITUDE: 98.5917
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: D. TOMHAVE DRILLER'S LOG:
GEOLOGIST: D. TOMHAVE GEOLOGIST'S LOG: X
DATE DRILLED: 10-19-1983 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1920.00 T
TOTAL DRILL HOLE DEPTH: 23 TEST HOLE NUMBER: A2-83-281
WATER RIGHTS WELL: SDGS WELL NAME: A2-83-281
OTHER WELL NAME: CK-HD-16B
BASIN: JAMES AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: PVC, MFG. SCREEN LENGTH: 2.5
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1923.00 T
CASING STICK-UP: 2.50 TOTAL CASING AND SCREEN: 25.5
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160009
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

WASHED CONCRETE SAND AROUND SANDPOINT. SEALED WITH BENTONITE PELLETS. BACKFILLED TO SURFACE WITH BENTONITE.

| | | |
|---|---|---|
| 0 - | 3 | CLAY, LIGHT-BROWN, SILTY, SANDY, PEBBLY; DRY, OXIDIZED, SOME COARSE PEBBLES (TILL) |
| 3 - | 23 | CLAY, BROWN, SILTY, SANDY, PEBBLY; MOIST, OXIDIZED (TILL) |

* * * *

COUNTY: HAND LOCATION: 110N-68W-22AABB 3
LEGAL LOCATION: NW NW NE NE SEC. 22, T. 110 N., R. 68 W.
LATITUDE: 44.1937 LONGITUDE: 98.5917
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: D. TOMHAVE DRILLER'S LOG:
GEOLOGIST: D. TOMHAVE GEOLOGIST'S LOG: X
DATE DRILLED: 10-19-1983 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1920.00 T
TOTAL DRILL HOLE DEPTH: 33 TEST HOLE NUMBER: A2-83-280
WATER RIGHTS WELL: SDGS WELL NAME: A2-83-280
OTHER WELL NAME: CK-HD-16C
BASIN: JAMES AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: PVC, MFG. SCREEN LENGTH: 2.5
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1923.00 T
CASING STICK-UP: 2.50 TOTAL CASING AND SCREEN: 35.5
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160009
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

WASHED CONCRETE SAND AROUND SANDPOINT. SEALED WITH BENTONITE PELLETS. BACKFILLED TO THE SURFACE WITH BENTONITE.

| | | |
|---|---|---|
| 0 - | 3 | CLAY, LIGHT-BROWN, SILTY, SANDY, PEBBLY; DRY, OXIDIZED (TILL) |
| 3 - | 26 | CLAY, BROWN, SILTY, SANDY, PEBBLY; MOIST, OXIDIZED (TILL) |
| 26 - | 33 | CLAY, GRAY, SILTY, SANDY, PEBBLY; MOIST, UNOXIDIZED (TILL) |

* * * *

COUNTY: HAND LOCATION: 112N-70W-14CCCC 1
LEGAL LOCATION: SW SW SW SW SEC. 14, T. 112 N., R. 70 W.
LATITUDE: 44.3002 LONGITUDE: 99.1331
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: D. TOMHAVE DRILLER'S LOG:
GEOLOGIST: D. TOMHAVE GEOLOGIST'S LOG: X
DATE DRILLED: 10-19-1983 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1812.00 T
TOTAL DRILL HOLE DEPTH: 13 TEST HOLE NUMBER: A2-83-285
WATER RIGHTS WELL: SDGS WELL NAME: A2-83-285
OTHER WELL NAME: CK-HD-17A
BASIN: JAMES AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: PVC, MFG. SCREEN LENGTH: 2.5
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1815.00 T
CASING STICK-UP: 2.50 TOTAL CASING AND SCREEN: 15.5
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160009
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

WASHED CONCRETE SAND AROUND SANDPOINT. SEALED WITH BENTONITE PELLETS. BACKFILLED TO SURFACE WITH BENTONITE.

| | | |
|---|---|---|
| 0 - | 3 | CLAY, BLACK, SILTY, SANDY; DRY (TOPSOIL) |
| 3 - | 6 | CLAY, BROWN, SILTY, SANDY, PEBBLY; DRY, OXIDIZED (TILL) |
| 6 - | 13 | CLAY, BROWN, SILTY, SANDY, PEBBLY; MOIST, OXIDIZED, VERY MOIST AT 12 FEET (TILL) |

* * * *

COUNTY: HAND LOCATION: 112N-70W-14CCCC 2
LEGAL LOCATION: SW SW SW SW SEC. 14, T. 112 N., R. 70 W.
LATITUDE: 44.3002 LONGITUDE: 99.1331
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: D. TOMHAVE DRILLER'S LOG:
GEOLOGIST: D. TOMHAVE GEOLOGIST'S LOG: X
DATE DRILLED: 10-19-1983 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1812.00 T
TOTAL DRILL HOLE DEPTH: 23 TEST HOLE NUMBER: A2-83-284
WATER RIGHTS WELL: SDGS WELL NAME: A2-83-284
OTHER WELL NAME: CK-HD-17B
BASIN: JAMES AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: PVC, MFG. SCREEN LENGTH: 2.5
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1815.00 T
CASING STICK-UP: 2.50 TOTAL CASING AND SCREEN: 25.5
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160009
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

WASHED CONCRETE SAND AROUND SANDPOINT. SEALED WITH BENTONITE PELLETS. BACKFILLED TO SURFACE WITH BENTONITE.

| | | |
|---|---|---|
| 0 - | 3 | CLAY, BLACK, SILTY, SANDY; DRY (TOPSOIL) |
| 3 - | 6 | CLAY, BROWN, SILTY, SANDY, PEBBLY; DRY, OXIDIZED (TILL) |
| 6 - | 23 | CLAY, BROWN, SILTY, SANDY, PEBBLY; MOIST, OXIDIZED, VERY MOIST AT 12 FEET (TILL) |

* * * *

COUNTY: HAND LOCATION: 112N-70W-14CCCC 3
LEGAL LOCATION: SW SW SW SW SEC. 14, T. 112 N., R. 70 W.
LATITUDE: 44.3002 LONGITUDE: 99.1331
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: D. TOMHAVE DRILLER'S LOG:
GEOLOGIST: D. TOMHAVE GEOLOGIST'S LOG: X
DATE DRILLED: 10-19-1983 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1812.00 T
TOTAL DRILL HOLE DEPTH: 33 TEST HOLE NUMBER: A2-83-283
WATER RIGHTS WELL: SDGS WELL NAME: A2-83-283
OTHER WELL NAME: CK-HD-17C
BASIN: JAMES AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: PVC, MFG. SCREEN LENGTH: 2.5
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1815.00 T
CASING STICK-UP: 2.50 TOTAL CASING AND SCREEN: 35.5
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160009
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

WASHED CONCRETE SAND AROUND SANDPOINT. SEALED WITH BENTONITE PELLETS. BACKFILLED TO SURFACE WITH BENTONITE.

| | | |
|---|---|---|
| 0 - | 3 | CLAY, BLACK, SILTY, SANDY; DRY (TOPSOIL) |
| 3 - | 6 | CLAY, BROWN, SILTY, SANDY, PEBBLY; DRY, OXIDIZED (TILL) |
| 6 - | 27 | CLAY, BROWN, SILTY, SANDY, PEBBLY; MOIST, OXIDIZED, VERY MOIST AT 12 FEET (TILL) |
| 27 - | 33 | CLAY, GRAY, SILTY, SANDY, PEBBLY; MOIST, UNOXIDIZED (TILL) |

* * * *

COUNTY: FAULK LOCATION: 117N-70W-31DDDC 1
LEGAL LOCATION: SW SE SE SE SEC. 31, T. 117 N., R. 70 W.
LATITUDE: 44.5350 LONGITUDE: 99.1835
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: D. TOMHAVE DRILLER'S LOG:
GEOLOGIST: D. TOMHAVE GEOLOGIST'S LOG: X
DATE DRILLED: 10-21-1983 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1960.00 T
TOTAL DRILL HOLE DEPTH: 18 TEST HOLE NUMBER: A2-83-300
WATER RIGHTS WELL: SDGS WELL NAME: A2-83-300
OTHER WELL NAME: CK-HD-18A
BASIN: JAMES AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: PVC, MFG. SCREEN LENGTH: 2.5
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1963.00 T
CASING STICK-UP: 2.50 TOTAL CASING AND SCREEN: 20.5
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160007
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

WASHED CONCRETE SAND AROUND SANDPOINT. SEALED WITH BENTONITE PELLETS. BACKFILLED TO SURFACE WITH BENTONITE.

| | | |
|---|---|---|
| 0 - | 2 | CLAY, LIGHT-BROWN, SILTY, SANDY; DRY, OXIDIZED (TOPSOIL) |
| 2 - | 18 | CLAY, DARK-BROWN, SILTY, SANDY, PEBBLY; MOIST, OXIDIZED (TILL) |

* * * *

COUNTY: FAULK LOCATION: 117N-70W-31DDDC 2
LEGAL LOCATION: SW SE SE SE SEC. 31, T. 117 N., R. 70 W.
LATITUDE: 44.5350 LONGITUDE: 99.1835
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: D. TOMHAVE DRILLER'S LOG:
GEOLOGIST: D. TOMHAVE GEOLOGIST'S LOG: X
DATE DRILLED: 10-21-1983 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1960.00 T
TOTAL DRILL HOLE DEPTH: 28 TEST HOLE NUMBER: A2-83-299
WATER RIGHTS WELL: SDGS WELL NAME: A2-83-299
OTHER WELL NAME: CK-HD-18B
BASIN: JAMES AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: PVC, MFG. SCREEN LENGTH: 2.5
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1963.00 T
CASING STICK-UP: 2.50 TOTAL CASING AND SCREEN: 30.5
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160007
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

WASHED CONCRETE SAND AROUND SANDPOINT. SEALED WITH BENTONITE PELLETS. BACKFILLED TO SURFACE WITH BENTONITE.

| | | |
|---|---|---|
| 0 - | 2 | CLAY, LIGHT-BROWN, SILTY, SANDY; DRY, OXIDIZED (TOPSOIL) |
| 2 - | 20 | CLAY, DARK-BROWN, SILTY, SANDY, PEBBLY; MOIST, OXIDIZED (TILL) |
| 20 - | 23 | CLAY, GRAY, SILTY, SANDY, PEBBLY; MOIST, UNOXIDIZED (TILL) |
| 23 - | 28 | CLAY, DARK-BROWN, SILTY, SANDY, PEBBLY; MOIST, OXIDIZED (TILL) |

* * * *

COUNTY: FAULK LOCATION: 117N-70W-31DDDC 3
LEGAL LOCATION: SW SE SE SE SEC. 31, T. 117 N., R. 70 W.
LATITUDE: 44.5350 LONGITUDE: 99.1835
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: D. TOMHAVE DRILLER'S LOG:
GEOLOGIST: D. TOMHAVE GEOLOGIST'S LOG: X
DATE DRILLED: 10-21-1983 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1960.00 T
TOTAL DRILL HOLE DEPTH: 48 TEST HOLE NUMBER: A2-83-298
WATER RIGHTS WELL: SDGS WELL NAME: A2-83-298
OTHER WELL NAME: CK-HD-18C
BASIN: JAMES AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: PVC, MFG. SCREEN LENGTH: 2.5
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1963.00 T
CASING STICK-UP: 2.50 TOTAL CASING AND SCREEN: 50.5
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160007
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

WASHED CONCRETE SAND AROUND SANDPOINT. SEALED WITH BENTONITE PELLETS. BACKFILLED TO SURFACE WITH BENTONITE.

| | | |
|---|---|---|
| 0 - | 2 | CLAY, LIGHT-BROWN, SILTY, SANDY; DRY, OXIDIZED (TOPSOIL) |
| 2 - | 37 | CLAY, DARK-BROWN, SILTY, SANDY, PEBBLY; MOIST, OXIDIZED (TILL) |
| 37 - | 48 | CLAY, DARK-GRAY, SILTY, SANDY, PEBBLY; MOIST, UNOXIDIZED (TILL) |

* * * *

COUNTY: FAULK LOCATION: 117N-70W-31DDDC 4
LEGAL LOCATION: SW SE SE SE SEC. 31, T. 117 N., R. 70 W.
LATITUDE: 44.5350 LONGITUDE: 99.1835
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: L. THOMAS DRILLER'S LOG: X
GEOLOGIST: M. JARRETT GEOLOGIST'S LOG:
DATE DRILLED: 09-05-1984 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1960.00 T
TOTAL DRILL HOLE DEPTH: 67 TEST HOLE NUMBER: A2-84-200
WATER RIGHTS WELL: SDGS WELL NAME: A2-84-200
OTHER WELL NAME: CK-HD-18D
BASIN: JAMES AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: SCREEN LENGTH:
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1962.00 T
CASING STICK-UP: 2.50 TOTAL CASING AND SCREEN: 70.6
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160007
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

SHELBIED. NO SCREEN. NO AQUIFER UNDER THE TILL.

| | | |
|---|---|---|
| 0 - | 19 | CLAY, LIGHT-BROWN, SILTY, SANDY, PEBBLY; DRY, OXIDIZED (TILL) |
| 19 - | 39 | CLAY, DARK-BROWN, SLIGHTLY SILTY, SANDY, PEBBLY; SLIGHTLY MOIST, OXIDIZED (TILL) |
| 39 - | 67 | CLAY, GRAY, SLIGHTLY SILTY, SANDY, PEBBLY; SLIGHTLY MOIST, UNOXIDIZED (TILL) |

219 FEET TO BEDROCK.

* * * *

COUNTY: FAULK                                    LOCATION: 117N-70W-31DDDC 5
LEGAL LOCATION: SW SE SE SE SEC. 31, T. 117 N., R. 70 W.
LATITUDE: 44.5350                                    LONGITUDE: 99.1835
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: L. THOMAS                                    DRILLER'S LOG: X
GEOLOGIST: M. JARRETT                                    GEOLOGIST'S LOG:
DATE DRILLED: 09-05-1984                                    DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1960.00 T
TOTAL DRILL HOLE DEPTH: 98                                    TEST HOLE NUMBER: A2-84-199
WATER RIGHTS WELL:                                    SDGS WELL NAME: A2-84-199
OTHER WELL NAME: CK-HD-18E
BASIN: JAMES                                    AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE:                                    SCREEN LENGTH:
CASING TYPE: PVC                                    CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1962.00 T
CASING STICK-UP: 2.50                                    TOTAL CASING AND SCREEN: 99.4
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160009
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL:                                    SINGLE POINT RESISTIVITY:
NATURAL GAMMA:                                    EXTRA:
SAMPLES:

SHELBY SAMPLE TAKEN.

| | | |
|---|---|---|
| 0 - | 19 | CLAY, LIGHT-BROWN, SILTY, SANDY, PEBBLY; DRY, OXIDIZED (TILL) |
| 19 - | 39 | CLAY, DARK-BROWN, BECOMING DARKER WITH DEPTH, SILTY, SANDY, PEBBLY; DRY, OXIDIZED |
| 39 - | 49 | CLAY, GRAY-BROWN, GRADING TO GRAY, SILTY, SANDY, PEBBLY; SLIGHTLY MOIST, UNOXIDIZED (TILL) |
| 49 - | 56 | CLAY, GRAY-BROWN, VERY SILTY, SANDY; SATURATED, UNOXIDIZED (TILL) |
| 56 - | 58 | CLAY, GRAY, VERY SILTY, PEBBLY; PARTIALLY SATURATED, UNOXIDIZED (TILL) |
| 58 - | 98 | CLAY, DARK-GRAY, GRADES TO BLUE-GRAY WITH DEPTH, SLIGHTLY SILTY, SANDY, PEBBLY; SLIGHTLY MOIST, UNOXIDIZED (TILL) |

* * * *

COUNTY: HYDE LOCATION: 115N-71W-13BBBB 2
LEGAL LOCATION: NW NW NW NW SEC. 13, T. 115 N., R. 71 W.
LATITUDE: 44.4648 LONGITUDE: 99.1954
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: M. YESKE DRILLER'S LOG:
GEOLOGIST: S. CRAVENS GEOLOGIST'S LOG: X
DATE DRILLED: 08-23-1983 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1749.00 T
TOTAL DRILL HOLE DEPTH: 18 TEST HOLE NUMBER: A2-83-249
WATER RIGHTS WELL: SDGS WELL NAME: A2-83-249
OTHER WELL NAME: CK-HY-1A
BASIN: JAMES AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: PVC, MFG. SCREEN LENGTH: 2.0
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1752.00 T
CASING STICK-UP: 2.50 TOTAL CASING AND SCREEN: 20.5
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160009
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

WASHED CONCRETE SAND AROUND SANDPOINT. SEALED WITH BENTONITE. BACKFILLED TO SURFACE WITH SAND AND BENTONITE.

| | | |
|---|---|---|
| 0 - | 1 | CLAY, DARK-BROWN, SILTY; MOIST (TOPSOIL) |
| 1 - | 18 | CLAY, TAN, SILTY; MOIST, OXIDIZED (TILL) |

* * * *

COUNTY: HYDE LOCATION: 115N-71W-13BBBB 3
LEGAL LOCATION: NW NW NW NW SEC. 13, T. 115 N., R. 71 W.
LATITUDE: 44.4648 LONGITUDE: 99.1954
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: C. SINGH DRILLER'S LOG:
GEOLOGIST: S. CRAVENS GEOLOGIST'S LOG: X
DATE DRILLED: 08-23-1983 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1749.00 T
TOTAL DRILL HOLE DEPTH: 33 TEST HOLE NUMBER: A1-83-208
WATER RIGHTS WELL: SDGS WELL NAME: A1-83-208
OTHER WELL NAME: CK-HY-1B
BASIN: JAMES AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: PVC, MFG. SCREEN LENGTH: 2.0
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1751.00 T
CASING STICK-UP: 2.40 TOTAL CASING AND SCREEN: 35.3
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160009
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

WASHED CONCRETE SAND AROUND SANDPOINT. SEALED WITH BENTONITE. BACKFILLED TO SURFACE WITH SAND AND BENTONITE.

| | | |
|---|---|---|
| 0 - | 1 | CLAY, BROWN, SILTY, SANDY; DRY, OXIDIZED (TOPSOIL) |
| 1 - | 33 | CLAY, BROWN, SILTY, SANDY, PEBBLY; DRY, OXIDIZED, MOIST AT 6 FEET (TILL) |

* * * *

COUNTY: HYDE LOCATION: 115N-71W-13BBBB 4
LEGAL LOCATION: NW NW NW NW SEC. 13, T. 115 N., R. 71 W.
LATITUDE: 44.4648 LONGITUDE: 99.1954
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: M. YESKE DRILLER'S LOG:
GEOLOGIST: S. CRAVENS GEOLOGIST'S LOG: X
DATE DRILLED: 08-23-1983 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1749.00 T
TOTAL DRILL HOLE DEPTH: 48 TEST HOLE NUMBER: A2-83-248
WATER RIGHTS WELL: SDGS WELL NAME: A2-83-248
OTHER WELL NAME: CK-HY-1C
BASIN: JAMES AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: PVC, MFG. SCREEN LENGTH: 2.0
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1752.00 T
CASING STICK-UP: 2.50 TOTAL CASING AND SCREEN: 50.6
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160009
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

WASHED CONCRETE SAND AROUND SANDPOINT. SEALED WITH BENTONITE. BACKFILLED TO SURFACE WITH SAND AND BENTONITE.

| | | |
|---|---|---|
| 0 - | 1 | SILT, DARK-BROWN, CLAYEY; MOIST, OXIDIZED (TOPSOIL) |
| 1 - | 4 | CLAY, TAN, SILTY, SANDY, PEBBLY; MOIST, OXIDIZED (TILL) |
| 4 - | 38 | CLAY, BROWN, SILTY, SANDY, PEBBLY; MOIST, OXIDIZED (TILL) |
| 38 - | 48 | CLAY, GRAY, SILTY, SANDY, PEBBLY; VERY MOIST, UNOXIDIZED (TILL) |

* * * *

COUNTY: HYDE LOCATION: 115N-71W-15BBBB 1
LEGAL LOCATION: NW NW NW NW SEC. 15, T. 115 N., R. 71 W.
LATITUDE: 44.4648 LONGITUDE: 99.2221
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: K. THOMPSON DRILLER'S LOG:
GEOLOGIST: S. CRAVENS GEOLOGIST'S LOG: X
DATE DRILLED: 08-23-1983 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1759.00 T
TOTAL DRILL HOLE DEPTH: 18 TEST HOLE NUMBER: A1-83-207
WATER RIGHTS WELL: SDGS WELL NAME: A1-83-207
OTHER WELL NAME: CK-HY-2A
BASIN: JAMES AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: PVC, MFG. SCREEN LENGTH: 2.0
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1762.00 T
CASING STICK-UP: 2.50 TOTAL CASING AND SCREEN: 20.5
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160009
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

WASHED CONCRETE SAND AROUND SANDPOINT. SEALED WITH BENTONITE. BACKFILLED TO SURFACE WITH SAND AND BENTONITE.

| | | |
|---|---|---|
| 0 - | 3 | CLAY, BROWN, SILTY, SANDY, PEBBLY; DRY, OXIDIZED (TOPSOIL) |
| 3 - | 18 | CLAY, BROWN, SILTY, SANDY, PEBBLY; MOIST, OXIDIZED (TILL) |

* * * *

COUNTY: HYDE LOCATION: 115N-71W-15BBBB 2
LEGAL LOCATION: NW NW NW NW SEC. 15, T. 115 N., R. 71 W.
LATITUDE: 44.4648 LONGITUDE: 99.2221
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: C. SINGH DRILLER'S LOG:
GEOLOGIST: S. CRAVENS GEOLOGIST'S LOG: X
DATE DRILLED: 08-23-1983 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1759.00 1
TOTAL DRILL HOLE DEPTH: 28 TEST HOLE NUMBER: A1-83-206
WATER RIGHTS WELL: SDGS WELL NAME: A1-83-206
OTHER WELL NAME: CK-HY-2B
BASIN: JAMES AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: PVC, MFG. SCREEN LENGTH: 2.0
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1762.00 T
CASING STICK-UP: 2.70 TOTAL CASING AND SCREEN: 30.5
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160009
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

WASHED CONCRETE SAND AROUND SANDPOINT. SEALED WITH BENTONITE. BACKFILLED TO SURFACE WITH SAND AND BENTONITE.

0 - 28 CLAY, BROWN, SILTY, SANDY, PEBBLY; MOIST, OXIDIZED (TILL)

* * * *

COUNTY: HYDE LOCATION: 115N-71W-15BBBB 3
LEGAL LOCATION: NW NW NW NW SEC. 15, T. 115 N., R. 71 W.
LATITUDE: 44.4648 LONGITUDE: 99.2221
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: M. YESKE DRILLER'S LOG:
GEOLOGIST: S. CRAVENS GEOLOGIST'S LOG: X
DATE DRILLED: 08-23-1983 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1759.00 T
TOTAL DRILL HOLE DEPTH: 48 TEST HOLE NUMBER: A2-83-247
WATER RIGHTS WELL: SDGS WELL NAME: A2-83-247
OTHER WELL NAME: CK-HY-2C
BASIN: JAMES AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: PVC, MFG. SCREEN LENGTH: 2.0
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1761.00 T
CASING STICK-UP: 2.20 TOTAL CASING AND SCREEN: 42.0
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160009
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

WASHED CONCRETE SAND AROUND SANDPOINT. SEALED WITH BENTONITE. BACKFILLED TO SURFACE WITH SAND AND BENTONITE.

| | | |
|---|---|---|
| 0 - | 42 | CLAY, BROWN, SILTY, SANDY, PEBBLY; MOIST, OXIDIZED (TILL) |
| 42 - | 48 | CLAY, GRAY, SILTY, SANDY, PEBBLY; MOIST, UNOXIDIZED (TILL) |

* * * *

COUNTY: HYDE LOCATION: 115N-72W-10CCCC 1
LEGAL LOCATION: SW SW SW SW SEC. 10, T. 115 N., R. 72 W.
LATITUDE: 44.4648 LONGITUDE: 99.2928
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: K. THOMPSON DRILLER'S LOG:
GEOLOGIST: S. CRAVENS GEOLOGIST'S LOG: X
DATE DRILLED: 08-23-1983 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1807.00 T
TOTAL DRILL HOLE DEPTH: 28 TEST HOLE NUMBER: A1-83-203
WATER RIGHTS WELL: SDGS WELL NAME: A1-83-203
OTHER WELL NAME: CK-HY-3A
BASIN: JAMES AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: PVC, MFG. SCREEN LENGTH: 2.0
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1810.00 T
CASING STICK-UP: 2.50 TOTAL CASING AND SCREEN: 27.9
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160009
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

WASHED CONCRETE SAND AROUND SANDPOINT. SEALED AND BACKFILLED TO SURFACE WITH BENTONITE.

| | | |
|---|---|---|
| 0 - | 3 | SILT, BROWN, CLAYEY, SANDY, PEBBLY; MOIST, OXIDIZED (TOPSOIL) |
| 3 - | 28 | CLAY, BROWN, SILTY, SANDY, PEBBLY; MOIST, OXIDIZED, VERY MOIST AT 21 FEET (TILL) |

* * * *

COUNTY: HYDE LOCATION: 115N-72W-10CCCC 3
LEGAL LOCATION: SW SW SW SW SEC. 10, T. 115 N., R. 72 W.
LATITUDE: 44.4648 LONGITUDE: 99.2928
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: L. THOMAS DRILLER'S LOG: X
GEOLOGIST: S. CRAVENS GEOLOGIST'S LOG:
DATE DRILLED: 06-20-1984 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1807.00 T
TOTAL DRILL HOLE DEPTH: 15 TEST HOLE NUMBER: A1-84-143
WATER RIGHTS WELL: SDGS WELL NAME: A1-84-143
OTHER WELL NAME: CK-HY-3A2
BASIN: JAMES AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: PVC, MFG. SCREEN LENGTH: 2.0
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1809.50 T
CASING STICK-UP: 2.50 TOTAL CASING AND SCREEN: 18.2
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160009
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

WASHED CONCRETE SAND AROUND SANDPOINT. SEALED AND BACKFILLED TO SURFACE WITH BENTONITE.

0 - 15 CLAY, BROWN, SILTY, SANDY, PEBBLY; MOIST, OXIDIZED (TILL)

* * * *

COUNTY: HYDE LOCATION: 115N-72W-10CCCC 2
LEGAL LOCATION: SW SW SW SW SEC. 10, T. 115 N., R. 72 W.
LATITUDE: 44.4648 LONGITUDE: 99.2928
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: M. YESKE DRILLER'S LOG:
GEOLOGIST: S. CRAVENS GEOLOGIST'S LOG: X
DATE DRILLED: 08-23-1983 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1807.00 T
TOTAL DRILL HOLE DEPTH: 43 TEST HOLE NUMBER: A2-83-244
WATER RIGHTS WELL: SDGS WELL NAME: A2-83-244
OTHER WELL NAME: CK-HY-3B
BASIN: JAMES AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: PVC, MFG. SCREEN LENGTH: 2.0
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1810.00 T
CASING STICK-UP: 2.50 TOTAL CASING AND SCREEN: 45.9
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160009
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

WASHED CONCRETE SAND AROUND SANDPOINT. SEALED AND BACKFILLED TO SURFACE WITH BENTONITE.

| | | |
|---|---|---|
| 0 - | 1 | SILT, DARK-BROWN, CLAYEY; MOIST (TOPSOIL) |
| 1 - | 4 | CLAY, LIGHT-BROWN, SILTY, SANDY, PEBBLY; MOIST, OXIDIZED (TILL) |
| 4 - | 33 | CLAY, BROWN, SILTY, SANDY, PEBBLY; MOIST, OXIDIZED (TILL) |
| 33 - | 43 | CLAY, BROWNISH-GRAY, SILTY, SANDY, PEBBLY; VERY MOIST, SLIGHTLY OXIDIZED TO UNOXIDIZED (TILL) |

* * * *

COUNTY: HYDE LOCATION: 115N-72W-10CCCC 4
LEGAL LOCATION: SW SW SW SW SEC. 10, T. 115 N., R. 72 W.
LATITUDE: 44.4648 LONGITUDE: 99.2928
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: L. THOMAS DRILLER'S LOG: X
GEOLOGIST: M. JARRETT GEOLOGIST'S LOG:
DATE DRILLED: 09-05-1984 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1807.00 T
TOTAL DRILL HOLE DEPTH: 78 TEST HOLE NUMBER: A2-84-198
WATER RIGHTS WELL: SDGS WELL NAME: A2-84-198
OTHER WELL NAME: CK-HY-3D
BASIN: JAMES AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: SCREEN LENGTH:
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1809.00 T
CASING STICK-UP: 2.50 TOTAL CASING AND SCREEN: 71.0
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160009
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

NO SCREEN.

| | | |
|---|---|---|
| 0 - | 25 | CLAY, BROWN, SILTY, SANDY, PEBBLY; MOIST, OXIDIZED (TILL) |
| 25 - | 27 | SAND, BROWN; SATURATED, OXIDIZED |
| 27 - | 31 | CLAY, BROWN, SILTY, SANDY, PEBBLY; MOIST, OXIDIZED (TILL) |
| 31 - | 37 | CLAY, GRAY, SILTY, SANDY, PEBBLY; VERY MOIST, UNOXIDIZED (TILL) |
| 37 - | 78 | CLAY, GRAY, VERY SANDY, VERY SILTY, PEBBLY; SATURATED, UNOXIDIZED (TILL) |

SHELBIED INTO CLAYEY SAND AT 78 FEET; GRAY UNOXIDIZED. TULARE AQUIFER UNDERLIES TILL AT 128 TO 140 FEET DEPTH. POSSIBLE PERMEABLE DEPOSITS BEGINNING AT 87 FEET.

* * * *

COUNTY: HYDE LOCATION: 115N-72W-07DDDD 1
LEGAL LOCATION: SE SE SE SE SEC. 07, T. 115 N., R. 72 W.
LATITUDE: 44.4648 LONGITUDE: 99.3155
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: T. STACK DRILLER'S LOG:
GEOLOGIST: S. CRAVENS GEOLOGIST'S LOG: X
DATE DRILLED: 08-23-1983 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1822.00 T
TOTAL DRILL HOLE DEPTH: 18 TEST HOLE NUMBER: A2-83-246
WATER RIGHTS WELL: SDGS WELL NAME: A2-83-246
OTHER WELL NAME: CK-HY-4A
BASIN: JAMES AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: PVC, MFG. SCREEN LENGTH: 2.0
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1825.00 T
CASING STICK-UP: 2.30 TOTAL CASING AND SCREEN: 20.3
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160009
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

WASHED CONCRETE SAND AROUND SANDPOINT. SEALED WITH BENTONITE PELLETS. BACKFILLED TO SURFACE WITH SAND AND BENTONITE.

| | | |
|---|---|---|
| 0 - | 1 | SILT, DARK-BROWN, CLAYEY (TOPSOIL) |
| 1 - | 2 | CLAY, LIGHT-BROWN, SILTY; MOIST, OXIDIZED |
| 2 - | 16 | CLAY, VERY LIGHT-BROWN, SILTY, SANDY, PEBBLY; MOIST, OXIDIZED (TILL) |
| 16 - | 18 | CLAY, LIGHT-GRAYISH-BROWN, SILTY, SANDY, PEBBLY; MOIST, SLIGHTLY OXIDIZED (TILL) |

* * * *

COUNTY: HYDE LOCATION: 115N-72W-07DDDD 5
LEGAL LOCATION: SE SE SE SE SEC. 07, T. 115 N., R. 72 W.
LATITUDE: 44.4648 LONGITUDE: 99.3155
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: L. THOMAS DRILLER'S LOG: X
GEOLOGIST: S. CRAVENS GEOLOGIST'S LOG:
DATE DRILLED: 06-20-1984 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1822.00 T
TOTAL DRILL HOLE DEPTH: 13 TEST HOLE NUMBER: A1-84-144
WATER RIGHTS WELL: SDGS WELL NAME: A1-84-144
OTHER WELL NAME: CK-HY-4A2
BASIN: JAMES AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: PVC, MFG. SCREEN LENGTH: 2.0
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1824.00 T
CASING STICK-UP: 2.00 TOTAL CASING AND SCREEN: 14.4
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160009
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

WASHED CONCRETE SAND AROUND SANDPOINT. SEALED WITH BENTONITE AT 2 FEET DUE TO BRIDGING.

0 - 13 CLAY, BROWN, SILTY, SANDY, PEBBLY; SATURATED FROM 2 FEET, OXIDIZED (TILL)

* * * *

COUNTY: HYDE                                    LOCATION: 115N-72W-07DDDD 2
LEGAL LOCATION: SE SE SE SE SEC. 07, T. 115 N., R. 72 W.
LATITUDE: 44.4648                                        LONGITUDE: 99.3155
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: K. THOMPSON                                           DRILLER'S LOG:
GEOLOGIST: S. CRAVENS                                        GEOLOGIST'S LOG: X
DATE DRILLED: 08-23-1983                         DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1822.00 T
TOTAL DRILL HOLE DEPTH: 28              TEST HOLE NUMBER: A1-83-205
WATER RIGHTS WELL:                               SDGS WELL NAME: A1-83-205
OTHER WELL NAME: CK-HY-4B
BASIN: JAMES                                AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: PVC, MFG.                                  SCREEN LENGTH: 2.0
CASING TYPE: PVC                                      CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1825.00 T
CASING STICK-UP: 2.50                   TOTAL CASING AND SCREEN: 30.5
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160009
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL:                            SINGLE POINT RESISTIVITY:
NATURAL GAMMA:                                                       EXTRA:
SAMPLES:

WASHED CONCRETE SAND AROUND SANDPOINT. SEALED WITH BENTONITE PELLETS. BACKFILLED TO SURFACE WITH SAND AND BENTONITE.

| | | |
|---|---|---|
| 0 - | 17 | CLAY, YELLOWISH-BROWN, VERY SILTY, SANDY, PEBBLY; MOIST, OXIDIZED, VERY MOIST AT 6 FEET (TILL) |
| 17 - | 28 | CLAY, BROWNISH-GRAY, SILTY, SANDY, PEBBLY; MOIST, SLIGHTLY OXIDIZED TO UNOXIDIZED (TILL) |

* * * *

COUNTY: HYDE LOCATION: 115N-72W-07DDDD 3
LEGAL LOCATION: SE SE SE SE SEC. 07, T. 115 N., R. 72 W.
LATITUDE: 44.4648 LONGITUDE: 99.3155
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: M. YESKE DRILLER'S LOG:
GEOLOGIST: S. CRAVENS GEOLOGIST'S LOG: X
DATE DRILLED: 08-23-1983 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1822.00 T
TOTAL DRILL HOLE DEPTH: 38 TEST HOLE NUMBER: A2-83-245
WATER RIGHTS WELL: SDGS WELL NAME: A2-83-245
OTHER WELL NAME: CK-HY-4C
BASIN: JAMES AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: PVC, MFG. SCREEN LENGTH: 2.0
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1825.00 T
CASING STICK-UP: 2.50 TOTAL CASING AND SCREEN: 40.8
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160009
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

WASHED CONCRETE SAND AROUND SANDPOINT. SEALED AND BACKFILLED TO SURFACE WITH BENTONITE.

| | | |
|---|---|---|
| 0 - | 1 | CLAY, DARK-BROWN, SILTY, SANDY; MOIST (TOPSOIL) |
| 1 - | 2 | CLAY, VERY LIGHT-BROWN, SILTY; MOIST, OXIDIZED |
| 2 - | 16 | CLAY, TAN, VERY SILTY, SANDY, PEBBLY; MOIST, OXIDIZED (TILL) |
| 16 - | 38 | CLAY, BROWNISH-GRAY, VERY SILTY, SANDY, PEBBLY; MOIST, SLIGHTLY OXIDIZED TO UNOXIDIZED (TILL) |

* * * *

COUNTY: HYDE LOCATION: 114N-72W-36CCCC 1
LEGAL LOCATION: SW SW SW SW SEC. 36, T. 114 N., R. 72 W.
LATITUDE: 44.3805 LONGITUDE: 99.2707
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: D. TOMHAVE DRILLER'S LOG:
GEOLOGIST: D. TOMHAVE GEOLOGIST'S LOG: X
DATE DRILLED: 10-19-1983 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1710.00 T
TOTAL DRILL HOLE DEPTH: 13 TEST HOLE NUMBER: A2-83-288
WATER RIGHTS WELL: SDGS WELL NAME: A2-83-288
OTHER WELL NAME: CK-HY-5A
BASIN: JAMES AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: PVC, MFG. SCREEN LENGTH: 2.5
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1713.00 T
CASING STICK-UP: 2.50 TOTAL CASING AND SCREEN: 15.5
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160009
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

WASHED CONCRETE SAND AROUND SANDPOINT. SEALED WITH BENTONITE PELLETS. BACKFILLED TO SURFACE WITH BENTONITE.

| | | |
|---|---|---|
| 0 - | 2 | CLAY, BROWN, SILTY, SANDY; DRY, OXIDIZED (TOPSOIL) |
| 2 - | 13 | CLAY, BROWN, SILTY, SANDY, PEBBLY; MOIST, OXIDIZED (TILL) |

* * * *

COUNTY: HYDE LOCATION: 114N-72W-36CCCC 2
LEGAL LOCATION: SW SW SW SW SEC. 36, T. 114 N., R. 72 W.
LATITUDE: 44.3805 LONGITUDE: 99.2707
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: D. TOMHAVE DRILLER'S LOG:
GEOLOGIST: D. TOMHAVE GEOLOGIST'S LOG: X
DATE DRILLED: 10-19-1983 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1710.00 T
TOTAL DRILL HOLE DEPTH: 28 TEST HOLE NUMBER: A2-83-287
WATER RIGHTS WELL: SDGS WELL NAME: A2-83-287
OTHER WELL NAME: CK-HY-5B
BASIN: JAMES AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: PVC, MFG. SCREEN LENGTH: 2.5
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1713.00 T
CASING STICK-UP: 2.50 TOTAL CASING AND SCREEN: 30.5
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160009
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

WASHED CONCRETE SAND AROUND SANDPOINT. SEALED WITH BENTONITE PELLETS. BACKFILLED TO SURFACE WITH BENTONITE.

| | | |
|---|---|---|
| 0 - | 2 | CLAY, BROWN, SILTY, SANDY; DRY, OXIDIZED (TOPSOIL) |
| 2 - | 28 | CLAY, BROWN, SILTY, SANDY, PEBBLY; MOIST, OXIDIZED (TILL) |

* * * *

COUNTY: HYDE LOCATION: 114N-72W-36CCCC 3
LEGAL LOCATION: SW SW SW SW SEC. 36, T. 114 N., R. 72 W.
LATITUDE: 44.3805 LONGITUDE: 99.2707
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: D. TOMHAVE DRILLER'S LOG:
GEOLOGIST: D. TOMHAVE GEOLOGIST'S LOG: X
DATE DRILLED: 10-19-1983 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1710.00 T
TOTAL DRILL HOLE DEPTH: 43 TEST HOLE NUMBER: A2-83-286
WATER RIGHTS WELL: SDGS WELL NAME: A2-83-286
OTHER WELL NAME: CK-HY-5C
BASIN: JAMES AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: PVC, MFG. SCREEN LENGTH: 2.5
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1713.00 T
CASING STICK-UP: 2.50 TOTAL CASING AND SCREEN: 45.5
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160009
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

WASHED CONCRETE SAND AROUND SANDPOINT. SEALED WITH BENTONITE PELLETS. BACKFILLED TO SURFACE WITH BENTONITE.

| | | |
|---|---|---|
| 0 - | 2 | CLAY, BROWN, SILTY, SANDY; DRY, OXIDIZED (TOPSOIL) |
| 2 - | 34 | CLAY, BROWN, SILTY, SANDY, PEBBLY; MOIST, OXIDIZED (TILL) |
| 34 - | 43 | CLAY, GRAY, SILTY, SANDY, PEBBLY; MOIST, UNOXIDIZED (TILL) |

* * * *

COUNTY: HYDE LOCATION: 114N-72W-36CCCC 4
LEGAL LOCATION: SW SW SW SW SEC. 36, T. 114 N., R. 72 W.
LATITUDE: 44.3805 LONGITUDE: 99.2707
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: L. THOMAS DRILLER'S LOG: X
GEOLOGIST: M. JARRETT GEOLOGIST'S LOG:
DATE DRILLED: 08-29-1984 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1710.00 T
TOTAL DRILL HOLE DEPTH: 67 TEST HOLE NUMBER: A2-84-194
WATER RIGHTS WELL: SDGS WELL NAME: A2-84-194
OTHER WELL NAME: CK-HY-5D
BASIN: JAMES AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: SCREEN LENGTH:
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1712.00 T
CASING STICK-UP: 2.50 TOTAL CASING AND SCREEN: 70.6
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160009
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

NO SCREEN.

| | | |
|---|---|---|
| 0 - | 1 | CLAY, BLACK, SILTY, SANDY (TOPSOIL) |
| 1 - | 15 | CLAY, GRAY-BROWN, SILTY, SANDY, PEBBLY; OXIDIZED (TILL) |
| 15 - | 26 | CLAY, BROWN, SILTY, SANDY, PEBBLY; OXIDIZED (TILL) |
| 26 - | 36 | CLAY, GRAY-BROWN, SILTY, SANDY, PEBBLY; MOIST, OXIDIZED (TILL) |
| 36 - | 40 | CLAY, OLIVE-GREEN TO GRAY, SILTY, SANDY, PEBBLY; MOIST, UNOXIDIZED (TILL) |
| 40 - | 67 | CLAY, GRAY, SILTY, SANDY, PEBBLY; MOIST, UNOXIDIZED (TILL) |

SHELBIED ONE FOOT INTO TILL. ONE-HALF-INCH SAND AT BOTTOM OF SHELBY. NO AQUIFER UNDER THE TILL. 222 FEET TO BEDROCK.

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COUNTY: HYDE LOCATION: 114N-72W-36CCCC 5
LEGAL LOCATION: SW SW SW SW SEC. 36, T. 114 N., R. 72 W.
LATITUDE: 44.3805 LONGITUDE: 99.2707
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: S. MITCHELL DRILLER'S LOG: X
GEOLOGIST: M. JARRETT GEOLOGIST'S LOG:
DATE DRILLED: 08-29-1984 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1710.00 T
TOTAL DRILL HOLE DEPTH: 97 TEST HOLE NUMBER: A2-84-195
WATER RIGHTS WELL: SDGS WELL NAME: A2-84-195
OTHER WELL NAME: CK-HY-5E
BASIN: JAMES AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: SCREEN LENGTH:
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1712.00 T
CASING STICK-UP: 2.50 TOTAL CASING AND SCREEN: 99.6
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160009
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

| | | |
|---|---|---|
| 0 - | 1 | CLAY, BLACK, SILTY, SANDY (TOPSOIL) |
| 1 - | 36 | CLAY, GRAY-BROWN, SILTY, SANDY, PEBBLY; OXIDIZED, MOIST (TILL) |
| 36 - | 40 | CLAY, OLIVE-GREEN TO GRAY, SILTY, SANDY, PEBBLY; MOIST, OXIDIZED(?) (TILL) |
| 40 - | 75 | CLAY, GRAY, SILTY, SANDY, PEBBLY; MOIST, UNOXIDIZED (TILL) |
| 75 - | 97 | CLAY, GRAY, VERY SILTY, SANDY, PEBBLY; VERY MOIST, UNOXIDIZED (TILL) |

* * * *

COUNTY: HYDE LOCATION: 114N-73W-03CCCC 1
LEGAL LOCATION: SW SW SW SW SEC. 03, T. 114 N., R. 73 W.
LATITUDE: 44.4227 LONGITUDE: 99.3649
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: D. TOMHAVE DRILLER'S LOG:
GEOLOGIST: D. TOMHAVE GEOLOGIST'S LOG: X
DATE DRILLED: 10-20-1983 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1781.00 T
TOTAL DRILL HOLE DEPTH: 13 TEST HOLE NUMBER: A2-83-291
WATER RIGHTS WELL: SDGS WELL NAME: A2-83-291
OTHER WELL NAME: CK-HY-6A
BASIN: JAMES AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: PVC, MFG. SCREEN LENGTH: 2.5
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1784.00 T
CASING STICK-UP: 2.50 TOTAL CASING AND SCREEN: 15.5
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160009
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

WASHED CONCRETE SAND AROUND SANDPOINT. SEALED WITH BENTONITE PELLETS. BACKFILLED TO SURFACE WITH BENTONITE.

| | | |
|---|---|---|
| 0 - | 4 | CLAY, LIGHT-BROWN, SILTY, SANDY; DRY, OXIDIZED |
| 4 - | 13 | CLAY, BROWN, SILTY, SANDY, PEBBLY; MOIST, OXIDIZED (TILL) |

* * * *

COUNTY: HYDE LOCATION: 114N-73W-03CCCC 2
LEGAL LOCATION: SW SW SW SW SEC. 03, T. 114 N., R. 73 W.
LATITUDE: 44.4227 LONGITUDE: 99.3649
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: D. TOMHAVE DRILLER'S LOG:
GEOLOGIST: D. TOMHAVE GEOLOGIST'S LOG: X
DATE DRILLED: 10-20-1983 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1781.00 T
TOTAL DRILL HOLE DEPTH: 23 TEST HOLE NUMBER: A2-83-290
WATER RIGHTS WELL: SDGS WELL NAME: A2-83-290
OTHER WELL NAME: CK-HY-6B
BASIN: JAMES AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: PVC, MFG. SCREEN LENGTH: 2.5
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1784.00 T
CASING STICK-UP: 2.50 TOTAL CASING AND SCREEN: 25.5
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160009
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

WASHED CONCRETE SAND AROUND SANDPOINT. SEALED WITH BENTONITE PELLETS. BACKFILLED TO SURFACE WITH BENTONITE.

| | | |
|---|---|---|
| 0 - | 4 | CLAY, LIGHT-BROWN, SILTY, SANDY; DRY, OXIDIZED |
| 4 - | 20 | CLAY, BROWN, SILTY, SANDY, PEBBLY; MOIST, OXIDIZED (TILL) |
| 20 - | 23 | CLAY, GRAY, SILTY, SANDY, PEBBLY; MOIST, UNOXIDIZED (TILL) |

* * * *

COUNTY: HYDE LOCATION: 114N-73W-03CCCC 4
LEGAL LOCATION: SW SW SW SW SEC. 03, T. 114 N., R. 73 W.
LATITUDE: 44.4227 LONGITUDE: 99.3649
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: L. THOMAS DRILLER'S LOG:
GEOLOGIST: S. CRAVENS GEOLOGIST'S LOG: X
DATE DRILLED: 06-20-1984 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1781.00 T
TOTAL DRILL HOLE DEPTH: 28 TEST HOLE NUMBER: A1-84-145
WATER RIGHTS WELL: SDGS WELL NAME: A1-84-145
OTHER WELL NAME: CK-HY-6B2
BASIN: JAMES AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: PVC, MFG. SCREEN LENGTH: 2.5
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1783.00 T
CASING STICK-UP: 2.00 TOTAL CASING AND SCREEN: 30.0
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160009
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

WASHED CONCRETE SAND AROUND SANDPOINT. SEALED AND BACKFILLED WITH BENTONITE.

| | | |
|---|---|---|
| 0 - | 20 | CLAY, BROWN, SILTY, SANDY, PEBBLY; MOIST, OXIDIZED (TILL) |
| 20 - | 28 | CLAY, GRAY, SILTY, SANDY, PEBBLY; MOIST, UNOXIDIZED (TILL) |

* * * *

COUNTY: HYDE LOCATION: 114N-73W-03CCCC 3
LEGAL LOCATION: SW SW SW SW SEC. 03, T. 114 N., R. 73 W.
LATITUDE: 44.4227 LONGITUDE: 99.3649
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: D. TOMHAVE DRILLER'S LOG:
GEOLOGIST: D. TOMHAVE GEOLOGIST'S LOG: X
DATE DRILLED: 10-20-1983 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1781.00 T
TOTAL DRILL HOLE DEPTH: 33 TEST HOLE NUMBER: A2-83-289
WATER RIGHTS WELL: SDGS WELL NAME: A2-83-289
OTHER WELL NAME: CK-HY-6C
BASIN: JAMES AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: PVC, MFG. SCREEN LENGTH: 2.5
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1784.00 T
CASING STICK-UP: 2.50 TOTAL CASING AND SCREEN: 35.5
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160009
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

WASHED CONCRETE SAND AROUND SANDPOINT. SEALED WITH BENTONITE PELLETS. BACKFILLED TO SURFACE WITH BENTONITE.

| | | |
|---|---|---|
| 0 - | 4 | CLAY, LIGHT-BROWN, SILTY, SANDY; DRY, OXIDIZED |
| 4 - | 20 | CLAY, BROWN, SILTY, SANDY, PEBBLY; MOIST, OXIDIZED (TILL) |
| 20 - | 33 | CLAY, GRAY, SILTY, SANDY, PEBBLY; MOIST, UNOXIDIZED (TILL) |

* * * *

COUNTY: HYDE LOCATION: 114N-73W-03CCCC 5
LEGAL LOCATION: SW SW SW SW SEC. 03, T. 114 N., R. 73 W.
LATITUDE: 44.4227 LONGITUDE: 99.3649
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: L. THOMAS DRILLER'S LOG: X
GEOLOGIST: M. JARRETT GEOLOGIST'S LOG:
DATE DRILLED: 09-04-1984 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1781.00 T
TOTAL DRILL HOLE DEPTH: 67 TEST HOLE NUMBER: A2-84-196
WATER RIGHTS WELL: SDGS WELL NAME: A2-84-196
OTHER WELL NAME: CK-HY-6D
BASIN: JAMES AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: SCREEN LENGTH:
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1783.00 T
CASING STICK-UP: 2.50 TOTAL CASING AND SCREEN: 71.4
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160009
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

NO AQUIFER. NO SCREEN.

| | | |
|---|---|---|
| 0 - | 33 | CLAY, BROWN, SILTY, SANDY, PEBBLY; DRY TO MOIST, OXIDIZED (TILL) |
| 33 - | 65 | CLAY, BROWN-GRAY, GRADING TO DARK GRAY, SILTY, SANDY, PEBBLY; DRY TO MOIST, UNOXIDIZED (TILL) |
| 65 - | 67 | CLAY, DARK-GRAY, SILTY, SANDY, PEBBLY; SLIGHTLY MOIST, UNOXIDIZED (TILL) |

SHELBY AT 68 FEET. GREATER THAN 200 FEET TO BEDROCK. GAS FLOWED FROM HOLE DURING PULLOUT; NON-FLAMMABLE. NO GAS FLOWING THE FOLLOWING MORNING. AUGER FLIGHT IN HOLE STAINED WITH A GREEN FILM DUE TO REDUCTION.

* * * *

COUNTY: HYDE LOCATION: 114N-73W-03CCCC 6
LEGAL LOCATION: SW SW SW SW SEC. 03, T. 114 N., R. 73 W.
LATITUDE: 44.4227 LONGITUDE: 99.3649
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: L. THOMAS DRILLER'S LOG: X
GEOLOGIST: M. JARRETT GEOLOGIST'S LOG:
DATE DRILLED: 09-05-1984 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1781.00 T
TOTAL DRILL HOLE DEPTH: 97 TEST HOLE NUMBER: A2-84-197
WATER RIGHTS WELL: SDGS WELL NAME: A2-84-197
OTHER WELL NAME: CK-HY-6E
BASIN: JAMES AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: SCREEN LENGTH:
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1783.00 T
CASING STICK-UP: 2.50 TOTAL CASING AND SCREEN:
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160009
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

| | | |
|---|---|---|
| 0 - | 26 | CLAY, BROWN, SILTY, SANDY, PEBBLY; MOIST, OXIDIZED (TILL) |
| 26 - | 35 | CLAY, BROWN-GRAY, SILTY, SANDY, PEBBLY; MOIST, PARTIALLY OXIDIZED (TILL) |
| 35 - | 97 | CLAY, GRAY, SILTY, SANDY, PEBBLY; MOIST, UNOXIDIZED (TILL) |

* * * *

COUNTY: HYDE LOCATION: 113N-73W-16DDDD 2
LEGAL LOCATION: SE SE SE SE SEC. 16, T. 113 N., R. 73 W.
LATITUDE: 44.3530 LONGITUDE: 99.3655
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: D. TOMHAVE DRILLER'S LOG:
GEOLOGIST: D. TOMHAVE GEOLOGIST'S LOG: X
DATE DRILLED: 10-20-1983 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1795.00 T
TOTAL DRILL HOLE DEPTH: 13 TEST HOLE NUMBER: A2-83-294
WATER RIGHTS WELL: SDGS WELL NAME: A2-83-294
OTHER WELL NAME: CK-HY-7A
BASIN: MISSOURI AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: PVC, MFG. SCREEN LENGTH: 2.5
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1798.00 T
CASING STICK-UP: 2.50 TOTAL CASING AND SCREEN: 15.5
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10140103
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

WASHED CONCRETE SAND AROUND SANDPOINT. SEALED WITH BENTONITE PELLETS. BACKFILLED TO SURFACE WITH BENTONITE.

| | | |
|---|---|---|
| 0 - | 4 | CLAY, LIGHT-BROWN, SILTY, SANDY; DRY, OXIDIZED |
| 4 - | 13 | CLAY, BROWN, SILTY, SANDY, PEBBLY; MOIST, OXIDIZED (TILL) |

* * * *

COUNTY: HYDE LOCATION: 113N-73W-16DDDD 3
LEGAL LOCATION: SE SE SE SE SEC. 16, T. 113 N., R. 73 W.
LATITUDE: 44.3530 LONGITUDE: 99.3655
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: D. TOMHAVE DRILLER'S LOG:
GEOLOGIST: D. TOMHAVE GEOLOGIST'S LOG: X
DATE DRILLED: 10-20-1983 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1795.00 T
TOTAL DRILL HOLE DEPTH: 23 TEST HOLE NUMBER: A2-83-293
WATER RIGHTS WELL: SDGS WELL NAME: A2-83-293
OTHER WELL NAME: CK-HY-7B
BASIN: MISSOURI AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: PVC, MFG. SCREEN LENGTH: 2.5
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1798.00 T
CASING STICK-UP: 2.50 TOTAL CASING AND SCREEN: 25.5
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10140103
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

WASHED CONCRETE SAND AROUND SANDPOINT. SEALED WITH BENTONITE PELLETS. BACKFILLED TO SURFACE WITH BENTONITE.

| | | |
|---|---|---|
| 0 - | 4 | CLAY, LIGHT-BROWN, SILTY, SANDY; DRY, OXIDIZED |
| 4 - | 23 | CLAY, BROWN, DARK-BROWN AT 16 FEET, SILTY, SANDY, PEBBLY; MOIST, OXIDIZED (TILL) |

* * * *

COUNTY: HYDE LOCATION: 113N-73W-16DDDD 4
LEGAL LOCATION: SE SE SE SE SEC. 16, T. 113 N., R. 73 W.
LATITUDE: 44.3530 LONGITUDE: 99.3655
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: D. TOMHAVE DRILLER'S LOG:
GEOLOGIST: D. TOMHAVE GEOLOGIST'S LOG: X
DATE DRILLED: 10-20-1983 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1795.00 T
TOTAL DRILL HOLE DEPTH: 33 TEST HOLE NUMBER: A2-83-292
WATER RIGHTS WELL: SDGS WELL NAME: A2-83-292
OTHER WELL NAME: CK-HY-7C
BASIN: MISSOURI AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: PVC, MFG. SCREEN LENGTH: 2.5
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1798.00 T
CASING STICK-UP: 2.50 TOTAL CASING AND SCREEN: 35.5
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10140103
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

WASHED CONCRETE SAND AROUND SANDPOINT. SEALED WITH BENTONITE PELLETS. BACKFILLED TO SURFACE WITH BENTONITE.

| | | |
|---|---|---|
| 0 - | 4 | CLAY, LIGHT-BROWN, SILTY, SANDY; DRY, OXIDIZED |
| 4 - | 23 | CLAY, BROWN, SILTY, SANDY, PEBBLY; MOIST, OXIDIZED, TURNS DARK-BROWN AT 16 FEET (TILL) |
| 23 - | 33 | CLAY, GRAY, SILTY, SANDY, PEBBLY; MOIST, UNOXIDIZED (TILL) |

* * * *

COUNTY: HYDE LOCATION: 113N-72W-20BBBB 1
LEGAL LOCATION: NW NW NW NW SEC. 20, T. 113 N., R. 72 W.
LATITUDE: 44.3527 LONGITUDE: 99.3202
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: D. TOMHAVE DRILLER'S LOG:
GEOLOGIST: D. TOMHAVE GEOLOGIST'S LOG: X
DATE DRILLED: 10-20-1983 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1792.00 T
TOTAL DRILL HOLE DEPTH: 13 TEST HOLE NUMBER: A2-83-297
WATER RIGHTS WELL: SDGS WELL NAME: A2-83-297
OTHER WELL NAME: CK-HY-8A
BASIN: JAMES AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: PVC, MFG. SCREEN LENGTH: 2.5
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1795.00 T
CASING STICK-UP: 2.00 TOTAL CASING AND SCREEN: 15.0
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160009
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

WASHED CONCRETE SAND AROUND SANDPOINT.
SEALED WITH BENTONITE PELLETS.
BACKFILLED TO SURFACE WITH BENTONITE.

| | | |
|---|---|---|
| 0 - | 6 | CLAY, DARK-BROWN, SILTY, SANDY, PEBBLY; DRY, OXIDIZED, ROCKS AT 5 FEET (TILL) |
| 6 - | 13 | CLAY, BROWN, SILTY, SANDY, PEBBLY; MOIST, OXIDIZED (TILL) |

* * * *

COUNTY: HYDE LOCATION: 113N-72W-20BBBB 2
LEGAL LOCATION: NW NW NW NW SEC. 20, T. 113 N., R. 72 W.
LATITUDE: 44.3527 LONGITUDE: 99.3202
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: D. TOMHAVE DRILLER'S LOG:
GEOLOGIST: D. TOMHAVE GEOLOGIST'S LOG: X
DATE DRILLED: 10-20-1983 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1792.00 T
TOTAL DRILL HOLE DEPTH: 23 TEST HOLE NUMBER: A2-83-296
WATER RIGHTS WELL: SDGS WELL NAME: A2-83-296
OTHER WELL NAME: CK-HY-8B
BASIN: JAMES AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: PVC, MFG. SCREEN LENGTH: 2.5
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1795.00 T
CASING STICK-UP: 2.50 TOTAL CASING AND SCREEN: 25.5
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160009
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

WASHED CONCRETE SAND AROUND SANDPOINT.
SEALED WITH BENTONITE PELLETS.
BACKFILLED TO SURFACE WITH BENTONITE.

| | | |
|---|---|---|
| 0 - | 6 | CLAY, DARK-BROWN, SILTY, SANDY, PEBBLY; DRY, OXIDIZED, ROCKS AT 5 FEET (TILL) |
| 6 - | 23 | CLAY, BROWN, SILTY, SANDY, PEBBLY; MOIST, OXIDIZED (TILL) |

* * * *

COUNTY: HYDE LOCATION: 113N-72W-20BBBB 3
LEGAL LOCATION: NW NW NW NW SEC. 20, T. 113 N., R. 72 W.
LATITUDE: 44.3527 LONGITUDE: 99.3202
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: D. TOMHAVE DRILLER'S LOG:
GEOLOGIST: D. TOMHAVE GEOLOGIST'S LOG: X
DATE DRILLED: 10-20-1983 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1792.00 T
TOTAL DRILL HOLE DEPTH: 33 TEST HOLE NUMBER: A2-83-295
WATER RIGHTS WELL: SDGS WELL NAME: A2-83-295
OTHER WELL NAME: CK-HY-8C
BASIN: JAMES AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: PVC, MFG. SCREEN LENGTH: 2.5
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1795.00 T
CASING STICK-UP: 2.50 TOTAL CASING AND SCREEN: 35.5
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160009
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

WASHED CONCRETE SAND AROUND SANDPOINT. SEALED WITH BENTONITE PELLETS. BACKFILLED TO SURFACE WITH BENTONITE.

| | | |
|---|---|---|
| 0 - | 6 | CLAY, DARK-BROWN, SILTY, SANDY, PEBBLY; DRY, OXIDIZED, ROCKS AT 5 FEET (TILL) |
| 6 - | 27 | CLAY, BROWN, SILTY, SANDY, PEBBLY; MOIST, OXIDIZED (TILL) |
| 27 - | 33 | CLAY, GRAY, SILTY, SANDY, PEBBLY; MOIST, UNOXIDIZED (TILL) |

* * * *

COUNTY: HYDE LOCATION: 113N-72W-20BBBB 4
LEGAL LOCATION: NW NW NW NW SEC. 20, T. 113 N., R. 72 W.
LATITUDE: 44.3527 LONGITUDE: 99.3202
LAND OWNER:
PROJECT: GLACIAL TILL RESEARCH
DRILLING COMPANY: SDGS
DRILLER: S. MITCHELL DRILLER'S LOG: X
GEOLOGIST: M. JARRETT GEOLOGIST'S LOG:
DATE DRILLED: 08-29-1984 DRILLING METHOD: AUGER
GROUND SURFACE ELEVATION: 1792.00 T
TOTAL DRILL HOLE DEPTH: 67 TEST HOLE NUMBER: A2-84-193
WATER RIGHTS WELL: SDGS WELL NAME: A2-84-193
OTHER WELL NAME: CK-HY-8D
BASIN: JAMES AQUIFER:
MANAGEMENT UNIT:
SCREEN TYPE: SCREEN LENGTH:
CASING TYPE: PVC CASING DIAMETER: 2.0
CASING TOP ELEVATION: 1794.00 T
CASING STICK-UP: 2.50 TOTAL CASING AND SCREEN: 70.0
WELL MAINTENANCE DATE:
USGS HYDROLOGICAL UNIT CODE: 10160009
ELECTRIC LOG INFORMATION:
SPONTANEOUS POTENTIAL: SINGLE POINT RESISTIVITY:
NATURAL GAMMA: EXTRA:
SAMPLES:

SHELBY TAKEN. NO SCREEN.

| | | |
|---|---|---|
| 0 - | 1 | CLAY, BLACK, SILTY, SANDY (TOPSOIL) |
| 1 - | 7 | CLAY, GRAY-BROWN, VERY SILTY, SANDY, PEBBLY; OXIDIZED (TILL) |
| 7 - | 24 | CLAY, BROWN, SILTY, SANDY, PEBBLY; MOIST, OXIDIZED (TILL) |
| 24 - | 67 | CLAY, GRAY, SILTY, SANDY, PEBBLY; MOIST, UNOXIDIZED (TILL) |

HIGHMORE AQUIFER UNDERLIES TILL AT 80 PLUS FEET DEPTH.

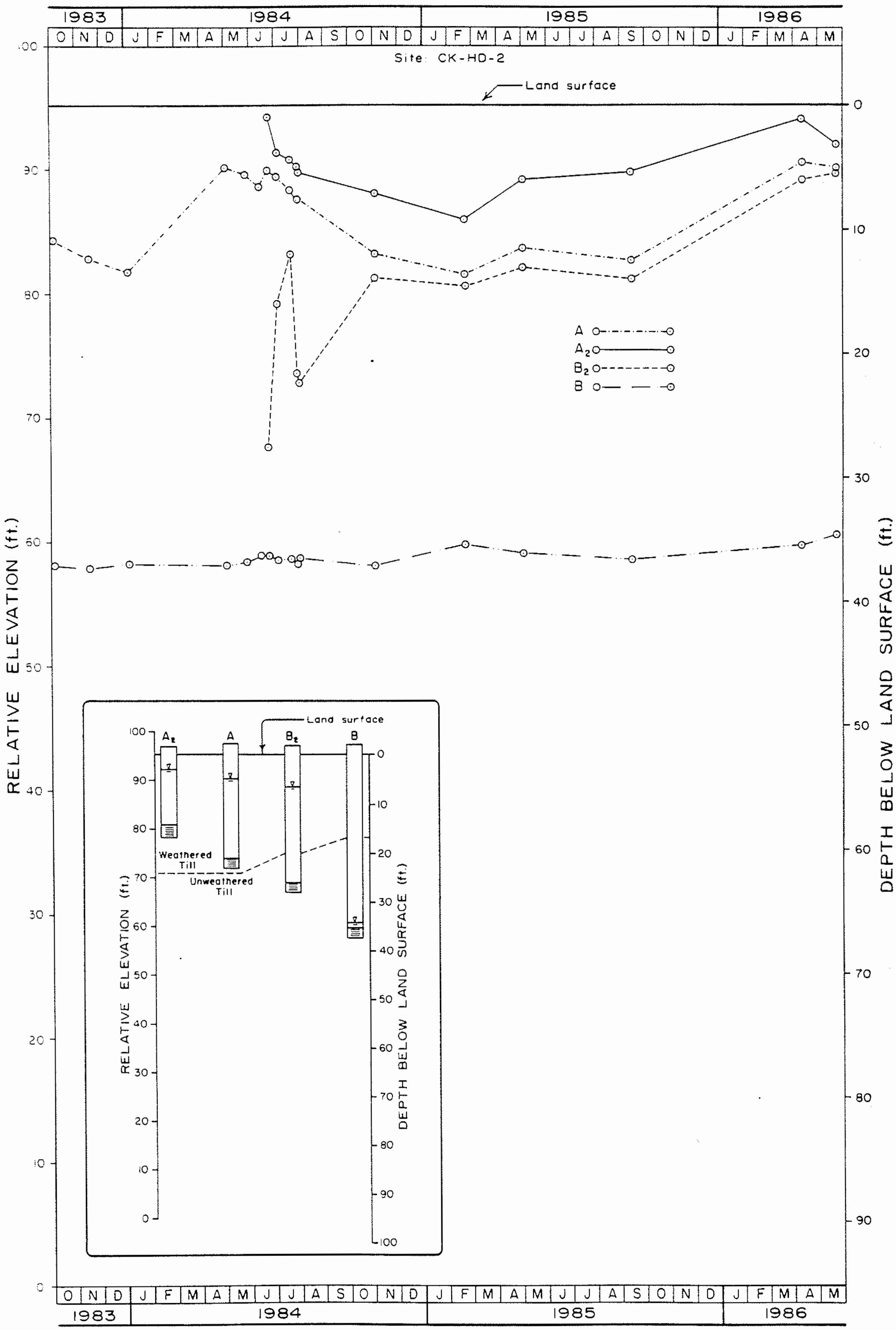
* * * *

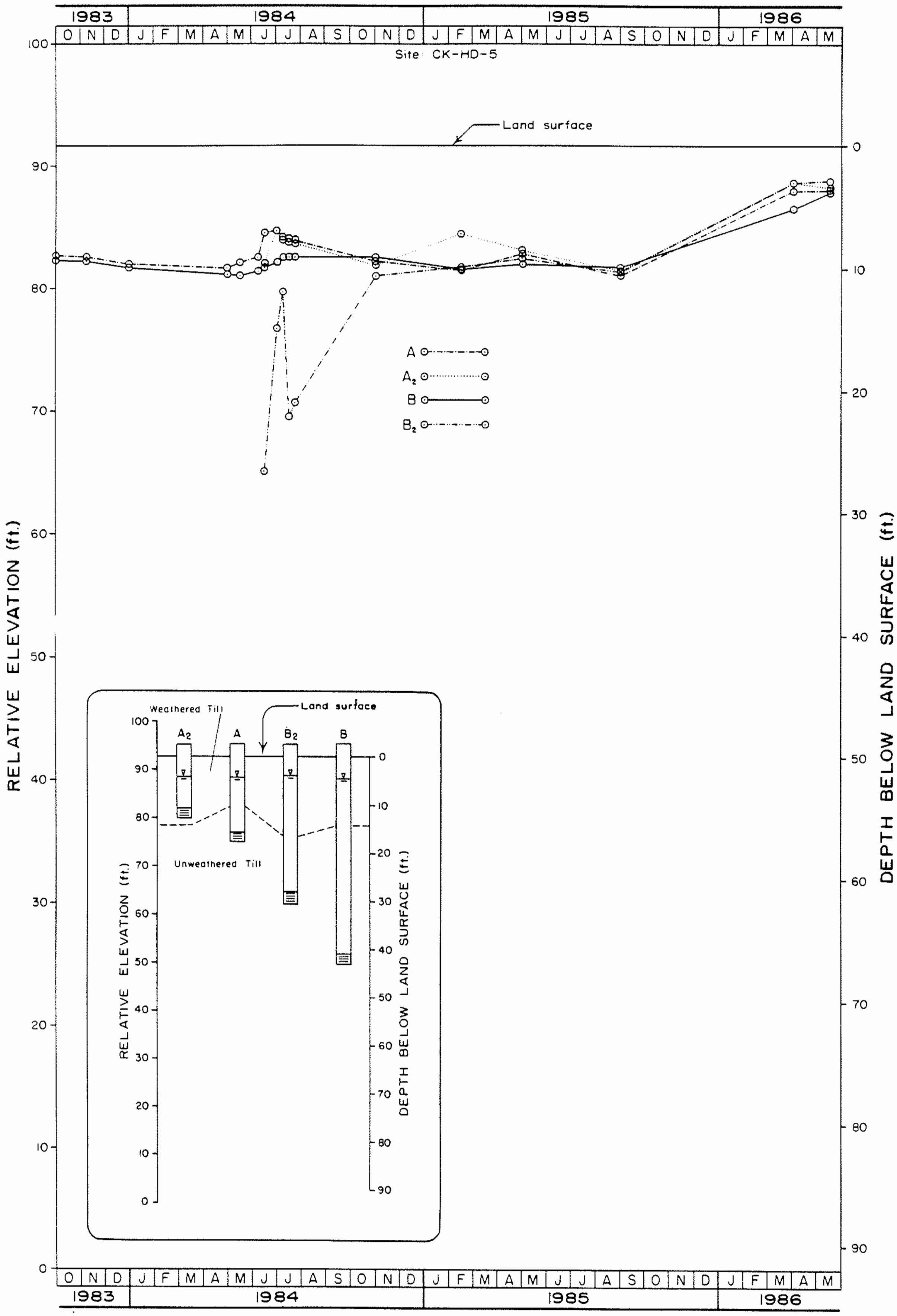
## APPENDIX C

### Water-level hydrographs for till piezometer nests

The hydrographs in this appendix depict the water levels in the till piezometers over time. Each circled dot represents the point in time at which the water level was measured. The gaps in numbering system for the piezometer nest sites are a result of several sites being abandoned due to failed piezometer installation and/or construction. The inset on each hydrograph depicts the piezometer construction. An asterisk (*) by the piezometer indicates that the casing top elevation was not surveyed and the relative altitude of the casing top was estimated by adding the measured casing stickup to the land-surface elevation. A piezometer intake with horizontal slashes indicates a screened-intake piezometer. A piezometer intake with a reduced diameter cylinder indicates a cored-intake piezometer. A piezometer intake with neither horizontal slashes nor a reduced diameter cylinder indicates an intake consisting only of the open-ended bottom of the piezometer. Site locations are listed below and correspond to site number on each hydrograph.

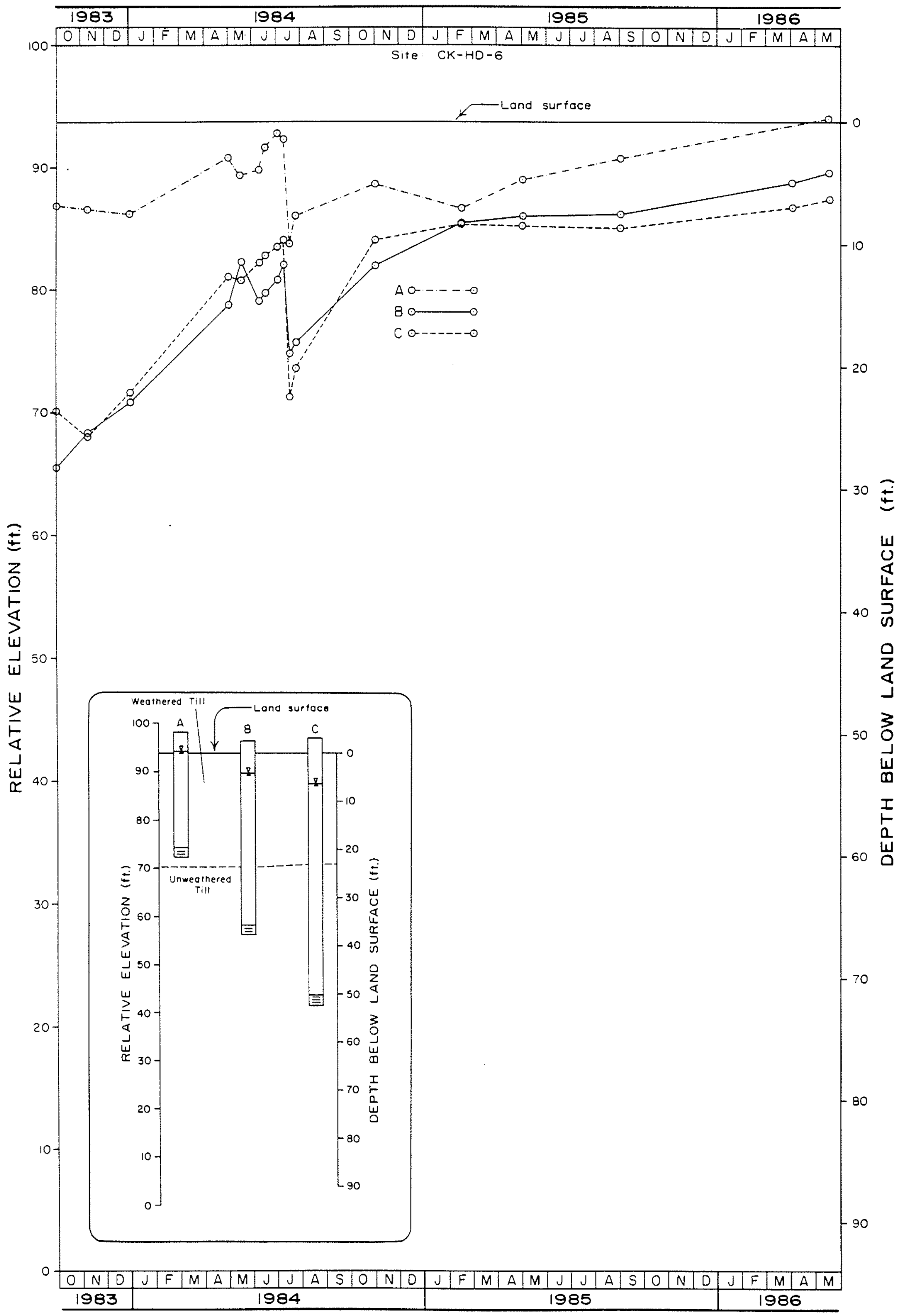
| SITE | LOCATION | SITE | LOCATION |
|---|---|---|---|
| CK-HD-2 | 115N-67W-18DDDD | CK-HD-16 | 110N-68W-22AABB |
| CK-HD-5 | 115N-70W-04AAAA | CK-HD-17 | 112N-70W-14CCCC |
| CK-HD-6 | 114N-70W-02BBBB | CK-HD-18 | 117N-70W-31DDDC |
| CK-HD-7 | 114N-66W-15CDDD | CK-HY-1 | 115N-71W-13BBBB |
| CK-HD-8 | 114N-67W-35AAAA | CK-HY-2 | 115N-71W-15BBBB |
| CK-HD-9 | 114N-66W-14CCCC | CK-HY-3 | 115N-72W-10CCCC |
| CK-HD-10 | 115N-69W-13BBBB | CK-HY-4 | 115N-72W-07DDDD |
| CK-HD-11 | 115N-69W-15BBBB | CK-HY-5 | 114N-72W-36CCCC |
| CK-HD-12 | 115N-69W-18AAAA | CK-HY-6 | 114N-73W-03CCCC |
| CK-HD-13 | 115N-70W-14AAAA | CK-HY-7 | 113N-73W-16DDDD |
| CK-HD-15 | 115N-70W-17BBBB | CK-HY-8 | 113N-72W-20BBBB |


1983
1984
1985
1986
O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M
Site: CK-HD-2
Land surface
A
A2
B2
B
RELATIVE ELEVATION (ft.)
DEPTH BELOW LAND SURFACE (ft.)
Land surface
Weathered Till
Unweathered Till

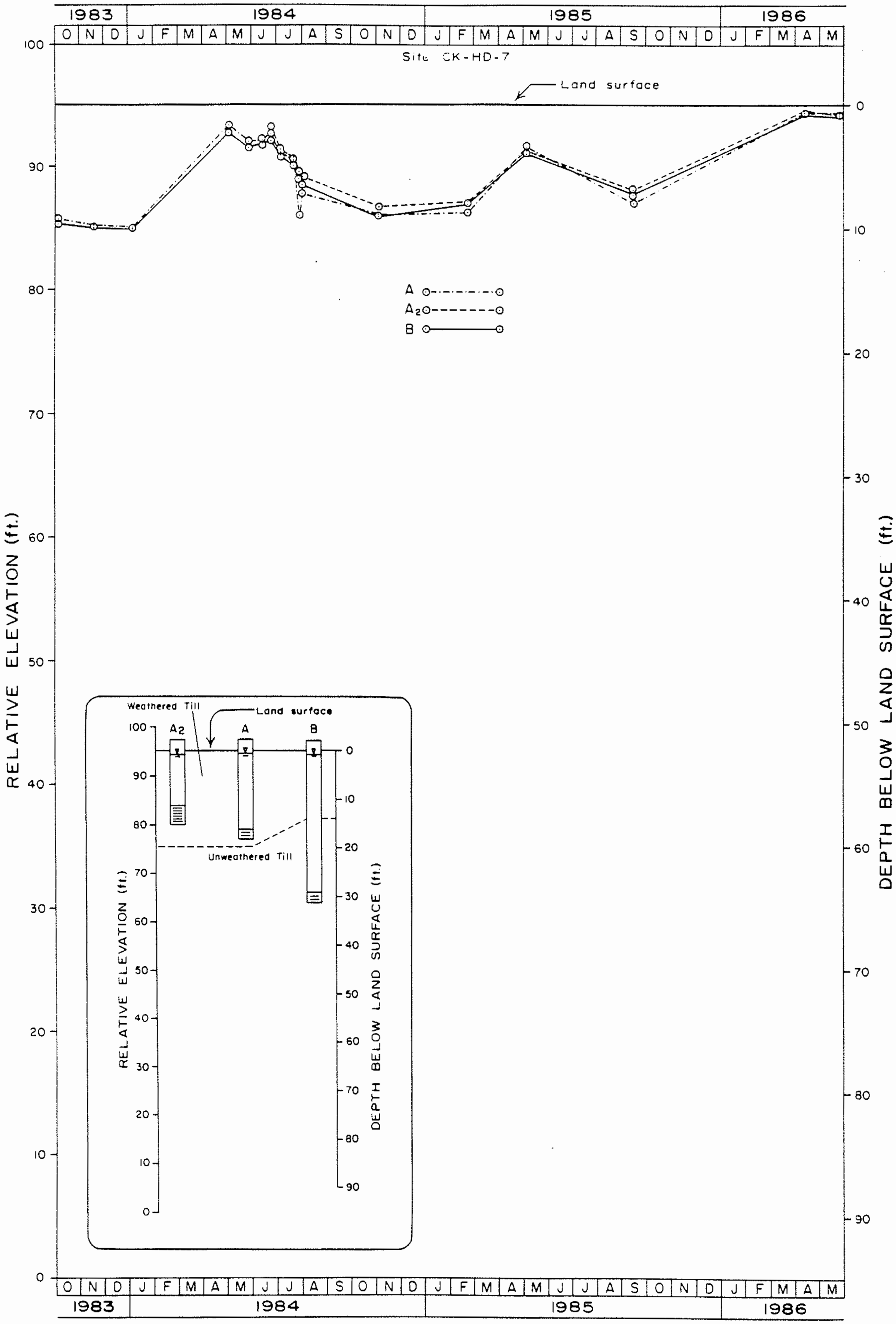


1983
1984
1985
1986
O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M
Site: CK-HD-5
Land surface
A
A2
B
B2
RELATIVE ELEVATION (ft.)
DEPTH BELOW LAND SURFACE (ft.)
Weathered Till
Land surface
Unweathered Till


Appendix C-3

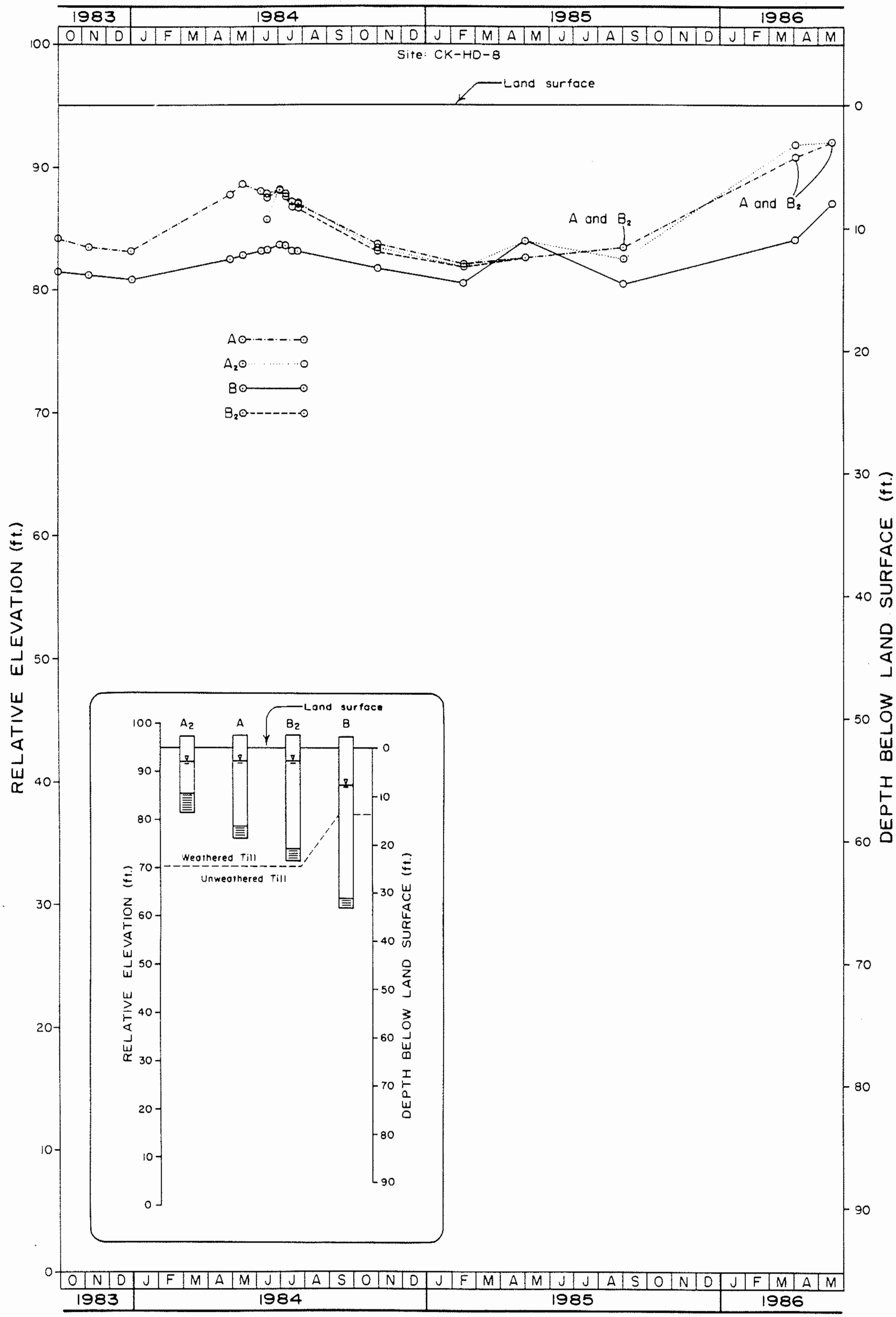

1983
1984
1985
1986
O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M
Site: CK-HD-6
Land surface
A
B
C
RELATIVE ELEVATION (ft.)
DEPTH BELOW LAND SURFACE (ft.)
Weathered Till
Land surface
Unweathered Till
RELATIVE ELEVATION (ft.)
DEPTH BELOW LAND SURFACE (ft.)

Appendix C-4

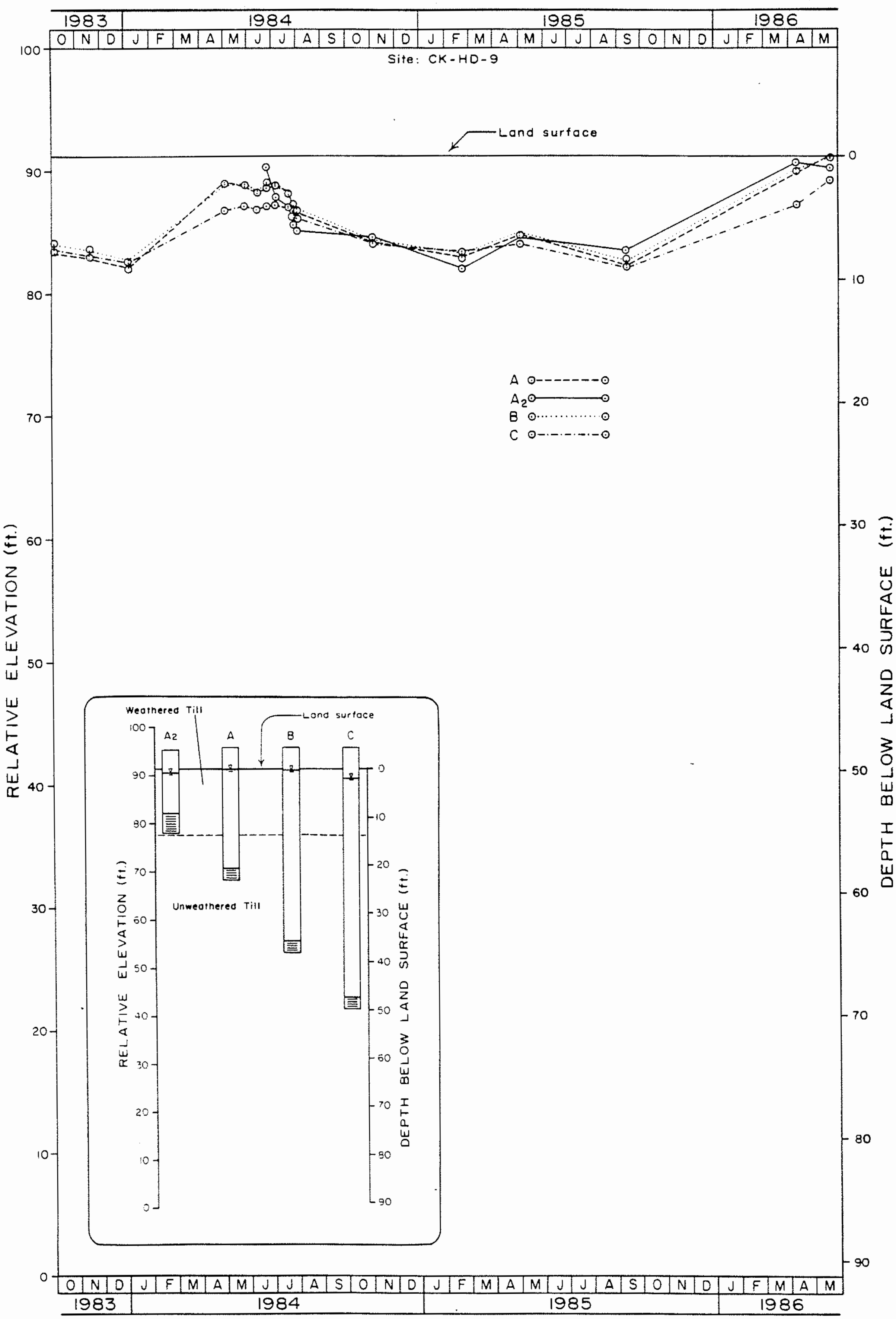


1983
1984
1985
1986
O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M
Site CK-HD-7
Land surface
A
A2
B
RELATIVE ELEVATION (ft.)
DEPTH BELOW LAND SURFACE (ft.)
Weathered Till
Land surface
Unweathered Till


Appendix C-5

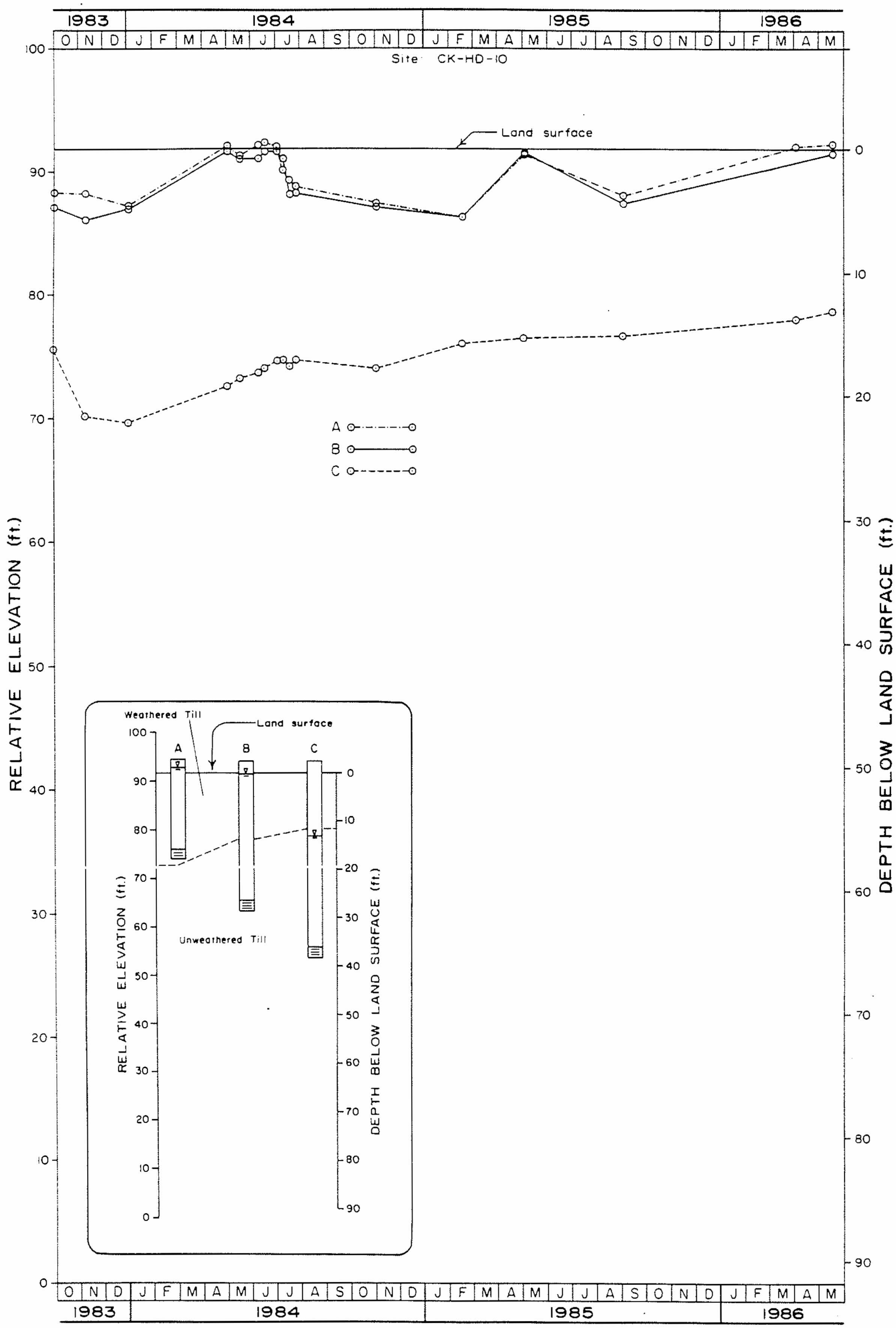

1983
1984
1985
1986
O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M
Site: CK-HD-8
Land surface
A and B₂
A and B₂
RELATIVE ELEVATION (ft.)
DEPTH BELOW LAND SURFACE (ft.)
A
A₂
B
B₂
Land surface
A₂
A
B₂
B
Weathered Till
Unweathered Till
RELATIVE ELEVATION (ft.)
DEPTH BELOW LAND SURFACE (ft.)

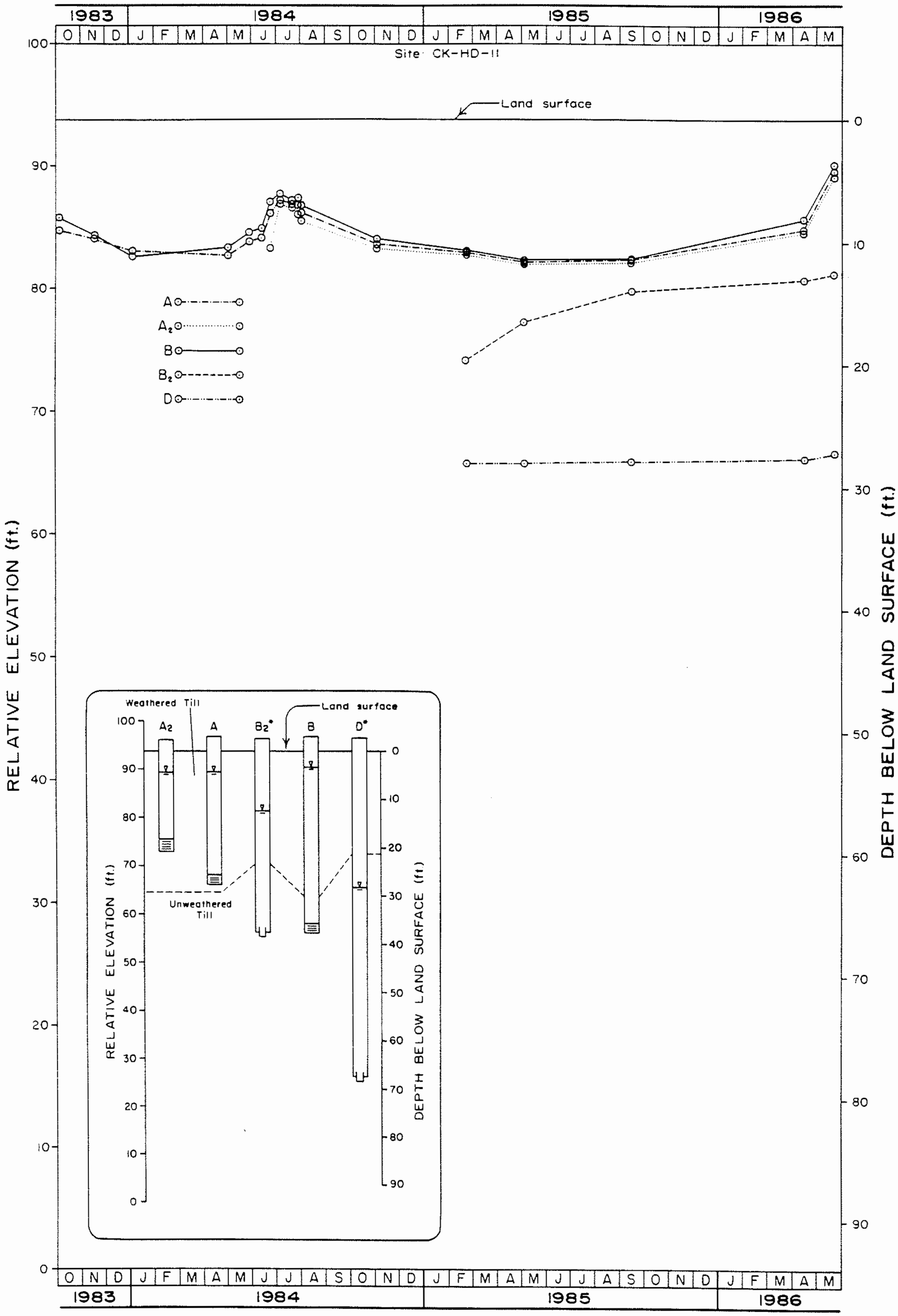
Appendix C–6



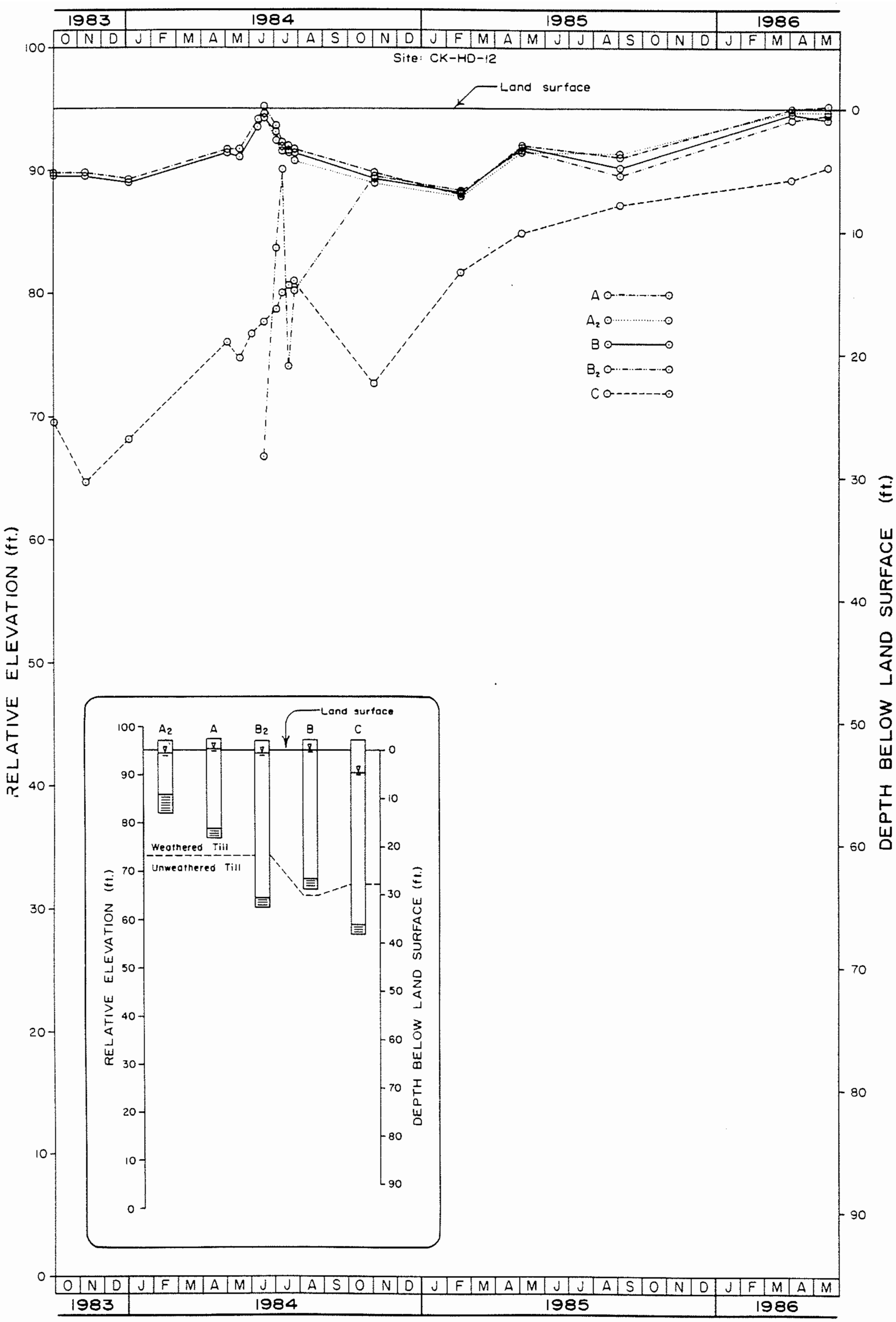
1983
1984
1985
1986
O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M
Site: CK-HD-9
Land surface
A
A2
B
C
RELATIVE ELEVATION (ft.)
DEPTH BELOW LAND SURFACE (ft.)
Weathered Till
Land surface
A2
A
B
C
Unweathered Till

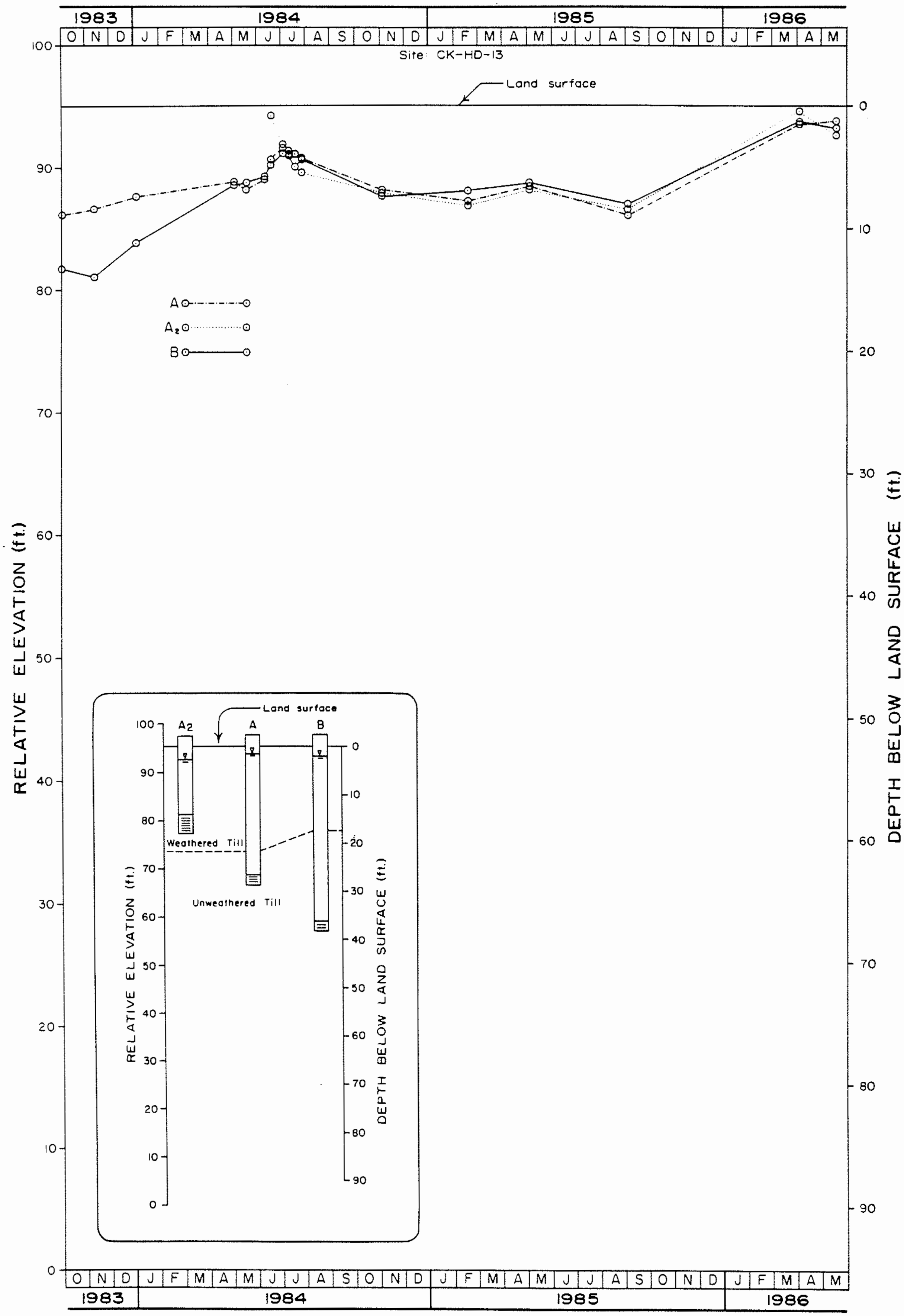

Appendix C-7

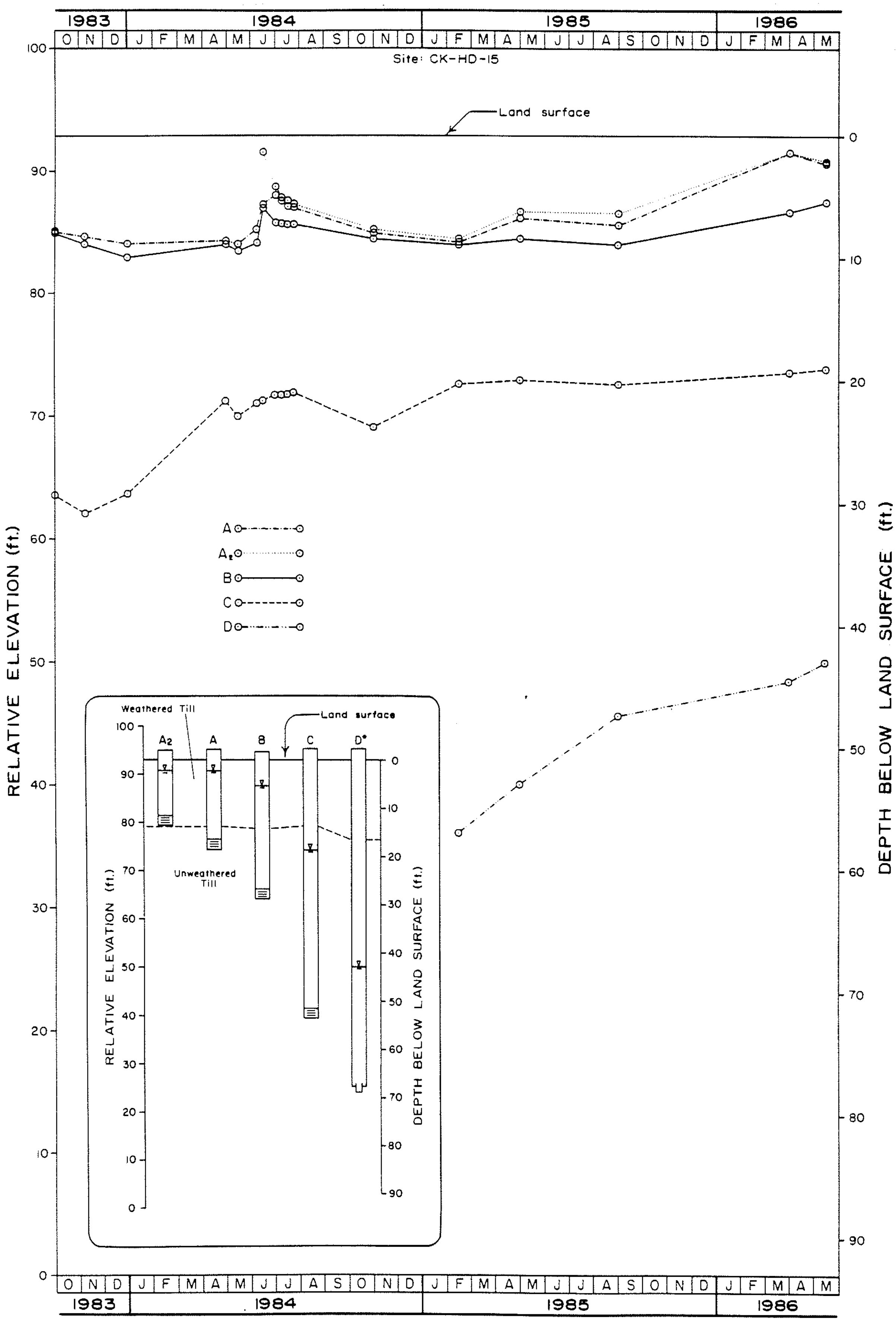

1983
1984
1985
1986
O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M
Site CK-HD-10
Land surface
A
B
C
RELATIVE ELEVATION (ft.)
DEPTH BELOW LAND SURFACE (ft.)
Weathered Till
Land surface
Unweathered Till



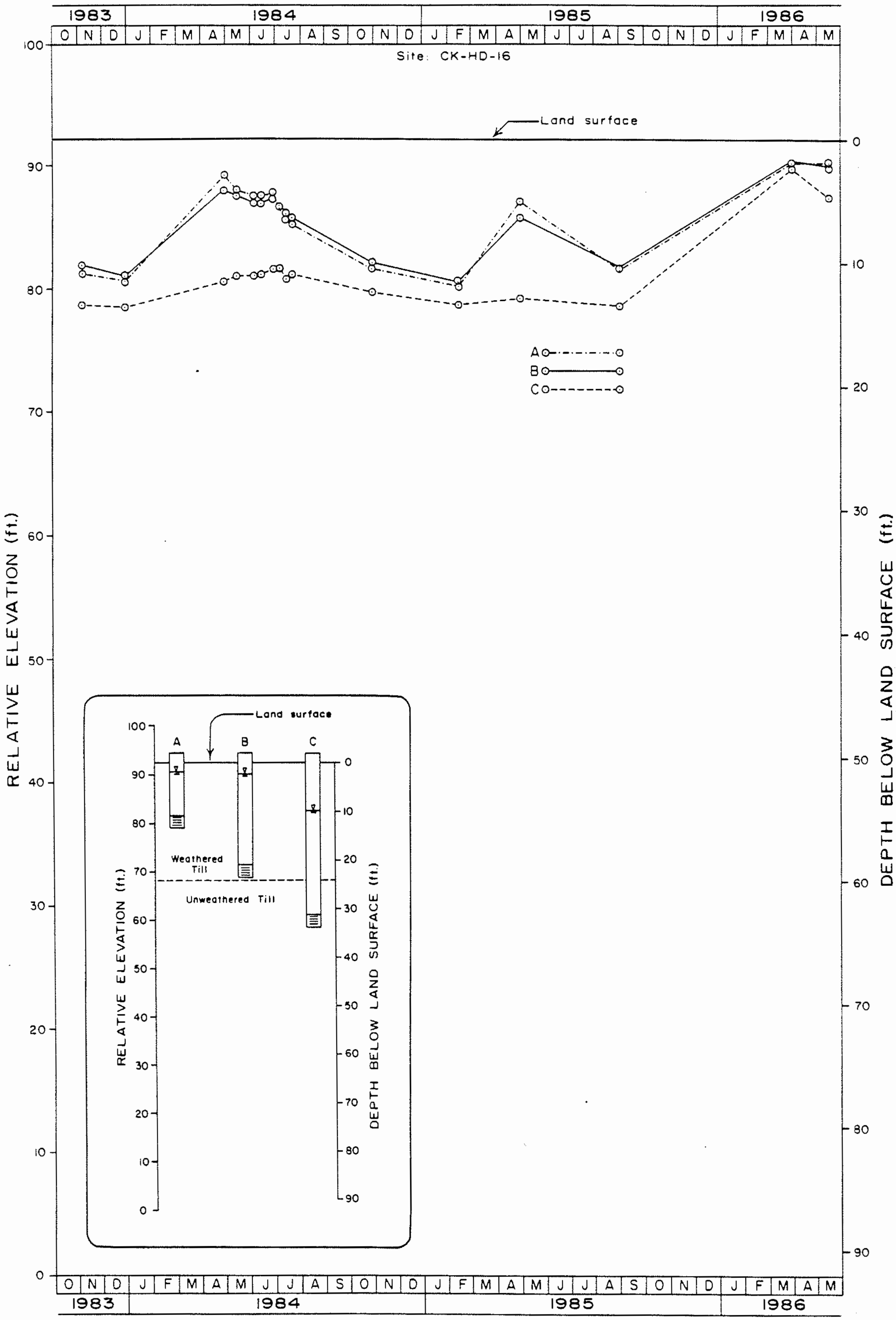
1983
1984
1985
1986
O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M
Site CK-HD-11
Land surface
A
A2
B
B2
D
RELATIVE ELEVATION (ft.)
DEPTH BELOW LAND SURFACE (ft.)
Weathered Till
Land surface
A2
A
B2*
B
D*
Unweathered Till


1983
1984
1985
1986
O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M
Site: CK-HD-12
Land surface
A
A2
B
B2
C
RELATIVE ELEVATION (ft.)
DEPTH BELOW LAND SURFACE (ft.)
Land surface
A2
A
B2
B
C
Weathered Till
Unweathered Till

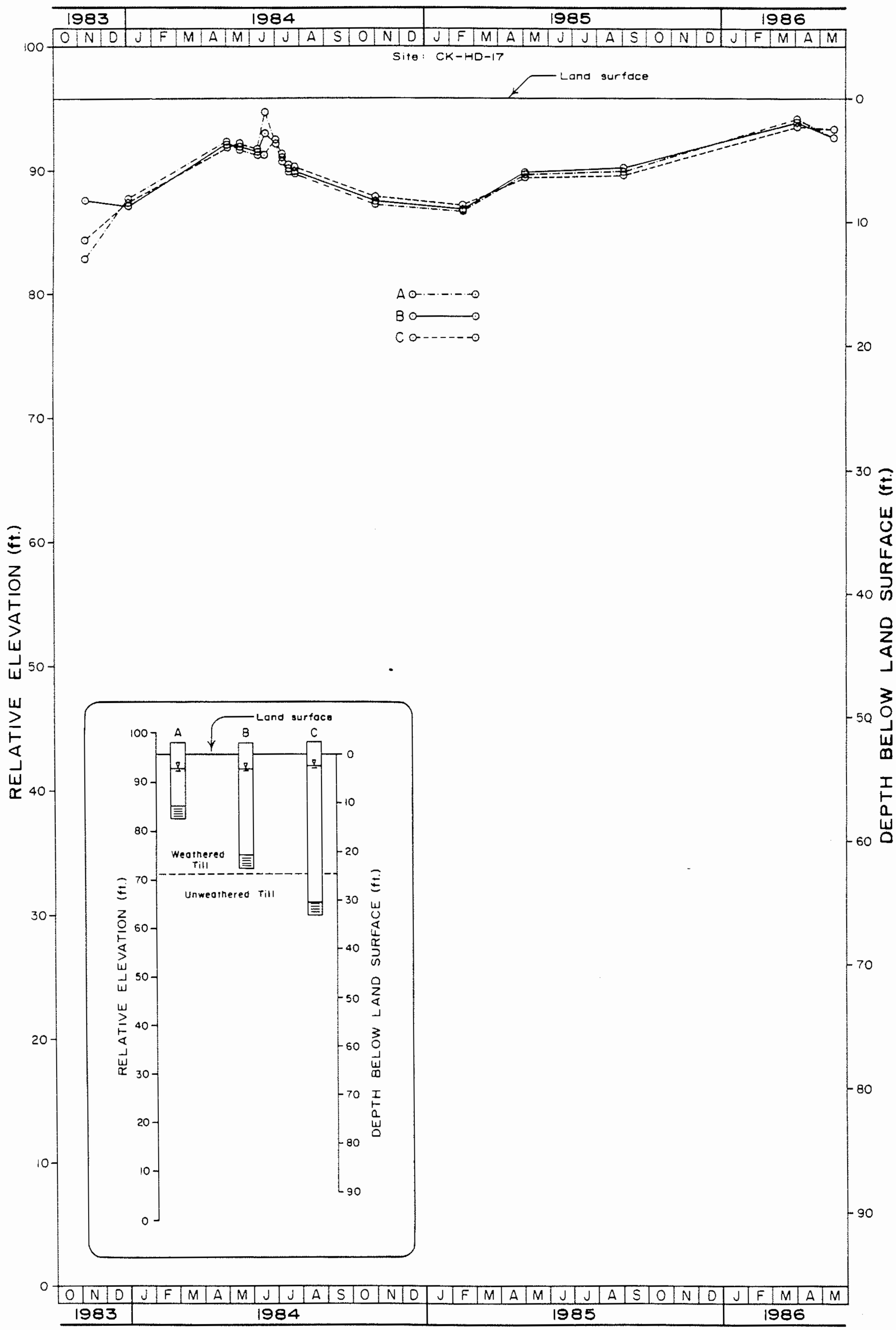

1983
1984
1985
1986
O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M
Site: CK-HD-13
Land surface
A
A2
B
RELATIVE ELEVATION (ft.)
DEPTH BELOW LAND SURFACE (ft.)
Land surface
A2
A
B
Weathered Till
Unweathered Till
RELATIVE ELEVATION (ft.)
DEPTH BELOW LAND SURFACE (ft.)



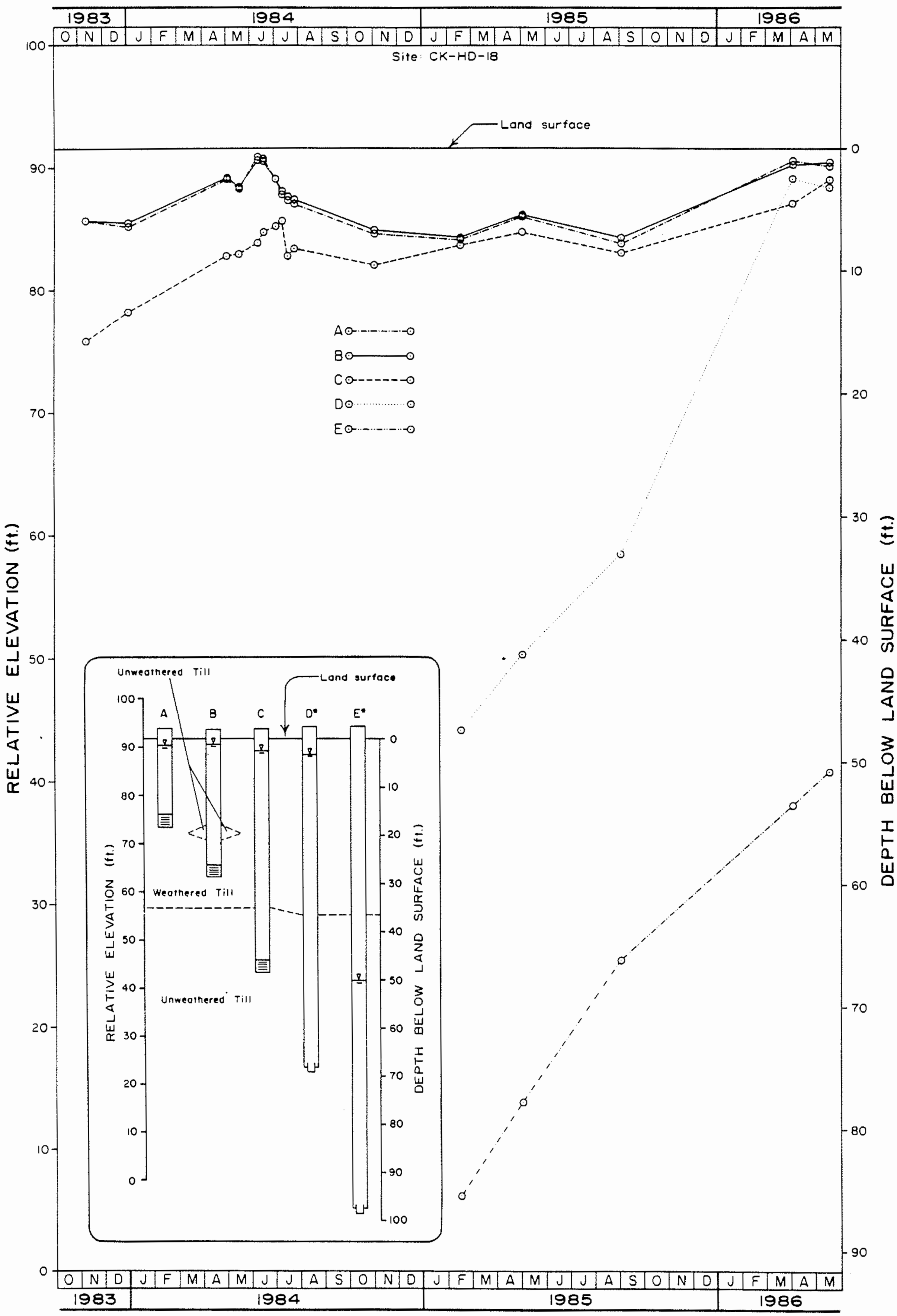
1983
1984
1985
1986
O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M
Site: CK-HD-15
Land surface
RELATIVE ELEVATION (ft.)
DEPTH BELOW LAND SURFACE (ft.)
A
A2
B
C
D
Weathered Till
Land surface
A2
A
B
C
D*
Unweathered Till
RELATIVE ELEVATION (ft.)
DEPTH BELOW LAND SURFACE (ft.)

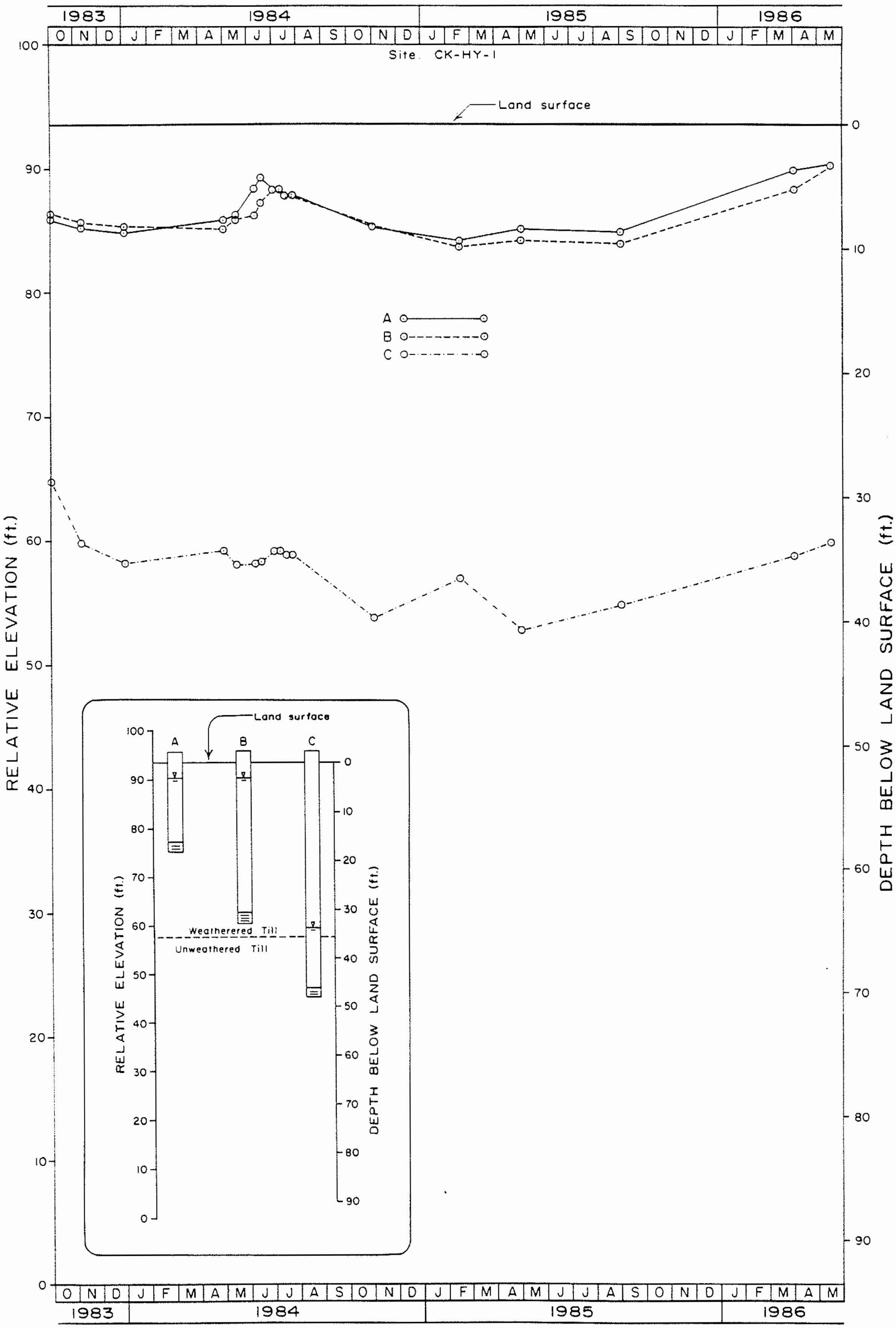


1983
1984
1985
1986
O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M
Site: CK-HD-16
Land surface
A
B
C
RELATIVE ELEVATION (ft.)
DEPTH BELOW LAND SURFACE (ft.)
Weathered Till
Unweathered Till

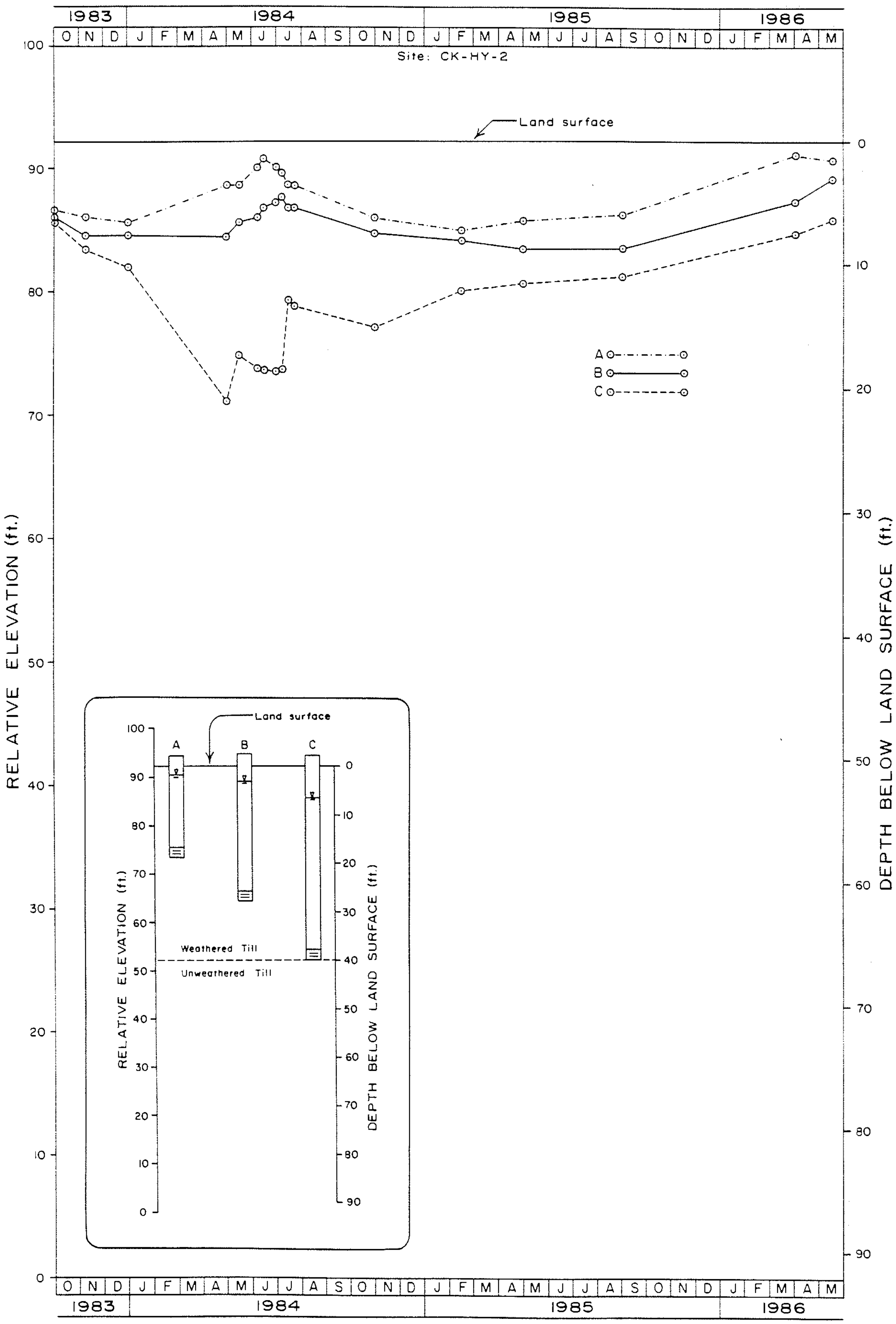


Site: CK-HD-17
Land surface
A
B
C
RELATIVE ELEVATION (ft.)
DEPTH BELOW LAND SURFACE (ft.)
1983
1984
1985
1986
O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M
Weathered Till
Unweathered Till

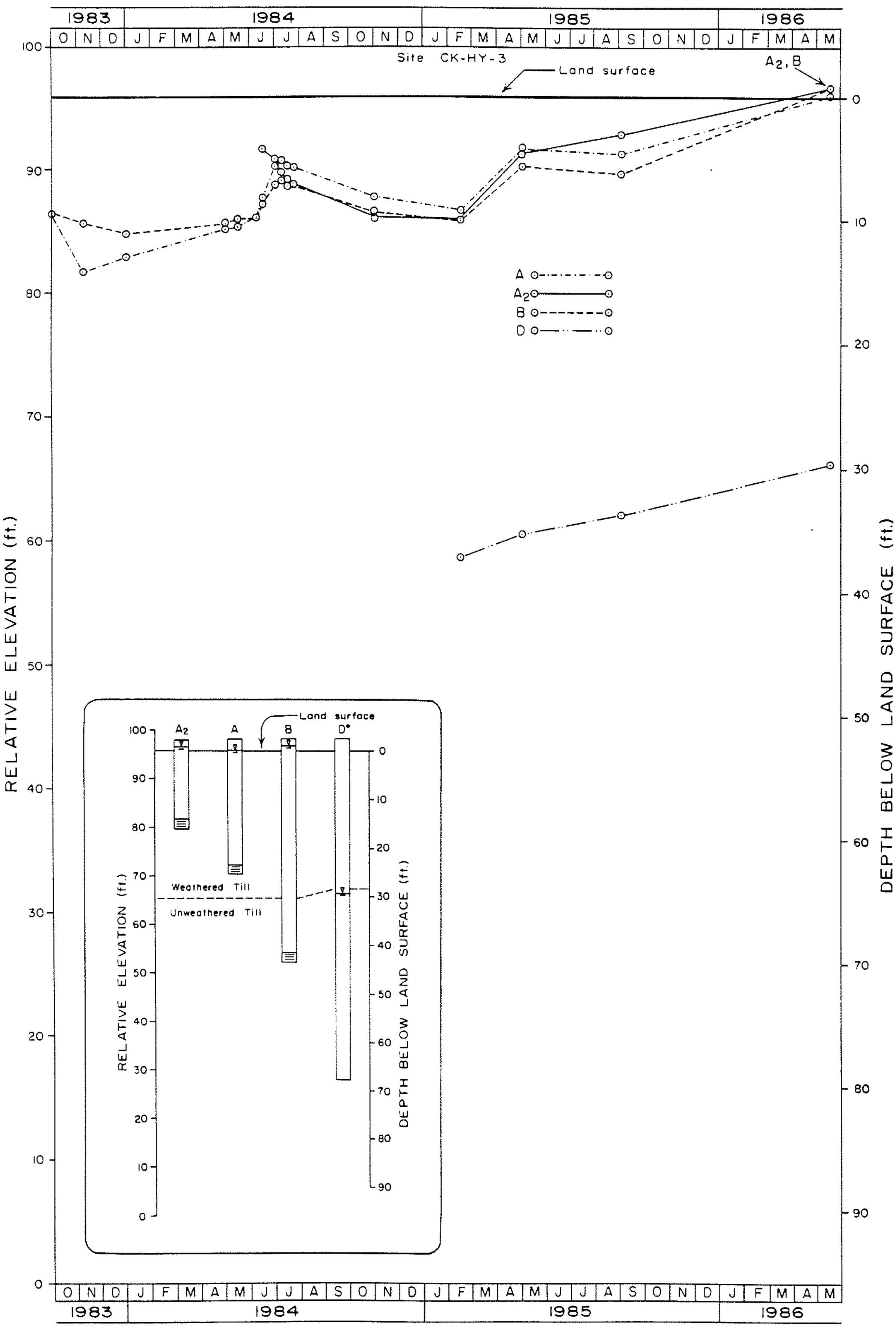

1983
1984
1985
1986
O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M
Site: CK-HD-18
Land surface
A
B
C
D
E
RELATIVE ELEVATION (ft.)
DEPTH BELOW LAND SURFACE (ft.)
Unweathered Till
Land surface
A B C D* E*
Weathered Till
Unweathered Till



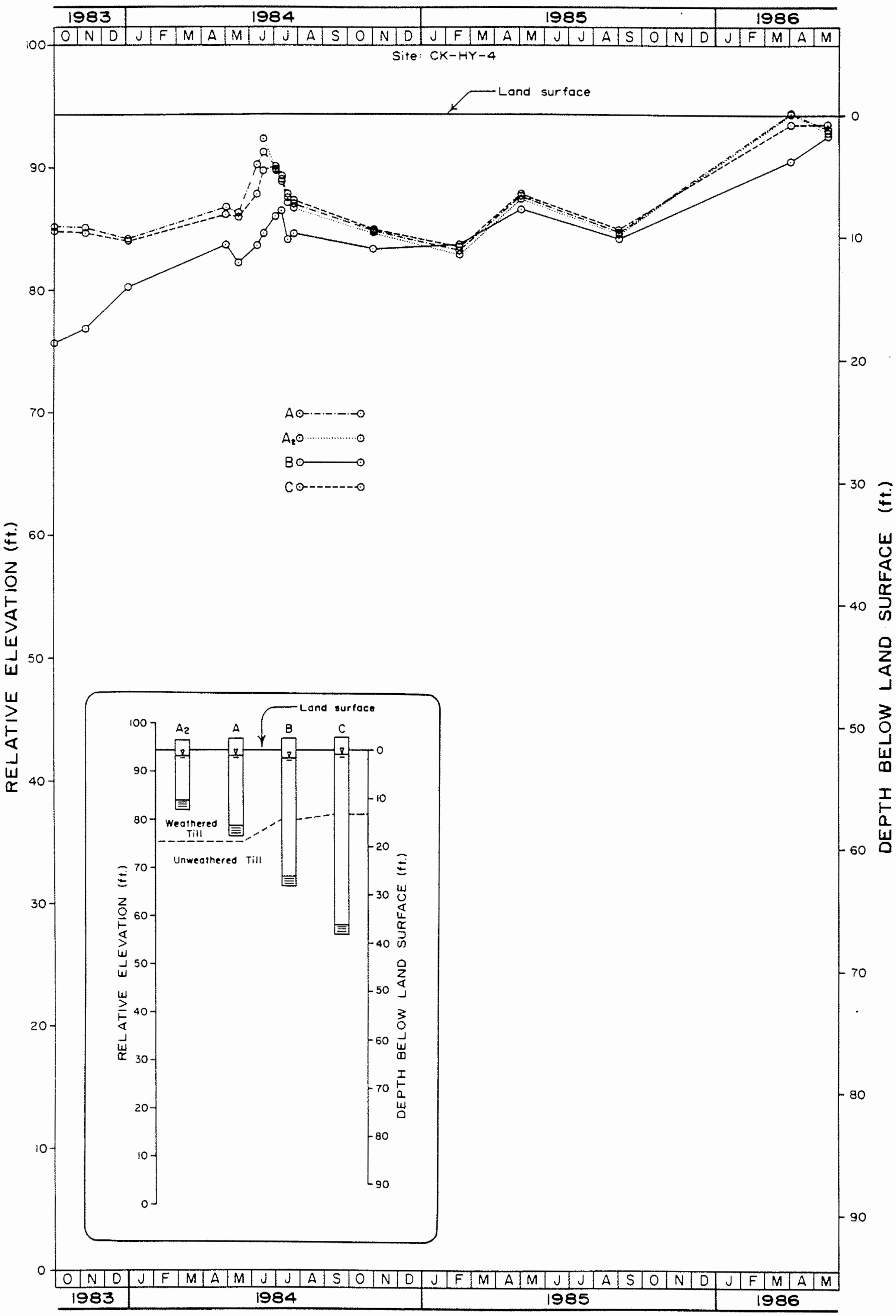
1983
1984
1985
1986
O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M
Site. CK-HY-1
Land surface
A
B
C
RELATIVE ELEVATION (ft.)
DEPTH BELOW LAND SURFACE (ft.)
Land surface
Weatherered Till
Unweathered Till



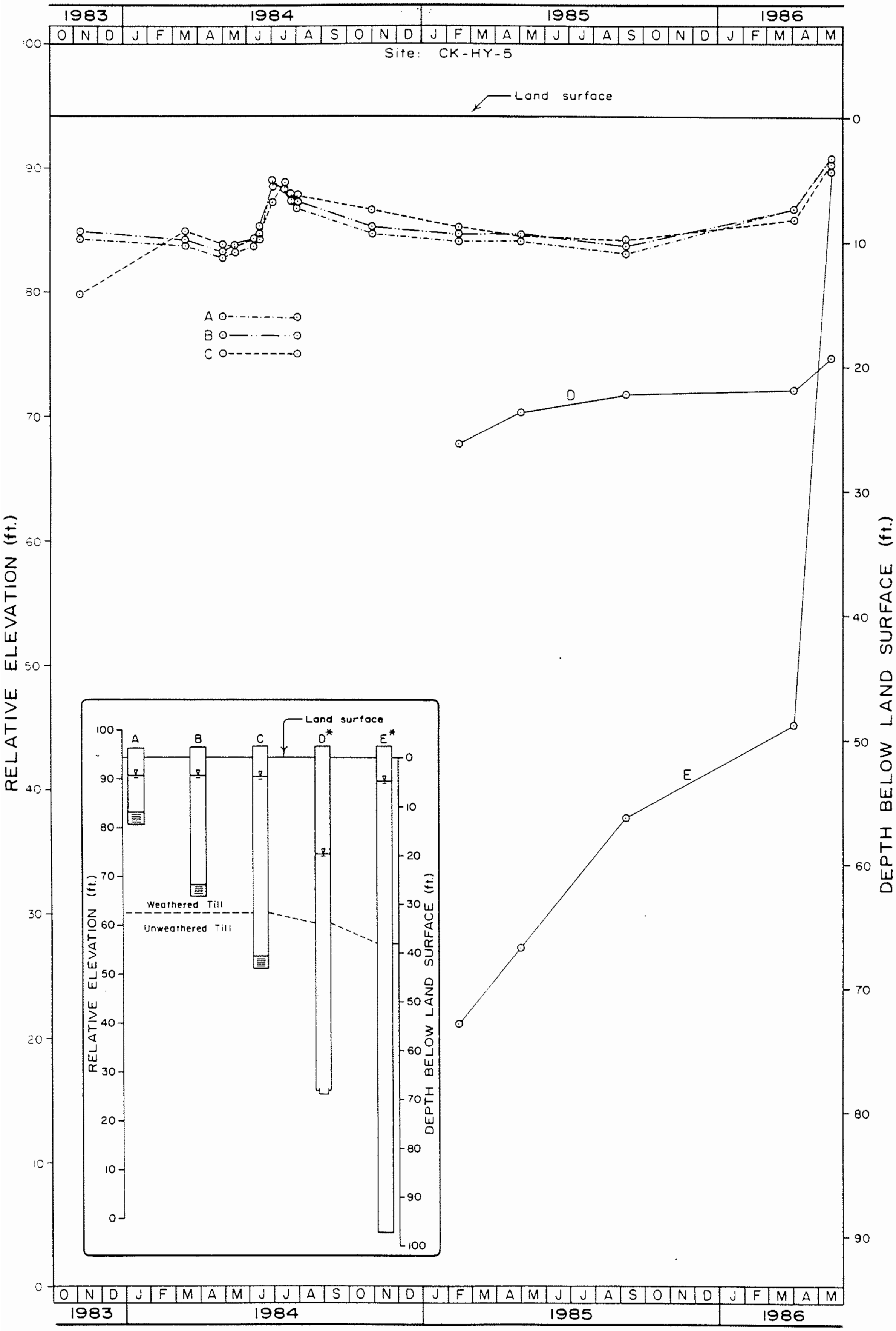
1983
1984
1985
1986
O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M
Site: CK-HY-2
Land surface
A
B
C
Weathered Till
Unweathered Till
RELATIVE ELEVATION (ft.)
DEPTH BELOW LAND SURFACE (ft.)



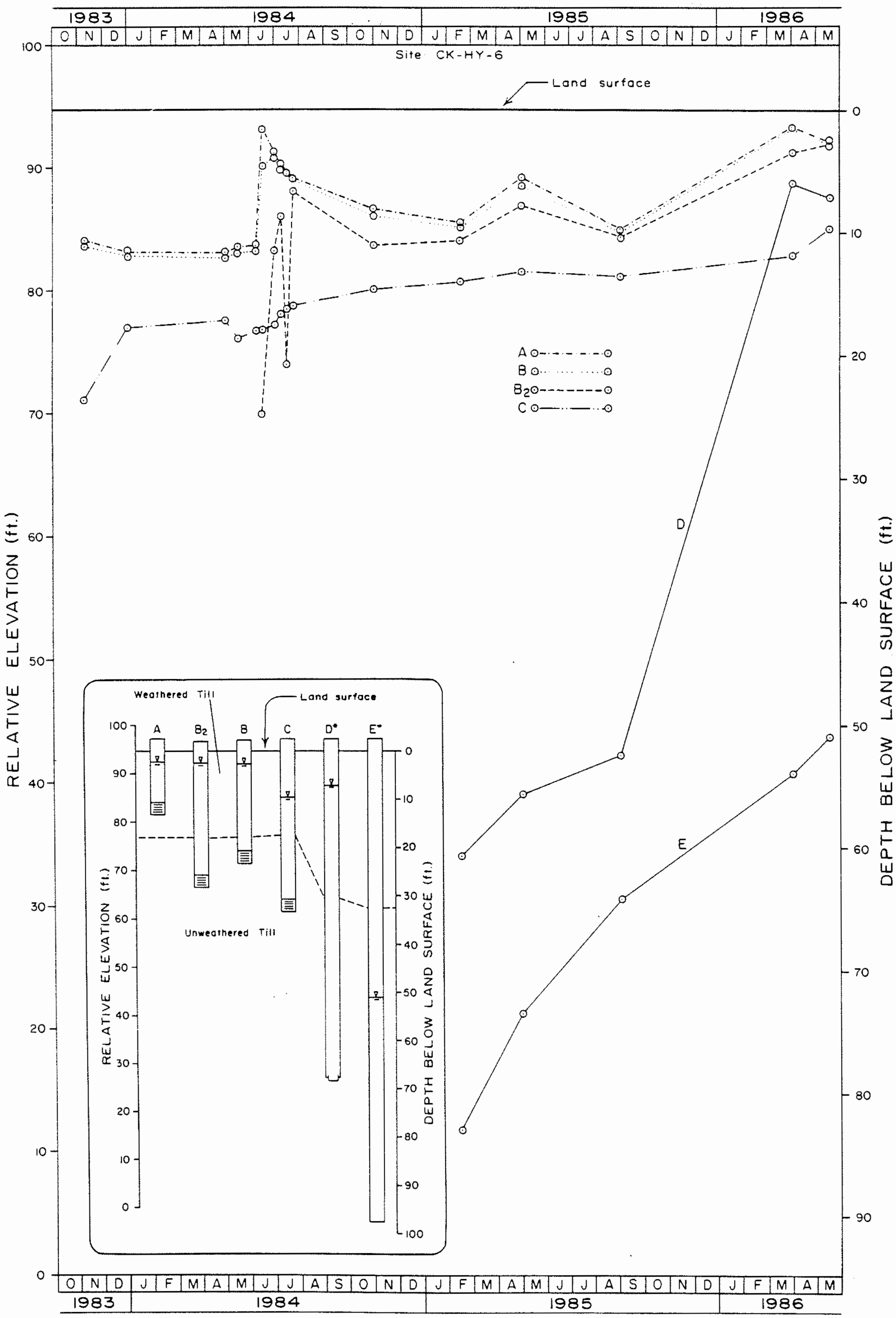
1983
1984
1985
1986
O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M
Site CK-HY-3
Land surface
A2, B
A
A2
B
D
RELATIVE ELEVATION (ft.)
DEPTH BELOW LAND SURFACE (ft.)
A2
A
B
D*
Weathered Till
Unweathered Till



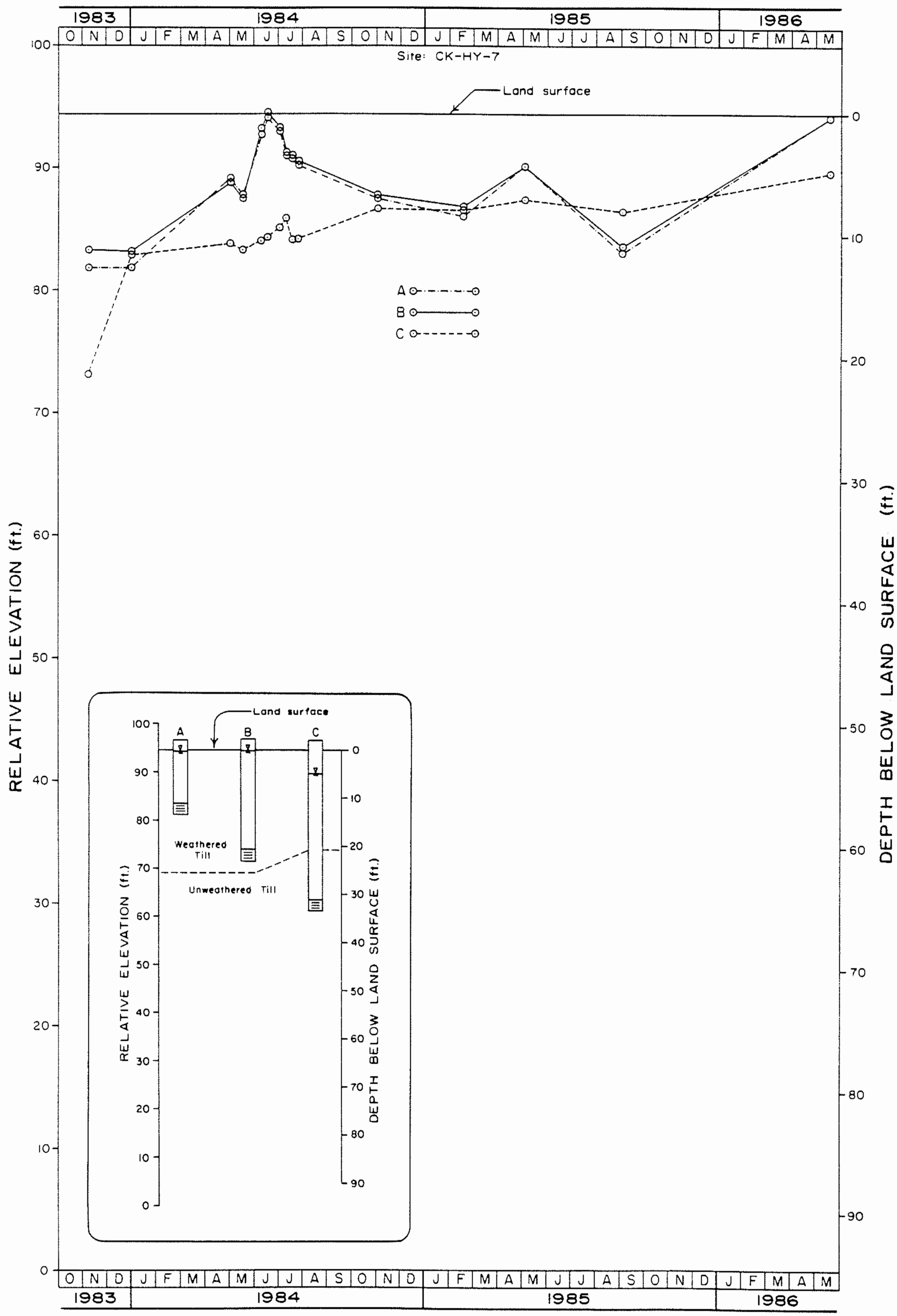
1983 1984 1985 1986
O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M
Site: CK-HY-4
Land surface
A
A2
B
C
RELATIVE ELEVATION (ft.)
DEPTH BELOW LAND SURFACE (ft.)
A2 A B C
Land surface
Weathered Till
Unweathered Till



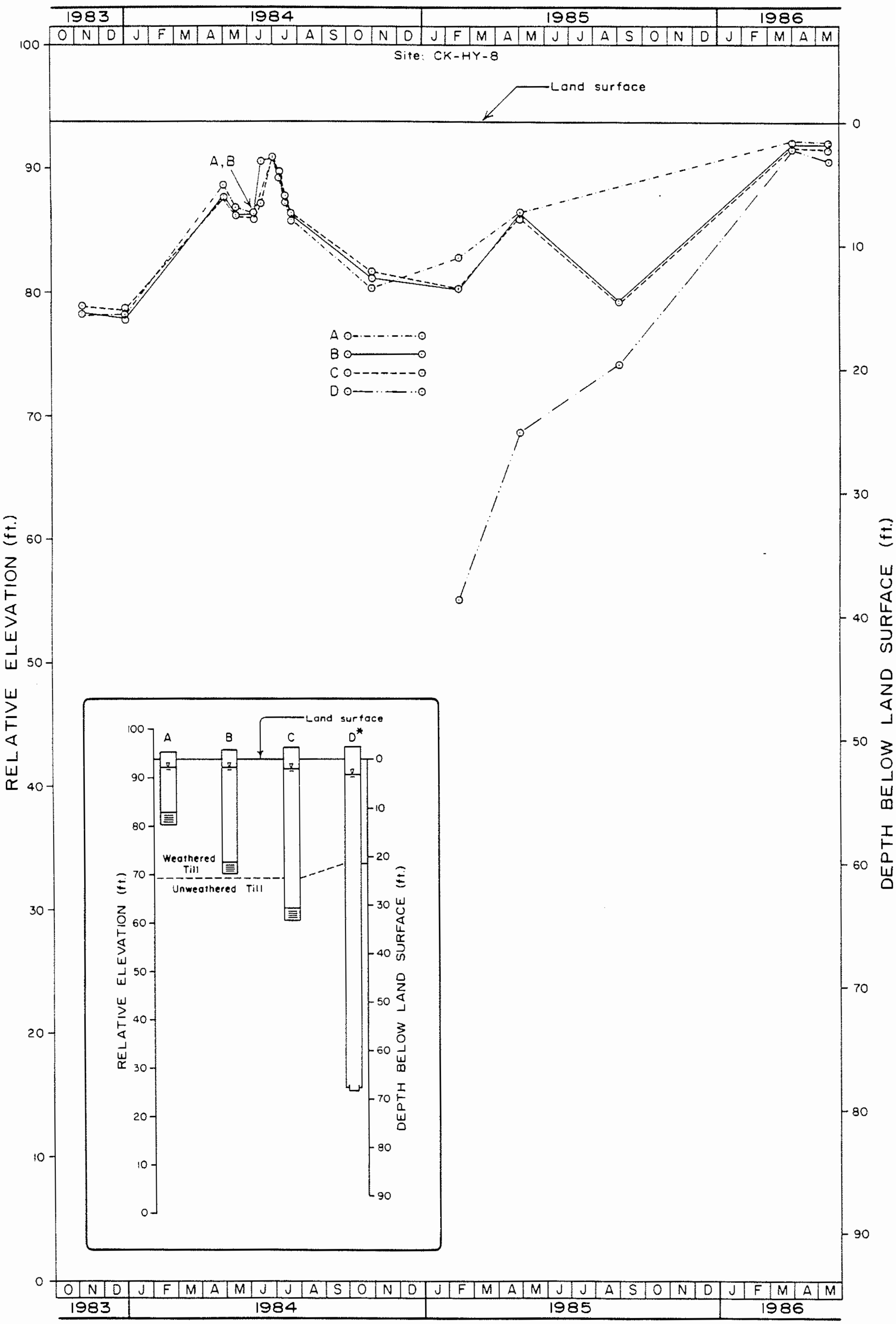
1983 1984 1985 1986
O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M
Site: CK-HY-5
Land surface
RELATIVE ELEVATION (ft.)
DEPTH BELOW LAND SURFACE (ft.)
A
B
C
D
E
Land surface
Weathered Till
Unweathered Till
D*
E*



1983
1984
1985
1986
O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M
Site CK-HY-6
Land surface
RELATIVE ELEVATION (ft.)
DEPTH BELOW LAND SURFACE (ft.)
A
B
B2
C
D
E
Weathered Till
Land surface
Unweathered Till
D*
E*



1983
1984
1985
1986
O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M
Site: CK-HY-7
Land surface
A
B
C
RELATIVE ELEVATION (ft.)
DEPTH BELOW LAND SURFACE (ft.)
Land surface
Weathered Till
Unweathered Till



1983
1984
1985
1986
O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M
Site: CK-HY-8
Land surface
A,B
A
B
C
D
RELATIVE ELEVATION (ft.)
DEPTH BELOW LAND SURFACE (ft.)
Land surface
D*
Weathered Till
Unweathered Till

# APPENDIX D

## Glacial till vertical hydraulic gradients and water-table measurements

The gradients and water-table measurements are listed by site in this appendix for each measurement date. Upward gradients (reversals) are indicated with a preceding negative sign. The "well" designation at the top of the columns indicates which piezometers the graient was calculated between. The letters following each gradient indicate which till zones the gradient was in. For example: W/W = intra-weathered till gradient; W/U = weathered till to unweathered till gradient; U/U = intra-unweathered till gradient. A "NO WAT LEV" entry indicates that no water-level reading was available for that piezometer on that date. The water-table values are reported in feet below land surface. The shallowest piezometer at each nest was selected to represent the water table. The last page of the appendix contains a statistical summary of the gradients and water-table measurements.

SITE: CK-HD-2

| Date | Gradients | | | Water Table (ft.) |
|---|---|---|---|---|
| | Well A2/ Well A | Well A / Well B2 | Well B2/ Well B | Well A2 |
| 10-04-83 | NO WAT LEV | NO WAT LEV | NO WAT LEV | NO WAT LEV |
| 11-15-83 | NO WAT LEV | NO WAT LEV | NO WAT LEV | NO WAT LEV |
| 01-05-84 | NO WAT LEV | NO WAT LEV | NO WAT LEV | NO WAT LEV |
| 05-01-84 | NO WAT LEV | NO WAT LEV | NO WAT LEV | NO WAT LEV |
| 05-24-84 | NO WAT LEV | NO WAT LEV | NO WAT LEV | NO WAT LEV |
| 06-12-84 | NO WAT LEV | NO WAT LEV | NO WAT LEV | NO WAT LEV |
| 06-21-84 | 0.725 W/W | 2.679 W/U | 1.413 U/U | 1.06 |
| 07-04-84 | 0.320 W/W | 1.236 W/U | 3.348 U/U | 3.99 |
| 07-18-84 | 0.383 W/W | 0.624 W/U | 3.982 U/U | 4.69 |
| 07-25-84 | 0.459 W/W | 1.667 W/U | 2.470 U/U | 5.10 |
| 07-31-84 | 0.381 W/W | 1.781 W/U | 2.271 U/U | 5.53 |
| 11-02-84 | 0.779 W/W | 0.238 W/U | 3.747 U/U | 7.33 |
| 02-20-85 | 0.693 W/W | 0.155 W/U | 3.353 U/U | 9.39 |
| 05-01-85 | 0.950 W/W | 0.178 W/U | 3.746 U/U | 6.03 |
| 09-10-85 | 1.196 W/W | 0.172 W/U | 3.674 U/U | 5.48 |
| 04-08-86 | 0.590 W/W | 0.266 W/U | 4.645 U/U | 1.25 |
| 05-20-86 | 0.338 W/W | 0.181 W/U | 4.554 U/U | 3.11 |

SITE: CK-HD-5

| Date | Gradients | | | Water Table (ft.) |
|---|---|---|---|---|
| | Well A2/ Well A | Well A / Well B2 | Well B2/ Well B | Well A2 |
| 10-04-83 | NO WAT LEV | NO WAT LEV | NO WAT LEV | NO WAT LEV |
| 11-15-83 | NO WAT LEV | NO WAT LEV | NO WAT LEV | NO WAT LEV |
| 01-05-84 | NO WAT LEV | NO WAT LEV | NO WAT LEV | NO WAT LEV |
| 05-01-84 | NO WAT LEV | NO WAT LEV | NO WAT LEV | NO WAT LEV |
| 05-24-84 | NO WAT LEV | NO WAT LEV | NO WAT LEV | NO WAT LEV |
| 06-12-84 | NO WAT LEV | NO WAT LEV | NO WAT LEV | NO WAT LEV |
| 06-21-84 | -0.477 W/U | 1.917 U/U | -1.107 U/U | 10.45 |
| 07-04-84 | 0.012 W/U | 0.772 U/U | -0.359 U/U | 7.88 |
| 07-18-84 | -0.029 W/U | 0.435 U/U | -0.179 U/U | 8.47 |
| 07-25-84 | -0.023 W/U | 1.523 U/U | -0.929 U/U | 8.74 |
| 07-31-84 | -0.049 W/U | 1.306 U/U | -0.783 U/U | 8.88 |
| 11-02-84 | -0.031 W/U | 0.127 U/U | -0.096 U/U | 10.40 |
| 02-20-85 | 0.580 W/U | -0.013 U/U | 0.011 U/U | 8.13 |
| 05-01-85 | 0.059 W/U | 0.044 U/U | 0.020 U/U | 9.38 |
| 09-10-85 | 0.057 W/U | -0.018 U/U | -0.028 U/U | 11.03 |
| 04-08-86 | 0.121 W/U | -0.057 U/U | 0.143 U/U | 3.85 |
| 05-20-86 | 0.008 W/U | -0.061 U/U | 0.064 U/U | 4.29 |

SITE: CK-HD-6

| Date | Gradients | | Water Table (ft.) |
|---|---|---|---|
| | Well A / Well B | Well B / Well C | Well B |
| 10-04-83 | 1.329 W/U | -0.305 U/U | 7.09 |
| 11-15-83 | 1.139 W/U | 0.020 U/U | 7.22 |
| 01-05-84 | 0.964 W/U | -0.048 U/U | 7.52 |
| 05-01-84 | 0.749 W/U | -0.163 U/U | 3.05 |
| 05-24-84 | 0.437 W/U | 0.111 U/U | 4.40 |
| 06-12-84 | 0.667 W/U | -0.212 U/U | 3.99 |
| 06-21-84 | 0.733 W/U | -0.201 U/U | 2.23 |
| 07-04-84 | 0.747 W/U | -0.176 U/U | 0.96 |
| 07-18-84 | 0.651 W/U | -0.147 U/U | 1.36 |
| 07-25-84 | 0.556 W/U | 0.226 U/U | 10.06 |
| 07-31-84 | 0.649 W/U | 0.141 U/U | 7.71 |
| 11-02-84 | 0.419 W/U | -0.152 U/U | 5.08 |
| 02-20-85 | 0.079 W/U | 0.001 U/U | 6.94 |
| 05-01-85 | 0.184 W/U | 0.059 U/U | 4.54 |
| 09-10-85 | 0.285 W/U | 0.082 U/U | 2.86 |
| 04-08-86 | NO WAT LEV | 0.131 U/U | NO WAT LEV |
| 05-20-86 | 0.278 W/U | 0.140 U/U | -0.25 |

SITE: CK-HD-7

| Date | Gradients | | Water Table (ft.) |
|---|---|---|---|
| | Well A2/ Well A | Well A / Well B | Well A2 |
| 10-04-83 | NO WAT LEV | 0.030 W/U | NO WAT LEV |
| 11-15-83 | NO WAT LEV | 0.014 W/U | NO WAT LEV |
| 01-05-84 | NO WAT LEV | 0.010 W/U | NO WAT LEV |
| 05-01-84 | NO WAT LEV | 0.045 W/U | NO WAT LEV |
| 05-24-84 | NO WAT LEV | 0.039 W/U | NO WAT LEV |
| 06-12-84 | NO WAT LEV | 0.031 W/U | NO WAT LEV |
| 06-21-84 | 0.192 W/W | 0.034 W/U | 1.74 |
| 07-04-84 | 0.007 W/W | 0.024 W/U | 3.60 |
| 07-18-84 | 0.072 W/W | 0.026 W/U | 4.35 |
| 07-25-84 | 1.168 W/W | -0.219 W/U | 5.41 |
| 07-31-84 | 0.438 W/W | -0.052 W/U | 5.89 |
| 11-02-84 | 0.205 W/W | 0.009 W/U | 8.25 |
| 02-20-85 | 0.240 W/W | -0.052 W/U | 7.92 |
| 05-01-85 | -0.031 W/W | 0.013 W/U | 3.64 |
| 09-10-85 | 0.332 W/W | -0.060 W/U | 6.96 |
| 04-08-86 | 0.017 W/W | 0.012 W/U | 0.44 |
| 05-20-86 | -0.065 W/W | 0.016 W/U | 0.80 |

SITE: CK-HD-8

| Date | Gradients | | | Water Table (ft.) |
|---|---|---|---|---|
| | Well A2/ Well A | Well A / Well B2 | Well B2/ Well B | Well A2 |
| 10-04-83 | NO WAT LEV | NO WAT LEV | NO WAT LEV | NO WAT LEV |
| 11-15-83 | NO WAT LEV | NO WAT LEV | NO WAT LEV | NO WAT LEV |
| 01-05-84 | NO WAT LEV | NO WAT LEV | NO WAT LEV | NO WAT LEV |
| 05-01-84 | NO WAT LEV | NO WAT LEV | NO WAT LEV | NO WAT LEV |
| 05-24-84 | NO WAT LEV | NO WAT LEV | NO WAT LEV | NO WAT LEV |
| 06-12-84 | NO WAT LEV | NO WAT LEV | NO WAT LEV | NO WAT LEV |
| 06-21-84 | -0.465 W/W | 0.057 W/U | 0.525 W/W | 9.23 |
| 07-04-84 | 0.006 W/W | 0.055 W/U | 0.549 W/W | 6.66 |
| 07-18-84 | -0.034 W/W | 0.047 W/U | 0.523 W/W | 7.13 |
| 07-25-84 | -0.047 W/W | 0.049 W/U | 0.459 W/W | 7.93 |
| 07-31-84 | 0.023 W/W | 0.055 W/U | 0.446 W/W | 7.64 |
| 11-02-84 | -0.045 W/W | 0.051 W/U | 0.204 W/W | 11.39 |
| 02-20-85 | -0.004 W/W | -0.002 W/U | 0.204 W/W | 12.71 |
| 05-01-85 | 0.309 W/W | 0.004 W/U | -0.190 W/W | 10.65 |
| 09-10-85 | -0.190 W/W | 0.004 W/U | 0.375 W/W | 12.27 |
| 04-08-86 | 0.190 W/W | 0.010 W/U | 0.837 W/W | 3.07 |
| 05-20-86 | 0.000 W/W | 0.000 W/U | 0.618 W/W | 2.84 |

SITE: CK-HD-9

| Date | Gradients | | | Water Table (ft.) |
|---|---|---|---|---|
| | Well A2/ Well A | Well A / Well B | Well B / Well C | Well A2 |
| 10-04-83 | NO WAT LEV | -0.042 U/U | 0.034 U/U | NO WAT LEV |
| 11-15-83 | NO WAT LEV | -0.040 U/U | 0.027 U/U | NO WAT LEV |
| 01-05-84 | NO WAT LEV | -0.034 U/U | 0.018 U/U | NO WAT LEV |
| 05-01-84 | NO WAT LEV | 0.002 U/U | 0.195 U/U | NO WAT LEV |
| 05-24-84 | NO WAT LEV | -0.002 U/U | 0.147 U/U | NO WAT LEV |
| 06-12-84 | NO WAT LEV | -0.007 U/U | 0.136 U/U | NO WAT LEV |
| 06-21-84 | -0.185 W/U | -0.027 U/U | 0.159 U/U | 0.90 |
| 07-04-84 | -0.093 W/U | 0.005 U/U | 0.123 U/U | 3.41 |
| 07-18-84 | -0.137 W/U | 0.019 U/U | 0.094 U/U | 4.24 |
| 07-25-84 | -0.092 W/U | -0.040 U/U | 0.059 U/U | 5.73 |
| 07-31-84 | -0.143 W/U | -0.017 U/U | 0.047 U/U | 6.13 |
| 11-02-84 | 0.023 W/U | -0.008 U/U | 0.026 U/U | 6.76 |
| 02-20-85 | -0.097 W/U | -0.023 U/U | -0.007 U/U | 9.19 |
| 05-01-85 | -0.005 W/U | -0.015 U/U | 0.081 U/U | 6.65 |
| 09-10-85 | 0.117 W/U | -0.020 U/U | 0.050 U/U | 7.78 |
| 04-08-86 | 0.087 W/U | -0.017 U/U | 0.240 U/U | 0.67 |
| 05-20-86 | -0.102 W/U | 0.016 U/U | 0.156 U/U | 0.97 |

SITE: CK-HD-10

| Date | Gradients | | Water Table (ft.) |
|---|---|---|---|
| | Well A / Well B | Well B / Well C | Well A |
| 10-04-83 | 0.126 W/U | 1.286 U/U | 3.35 |
| 11-15-83 | 0.186 W/U | 1.793 U/U | 3.40 |
| 01-05-84 | 0.025 W/U | 1.931 U/U | 4.50 |
| 05-01-84 | 0.041 W/U | 2.117 U/U | -0.29 |
| 05-24-84 | 0.034 W/U | 1.971 U/U | 0.32 |
| 06-12-84 | 0.085 W/U | 1.931 U/U | -0.33 |
| 06-21-84 | 0.076 W/U | 1.953 U/U | -0.68 |
| 07-04-84 | 0.034 W/U | 1.869 U/U | -0.20 |
| 07-18-84 | -0.076 W/U | 1.795 U/U | 1.62 |
| 07-25-84 | 0.114 W/U | 1.530 U/U | 2.35 |
| 07-31-84 | 0.031 W/U | 1.509 U/U | 2.99 |
| 11-02-84 | 0.016 W/U | 1.464 U/U | 4.28 |
| 02-20-85 | -0.001 W/U | 1.124 U/U | 5.34 |
| 05-01-85 | -0.008 W/U | 1.667 U/U | 0.28 |
| 09-10-85 | 0.068 W/U | 1.193 U/U | 3.55 |
| 04-08-86 | NO WAT LEV | NO WAT LEV | -0.27 |
| 05-20-86 | 0.085 W/U | 1.399 U/U | -0.63 |

SITE: CK-HD-11

| Date | Gradients | | | | Water Table (ft.) |
|---|---|---|---|---|---|
| | Well A2/ Well A | Well A / Well B | Well B / Well D | Well D / Well B2 | Well A2 |
| 10-04-83 | NO WAT LEV | -0.108 W/U | NO WAT LEV | NO WAT LEV | NO WAT LEV |
| 11-15-83 | NO WAT LEV | -0.038 W/U | NO WAT LEV | NO WAT LEV | NO WAT LEV |
| 01-05-84 | NO WAT LEV | 0.038 W/U | NO WAT LEV | NO WAT LEV | NO WAT LEV |
| 05-01-84 | NO WAT LEV | -0.078 W/U | NO WAT LEV | NO WAT LEV | NO WAT LEV |
| 05-24-84 | NO WAT LEV | -0.060 W/U | NO WAT LEV | NO WAT LEV | NO WAT LEV |
| 06-12-84 | NO WAT LEV | -0.073 W/U | NO WAT LEV | NO WAT LEV | NO WAT LEV |
| 06-21-84 | -0.408 W/W | -0.087 W/U | NO WAT LEV | NO WAT LEV | 10.47 |
| 07-04-84 | -0.036 W/W | -0.055 W/U | NO WAT LEV | NO WAT LEV | 6.92 |
| 07-18-84 | -0.030 W/W | -0.054 W/U | NO WAT LEV | NO WAT LEV | 7.31 |
| 07-25-84 | -0.211 W/W | 0.062 W/U | NO WAT LEV | NO WAT LEV | 7.84 |
| 07-31-84 | -0.113 W/W | -0.052 W/U | NO WAT LEV | NO WAT LEV | 8.36 |
| 11-02-84 | -0.028 W/W | -0.048 W/U | NO WAT LEV | NO WAT LEV | 10.47 |
| 02-20-85 | -0.007 W/W | -0.014 W/U | 0.580 U/U | 0.283 U/U | 11.08 |
| 05-01-85 | -0.004 W/W | -0.006 W/U | 0.553 U/U | 0.383 U/U | 11.72 |
| 09-10-85 | -0.003 W/W | -0.002 W/U | 0.552 U/U | 0.460 U/U | 11.63 |
| 04-08-86 | -0.037 W/W | -0.085 W/U | 0.659 U/U | 0.482 U/U | 9.26 |
| 05-20-86 | -0.067 W/W | -0.052 W/U | 0.797 U/U | 0.492 U/U | 4.76 |

SITE: CK-HD-12

| Date | Gradients | | | | Water Table (ft.) |
|---|---|---|---|---|---|
| | Well A2/ Well A | Well A / Well B | Well B / Well B2 | Well B2/ Well C | Well A2 |
| 10-04-83 | NO WAT LEV | 0.015 W/W | NO WAT LEV | NO WAT LEV | NO WAT LEV |
| 11-15-83 | NO WAT LEV | 0.022 W/W | NO WAT LEV | NO WAT LEV | NO WAT LEV |
| 01-05-84 | NO WAT LEV | 0.022 W/W | NO WAT LEV | NO WAT LEV | NO WAT LEV |
| 05-01-84 | NO WAT LEV | 0.021 W/W | NO WAT LEV | NO WAT LEV | NO WAT LEV |
| 05-24-84 | NO WAT LEV | 0.015 W/W | NO WAT LEV | NO WAT LEV | NO WAT LEV |
| 06-12-84 | NO WAT LEV | 0.089 W/W | NO WAT LEV | NO WAT LEV | NO WAT LEV |
| 06-21-84 | -0.128 W/W | 0.093 W/W | 4.668 W/U | -2.000 U/U | 0.46 |
| 07-04-84 | -0.250 W/W | 0.065 W/W | 1.566 W/U | 0.886 U/U | 2.57 |
| 07-18-84 | -0.160 W/W | 0.036 W/W | 0.308 W/U | 1.813 U/U | 3.45 |
| 07-25-84 | -0.169 W/W | 0.039 W/W | 2.941 W/U | -1.176 U/U | 3.82 |
| 07-31-84 | -0.190 W/W | 0.033 W/W | 1.874 W/U | -0.138 U/U | 4.18 |
| 11-02-84 | -0.147 W/W | 0.041 W/W | -0.042 W/U | 3.113 U/U | 5.80 |
| 02-20-85 | 0.017 W/W | 0.000 W/W | -0.035 W/U | 1.169 U/U | 6.83 |
| 05-01-85 | -0.062 W/W | -0.027 W/W | 0.054 W/U | 1.234 U/U | 3.48 |
| 09-10-85 | 0.075 W/W | 0.062 W/W | 0.153 W/U | 0.388 U/U | 3.74 |
| 04-08-86 | -0.013 W/W | -0.001 W/W | 0.131 W/U | 0.880 U/U | 0.12 |
| 05-20-86 | -0.130 W/W | 0.029 W/W | 0.084 W/U | 0.744 U/U | 0.38 |

SITE: CK-HD-13

| Date | Gradients | | Water Table (ft.) |
|---|---|---|---|
| | Well A2/ Well A | Well A / Well B | Well A2 |
| 10-04-83 | NO WAT LEV | 0.451 U/U | NO WAT LEV |
| 11-15-83 | NO WAT LEV | 0.560 U/U | NO WAT LEV |
| 01-05-84 | NO WAT LEV | 0.367 U/U | NO WAT LEV |
| 05-01-84 | NO WAT LEV | 0.029 U/U | NO WAT LEV |
| 05-24-84 | NO WAT LEV | -0.057 U/U | NO WAT LEV |
| 06-12-84 | NO WAT LEV | -0.019 U/U | NO WAT LEV |
| 06-21-84 | 0.366 W/U | 0.037 U/U | 0.83 |
| 07-04-84 | 0.018 W/U | 0.047 U/U | 3.45 |
| 07-18-84 | -0.037 W/U | 0.037 U/U | 4.13 |
| 07-25-84 | -0.098 W/U | 0.023 U/U | 5.08 |
| 07-31-84 | -0.129 W/U | 0.011 U/U | 5.67 |
| 11-02-84 | -0.024 W/U | 0.042 U/U | 7.31 |
| 02-20-85 | -0.035 W/U | -0.078 U/U | 8.19 |
| 05-01-85 | -0.007 W/U | -0.030 U/U | 6.73 |
| 09-10-85 | 0.043 W/U | -0.084 U/U | 8.50 |
| 04-08-86 | 0.103 W/U | -0.011 U/U | 0.57 |
| 05-20-86 | -0.107 W/U | 0.047 U/U | 2.46 |

SITE: CK-HD-15

| Date | Gradients | | | | Water Table (ft.) |
|---|---|---|---|---|---|
| | Well A2/ Well A | Well A / Well B | Well B / Well C | Well C / Well D | Well A2 |
| 10-04-83 | NO WAT LEV | 0.009 U/U | 0.874 U/U | NO WAT LEV | NO WAT LEV |
| 11-15-83 | NO WAT LEV | 0.050 U/U | 0.886 U/U | NO WAT LEV | NO WAT LEV |
| 01-05-84 | NO WAT LEV | 0.098 U/U | 0.781 U/U | NO WAT LEV | NO WAT LEV |
| 05-01-84 | NO WAT LEV | 0.004 U/U | 0.525 U/U | NO WAT LEV | NO WAT LEV |
| 05-24-84 | NO WAT LEV | 0.054 U/U | 0.545 U/U | NO WAT LEV | NO WAT LEV |
| 06-12-84 | NO WAT LEV | 0.104 U/U | 0.538 U/U | NO WAT LEV | NO WAT LEV |
| 06-21-84 | 0.892 W/U | 0.013 U/U | 0.645 U/U | NO WAT LEV | 1.37 |
| 07-04-84 | 0.144 W/U | 0.206 U/U | 0.569 U/U | NO WAT LEV | 4.25 |
| 07-18-84 | 0.061 W/U | 0.177 U/U | 0.564 U/U | NO WAT LEV | 5.08 |
| 07-25-84 | 0.051 W/U | 0.165 U/U | 0.557 U/U | NO WAT LEV | 5.38 |
| 07-31-84 | 0.042 W/U | 0.155 U/U | 0.553 U/U | NO WAT LEV | 5.59 |
| 11-02-84 | 0.036 W/U | 0.035 U/U | 0.625 U/U | NO WAT LEV | 7.80 |
| 02-20-85 | -0.006 W/U | 0.021 U/U | 0.471 U/U | 2.474 U/U | 8.51 |
| 05-01-85 | 0.091 W/U | 0.163 U/U | 0.471 U/U | 2.245 U/U | 6.15 |
| 09-10-85 | 0.210 W/U | 0.139 U/U | 0.466 U/U | 1.835 U/U | 6.33 |
| 04-08-86 | 0.006 W/U | 0.452 U/U | 0.535 U/U | 1.714 U/U | 1.33 |
| 05-20-86 | 0.011 W/U | 0.305 U/U | 0.548 U/U | 1.636 U/U | 2.06 |

SITE: CK-HD-16

| Date | Gradients | | Water Table (ft.) |
|---|---|---|---|
| | Well A / Well B | Well B / Well C | Well A |
| 11-15-83 | -0.065 W/W | 0.323 W/W | 10.74 |
| 01-05-84 | -0.040 W/W | 0.253 W/W | 11.44 |
| 05-01-84 | 0.126 W/W | 0.743 W/W | 2.96 |
| 05-24-84 | 0.048 W/W | 0.652 W/W | 4.11 |
| 06-12-84 | 0.073 W/W | 0.577 W/W | 4.42 |
| 06-21-84 | 0.072 W/W | 0.569 W/W | 4.46 |
| 07-04-84 | 0.027 W/W | 0.591 W/W | 4.41 |
| 07-18-84 | -0.015 W/W | 0.511 W/W | 5.63 |
| 07-25-84 | -0.025 W/W | 0.516 W/W | 6.32 |
| 07-31-84 | -0.041 W/W | 0.455 W/W | 6.76 |
| 11-02-84 | -0.048 W/W | 0.228 W/W | 10.44 |
| 02-20-85 | -0.019 W/W | 0.179 W/W | 11.76 |
| 05-01-85 | 0.137 W/W | 0.648 W/W | 4.93 |
| 09-10-85 | -0.013 W/W | 0.300 W/W | 10.62 |
| 04-08-86 | -0.008 W/W | 0.056 W/W | 1.86 |
| 05-20-86 | 0.036 W/W | 0.755 W/W | 1.79 |

SITE: CK-HD-17

| Date | Gradients | | Water Table (ft.) |
|---|---|---|---|
| | Well A / Well B | Well B / Well C | Well A |
| 11-15-83 | -0.469 W/W | 0.337 W/U | 12.80 |
| 01-05-84 | 0.053 W/W | -0.018 W/U | 8.10 |
| 05-01-84 | 0.004 W/W | 0.006 W/U | 3.35 |
| 05-24-84 | -0.014 W/W | -0.012 W/U | 4.01 |
| 06-12-84 | -0.007 W/W | -0.011 W/U | 4.44 |
| 06-21-84 | 0.182 W/W | 0.167 W/U | 0.82 |
| 07-04-84 | -0.004 W/W | -0.038 W/U | 3.67 |
| 07-18-84 | -0.009 W/W | -0.058 W/U | 5.08 |
| 07-25-84 | -0.005 W/W | 0.032 W/U | 5.51 |
| 07-31-84 | -0.009 W/W | -0.051 W/U | 6.07 |
| 11-02-84 | -0.009 W/W | -0.042 W/U | 8.31 |
| 02-20-85 | -0.006 W/W | -0.039 W/U | 8.98 |
| 05-01-85 | -0.003 W/W | 0.022 W/U | 6.11 |
| 09-10-85 | -0.013 W/W | 0.040 W/U | 5.71 |
| 04-08-86 | 0.001 W/W | 0.052 W/U | 1.64 |
| 05-20-86 | -0.004 W/W | -0.044 W/U | 2.85 |

SITE: CK-HD-18

| Date | Gradients | | | | Water Table (ft.) |
|---|---|---|---|---|---|
| | Well A / Well B | Well B / Well C | Well C / Well D | Well D / Well E | Well A |
| 11-15-83 | 0.006 W/W | 0.750 W/U | NO WAT LEV | NO WAT LEV | 5.94 |
| 01-05-84 | -0.014 W/W | 0.363 W/U | NO WAT LEV | NO WAT LEV | 6.34 |
| 05-01-84 | -0.004 W/W | 0.313 W/U | NO WAT LEV | NO WAT LEV | 2.57 |
| 05-24-84 | -0.016 W/W | 0.264 W/U | NO WAT LEV | NO WAT LEV | 3.47 |
| 06-12-84 | 0.017 W/W | 0.341 W/U | NO WAT LEV | NO WAT LEV | 0.68 |
| 06-21-84 | 0.008 W/W | 0.298 W/U | NO WAT LEV | NO WAT LEV | 0.86 |
| 07-04-84 | -0.002 W/W | 0.185 W/U | NO WAT LEV | NO WAT LEV | 2.58 |
| 07-18-84 | -0.017 W/W | 0.125 W/U | NO WAT LEV | NO WAT LEV | 3.71 |
| 07-25-84 | -0.017 W/W | 0.235 W/U | NO WAT LEV | NO WAT LEV | 4.17 |
| 07-31-84 | -0.018 W/W | 0.188 W/U | NO WAT LEV | NO WAT LEV | 4.54 |
| 11-02-84 | -0.014 W/W | 0.133 W/U | NO WAT LEV | NO WAT LEV | 6.87 |
| 02-20-85 | -0.021 W/W | 0.030 W/U | 1.982 U/U | 1.322 U/U | 7.44 |
| 05-01-85 | 0.002 W/W | 0.060 W/U | 1.722 U/U | 1.270 U/U | 5.56 |
| 09-10-85 | -0.055 W/W | 0.064 W/U | 1.232 U/U | 1.146 U/U | 7.69 |
| 04-08-86 | 0.006 W/W | 0.169 W/U | -0.107 U/U | 1.762 U/U | 1.05 |
| 05-20-86 | -0.019 W/W | 0.064 W/U | 0.026 U/U | 1.651 U/U | 1.46 |

SITE: CK-HY-1

| Date | Gradients | | Water Table (ft.) |
|---|---|---|---|
| | Well A / Well B | Well B / Well C | Well A |
| 10-04-83 | -0.046 W/W | 1.330 W/U | 7.80 |
| 11-15-83 | -0.030 W/W | 1.593 W/U | 8.30 |
| 01-05-84 | -0.021 W/W | 1.672 W/U | 8.60 |
| 05-01-84 | 0.055 W/W | 1.597 W/U | 7.68 |
| 05-24-84 | 0.025 W/W | 1.717 W/U | 7.22 |
| 06-12-84 | 0.152 W/W | 1.719 W/U | 5.11 |
| 06-21-84 | 0.144 W/W | 1.785 W/U | 4.07 |
| 07-04-84 | 0.011 W/W | 1.795 W/U | 5.03 |
| 07-18-84 | -0.008 W/W | 1.797 W/U | 5.28 |
| 07-25-84 | -0.003 W/W | 1.779 W/U | 5.82 |
| 07-31-84 | 0.003 W/W | 1.783 W/U | 5.67 |
| 11-02-84 | -0.002 W/W | 1.936 W/U | 8.22 |
| 02-20-85 | 0.029 W/W | 1.652 W/U | 9.32 |
| 05-01-85 | 0.063 W/W | 1.937 W/U | 8.35 |
| 09-10-85 | 0.065 W/W | 1.793 W/U | 8.57 |
| 04-08-86 | 0.111 W/W | 1.822 W/U | 3.54 |
| 05-20-86 | 0.008 W/W | 1.872 W/U | 3.19 |

SITE: CK-HY-2

| Date | Gradients | | Water Table (ft.) |
| --- | --- | --- | --- |
| | Well A / Well B | Well B / Well C | Well A |
| 10-04-83 | 0.055 W/W | 0.029 W/U | 5.61 |
| 11-15-83 | 0.152 W/W | 0.103 W/U | 6.10 |
| 01-05-84 | 0.095 W/W | 0.226 W/U | 6.65 |
| 05-01-84 | 0.420 W/W | 1.126 W/U | 3.70 |
| 05-24-84 | 0.295 W/W | 0.912 W/U | 3.68 |
| 06-12-84 | 0.407 W/W | 1.039 W/U | 2.23 |
| 06-21-84 | 0.410 W/W | 1.119 W/U | 1.44 |
| 07-04-84 | 0.291 W/W | 1.162 W/U | 2.18 |
| 07-18-84 | 0.225 W/W | 1.174 W/U | 2.52 |
| 07-25-84 | 0.198 W/W | 0.631 W/U | 3.50 |
| 07-31-84 | 0.180 W/W | 0.669 W/U | 3.68 |
| 11-02-84 | 0.126 W/W | 0.644 W/U | 6.25 |
| 02-20-85 | 0.084 W/W | 0.347 W/U | 7.22 |
| 05-01-85 | 0.244 W/W | 0.230 W/U | 6.46 |
| 09-10-85 | 0.283 W/W | 0.184 W/U | 6.03 |
| 04-08-86 | 0.372 W/W | 0.237 W/U | 1.24 |
| 05-20-86 | 0.149 W/W | 0.285 W/U | 1.69 |

SITE: CK-HY-3

| Date | Gradients | | | Water Table (ft.) |
|---|---|---|---|---|
| | Well A2/ Well A | Well A / Well B | Well B / Well D | Well A2 |
| 10-04-83 | NO WAT LEV | -0.002 W/W | NO WAT LEV | NO WAT LEV |
| 11-15-83 | NO WAT LEV | -0.215 W/W | NO WAT LEV | NO WAT LEV |
| 01-05-84 | NO WAT LEV | -0.107 W/W | NO WAT LEV | NO WAT LEV |
| 05-01-84 | NO WAT LEV | -0.018 W/W | NO WAT LEV | NO WAT LEV |
| 05-24-84 | NO WAT LEV | -0.035 W/W | NO WAT LEV | NO WAT LEV |
| 06-12-84 | NO WAT LEV | 0.003 W/W | NO WAT LEV | NO WAT LEV |
| 06-21-84 | 0.447 W/W | 0.021 W/W | NO WAT LEV | 4.06 |
| 07-04-84 | 0.074 W/W | 0.075 W/W | NO WAT LEV | 4.79 |
| 07-18-84 | -0.095 W/W | 0.083 W/W | NO WAT LEV | 5.92 |
| 07-25-84 | -0.119 W/W | 0.089 W/W | NO WAT LEV | 6.37 |
| 07-31-84 | -0.154 W/W | 0.077 W/W | NO WAT LEV | 6.86 |
| 11-02-84 | -0.173 W/W | 0.067 W/W | NO WAT LEV | 9.43 |
| 02-20-85 | -0.083 W/W | 0.046 W/W | 1.082 W/U | 9.64 |
| 05-01-85 | -0.027 W/W | 0.070 W/W | 1.177 W/U | 4.38 |
| 09-10-85 | 0.195 W/W | 0.074 W/W | 1.096 W/U | 2.87 |
| 05-20-86 | 0.084 W/W | -0.047 W/W | 1.200 W/U | -0.83 |

SITE: CK-HY-4

| Date | Gradients | | | Water Table (ft.) |
|---|---|---|---|---|
| | Well A2/ Well A | Well A / Well B | Well B / Well C | Well A2 |
| 10-04-83 | NO WAT LEV | 0.927 W/W | -0.928 W/W | NO WAT LEV |
| 11-15-83 | NO WAT LEV | 0.792 W/W | -0.772 W/W | NO WAT LEV |
| 01-05-84 | NO WAT LEV | 0.376 W/W | -0.385 W/W | NO WAT LEV |
| 05-01-84 | NO WAT LEV | 0.311 W/W | -0.267 W/W | NO WAT LEV |
| 05-24-84 | NO WAT LEV | 0.401 W/W | -0.379 W/W | NO WAT LEV |
| 06-12-84 | NO WAT LEV | 0.634 W/W | -0.426 W/W | NO WAT LEV |
| 06-21-84 | 0.193 W/W | 0.657 W/W | -0.521 W/W | 1.94 |
| 07-04-84 | -0.018 W/W | 0.379 W/W | -0.412 W/W | 4.57 |
| 07-18-84 | -0.029 W/W | 0.250 W/W | -0.280 W/W | 5.47 |
| 07-25-84 | -0.044 W/W | 0.362 W/W | -0.314 W/W | 6.88 |
| 07-31-84 | -0.066 W/W | 0.235 W/W | -0.256 W/W | 7.74 |
| 11-02-84 | -0.022 W/W | 0.119 W/W | -0.127 W/W | 9.80 |
| 02-20-85 | -0.053 W/W | 0.035 W/W | 0.011 W/W | 11.33 |
| 05-01-85 | -0.018 W/W | 0.102 W/W | -0.105 W/W | 6.81 |
| 09-10-85 | -0.011 W/W | 0.036 W/W | -0.046 W/W | 9.66 |
| 04-08-86 | -0.002 W/W | 0.382 W/W | -0.294 W/W | -0.19 |
| 05-20-86 | -0.031 W/W | 0.031 W/W | -0.063 W/W | 1.29 |

SITE: CK-HY-5

| Date | Gradients | | | | Water Table (ft.) |
|---|---|---|---|---|---|
| | Well A / Well B | Well B / Well C | Well C / Well D | Well D / Well E | Well A |
| 11-15-83 | -0.034 W/W | 0.342 W/U | NO WAT LEV | NO WAT LEV | 9.89 |
| 01-05-84 | -0.034 W/W | -0.049 W/U | NO WAT LEV | NO WAT LEV | 10.59 |
| 05-01-84 | -0.044 W/W | -0.032 W/U | NO WAT LEV | NO WAT LEV | 11.61 |
| 05-24-84 | -0.056 W/W | 0.009 W/U | NO WAT LEV | NO WAT LEV | 11.18 |
| 06-12-84 | -0.051 W/W | -0.001 W/U | NO WAT LEV | NO WAT LEV | 10.68 |
| 06-21-84 | -0.059 W/W | 0.044 W/U | NO WAT LEV | NO WAT LEV | 9.90 |
| 07-04-84 | 0.008 W/W | 0.101 W/U | NO WAT LEV | NO WAT LEV | 5.47 |
| 07-18-84 | -0.019 W/W | 0.040 W/U | NO WAT LEV | NO WAT LEV | 6.11 |
| 07-25-84 | -0.023 W/W | 0.008 W/U | NO WAT LEV | NO WAT LEV | 7.04 |
| 07-31-84 | -0.036 W/W | -0.015 W/U | NO WAT LEV | NO WAT LEV | 7.43 |
| 11-02-84 | -0.037 W/W | -0.083 W/U | NO WAT LEV | NO WAT LEV | 9.45 |
| 02-20-85 | -0.045 W/W | -0.032 W/U | 0.686 U/U | 1.617 U/U | 10.21 |
| 05-01-85 | -0.035 W/W | 0.006 W/U | 0.564 U/U | 1.482 U/U | 10.13 |
| 09-10-85 | -0.033 W/W | -0.024 W/U | 0.501 U/U | 1.168 U/U | 10.93 |
| 04-08-86 | -0.003 W/W | 0.056 W/U | 0.551 U/U | 0.927 U/U | 7.56 |
| 05-20-86 | 0.002 W/W | 0.013 W/U | 0.620 U/U | -0.516 U/U | 3.67 |

SITE: CK-HY-6

| Date | Gradients | | | | | Water Table (ft.) |
|---|---|---|---|---|---|---|
| | Well A / Well B | Well B / Well B2 | Well B2/ Well C | Well C / Well D | Well D / Well E | Well A |
| 11-15-83 | 0.046 W/U | NO WAT LEV | NO WAT LEV | NO WAT LEV | NO WAT LEV | 10.53 |
| 01-05-84 | 0.032 W/U | NO WAT LEV | NO WAT LEV | NO WAT LEV | NO WAT LEV | 11.38 |
| 05-01-84 | 0.045 W/U | NO WAT LEV | NO WAT LEV | NO WAT LEV | NO WAT LEV | 11.46 |
| 05-24-84 | 0.047 W/U | NO WAT LEV | NO WAT LEV | NO WAT LEV | NO WAT LEV | 11.09 |
| 06-12-84 | 0.053 W/U | NO WAT LEV | NO WAT LEV | NO WAT LEV | NO WAT LEV | 10.85 |
| 06-21-84 | 0.294 W/U | 4.198 U/U | -1.320 U/U | NO WAT LEV | NO WAT LEV | 1.45 |
| 07-04-84 | 0.034 W/U | 1.572 U/U | 1.175 U/U | NO WAT LEV | NO WAT LEV | 3.34 |
| 07-18-84 | 0.028 W/U | 0.807 U/U | 1.518 U/U | NO WAT LEV | NO WAT LEV | 4.37 |
| 07-25-84 | 0.034 W/U | 3.202 U/U | -0.846 U/U | NO WAT LEV | NO WAT LEV | 4.77 |
| 07-31-84 | 0.030 W/U | 0.185 U/U | 1.786 U/U | NO WAT LEV | NO WAT LEV | 5.28 |
| 11-02-84 | 0.039 W/U | 0.534 U/U | 0.686 U/U | NO WAT LEV | NO WAT LEV | 7.99 |
| 02-20-85 | 0.021 W/U | 0.241 U/U | 0.647 U/U | 1.301 U/U | 0.789 U/U | 9.16 |
| 05-01-85 | 0.024 W/U | 0.414 U/U | 1.085 U/U | 1.178 U/U | 0.636 U/U | 5.31 |
| 09-10-85 | 0.020 W/U | 0.083 U/U | 0.611 U/U | 1.088 U/U | 0.420 U/U | 9.60 |
| 04-08-86 | 0.010 W/U | 0.416 U/U | 1.618 U/U | -0.165 U/U | 1.700 U/U | 1.27 |
| 05-20-86 | 0.009 W/U | 0.012 U/U | 1.347 U/U | -0.073 U/U | 1.560 U/U | 2.54 |

SITE: CK-HY-7

| Date | Gradients | | Water Table (ft.) |
|---|---|---|---|
| | Well A / Well B | Well B / Well C | Well A |
| 11-15-83 | -0.162 W/W | 1.025 W/U | 12.66 |
| 01-05-84 | -0.131 W/W | 0.004 W/U | 12.66 |
| 05-01-84 | 0.015 W/W | 0.493 W/U | 5.39 |
| 05-24-84 | 0.011 W/W | 0.403 W/U | 6.86 |
| 06-12-84 | -0.063 W/W | 0.922 W/U | 1.74 |
| 06-21-84 | -0.049 W/W | 1.007 W/U | 0.39 |
| 07-04-84 | -0.046 W/W | 0.823 W/U | 1.50 |
| 07-18-84 | -0.018 W/W | 0.531 W/U | 3.32 |
| 07-25-84 | -0.017 W/W | 0.669 W/U | 3.63 |
| 07-31-84 | -0.016 W/W | 0.618 W/U | 4.08 |
| 11-02-84 | -0.013 W/W | 0.085 W/U | 6.89 |
| 02-20-85 | -0.060 W/W | 0.007 W/U | 8.28 |
| 05-01-85 | -0.001 W/W | 0.278 W/U | 4.16 |
| 09-10-85 | -0.050 W/W | -0.283 W/U | 11.31 |
| 05-20-86 | -0.004 W/W | 0.443 W/U | 0.36 |

SITE: CK-HY-8

| Date | Gradients | | | Water Table (ft.) |
|---|---|---|---|---|
| | Well A / Well B | Well B / Well C | Well C / Well D | Well A |
| 11-15-83 | -0.014 W/W | -0.059 W/U | NO WAT LEV | 15.48 |
| 01-05-84 | 0.027 W/W | -0.059 W/U | NO WAT LEV | 15.48 |
| 05-01-84 | 0.076 W/W | 0.033 W/U | NO WAT LEV | 5.05 |
| 05-24-84 | 0.053 W/W | -0.007 W/U | NO WAT LEV | 6.76 |
| 06-12-84 | 0.000 W/W | 0.025 W/U | NO WAT LEV | 7.29 |
| 06-21-84 | NO WAT LEV | 0.339 W/U | NO WAT LEV | NO WAT LEV |
| 07-04-84 | -0.004 W/W | -0.015 W/U | NO WAT LEV | 2.91 |
| 07-18-84 | -0.004 W/W | -0.036 W/U | NO WAT LEV | 4.46 |
| 07-25-84 | -0.021 W/W | -0.032 W/U | NO WAT LEV | 6.44 |
| 07-31-84 | -0.037 W/W | -0.059 W/U | NO WAT LEV | 7.79 |
| 11-02-84 | -0.088 W/W | -0.040 W/U | NO WAT LEV | 13.30 |
| 02-20-85 | 0.269 W/W | -0.012 W/U | 0.724 U/U | 10.93 |
| 05-01-85 | -0.003 W/W | 0.014 W/U | 0.510 U/U | 7.23 |
| 09-10-85 | NO WAT LEV | 0.027 W/U | 0.140 U/U | NO WAT LEV |
| 04-08-86 | 0.025 W/W | 0.034 W/U | 0.001 U/U | 1.31 |
| 05-20-86 | 0.003 W/W | 0.020 W/U | 0.039 U/U | 1.57 |

## GRADIENT STATISTICS

### Intra-Weathered Till Gradients

Number = 297
Average = 0.065
Stand. Dev. = 0.2517
Minimum Grad. = -0.928
Maximum Grad. = 1.196
Grad. Reversals = 142

### Weathered Till to Unweathered Till Gradients

Number = 276
Average = 0.339
Stand. Dev. = 0.6189
Minimum Grad. = -0.477
Maximum Grad. = 4.668
Grad. Reversals = 71

### Intra-Unweathered Till Gradients

Number = 234
Average = 0.652
Stand. Dev. = 1.0026
Minimum Grad. = -2.000
Maximum Grad. = 4.645
Grad. Reversals = 48

## WATER TABLE STATISTICS

Datum = Ground Surface
Number = 296
Average = 5.68 feet
Stand. Dev. = 3.40 feet
Minimum Water Table Depth = -0.83 feet
Maximum Water Table Depth = 15.48 feet

# APPENDIX E

## Locations and results of in situ and laboratory hydraulic conductivity tests for glacial till

This appendix reports the locations and values for each individual hydraulic conductivity test conducted in or on glacial till in the CENDAK area. The location is given in the township/range/section format (all townships are north and all ranges are west) and the hydraulic conductivites are reported in centimeters per second. If the test was conducted in a specifically identified piezometer, that piezometer is identified below the location. The test/sample depth indicates the depth at which the test was conducted if it was a field test or the depth from which the sample came if it was a lab test. The depth values are in feet below ground surface if no piezometer is reported or in feet below casing top if a piezometer is reported. A "W" following the depth indicates weathered till, a "T" following depth indicates transition zone, and a "U" following depth indicates unweathered till. A "Kh" following the hydraulic conductivity indicates a horizontal hydraulic conductivity test. In addition, the type of testing procedure is indicated (field or laboratory).

| Investigator | Location | Test/Sample Depth | Hydraulic Conductivity | Method |
|---|---|---|---|---|
| Bender and Carlson (1984) | 113N-71W-06CD (D-4-16) | ca. 16 W | 3.06E-07 | Field |
| | 113N-71W-06-CD (C-5-16) | ca. 16 W | 5.28E-08 | Field |
| | 113N-71W-06CD (BC-5-15) | ca. 15 W | 2.72E-07 | Field |
| | 113N-71W-06CD (BC-5-16) | ca. 16 W | 1.89E-07 | Field |
| | 113N-71W-06CD (B-4-15) | ca. 15 W | 1.00E-07 | Field |
| Bender and others (1983) | 111N-78W-08 | 6.0 W | 4.94E-05 | Field |
| | 113N-72W-25 | 6.0 W | 2.06E-04 | Field |
| | 111N-77W-17 | 6.0 W | 4.30E-04 | Field |
| | 112N-75W-31 | 6.0 W | 3.24E-04 | Field |
| | 111N-77W-17 | 6.0 W | 1.41E-06 | Lab |
| | 111N-77W-17 | 11.5 W | 1.83E-04 | Lab |
| | 111N-77W-17 | 6.5 W | 4.94E-06 | Lab |
| | 111N-77W-17 | 9.5 W | 4.23E-04 | Lab |
| | 111N-77W-17 | 15.0 W | 1.41E-05 | Lab |

| Investigator | Location | Test/Sample Depth | Hydraulic Conductivity | Method |
|---|---|---|---|---|
| | 111N-77W-17 | 13.7 W | 3.53E-05 | Lab |
| | 111N-77W-17 | 14.8 W | 1.41E-05 | Lab |
| | 111N-77W-17 | 12.6 W | 3.53E-08 | Lab |
| | 111N-79W-13 | 17.0 W | 4.23E-07 | Lab |
| | 111N-78W-08 | 20.0 W | 6.35E-10 | Lab |
| | 111N-78W-08 | 16.0 W | 2.82E-08 | Lab |
| | 111N-78W-36 | 25.5 W | 6.35E-08 | Lab |
| | 112N-75W-02 | 5.5 W | 3.10E-05 | Lab |
| | 112N-75W-02 | 6.0 W | 4.30E-04 | Lab |
| | 112N-75W-02 | 11.3 W | 1.41E-08 | Lab |
| | 112N-75W-02 | 16.0 W | 7.06E-09 | Lab |
| | 112N-75W-02 | 28.0 W | 2.12E-06 | Lab |
| | 112N-75W-02 | 32.0 W | 4.23E-09 | Lab |
| | 112N-75W-02 | 11.0 U | 7.76E-07 | Lab |
| | 112N-75W-02 | 16.0 U | 7.06E-09 | Lab |
| | 112N-75W-02 | 31.0 U | 2.12E-08 | Lab |

| Investigator | Location | Test/Sample Depth | Hydraulic Conductivity | Method |
|---|---|---|---|---|
| | 112N-75W-03 | 17.0 W | 7.06E-08 | Lab |
| | 112N-75W-03 | 26.0 W | 6.35E-07 | Lab |
| | 112N-75W-03 | 32.0 U | 1.41E-09 | Lab |
| | 112N-75W-17 | 7.0 W | 2.82E-09 | Lab |
| | 112N-75W-17 | 11.0 W | 1.34E-04 | Lab |
| | 112N-75W-17 | 21.0 U | 2.82E-09 | Lab |
| | 112N-75W-17 | 26.0 U | 4.23E-08 | Lab |
| | 112N-75W-17 | 31.0 U | 4.94E-09 | Lab |
| | 112N-75W-29 | 7.0 W | 6.35E-09 | Lab |
| | 112N-75W-29 | 12.0 W | 6.35E-09 | Lab |
| | 112N-75W-29 | 15.0 W | 3.53E-09 | Lab |
| | 112N-75W-29 | 21.0 U | 2.12E-08 | Lab |
| | 112N-75W-29 | 31.0 U | 4.94E-09 | Lab |
| | 113N-72W-36 | 11.5 W | 2.12E-07 | Lab |
| | 113N-72W-36 | 16.5 W | 2.12E-08 | Lab |
| | 113N-72W-36 | 21.0 W | 4.44E-04 | Lab |

| Investigator | Location | Test/Sample Depth | Hydraulic Conductivity | Method |
|---|---|---|---|---|
| | 113N-72W-36 | 26.0 W | 2.82E-08 | Lab |
| | 113N-72W-36 | 31.0 U | 7.06E-10 | Lab |
| | 113N-72W-25 | 16.0 W | 7.06E-09 | Lab |
| | 113N-72W-25 | 21.0 U | 5.64E-09 | Lab |
| | 113N-72W-25 | 26.0 U | 7.06E-09 | Lab |
| | 113N-72W-25 | 31.0 U | 2.12E-09 | Lab |
| | 114N-71W-08 | 14.0 W | 7.06E-06 | Lab |
| | 113N-73W-24 | 21.0 W | 7.06E-08 | Lab |
| | 113N-73W-24 | 26.0 W | 1.41E-07 | Lab |
| | 113N-73W-24 | 31.0 W | 4.23E-09 | Lab |
| | 113N-73W-24 | 16.0 W | 2.12E-07 | Lab |
| | 113N-73W-24 | 21.0 U | 1.41E-08 | Lab |
| | 113N-73W-24 | 25.5 U | 2.82E-08 | Lab |
| | 113N-73W-24 | 31.0 U | 2.82E-09 | Lab |
| | 116N-73W-13 | 6.0 W | 1.62E-04 | Lab |
| | 116N-73W-13 | 11.5 W | 1.62E-05 | Lab |

| Investigator | Location | Test/Sample Depth | Hydraulic Conductivity | Method |
|---|---|---|---|---|
| | 116N-73W-13 | 21.0 U | 7.06E-09 | Lab |
| | 116N-73W-13 | 26.0 W | 5.64E-07 | Lab |
| | 116N-73W-13 | 31.0 W | 7.06E-09 | Lab |
| | 116N-73W-13 | 11.0 W | 1.20E-04 | Lab |
| | 116N-73W-13 | 26.0 U | 2.82E-07 | Lab |
| | 115N-72W-13 | 7.0 W | 1.41E-08 | Lab |
| | 115N-72W-13 | 17.0 W | 3.10E-04 | Lab |
| | 115N-72W-13 | 21.0 W | 1.41E-08 | Lab |
| | 115N-72W-13 | 26.0 W | 2.12E-08 | Lab |
| | 115N-72W-13 | 31.0 W | 4.23E-09 | Lab |
| | 115N-72W-13 | 17.0 W | 7.06E-09 | Lab |
| | 115N-72W-13 | 21.0 W | 6.35E-09 | Lab |
| | 112N-69W-24 | 7.0 W | 2.82E-08 | Lab |
| | 112N-69W-24 | 11.0 W | 3.53E-08 | Lab |
| | 112N-69W-24 | 21.0 U | 2.82E-08 | Lab |
| | 112N-69W-24 | 26.0 U | 7.06E-09 | Lab |

| Investigator | Location | Test/Sample Depth | Hydraulic Conductivity | Method |
|---|---|---|---|---|
| | 112N-69W-24 | 31.0 U | 5.64E-07 | Lab |
| | 112N-68W-30 | 7.0 W | 1.41E-07 | Lab |
| | 112N-68W-30 | 11.0 W | 5.79E-04 | Lab |
| | 112N-68W-30 | 16.0 W | 1.41E-06 | Lab |
| | 112N-68W-30 | 21.0 W | 7.06E-09 | Lab |
| | 112N-68W-30 | 26.0 W | 2.82E-09 | Lab |
| | 112N-68W-18 | 12.0 W | 2.12E-05 | Lab |
| | 112N-68W-18 | 17.0 W | 4.94E-07 | Lab |
| | 112N-68W-18 | 22.0 U | 5.64E-08 | Lab |
| | 112N-68W-18 | 26.0 U | 2.82E-09 | Lab |
| | 112N-68W-18 | 31.0 U | 1.41E-08 | Lab |
| | 111N-67W-30 | 7.0 W | 6.35E-08 | Lab |
| | 111N-67W-30 | 11.5 W | 4.09E.04 | Lab |
| | 111N-67W-30 | 17.0 W | 7.06E-09 | Lab |
| | 111N-67W-30 | 31.0 U | 7.06E-07 | Lab |
| | 111N-67W-02 | 12.0 W | 2.82E-06 | Lab |

| Investigator | Location | Test/Sample Depth | Hydraulic Conductivity | Method |
|---|---|---|---|---|
| | 111N-67W-02 | 16.0 W | 7.06E-09 | Lab |
| | 111N-67W-04 | 11.0 W | 4.09E-04 | Lab |
| | 111N-67W-04 | 21.0 W | 1.41E-08 | Lab |
| | 113N-67W-16 | 7.0 W | 4.23E-09 | Lab |
| | 113N-67W-16 | 16.0 W | 4.23E-08 | Lab |
| | 113N-67W-16 | 26.0 U | 1.41E-07 | Lab |
| | 113N-67W-27 | 6.0 W | 2.82E-05 | Lab |
| | 113N-67W-27 | 26.0 U | 3.53E-08 | Lab |
| | 113N-67W-27 | 31.0 U | 1.41E-06 | Lab |
| | 113N-69W-24 | 6.0 W | 4.94E-05 | Lab |
| | 113N-69W-24 | 12.0 W | 2.12E-08 | Lab |
| | 113N-69W-24 | 21.0 U | 2.12E-08 | Lab |
| | 113N-69W-24 | 26.0 U | 1.41E-08 | Lab |
| | 113N-69W-24 | 31.0 U | 1.41E-07 | Lab |
| | 113N-69W-13 | 11.0 W | 4.94E-08 | Lab |
| | 113N-69W-13 | 21.0 W | 1.41E-08 | Lab |

| Investigator | Location | Test/Sample Depth | | Hydraulic Conductivity | Method |
|---|---|---|---|---|---|
| | 113N-69W-13 | 27.0 | U | 1.41E-08 | Lab |
| | 113N-69W-13 | 31.0 | U | 6.35E-08 | Lab |
| | 116N-68W-34 | 11.0 | W | 2.12E-08 | Lab |
| | 116N-68W-34 | 17.0 | W | 1.41E-07 | Lab |
| | 116N-68W-34 | 22.0 | U | 7.06E-09 | Lab |
| | 116N-68W-36 | 21.0 | W | 2.12E-07 | Lab |
| Cowman (in prep.) | 114N-70W-02BBBB (CK-HD-6B) | 38 | U | 1.0E-08 | Field |
| | 114N-70W-02BBBB (CK-HD-6C) | 53 | U | 4.8E-08 | Field |
| | 115N-69W-15BBBB (CK-HD-11B2) | 37 | U | 2.4E-08 | Field |
| | 115N-69W-18AAAA (CK-HD-12C) | 38 | U | 1.1E-08 | Field |
| | 115N-70W-17BBBB (CK-HD-15D) | 67 | U | 1.0E-08 | Field |
| | 117N-70W-31DDDC (CK-HD-18D) | 67 | U | 1.1E-08 | Field |
| | 117N-70W-31DDDC (CK-HD-18E) | 98 | U | 6.2E-08 | Field |

| Investigator | Location | Test/Sample Depth | | Hydraulic Conductivity | Method |
|---|---|---|---|---|---|
| | 115N-72W-10CCCC (CK-HY-3D) | 78 | U | 1.8E-08 | Field |
| | 114N-72W-36CCCC (CK-HY-5D) | 67 | U | 3.2E-08 | Field |
| | 114N-73W-03CCCC (CK-HY-6D) | 67 | U | 1.5E-08 | Field |
| | 113N-72W-20BBBB (CK-HY-8D) | 67 | U | 2.4E-08 | Field |
| Cravens (1985) | 115N-67W-18DDDD (CK-HD-2A) | 23 | T | 1.04E-06 | Field |
| | 115N-67W-18DDDD (CK-HD-2B2) | 30 | U | 1.31E-07 | Field |
| | 115N-70W-04AAAA (CK-HD-5A) | 18 | U | 8.54E-07 | Field |
| | 115N-70W-04AAAA (CK-HD-5B2) | 28 | U | 7.00E-08 | Field |
| | 115N-70W-04AAAA (CK-HD-5B) | 43 | U | 1.16E-06 | Field |
| | 114N-70W-02BBBB (CK-HD-6A) | 23 | U | 4.43E-07 | Field |
| | 114N-70W-02BBBB (CK-HD-6B) | 38 | U | 1.24E-07 | Field |
| | 114N-70W-02BBBB (CK-HD-6C) | 53 | U | 4.00E-07 | Field |

| Investigator | Location | Test/Sample Depth | | Hydraulic Conductivity | Method |
|---|---|---|---|---|---|
| | 114N-66W-15CDDD (CK-HD-7A2) | 15 | U | 1.83E-04 | Field |
| | 114N-66W-15CDDD (CK-HD-7A) | 18 | U | 5.86E-07 | Field |
| | 114N-66W-15CDDD (CK-HD-7B) | 33 | U | 2.90E-05 | Field |
| | 114N-67W-35AAAA (CK-HD-8A) | 18 | T | 6.91E-06 | Field |
| | 114N-67W-35AAAA (CK-HD-8B2) | 26 | T | 5.71E-06 | Field |
| | 114N-67W-35AAAA (CK-HD-8B) | 33 | U | 7.91E-06 | Field |
| | 114N-66W-14CCCC (CK-HD-9A) | 23 | U | 2.73E-07 | Field |
| | 114N-66W-14CCCC (CK-HD-9B) | 38 | U | 2.13E-06 | Field |
| | 114N-66W-14CCCC (CK-HD-9C) | 53 | U | 3.11E-06 | Field |
| | 115N-69W-13BBBB (CK-HD-10A) | 18 | W | 8.42E-06 | Field |
| | 115N-69W-13BBBB (CK-HD-10B) | 28 | U | 2.95E-07 | Field |
| | 115N-69W-13BBBB (CK-HD-10C) | 38 | U | 2.41E-06 | Field |

| Investigator | Location | Test/Sample Depth | | Hydraulic Conductivity | Method |
|---|---|---|---|---|---|
| | 115N-69W-15BBBB (CK-HD-11A) | 28 | W | 6.02E-06 | Field |
| | 115N-69W-15BBBB (CK-HD-11B) | 38 | U | 1.89E-06 | Field |
| | 115N-69W-18AAAA (CK-HD-12A) | 18 | W | 3.59E-05 | Field |
| | 115N-69W-18AAAA (CK-HD-12B) | 28 | T | 1.04E-05 | Field |
| | 115N-69W-18AAAA (CK-HD-12B2) | 32 | U | 1.25E-06 | Field |
| | 115N-69W-18AAAA (CK-HD-12C) | 38 | U | 7.10E-08 | Field |
| | 115N-70W-14AAAA (CK-HD-13A) | 28 | U | 1.53E-07 | Field |
| | 115N-70W-14AAAA (CK-HD-13B) | 38 | U | 3.27E-07 | Field |
| | 115N-70W-17BBBB (CK-HD-15A2) | 13 | W | 1.7 E-04 | Field |
| | 115N-70W-17BBBB (CK-HD-15A) | 18 | U | 2.32E-07 | Field |
| | 115N-70W-17BBBB (CK-HD-15B) | 28 | U | 3.56E-07 | Field |
| | 115N-70W-17BBBB (CK-HD-15C) | 53 | U | 9.69E-08 | Field |

| Investigator | Location | Test/Sample Depth | | Hydraulic Conductivity | Method |
|---|---|---|---|---|---|
| | 110N-68W-22AABB (CK-HD-16A) | 13 | W | 4.21E-06 | Field |
| | 110N-68W-22AABB (CK-HD-16B) | 23 | W | 7.23E-06 | Field |
| | 110N-68W-22AABB (CK-HD-16C) | 33 | U | 1.00E-06 | Field |
| | 112N-70W-14CCCC (CK-HD-17A) | 13 | W | 9.00E-05 | Field |
| | 112N-70W-14CCCC (CK-HD-17B) | 23 | W | 1.22E-05 | Field |
| | 112N-70W-14CCCC (CK-HD-17C) | 33 | U | 5.39E-07 | Field |
| | 117N-70W-31DDDC (CK-HD-18A) | 18 | W | 3.28E-06 | Field |
| | 117N-70W-31DDDC (CK-HD-18B) | 28 | W | 6.31E-06 | Field |
| | 117N-70W-31DDDC (CK-HD-18C) | 48 | U | 2.20E-07 | Field |
| | 115N-71W-13BBBB (CK-HY-1A) | 18 | W | 2.02E-04 | Field |
| | 115N-71W-13BBBB (CK-HY-1B) | 33 | U | 1.42E-06 | Field |
| | 115N-71W-13BBBB (CK-HY-1C) | 48 | U | 4.22E-07 | Field |

| Investigator | Location | Test/Sample Depth | | Hydraulic Conductivity | Method |
|---|---|---|---|---|---|
| | 115N-71W-15BBBB (CK-HY-2A) | 18 | W | 1.04E-06 | Field |
| | 115N-71W-15BBBB (CK-HY-2B) | 28 | W | 6.44E-05 | Field |
| | 115N-71W-15BBBB (CK-HY-2C) | 48 | W | 2.30E-06 | Field |
| | 115N-72W-10CCCC (CK-HY-3A2) | 15 | W | 4.10E-06 | Field |
| | 115N-72W-10CCCC (CK-HY-3A) | 28 | W | 4.94E-07 | Field |
| | 115N-72W-10CCCC (CK-HY-3B) | 43 | U | 3.89E-06 | Field |
| | 115N-72W-07DDDD (CK-HY-4A) | 18 | T | 1.95E-06 | Field |
| | 115N-72W-07DDDD (CK-HY-4B) | 28 | U | 7.01E-08 | Field |
| | 115N-72W-07DDDD (CK-HY-4C) | 38 | W | 3.02E-07 | Field |
| | 114N-72W-36CCCC (CK-HY-5A) | 13 | W | 5.20E-06 | Field |
| | 114N-72W-36CCCC (CK-HY-5B) | 28 | W | 5.13E-06 | Field |
| | 114N-72W-36CCCC (CK-HY-5C) | 43 | U | 9.43E-07 | Field |

| Investigator | Location | Test/Sample Depth | | Hydraulic Conductivity | Method |
|---|---|---|---|---|---|
| | 114N-73W-03CCCC (CK-HY-6A) | 13 | W | 4.12E-05 | Field |
| | 114N-73W-03CCCC (CK-HY-6B) | 23 | U | 3.75E-06 | Field |
| | 114N-73W-03CCCC (CK-HY-6B2) | 28 | U | 5.84E-08 | Field |
| | 114N-73W-03CCCC (CK-HY-6C) | 33 | U | 2.53E-07 | Field |
| | 113N-73W-16DDDD (CK-HY-7A) | 13 | W | 5.59E-05 | Field |
| | 113N-73W-16DDDD (CK-HY-7B) | 23 | W | 7.50E-06 | Field |
| | 113N-73W-16DDDD (CK-HY-7C) | 33 | U | 4.25E-07 | Field |
| | 113N-72W-20BBBB (CK-HY-8A) | 13 | W | 4.42E-05 | Field |
| | 113N-72W-20BBBB (CK-HY-8B) | 23 | W | 5.23E-05 | Field |
| | 113N-72W-20BBBB (CK-HY-8C) | 33 | U | 1.53E-06 | Field |
| Faris (1986a) | 113N-67W-20CCCC | 47.5-50 | U | 5.0 E-09 | Lab |
| | 113N-67W-20CCCC | 47.5-50 | U | 4.7 E-09 | Lab |

| Investigator | Location | Test/Sample Depth | Hydraulic Conductivity | Method |
|---|---|---|---|---|
| | 116N-68W-29DCDC | 47.5-50 U | 2.4 E-09 | Lab |
| | 116N-68W-29DCDC | 47.5-50 U | 1.2 E-08 (Kh) | Lab |
| Strube Fossen (1986) | 113N-72W-23D | 0- 2 W | 4.23E-05 | Field |
| | 113N-72W-23D | 2- 4 W | 2.12E-05 | Field |
| | 113N-72W-23D | 4- 6 W | 7.76E-05 | Field |
| | 113N-72W-23D | 6- 8 W | 2.82E-05 | Field |
| | 113N-72W-23D | 5- 7 W | 1.20E-04 (Kh) | Field |
| | 113N-72W-23D | 5- 7 W | 9.88E-05 (Kh) | Field |
| | 112N-71W-03D | 0- 2 W | 3.53E-05 | Field |
| | 112N-71W-03D | 2- 4 W | 2.82E-05 | Field |
| | 112N-71W-03D | 4- 6 W | 2.12E-05 | Field |
| | 112N-71W-03D | 6- 8 W | 9.2 E-05 | Field |
| | 112N-71W-03D | 3- 6 W | 2.12E-05 (Kh) | Field |
| | 112N-71W-03D | 3- 6 W | 1.41E-05 (Kh) | Field |
| | 112N-71W-03D | 6- 9 W | 2.12E-05 (Kh) | Field |
| | 114N-69W-01B | 0- 2 W | 2.82E-05 | Field |

| Investigator | Location | Test/Sample Depth | Hydraulic Conductivity | Method |
|---|---|---|---|---|
| | 114N-69W-01B | 2- 4 W | 2.12E-05 | Field |
| | 114N-69W-01B | 4- 6 W | 6.35E-05 | Field |
| | 114N-69W-01B | 6- 8 W | 2.82E-05 | Field |
| | 114N-69W-01B | 3- 6 W | 2.82E-05 (Kh) | Field |
| | 114N-69W-01B | 3- 6 W | 4.94E-05 (Kh) | Field |
| | 114N-69W-01B | 7-10 W | 1.41E-o6 (Kh) | Field |
| | 114N-69W-01B | 7-10 W | 9.88E-06 (Kh) | Field |
| | 116N-68W-33B | 0- 2 W | 2.12E-05 | Field |
| | 116N-68W-33B | 2- 4 W | 6.35E-05 | Field |
| | 116N-68W-33B | 4- 6 W | 2.82E-05 | Field |
| | 116N-68W-33B | 6- 8 W | 2.82E-05 | Field |
| | 116N-68W-33B | 3 -6 W | 7.76E-05 (Kh) | Field |
| | 116N-68W-33B | 3- 6 W | 2.82E-05 (Kh) | Field |
| | 116N-68W-33B | 7- 9 W | 1.41E-05 (Kh) | Field |
| Jewell (1986) | 113N-72W-23D | 4- 6 W | 7.06E-05 | Field |
| | 113N-72W-23D | 6- 8 W | 3.53E-05 | Field |

| Investigator | Location | Test/Sample Depth | Hydraulic Conductivity | Method |
|---|---|---|---|---|
| | 113N-72W-23D | 0- 8 W | 2.82E-04 | Field |
| | 113N-72W-23D | 6- 8 W | 1.76E-04 (Kh) | Field |
| | 113N-72W-23D | 6- 8 W | 8.47E-05 (Kh) | Field |
| | 113N-72W-23D | 8-10 W | 2.82E-05 (Kh) | Field |
| | 113N-72W-23D | 8-10.5 W | 3.53E-05 (Kh) | Field |
| | 113N-72W-23D | 9-11 W | 2.12E-05 (Kh) | Field |
| | 113N-72W-23D | 12-15 W | 2.40E-05 (Kh) | Field |
| | 113N-72W-23D | 13-15 W | 6.35E-06 (Kh) | Field |
| | 112N-71W-03D | 2- 6 W | 1.13E-05 | Field |
| | 112N-71W-03D | 6- 8 W | 2.12E-05 | Field |
| | 112N-71W-03D | 0- 8 W | 1.69E-04 | Field |
| | 112N-71W-03D | 6- 8 W | 2.82E-05 (Kh) | Field |
| | 112N-71W-03D | 8-10 W | 1.41E-05 (Kh) | Field |
| | 112N-71W-03D | 10-12 W | 9.17E-05 (Kh) | Field |
| | 112N-71W-03D | 10-12 W | 2.82E-05 (Kh) | Field |
| | 112N-71W-03D | 11-13 W | 2.82E-05 (Kh) | Field |

| Investigator | Location | Test/Sample Depth | Hydraulic Conductivity | Method |
|---|---|---|---|---|
| | 114N-69W-01B | 2- 4 W | 3.74E-04 | Field |
| | 114N-69W-01B | 4- 6 W | 1.83E-04 | Field |
| | 114N-69W-01B | 6- 8 W | 2.82E-05 | Field |
| | 114N-69W-01B | 6- 8 W | 1.08E-03 | Field |
| | 114N-69W-01B | 4- 6 W | 5.64E-05 (Kh) | Field |
| | 114N-69W-01B | 4- 6 W | 1.06E-04 (Kh) | Field |
| | 114N-69W-01B | 8- 9 W | 2.75E-04 (Kh) | Field |
| | 114N-69W-01B | 8-10 W | 1.48E-04 (Kh) | Field |
| | 114N-69W-01B | 15.5-16 W | 1.41E-04 (Kh) | Field |
| | 116N-68W-33B | 3- 6 W | 2.47E-05 | Field |
| | 116N-68W-33B | 6- 8 W | 4.94E-05 | Field |
| | 116N-68W-33B | 11-14 W | 2.12E-05 (Kh) | Field |
| | 116N-68W-33B | 11-14 W | 2.12E-05 (Kh) | Field |
| | 116N-68W-33B | 16-24 W | 0.00 (Kh) | Field |
| USBR (1960) | 117N-62W-22DAAA | 3.05 W | 7.15E-05 | Field |
| | 117N-62W-10BBBB | 2.00 W | 1.55E-04 | Field |

| Investigator | Location | Test/Sample Depth | Hydraulic Conductivity | Method |
|---|---|---|---|---|
| | 117N-62W-12ABBB | 3.90 W | 2.17E-04 | Field |
| | 117N-62W-12ABBB | 3.90 W | 3.87E-08 | Lab |
| | 115N-78W-18ADDD | 5.70 W | 8.22E-05 | Field |
| | 116N-79W-36DAAA | 5.50 W | 8.50E-05 | Field |
| | 115N-78W-04BCCC | 5.50 W | 9.18E-05 | Field |
| | 116N-68W-05 | 0.5-17 W | 2.90E-08 | Lab |
| USBR (1986) | 113N-64W-04D | 20-40 U | 9.0E-09 | Field |
| | 113N-64W-04D | 20-40 U | 1.2E-07 | Field |
| | 113N-64W-04D | 20-40 U | 6.1E-08 | Field |
| | 113N-64W-04D | 20-40 U | 9.0E-07 | Field |
| | 113N-64W-04D | 20-40 U | 2.6E-07 | Field |
| | 113N-64W-04D | 20-40 U | 4.2E-08 | Field |

## APPENDIX F

### Observation wells in the CENDAK area

(1) B = Buried aquifer
S = Surface aquifer

(2) U = Unconfined
BU = Buried, unconfined
BC = Buried, confined

| Location | Well Name | Date of Record | Total Casing and Screen (ft) | Aquifer Classification (1) | Aquifer Type (2) | Range of Water-level Fluctuations (ft) |
|---|---|---|---|---|---|---|
| **BEADLE COUNTY** | | | | | | |
| 109N-61W- 2DDDD | BD-76N | 10-15-76 to 11-05-85 | 48.2 | B | BC | 26.7- 36.1 |
| 109N-61W-30AAAA | BD-79J | 06-04-79 to 11-05-85 | 89.2 | B | BC | 22.7- 35.8 |
| 109N-62W-13BBBB | BD-76M | 10-15-76 to 11-05-85 | 106.0 | B | BC | 34.9- 55.9 |
| 109N-63W-21AAAA2 | BD-76H | 04-05-77 to 03-11-86 | 65.8 | B | BC | 34.6- 42.2 |
| 109N-63W-36AAAA | BD-79K | 06-05-79 to 11-05-85 | 96.4 | B | BC | 32.0- 39.1 |
| 110N-61W- 1DCCC | BD-68A | 06-11-68 to 11-06-85 | 107.6 | B | BC | 12.2- 29.2 |
| 110N-61W-13ADDD | BD-68D | 06-11-68 to 11-06-85 | 86.6 | B | BC | 9.5- 21.2 |
| 110N-61W-19AAAA | BD-60H | 05-24-82 to 09-30-85 | 61.0 | B | BC | 10.1- 14.8 |

APPENDIX F -- continued.

| Location | Well Name | Date of Record | Total Casing and Screen (ft) | Aquifer Classification (1) | Aquifer Type (2) | Range of Water-level Fluctuations (ft) |
|---|---|---|---|---|---|---|
| 110N-61W-21BBBC | BD-65A | 03-15-66 to 11-05-85 | 55.5 | B | BC | 19.4- 35.0 |
| 110N-61W-26CCCC | BD-79L | 10-17-79 to 11-05-85 | 65.7 | B | BC | 25.4- 34.7 |
| 110N-61W-29DDDD | BD-60I | 06-16-60 to 10-01-85 | 64.8 | B | BC(?) | 39.8- 58.9 |
| 110N-62W- 7BBBB | BD-76I | 12-01-76 to 11-05-85 | 65.3 | B | BC | 41.3- 53.0 |
| 110N-62W- 9CCCC2 | BD-76K | 10-08-76 to 11-05-85 | 95.0 | B | BU | 29.4- 50.1 |
| 110N-62W-16DCCC | BD-60F | 06-16-60 to 11-05-85 | 82.4 | B | BU | 20.6- 51.7 |
| 110N-62W-19AAAA2 | BD-82A | 10-08-76 to 11-05-85 | 85.9 | B | BC | 26.2- 53.3 |
| 110N-62W-25CCCC | BD-76L | 12-01-76 to 11-05-85 | 75.6 | B | BC | 28.0- 47.5 |
| 110N-62W-31DDDD2 | BD-79I | 06-05-79 to 11-05-85 | 89.2 | B | BC | 9.1- 15.5 |
| 110N-65W- 5DDDD | BD-76F | 11-30-76 to 11-04-85 | 68.0 | B | BC | 9.6- 25.9 |
| 110N-65W-26CCCC | BD-76G | 10-13-76 to 11-04-85 | 95.8 | B | BC | 36.6- 49.0 |

APPENDIX F -- continued.

| Location | Well Name | Date of Record | Total Casing and Screen (ft) | Aquifer Classification (1) | Aquifer Type (2) | Range of Water-level Fluctuations (ft) |
|---|---|---|---|---|---|---|
| 111N-61W-11BBBB1 | BD-63C | 04-27-82 to 11-04-85 | 76.5 | B | BC | 12.5- 19.5 |
| 111N-62W-32ADAA2 | BD-79C | 06-26-79 to 11-05-85 | 105.3 | B | BC | 32.3- 46.8 |
| 111N-63W- 2CCCC | BD-60A | 06-16-60 to 06-03-86 | 60.5 | B | BC(?) | 13.4- 44.7 |
| 111N-63W- 9BBBB | BD-76C | 12-01-76 to 11-04-85 | 105.8 | B | BC | 39.0- 55.2 |
| 111N-63W-12AAAA | BD-79A | 06-04-79 to 07-01-86 | 85.4 | B | BC | 26.9- 41.4 |
| 111N-63W-14CCCC | BD-79B | 06-05-79 to 11-04-85 | 81.0 | B | BC | 30.5- 44.7 |
| 111N-63W-24DDDD | BD-60C | 06-16-60 to 11-04-85 | 66.3 | B | BC | 16.0- 49.7 |
| 111N-64W-11CDCC2 | BD-80E | 10-07-80 to 11-04-85 | 62.8 | B | BU | 0 - 50.0 |
| 111N-64W-16CCCC2 | BD-80F | 10-07-80 to 11-04-85 | 20.3 | S | U | 1.9- 7.6 |
| 112N-61W-18CBBB2 | BD-80D | 05-03-63 to 11-04-85 | 65.4 | B | BU | 34.4- 43.1 |
| 112N-61W-33BBBB | BD-66A | 06-21-66 to 11-04-85 | 83.6 | B | BU | 49.0- 63.8 |

APPENDIX F -- continued.

| Location | Well Name | Date of Record | Total Casing and Screen (ft) | Aquifer Classification (1) | Aquifer Type (2) | Range of Water-level Fluctuations (ft) |
|---|---|---|---|---|---|---|
| 112N-62W-10BBBB | BD-77K | 08-01-78 to 06-03-86 | 81.7 | B | BC | 56.1- 58.5 |
| 112N-63W-36BBBB | BD-76B | 10-22-76 to 11-04-85 | 65.5 | B | BC | 18.9- 24.6 |
| 112N-64W-35BBBB | BD-76D | 12-01-76 to 11-04-85 | 60.9 | B | BC | 21.9- 35.5 |
| 112N-65W-19DDDD | BD-77G | 11-30-77 to 10-15-85 | 50.6 | B | BC | 17.0- 26.0 |
| 113N-62W-22DDDD | BD-80C | 09-25-80 to 11-04-85 | 85.0 | B | BU | 18.4- 21.1 |
| 113N-63W- 2BBBB | BD-77A | 08-19-77 to 11-04-85 | 71.0 | B | BU | 27.9- 30.4 |
| 113N-63W- 5BBBB | BD-80J | 04-27-82 to 11-04-85 | 145.8 | B | BC | 32.1- 44.3 |
| 113N-63W- 6AAAA1 | BD-76A | 07-27-77 to 06-20-86 | 70.3 | B(?) | BU(?) | 24.4- 46.7 |
| 113N-64W- 4DDDD | BD-80A | 07-30-80 to 11-04-85 | 83.1 | B | BC | 13.0- 48.8 |
| 113N-64W-15AAAA | BD-80B | 07-30-80 to 11-05-85 | 83.4 | B | BC | 15.5- 50.5 |

APPENDIX F -- continued.

| Location | Well Name | Date of Record | Total Casing and Screen (ft) | Aquifer Classification (1) | Aquifer Type (2) | Range of Water-level Fluctuations (ft) |
|---|---|---|---|---|---|---|
| FAULK COUNTY | | | | | | |
| 118N-68W-24DCDD2 | FA-71B | 04-14-80 to 10-09-85 | 151.0 | B | BC | 8.4- 10.2 |
| 120N-69W- 3ABBB | FA-80A | 07-02-80 to 10-09-85 | 272.0 | B | BC | 154.9-156.1 |
| HAND COUNTY | | | | | | |
| 111N-66W- 2CDCC | HD-78E | 05-15-79 to 11-04-85 | 34.8 | B | BC | 13.0- 17.2 |
| 111N-66W-14DCCC | HD-77A | 12-01-77 to 11-04-85 | 125.7 | B | BC | 37.3- 45.4 |
| 112N-66W- 3DDDC1 | HD-73W | 09-09-77 to 10-15-85 | 31.3 | S | U(?) | 2.8- 8.4 |
| 112N-66W-14ADDA | HD-73V | 09-09-77 to 10-15-85 | 18.2 | S | U | 7.3- 11.2 |
| 112N-66W-36CCCC2 | HD-73Y | 09-09-77 to 10-15-85 | 17.2 | S(?) | (?) | 0.5- 13.1 |
| 112N-67W-33CCCC | HD-74A | 06-02-80 to 10-15-85 | 288.0 | B | BC | 199.8-201.3 |
| 113N-66W- 8BCCB | HD-73H | 09-06-77 to 11-06-85 | 19.7 | S | U(?) | 4.1- 15.8 |

APPENDIX F -- continued.

| Location | Well Name | Date of Record | Total Casing and Screen (ft) | Aquifer Classification (1) | Aquifer Type (2) | Range of Water-level Fluctuations (ft) |
|---|---|---|---|---|---|---|
| 113N-66W-11CBCC | HD-73X | 09-06-77 to 11-06-85 | 39.8 | B | BC | 7.2- 32.2 |
| 113N-66W-31CCCC3 | HD-50A | 09-06-77 to 10-15-85 | 19.4 | S(?) | (?) | 5.5- 14.0 |
| 113N-66W-33CCCC1 | HD-49A | 09-09-77 to 10-15-85 | 21.3 | B | BC(?) | 2.9- 17.5 |
| 113N-67W- 1BBCC2 | HD-73I | 09-06-77 to 11-06-85 | 39.9 | S | U | 12.5- 21.2 |
| 113N-67W- 8BBBB | HD-78D | 05-15-79 to 11-06-85 | 65.4 | B | BC | 18.6- 24.5 |
| 113N-68W- 1BCCC | HD-73U | 09-08-77 to 11-06-85 | 19.9 | S | U | 10.5- 15.7 |
| 114N-66W- 4ADDD | HD-73E | 09-08-77 to 11-06-85 | 19.1 | S(?) | U(?) | 2.9- 8.5 |
| 114N-66W- 9AADD | HD-73F | 05-15-77 to 11-06-85 | 26.6 | B | BC(?) | 10.7- 14.7 |
| 114N-66W-10CCBB | HD-73G | 07-26-70 to 11-06-85 | 30.7 | S | U(?) | 9.3- 16.7 |
| 114N-66W-15CDDD1 | HD-51A | 09-08-77 to 11-06-85 | 118.7 | B | BC | 19.6- 27.0 |
| 114N-66W-17BCCB | HD-73J | 09-08-77 to 11-06-85 | 23.3 | S | U | 10.0- 16.9 |

APPENDIX F -- continued.

| Location | Well Name | Date of Record | Total Casing and Screen (ft) | Aquifer Classification (1) | Aquifer Type (2) | Range of Water-level Fluctuations (ft) |
|---|---|---|---|---|---|---|
| 114N-67W- 8BBCC | HD-73C | 09-07-77 to 11-06-85 | 18.9 | S | U | 6.9- 11.2 |
| 114N-67W-15BBBB | HD-73S | 10-04-77 to 11-06-85 | 28.0 | S | U(?) | 6.8- 13.4 |
| 114N-67W-27CCCB | HD-73T | 09-07-77 to 11-06-85 | 29.7 | S | U | 11.8- 17.2 |
| 114N-67W-35AAAA | HD-53C | 09-07-77 to 11-06-85 | 105.6 | B(?) | BU(?) | 14.8- 22.7 |
| 114N-70W-35CCCC | HD-77B | 10-04-77 to 10-17-85 | 238.1 | B | BC | 12.9- 15.5 |
| 115N-66W- 2AAAA | HD-53A | 10-04-77 to 03-27-86 | 62.0 | B | BC | 28.6- 31.4 |
| 115N-66W-11DAAA2 | HD-80A | 10-09-80 to 11-06-85 | 95.9 | B | BC | 19.6- 26.4 |
| 115N-66W-14AADD | HD-73Q | 09-08-77 to 11-06-85 | 29.3 | S | U | 4.1- 10.1 |
| 115N-66W-21BBBB2 | HD-80B | 11-20-80 to 11-06-85 | 125.6 | B | BC | 33.4- 48.9 |
| 115N-66W-31BCBB | HD-73D | 09-07-77 to 11-06-85 | 23.2 | B(?) | BC(?) | 3.4- 11.4 |
| 115N-67W-13CDDD1 | HD-51B | 06-27-79 to 11-06-85 | 85.0 | B | BU(?) | 30.2- 55.2 |

APPENDIX F -- continued.

| Location | Well Name | Date of Record | Total Casing and Screen (ft) | Aquifer Classification (1) | Aquifer Type (2) | Range of Water-level Fluctuations (ft) |
|---|---|---|---|---|---|---|
| 115N-67W-18DDDD | HD-78B | 05-15-79 to 06-11-86 | 142.8 | B | BC | 86.9-142.0 |
| 115N-67W-25AAAA | HD-78C | 12-01-78 to 03-27-86 | 105.6 | B | BC | 28.0- 53.4 |
| 115N-67W-36CDDC | HD-73R | 09-07-77 to 11-06-85 | 39.8 | B | BC(?) | 14.5- 20.4 |
| 115N-68W- 8CDCC | HD-73K | 10-04-77 to 10-10-85 | 19.5 | S(?) | U | 8.8- 13.6 |
| 115N-68W-35BBBB | HD-73B | 10-04-77 to 10-10-85 | 23.5 | S | U | 5.4- 9.8 |
| 115N-70W- 4AAAA1 | HD-79B | 10-03-79 to 11-06-85 | 105.2 | B | BC | 8.7- 19.0 |
| 115N-70W- 6AAAA | HD-79A | 10-03-79 to 10-10-85 | 44.4 | S(?) | U(?) | 16.8- 19.7 |
| 116N-67W- 1BBBB | HD-73N | 10-04-77 to 10-10-85 | 12.1 | S | U | 3.3- 8.8 |
| 116N-67W-12DADD | HD-73O | 10-04-77 to 10-10-85 | 19.9 | B | BC(?) | 5.0- 10.7 |
| 116N-67W-25DDDD | HD-73P | 10-04-77 to 11-06-85 | 39.7 | B | BC | 6.9- 21.1 |
| 116N-67W-32CDDC | HD-73L | 09-08-77 to 10-10-85 | 19.2 | S | U | 4.3- 9.6 |

APPENDIX F -- continued.

| Location | Well Name | Date of Record | Total Casing and Screen (ft) | Aquifer Classification (1) | Aquifer Type (2) | Range of Water-level Fluctuations (ft) |
|---|---|---|---|---|---|---|
| 116N-67W-34DDDD | HD-78A | 06-27-79 to 11-06-85 | 78.5 | B | BC | 25.6- 58.2 |
| 116N-68W-12AAAD | HD-73M | 10-04-77 to 10-10-85 | 18.5 | S | U(?) | 5.2- 9.7 |
| HUGHES COUNTY | | | | | | |
| 111N-77W-14AAAA | HU-81G | 09-03-81 to 10-18-85 | 306.8 | B | BC | 191.3-193.1 |
| 111N-77W-22ABAB2 | HU-81H | 09-03-81 to 10-18-85 | 186.7 | B | BU | 159.4-160.6 |
| 111N-77W-32BCCC | HU-80E | 02-24-81 to 10-18-85 | 198.5 | B | BU | 167.1-168.3 |
| 111N-78W-20BBBA | HU-80D | 02-24-81 to 10-18-85 | 140.3 | B | BC | 60.2- 61.5 |
| 112N-74W-17ADAA | HU-81C | 06-30-65 to 10-18-85 | 25.3 | S | U | 7.5- 14.5 |
| 112N-75W-14BBBB2 | HU-82A | 08-17-82 to 10-18-85 | 118.5 | B | BC | 27.1- 32.4 |
| 112N-76W- 8DBCC | HU-75B | 07-03-80 to 04-19-84 | 41.6 | S(?) | U(?) | 14.5- 26.3 |
| 112N-76W- 9CBAA | HU-75A | 06-11-80 to 10-17-85 | 35.6 | S(?) | U(?) | 10.3- 21.3 |

APPENDIX F -- continued.

| Location | Well Name | Date of Record | Total Casing and Screen (ft) | Aquifer Classification (1) | Aquifer Type (2) | Range of Water-level Fluctuations (ft) |
|---|---|---|---|---|---|---|
| 112N-76W-10BBBB | HU-57A | 11-19-57 to 10-17-85 | 26.7 | S(?) | U(?) | 9.8- 19.5 |
| 112N-76W-16DAAD | HU-75C | 06-11-80 to 10-17-85 | 38.8 | B | BC | 12.1- 20.2 |
| 112N-78W-17CCCC | HU-81E | 07-23-81 to 10-07-85 | 276.1 | B | BC | 202.2-204.6 |
| 112N-78W-23BBBB | HU-81F | 07-23-81 to 10-07-85 | 285.8 | B | BC(?) | 228.2-229.9 |
| 112N-79W-14CCCC | HU-81D | 07-23-81 to 10-07-85 | 204.5 | B | BU | 153.5-155.7 |
| 112N-79W-16CCCC | HU-80C | 07-21-80 to 10-07-85 | 128.4 | B | BU | 106.6-108.5 |
| 112N-79W-19BBBB | HU-80B | 07-21-80 to 10-07-85 | 168.7 | B | BC | 113.5-116.4 |
| **HYDE COUNTY** | | | | | | |
| 112N-72W-17BCCB2 | HY-57A | 10-03-77 to 11-04-85 | 19.2 | S | U | 8.9- 19.4 |
| 112N-72W-23DDDD | HY-74A | 12-01-77 to 11-04-85 | 53.8 | B(?) | BU | 6.8- 17.4 |
| 112N-73W-15BBCC | HY-78D | 03-07-79 to 11-04-85 | 41.1 | S(?) | U(?) | 2.8- 7.8 |

APPENDIX F -- continued.

| Location | Well Name | Date of Record | Total Casing and Screen (ft) | Aquifer Classifi-cation (1) | Aquifer Type (2) | Range of Water-level Fluctuations (ft) |
|---|---|---|---|---|---|---|
| 112N-73W-18BBBB | HY-78C | 05-18-79 to 10-15-85 | 24.0 | S(?) | U(?) | 4.1- 9.8 |
| 114N-72W-25BBBB1 | HY-73A | 11-01-77 to 10-15-85 | 278.6 | B | BC | 47.9- 58.1 |
| 115N-71W- 1BBCC | HY-79A | 07-12-79 to 11-06-85 | 65.4 | B | BC | 0 - 13.4 |
| 115N-72W- 1BBBB | HY-76A | 02-01-77 to 11-06-85 | 94.5 | B | BC | 31.6- 81.2 |
| 115N-72W- 7DDDD | HY-78A | 12-01-78 to 11-06-85 | 143.2 | B | BC | 97.0-111.1 |
| 115N-72W-16AAAA | HY-78B | 12-01-78 to 11-06-85 | 145.0 | B | BC | 63.4- 93.7 |
| SPINK COUNTY | | | | | | |
| 114N-62W- 2DDDD | SP-77U | 11-30-77 to 11-04-85 | 80.4 | B | BU | 28.9- 34.2 |
| 114N-62W- 7BBBB | SP-77H | 06-09-77 to 11-04-85 | 65.7 | S(?) | U(?) | 16.2- 17.9 |
| 114N-62W-16CCCC | SP-79J | 12-11-79 to 11-04-85 | 45.3 | B | BU | 17.7- 18.5 |
| 114N-62W-19CCCC | SP-77I | 06-09-77 to 11-04-85 | 45.5 | B | BU | 16.7- 18.5 |

APPENDIX F -- continued.

| Location | Well Name | Date of Record | Total Casing and Screen (ft) | Aquifer Classification (1) | Aquifer Type (2) | Range of Water-level Fluctuations (ft) |
|---|---|---|---|---|---|---|
| 114N-62W-22AAAA | SP-79K | 12-11-79 to 11-04-85 | 72.2 | B | BU | 27.8- 29.1 |
| 114N-62W-24DDDD | SP-77P | 06-09-77 to 11-04-85 | 65.5 | B | BU | 39.0- 40.9 |
| 114N-62W-33CCCC | SP-79N | 10-17-79 to 09-12-85 | 61.9 | B | BU | 27.4- 29.6 |
| 114N-62W-34DDDD | SP-79O | 10-17-79 to 09-12-85 | 34.6 | S | U | 31.2- 34.6 |
| 114N-63W- 5CCCC | SP-78C | 12-01-78 to 11-04-85 | 85.7 | B | BC | 25.0- 27.1 |
| 114N-63W-15AAAA | SP-80D | 07-29-80 to 11-04-85 | 66.1 | B | BU | 21.8- 23.3 |
| 114N-63W-20BBBB | SP-77X | 07-27-78 to 11-04-85 | 99.8 | B | BC | 58.7- 64.6 |
| 114N-63W-21DDDD2 | SP-80F | 07-29-80 to 11-04-85 | 65.3 | B | BC | 20.1- 22.7 |
| 114N-64W-11BBBB | SP-53B | 04-03-53 to 11-04-85 | 63.0 | B | BC | 6.3- 28.3 |
| 114N-64W-15AAAA | SP-80G | 07-31-80 to 11-04-85 | 90.5 | B | BC | 10.1- 27.8 |
| 114N-64W-16BBBB | SP-80C | 07-30-80 to 11-04-85 | 84.1 | B | BC | 25.5- 51.0 |

APPENDIX F -- continued.

| Location | Well Name | Date of Record | Total Casing and Screen (ft) | Aquifer Classification (1) | Aquifer Type (2) | Range of Water-level Fluctuations (ft) |
|---|---|---|---|---|---|---|
| 114N-64W-16DDDD | SP-77G | 06-09-77 to 11-04-85 | 63.3 | B | BC | 27.3- 50.5 |
| 114N-64W-22DDDD | SP-80H | 07-31-80 to 11-04-85 | 105.6 | B | BC | 24.8- 49.1 |
| 114N-64W-25BBBB1 | SP-78D | 12-01-78 to 11-04-85 | 72.5 | B | BC | 22.0- 41.2 |
| 114N-64W-29AAAD | SP-80E | 08-12-80 to 11-04-85 | 95.5 | B | BC | 33.8- 53.5 |
| 115N-62W- 4BBBB | SP-79F | 12-11-79 to 11-05-85 | 38.1 | S | U | 7.3- 13.5 |
| 115N-62W-14DDDD | SP-77L | 06-09-77 to 11-04-85 | 85.5 | B | BC | 17.1- 33.6 |
| 115N-62W-33CDDD | SP-77W | 11-30-77 to 11-04-85 | 65.7 | B | BU | 37.7- 39.9 |
| 115N-62W-35BBBB | SP-79G | 12-11-79 to 11-04-85 | 105.8 | B | BU | 49.7- 53.6 |
| 115N-63W- 1DDDD | SP-71A | 05-02-71 to 07-01-86 | 52.5 | B | BC | 5.3- 18.4 |
| 115N-63W- 7CCDC1 | SP-63G | 07-07-64 to 09-01-82 | 58.7 | B | BC | 18.9- 23.6 |
| 115N-63W- 7CCDC2 | SP-82D | 09-16-82 to 11-06-85 | 45.7 | B | BC | 21.1- 23.1 |

APPENDIX F -- continued.

| Location | Well Name | Date of Record | Total Casing and Screen (ft) | Aquifer Classification (1) | Aquifer Type (2) | Range of Water-level Fluctuations (ft) |
|---|---|---|---|---|---|---|
| 115N-63W-12CCCC | SP-82G | 09-16-82 to 11-06-85 | 33.1 | B(?) | BU(?) | 15.0- 15.8 |
| 115N-63W-14BBBC | SP-82F | 09-16-82 to 11-06-85 | 45.8 | B | BU | 14.0- 24.8 |
| 115N-63W-20AAAA | SP-82E | 09-16-82 to 11-06-85 | 56.8 | B | BU | 18.5- 20.9 |
| 115N-63W-25BBBB | SP-78B | 01-28-79 to 03-27-86 | 46.7 | B | BU | 28.2- 30.5 |
| 115N-63W-33DDDD2 | SP-80B | 07-29-80 to 11-04-85 | 52.2 | B | BU | 19.5- 21.0 |
| 115N-64W- 6BBBB | SP-80L | 10-06-80 to 11-06-85 | 86.8 | B | BC(?) | 15.9- 27.0 |
| 115N-64W-14CCCB | SP-66K | 06-09-67 to 11-06-85 | 65.7 | B | BC | 14.3- 17.7 |
| 115N-64W-22CCCC1 | SP-66M | 06-09-67 to 11-06-85 | 61.6 | B | BC | 9.7- 15.8 |
| 115N-64W-28BBBC2 | SP-80Q | 10-06-80 to 11-06-85 | 85.5 | B | BC | 12.7- 23.7 |
| 115N-64W-33CCCC | SP-80A | 07-30-80 to 11-06-85 | 105.0 | B | BC | 16.1- 34.2 |
| 115N-65W- 9CCCC | SP-80M | 10-09-80 to 11-06-85 | 67.7 | B | BC | 12.0- 16.2 |

APPENDIX F -- continued.

| Location | Well Name | Date of Record | Total Casing and Screen (ft) | Aquifer Classification (1) | Aquifer Type (2) | Range of Water-level Fluctuations (ft) |
|---|---|---|---|---|---|---|
| 115N-65W-14BBBB | SP-80N | 10-08-80 to 11-06-85 | 87.4 | B | BU(?) | 24.9- 37.2 |
| 115N-65W-19BBCC | SP-66G | 06-09-67 to 11-06-85 | 100.3 | B | BC | 7.3- 13.9 |
| 115N-65W-25AAAD1 | SP-66H | 06-09-67 to 11-06-85 | 82.1 | B | BC | 15.4- 37.2 |
| 115N-65W-26BBBB | SP-80P | 10-07-80 to 11-06-85 | 106.8 | B | BC | 17.0- 22.4 |
| 115N-65W-29AAAA1 | SP-80O | 10-08-80 to 11-06-85 | 125.5 | B | BC | 20.7- 27.7 |
| 115N-65W-35ABAB | SP-63E | 07-15-63 to 10-16-85 | 112.1 | B | BC(?) | 26.0- 40.9 |
| 115N-65W-36DDDD | SP-80R | 10-02-80 to 11-06-85 | 125.7 | B | BC | 20.9- 56.3 |
| 116N-62W-10ABBB | SP-82A | 05-26-82 to 11-05-85 | 34.2 | B | BC | 10.1- 14.5 |
| 116N-62W-11BBBB | SP-82B | 05-26-82 to 11-05-85 | 105.0 | B | BC | 18.9- 21.1 |
| 116N-62W-13BAAA2 | SP-80K | 06-09-67 to 11-05-85 | 49.4 | B(?) | BU | 18.1- 28.8 |
| 116N-62W-25AAAA | SP-77J | 06-09-77 to 11-05-85 | 66.0 | B | BU | 28.7- 33.6 |

APPENDIX F -- continued.

| Location | Well Name | Date of Record | Total Casing and Screen (ft) | Aquifer Classification (1) | Aquifer Type (2) | Range of Water-level Fluctuations (ft) |
|---|---|---|---|---|---|---|
| 116N-62W-34DDDD | SP-79E | 12-12-79 to 11-05-85 | 82.4 | B | BC | 31.7- 38.8 |
| 116N-63W- 2BABA2 | SP-77Q | 06-22-77 to 11-05-85 | 85.8 | B | BU(?) | 27.1- 43.8 |
| 116N-63W-27AADA | SP-77Y | 11-30-77 to 11-06-85 | 39.5 | B(?) | BC(?) | 8.8- 15.7 |
| SULLY COUNTY | | | | | | |
| 113N-74W- 9DAAA | SU-82B | 10-04-82 to 05-26-86 | 125.0 | B | BU | 76.4- 77.7 |
| 113N-75W-24DCCD | SU-65B | 06-30-65 to 05-26-86 | 38.8 | S | U | 7.8- 14.9 |

CHAPTER 5.B.

# HYDROGEOLOGY OF IRRIGATED LANDS IN SOUTHERN ALBERTA, CANADA

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1987

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## 5.B.1. INTRODUCTION

The development of irrigation in Alberta has been a gradual and continual process since the 1890's. There are presently thirteen Irrigation Districts in southern Alberta (Figure 1). All are located within the South Saskatchewan River Basin. These Irrigation Districts contain over 1 million acres of assessed irrigable land. This accounts for 84 percent of all irrigation in the province [Prairie Farm Rehabilition Administration, 1982]. The remaining irrigation projects are privately owned and operated.

The objective of this report is to summarize the present understanding of hydrogeology of irrigated lands in southern Alberta with emphasis on the hydrogeology of glacial tills. The United, Leavitt, Aetna, Mountain View, Western and Ross Creek Irrigation Districts are minor Irrigation Districts (with respect to crops and irrigation water use) and as such are not discussed in detail in this report. Many of the major hydrogeological studies have been conducted in or adjacent to the more intensively irrigated St. Mary River, Bow River, Taber and Lethbridge Northern Irrigation Districts. As a result, most of the hydrogeologic information contained in this report was collected from these areas.

## 5.B.2 GEOLOGY

### 5.B.2.1 Bedrock Geology

Granites and gneisses of the Precambrian Canadian Shield extend from northeastern Alberta through the Lethbridge area and west to the Rocky Mountains. The Precambrian Shield has been encountered in the Eastern Plains Region at depths of two kilometres or more by deep oil wells. These rocks are considered to be older than 600 million years. Although Cambrian to Jurassic rocks are encountered over Precambrian bedrock in the Eastern Plains Region, they are not considered important to the objectives of this study. Information on these rocks can be obtained from Alberta Society of Petroleum Geologists [1966].

The remainder of this section describes the bedrock from the Lower and Upper Cretaceous and Tertiary Periods which outcrop or subcrop in the Eastern Plains Region. In ascending order these are the Colorado, Milk River, Pakowki, Foremost, Oldman, Bearpaw, Blood Reserve, St. Mary River, Willow Creek, and Porcupine Hills Formations (Table 1). With the exception of an unconformity at the top of the Milk River Formation, the formations follow each other with apparent uniformity. A description of each formation, from oldest to youngest, is presented below.

Table 1. Bedrock formations of the Eastern Plains Region, southern Alberta.

| Period | Epoch | Formation | Age (x 106 years before present) |
|---|---|---|---|
| Quaternary | Pleistocene | Glacial and drift | 0.012 |
| | | | 2 |
| Tertiary | Oligocene | /////////////////////////// | |
| | | | 38 |
| | Eocene | Porcupine Hills (Tph) | |
| | | | 68 |
| | | Willow Creek (Tkw) | |
| | | St. Mary River (Ksm) | |
| Upper Cretaceous | | Blood Reserve (Kbr) | |
| | | Bearpaw (Kpb)<br>Belly River Group -<br>Oldman (Ko)<br>Foremost (Kfm)<br>Pakowki (Kpa) | |
| | | /////////////////////////// | |
| | | Milk River (Kmr) | |
| Lower Cretaceous | | Colorado (Ka) | 136 |

/////// represents unconformity

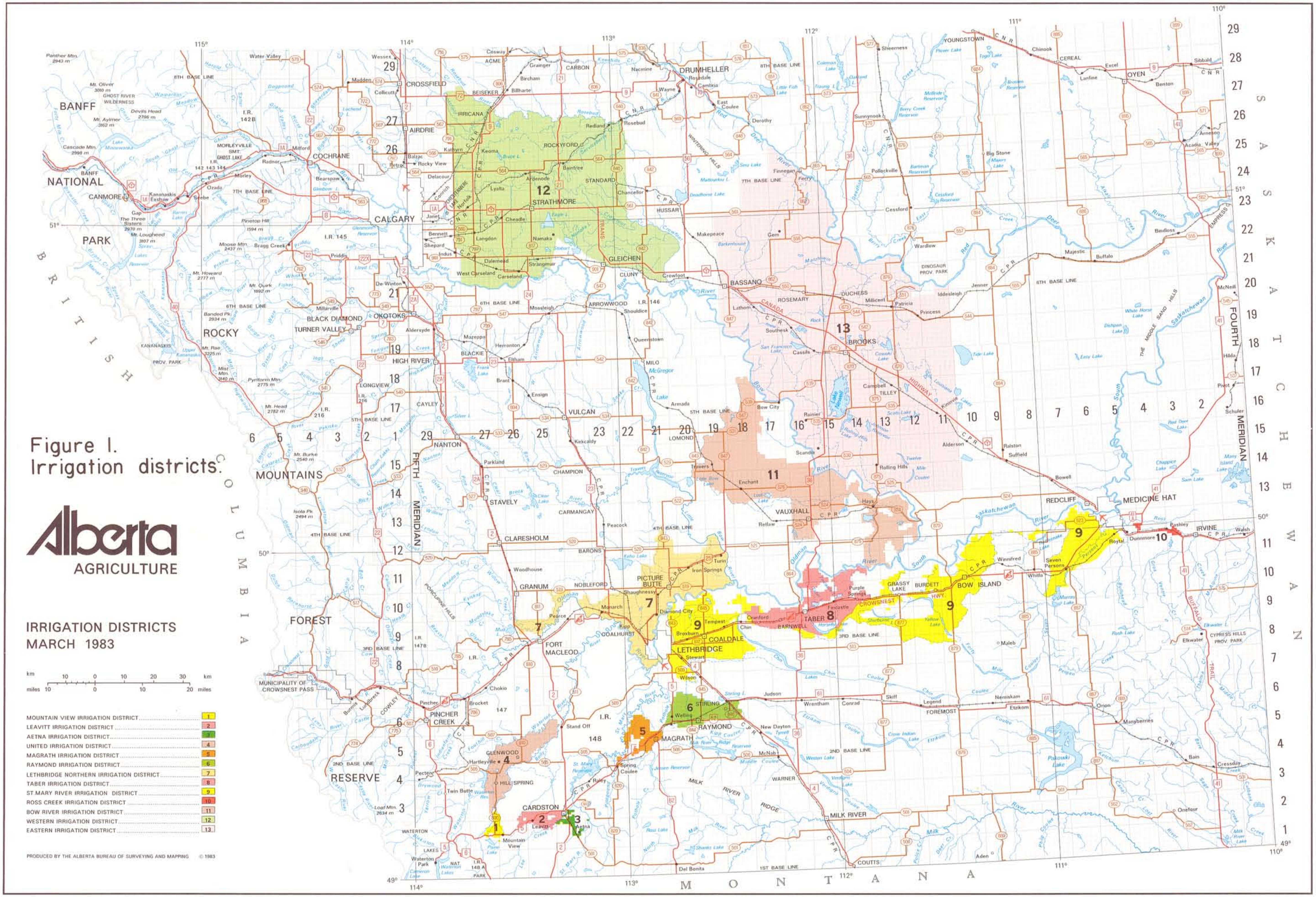


Figure 1. Irrigation districts.

### 5.B.2.1.1 Colorado Formation (Ka)

The Colorado Formation is predominantly dark grey to black marine shale and silty shale with outcrops in small areas south of the Milk River east of Coutts (Figure 2). The Colorado Formation is divided into two members; the Lower Cretaceous Blackleaf sandy member and the Upper Cretaceous Colorado shale member. The Blackleaf sandy member is composed of three sandstone zones separated by shales, whereas the Colorado shale member is predominantly bentonitic shales. The three sandstones of the Blackleaf member, in ascending order, are the Basal Colorado sandstone, the Bow Island sandstone and the Fish Scale sandstone. Black bentonitic shales separate these sandstones. The Basal sandstone is a thin (approximately 3 m thick) fine to medium grained light grey sandstone interspersed with light to dark grey shales. It pinches out to the north [Glaister, 1958]. The Bow Island sandstone, which occurs near the middle of the Blackleaf member, is the major sandstone unit in the Colorado Formation. It is approximately 22 m thick and consists of a series of fine grained sandstones with traces of glauconite. The Bow Island sandstone is the producing zone of several gas fields in southern Alberta. The Fish Scale sandstone is a thin, poorly sorted sandstone with numerous fish scales. It is generally only a few centimetres thick.

The top of the Colorado Formation is arbitrarily chosen as a thin zone of dark grey to black calcareous sandy shale containing white speckles. This marker can be up to 10 m below the first dark grey shale of the Colorado Formation. The Colorado shale member is typically 300 to 400 m thick, whereas the Blackleaf sandy member is typically 230 m thick.

### 5.B.2.1.2 Milk River Formation (Kmr)

The Cretaceous Milk River Formation conformably overlies the Colorado Formation and is divided into two members; the Lower Milk River and the Upper Milk River. The Upper member was deposited in a nonmarine environment whereas the Lower member was deposited in a freshwater to brackish or marine environment.

The Lower Milk River consists of massive crossbedded sandstone beds interbedded with one to several sequences of grey shale. These sandstones are fine to medium grained and commonly contain thin beds of lignite and ironstone concretions. The sandstone beds grade downward into the sandy shales and siltstones of the transition zone to the Colorado Formation [Alberta Society of Petroleum Geologists, 1966]. The sandstone outcrops along the Milk River (Figure 2) where it has an average thickness of about 100 m. It thins considerably to the north and east. In these areas sandy shales predominate.

The Upper Milk River member is composed of irregular beds of light grey to buff, soft friable sandstones; light to dark grey carbonaceous shales and siltstones; and a few beds of lignite. The thickness of the upper member is about 40 m.

The top of the Milk River Formation is marked by dark shales and a thin chert pebble conglomerate. The conglomerate represents an erosional surface (Table 1) some 100 million years old.

### 5.B.2.1.3 Pakowki Formation (Kp)

Disconformably overlying the Milk River Formation are the marine shales of the Pakowki Formation which consist of grey to dark grey bentonitic shales with thin bentonite beds [Alberta Society of Petroleum Geologists, 1966]. The main outcrops are north of the Milk River (Figure 2). The Pakowki Formation thins from approximately 120 m at Medicine Hat to nil in the foothills of the Rocky Mountains [Nielsen, 1970]. It is typically 60 to 90 m in thickness in the Eastern Plains Region.

There is usually a gradual transition upward into the overlying Foremost Formation, making it difficult to determine the exact upper boundary for the Milk River Formation. The top of this formation is typified by minor amounts of interbedded sandstone with a greenish grey sandstone at the top.

### 5.B.2.1.4 Foremost and Oldman Formations (Kfm-Ko)

The Foremost and Oldman Formations represent a series of fresh and brackish water deposits overlying the Pakowki Formation. The dark shales and sandstones of the Foremost Formation gradually grade into the light colored argillaceous sandstones and sandy shales of the Oldman Formation. This makes the boundary between the two formations very difficult to identify. As a result, many geologists and engineers discuss these formations together as the Belly River Group (Table 1). Although both of these formations are alike in many respects and the boundary between them is poorly defined, they are sufficiently different to form two distinct mapping units. The major distinction between the two formations can be made on the basis of color. Beds of the Oldman Formation are much lighter in color than those of the Foremost Formation.

Outcrops and subcrops of these formations occupy most of the area south of the Red Deer River and west as far as Lethbridge (Figure 2). Bedrock of the Belly River Group underlies much of the irrigated land in southern Alberta; specifically in the St. Mary River, Taber, Bow River, Raymond, Lethbridge Northern and Eastern Irrigation Districts.

The Belly River Group is the main coal producing strata in southern Alberta. The coal mines at Lethbridge are located in the Oldman Formation while those at Taber are in the Foremost.

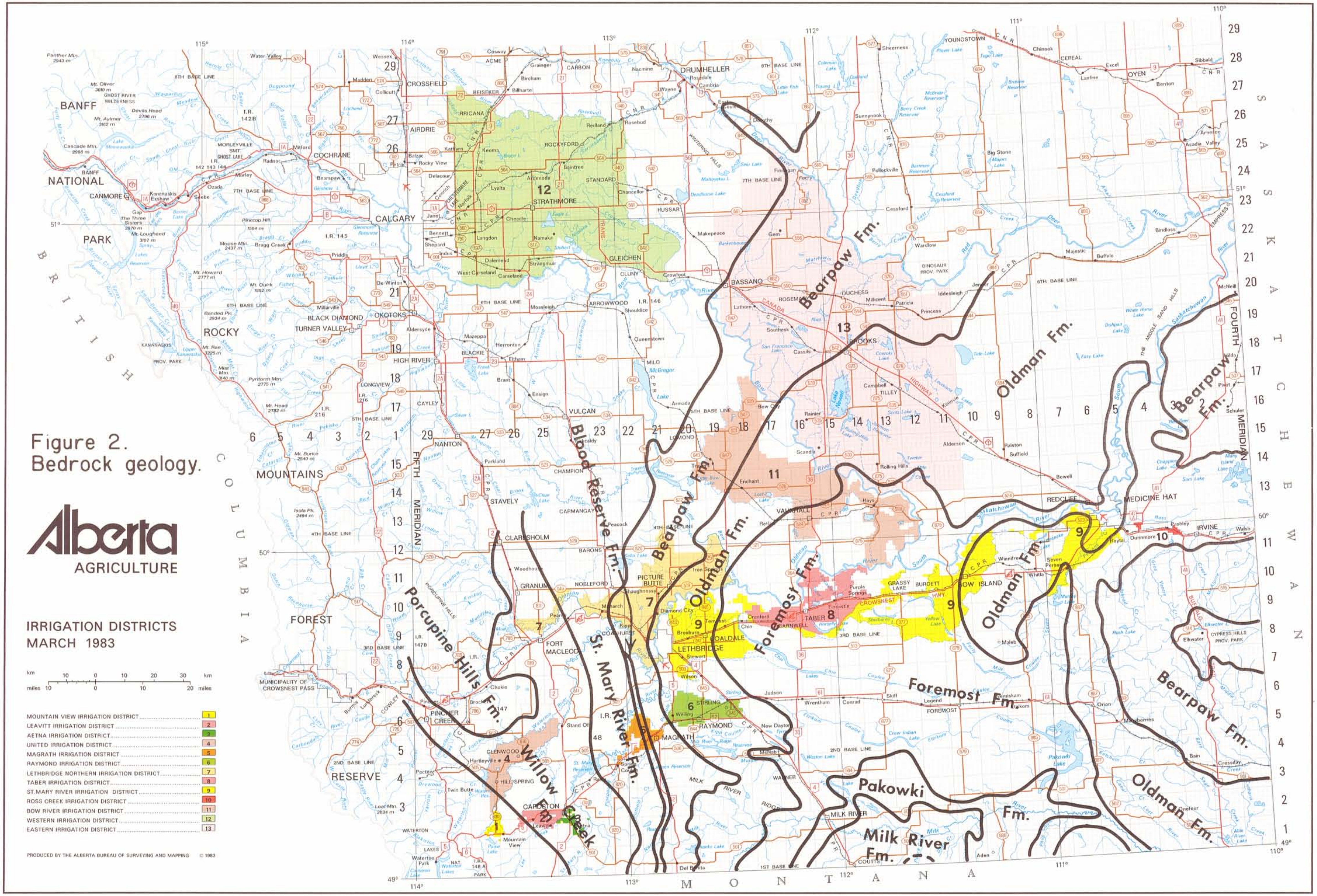


Figure 2. Bedrock geology.

The Belly River Group is typically about 200 m thick. Each formation being approximately 100 m thick. Nielsen [1970] states that the Belly River Group thins from about 500 m at Lethbridge to 200 m at Medicine Hat.

### 5.B.2.1.5 Bearpaw Formation (Kbp)

The Bearpaw Formation conformably overlies the Oldman Formation (Table 1) and outcrops or subcrops around the base of the Cypress Hills and just west of Lethbridge (Figure 2). This formation subcrops beneath parts of the Lethbridge Northern, Eastern, Bow River and Magrath Irrigation Districts. The lower contact is identified by the presence of the coal beds of the Oldman Formation.

The Bearpaw Formation typically consists of grey to brownish-grey, soft fossil marine shale [Byrne and Farvolden, 1959]. Beds of soft fine grained argillaceous sandstone and beds of bentonite are common. The bentonitic beds vary from a few centimetres to a few metres in thickness [Byrne and Farvolden, 1959].

The Bearpaw Formation is approximately 180 m thick in southern Alberta.

### 5.B.2.1.6 Blood Reserve Formation (Kbr)

The Blood Reserve Formation conformably overlies the Bearpaw Formation. It consists of a variable sequence of brown, grey and green marine sandstones and sandy shales. Most of the sandy shale is fine grained, colloided and may be bentonitic. Black carbonaceous bands and beds of oyster shells are common.

The Blood Reserve Formation outcrops or subcrops to the southwest of Lethbridge (Figure 2), however, it has not been mapped further north. This formation is typically 10 to 25 m thick.

### 5.B.2.1.7 St. Mary River Formation (Ksm)

This formation conformably overlies the Blood Reserve Formation and outcrops in the St. Mary River and Oldman River valleys and subcrops throughout a northerly trending area west of Lethbridge (Figure 2). It underlies parts of the Lethbridge Northern and Magrath Irrigation Districts. The St. Mary River Formation consists of alternating greenish sandstones and siltstones [Carrigy, 1971]. The St. Mary River Formation was deposited in fresh and brackish waters [Russell and Landes, 1940].

This formation is approximately 500 m thick in the Oldman River. The upper contact of this formation is marked by the presence of red shale beds.

#### 5.B.2.1.8 Willow Creek Formation (Tkw)

The Willow Creek Formation conformably overlies the St. Mary River Formation. It subcrops and outcrops in the Cardston-Glenwood-Fort MacLeod area (Figure 2) and underlies parts of the Lethbridge Northern, United, Leavitt and Aetna Irrigation Districts. This formation consists of interbedded bentonitic shales and soft sandstones of freshwater origin [Carrigy, 1971].

The Willow Creek Formation is approximately 300 m thick. The top of this formation is marked by grey sandstone.

#### 5.B.2.1.9 Porcupine Hills Formation (Tph)

The Porcupine Hills are a prominent topographic feature in southwestern Alberta rising approximately 750 m above the surrounding plains. Outcropping extensively in these hills is a series of fine grained crossbedded freshwater sandstones and calcareous bentonitic shales of freshwater origin called the Porcupine Hills Formation [Carrigy, 1971] (Figure 2).

The Porcupine Hills Formation is up to 1000 m thick. The top of the Porcupine Hills Formation is marked by an exposed erosional surface.

### 5.B.2.2 Structural Geology

The Eastern Plains Region of southern Alberta is situated on a broad northerly plunging anticlinorium known as the Sweetgrass Arch. The actual age of the Sweetgrass Arch is difficult to determine because of erosional removal of Tertiary and Cretaceous strata [Meyboom, 1960]. Russell and Landes [1940] report secondary folds in younger strata. This suggests early Tertiary tectonism. This is in keeping with the statement by Rhoades [1955] that the uplift of the Sweetgrass Arch occurred during the Laramide Revolution. Tovell [1958] indicates that this anticlinorium had a history of movement as far back as Mississippian times.

The uplift of the Sweetgrass Arch was caused by vertical movement of the basement complex. This uplift is reflected in the geologic map of the outcropping and subcropping bedrock of the Eastern Plains Region (Figure 2); progressively younger rocks are exposed to the northwest and east. The younger rocks, which were present in the south, were eroded during and/or slightly after the Laramide Revolution. Dips of bedrock units rarely exceed 40 m/km.

Faulting of the Lower and Upper Cretaceous and Tertiary bedrock in the Eastern Plains Region is rare [Nielsen, 1970]. A few normal faults are known to exist in the coal layers of the Oldman Formation and in bedrock outcrops along the Oldman River. The displacement of these faults is typically less than 1 metre.

Joint systems are widespread. Two systems are considered to exist, one system almost normal to the other. Although such joints were formed during or immediately after the Laramide orogeny, some adjustment appears to have occurred during the Quaternary Era. This is evidenced by the presence of lineations in surficial deposits as well as the underlying bedrock material [Nielsen, 1970].

### 5.B.2.3 Surficial Deposits

The mapping of surficial deposits in southern Alberta is far from complete. Glacial deposits in southern Alberta have been under study intermittently for some 80 years. Most of the early work involved the examination of sections along the major river valleys. Detailed mapping was accelerated after the second World War by the Geological Survey of Canada and the Research Council of Alberta.

Prior to the advance of the first Laurentide glacier over southern Alberta, the preglacial drainage patterns are considered to be as presented in Figure 3. It is not known whether these drainage patterns are Late Tertiary or Early Pleistocene in age. The thalweg of the drainage channels in southern Alberta trend east-northeast. The preglacial drainage channels have been studied by Gravenor and Bayrock [1961], Stalker [1961], Farvolden [1963] and Geiger [1965]. The bedrock channels occupied broad lowland areas between widely separated low and rounded upland areas [Farvolden, 1963]. These channels transmitted water from the Rocky Mountains to the east [Horberg, 1952].

Neither subsequent glacial erosion nor glacial deposition changed the dominant preglacial topography to any great extent. The surficial deposits are typically thicker in the preglacial channels and thinner in the preglacial uplands.

The remainder of this section describes the dominant surficial deposits in the Eastern Plains Region, and in particular those which are found in the major Irrigation Districts. These surficial deposits are: the Saskatchewan sands and gravels, glacial till and the lacustrine, outwash and eolean deposits of postglacial origin.

#### 5.B.2.3.1 Saskatchewan Sands and Gravels

The Saskatchewan sands and gravels are the oldest surficial deposits. These deposits were laid down prior to glaciation [Stalker, 1968] by the preglacial rivers in the drainage channels presented in Figure 3 [Westgate and Bayrock, 1964]. Radiocarbon analyses indicate that these gravel deposits are older than 54,500 years [Westgate, 1968].

The dominant clasts in the Saskatchewan sands and gravels are quartzites, hard sandstone and Crowsnest volcanics [Stalker, 1962]. Clasts are subangular to well-rounded although the majority are sub- to well-rounded. Clast size ranges from 30 mm to 150 mm and the matrix comprises medium to coarse sand. Secondary carbonate cementation and iron-oxide staining are observed close to the upper and lower contacts of the deposit.

This deposit has been observed to be up to 15 m thick and underlies large portions of the irrigated land (Figure 3).

Wolf Island sediments, which are preglacial lacustrine sediments, conformably overlie the Saskatchewan sands and gravels in some preglacial valleys but sit directly on the bedrock in tributary valleys. These are much finer than the sands and gravels (clay to fine sands). Little is known about their distribution or characteristics and they are presented only for the sake of completeness.

### 5.B.2.3.2 Glacial Till

#### 5.B.2.3.2.1 GLACIAL STRATIGRAPHY

It is generally accepted that North America has undergone four major glacial advances during the Pleistocene. These are, from oldest to youngest, Nebraskan, Kansan, Illinoian, and Wisconsin. They are separated by interglacials which are, from oldest to youngest, the Aftonian, Yarmouthian and Sagamonian. Exactly when the first glacier entered southern Alberta is not known, however, it is estimated by some glacial geologists [Alberta Society of Petroleum Geologists, 1966] that the onset of glaciation occurred approximately one million years ago. Although it is generally recognized that two or more glacial advances occurred in southern Alberta, no evidence of long-term interglacial periods have been found. The last glacial advance (late Wisconsin glacial stage) is the best understood; it advanced over southern Alberta 24,000 to 20,000 years ago [Westgate, 1968] and southern Alberta remained under ice until about 13,000 years B.P. [Christianson, 1965]. Westgate [1968] identified four drift sheets which were deposited during the late Wisconsin stage: the oldest late Wisconsin drift sheet extended well into Montana (Wild Horse drift); the second oldest drift sheet extended as far south as Verdigris Coulee and the Milk River Channel (Pakowki drift); the third oldest drift sheet extended as far south as Etzikom coulee (Etzikom drift); and the youngest Wisconsin drift sheet extended as far south as the South Saskatchewan River (Oldman drift). The oldest drift sheet identified in southern Alberta is believed to be of early Wisconsin time. It extended well into Montana (Elkwater drift). All but the last drift sheet covered all of the Irrigation Districts. The last till sheet only covered the irrigated lands located north of the South Saskatchewan River (Figure 1).

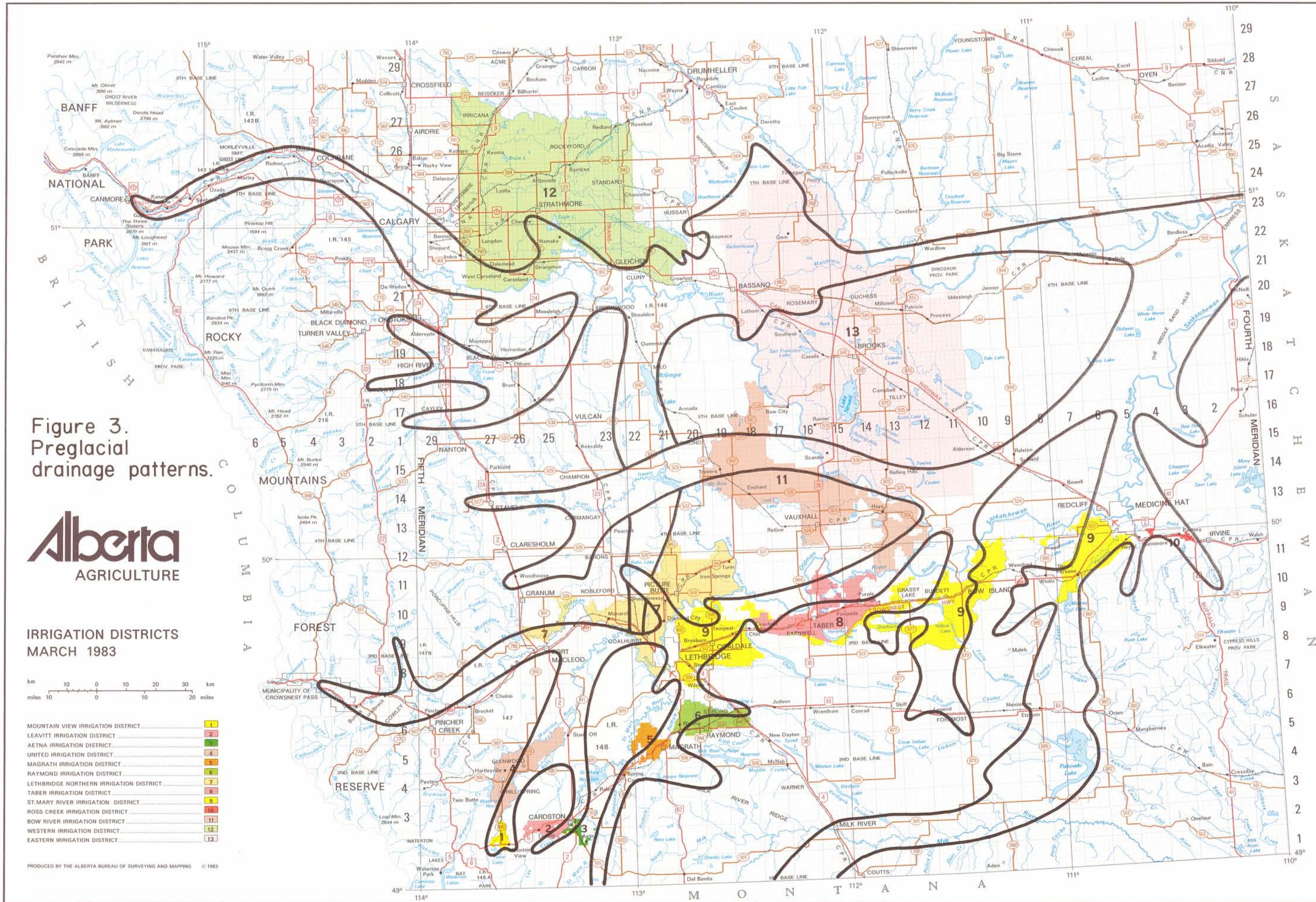


Figure 3. Preglacial drainage patterns.

As noted above, till deposits older than Wisconsin are difficult to recognize in western Canada. It has been stated that the lack of pre Wisconsin tills in the subsurface over most of western Canada may be due to their removal and incorporation during the advance of the Wisconsin ice or, alternatively, they may not have been deposited [Alberta Society of Petroleum Geologists, 1966].

A correlation of the till sheets presented above, which has been applied to the surficial geology from Taber to Medicine Hat (Figure 1), to that of Horberg [1952] is presented in Table 2. Because of the more abundant usage of the Horberg nomenclature, the drift units will be described individually in that context.

Table 2. Stratigraphy of glacial and interglacial deposits, southern Alberta. (after Nielsen, 1970)

| Stage | after Westgate [1968] | after Horberg [1952] |
|---|---|---|
| | Upper silts and sands | |
| | Oldman drift | Upper silts and sands |
| | Etzikom drift | Upper till |
| | | Lenzie silts |
| Wisconsin | Pakowki drift | Lower till No. 2 |
| | | Bedrock masses horz. |
| | Wild Horse drift | Lower till No. 1 |
| | Elkwater drift | Basal till |
| Nebraskan to Wisconsin | Saskatchewan sands and gravels | Saskatchewan sands and gravels |

The Basal till (Elkwater drift of Westgate [1968]) is a relatively thin, well-indurated till which lies directly on bedrock, or on Saskatchewan sands and gravels, where present. A thin gravel or sand layer is encountered at the top of this till. The maximum thickness observed by Nielsen [1970] in the St. Mary River Irrigation District between Lethbridge and the Chin Lakes (Figure 1) was 5 m and the mean thickness was 2 m. In general, the Basal till tends to be thickest over preglacial valleys and thinnest over preglacial knolls. This till is characterized by a slightly darker color than that of the overlying tills. Pebbles are present, but cobbles and boulders are rare. In surface exposures, it is highly columnar with salt deposits along the vertical joints.

The Lower till (Pakowki and Wild Horse drifts of Westgate [1968]) is relatively easy to recognize in surface exposures, but its upper boundary is difficult to identify during drilling, even using electric logs. This till, as was the case for the Basal till, tends to be thickest in preglacial valleys. The thickest section interpreted from drilling was 40 m and the thinnest about 5 m [Nielsen, 1970]. Like the Basal till, this till is also columnar in outcrops but the columns are less perfectly formed and consist of softer material. Nevertheless, it weathers in outcrop to vertical and near vertical slopes. The Lower till includes true till deposits, as well as glacio-fluvial stratified sediments. Discontinuous sheets of Cretaceous bedrock, called "Bedrock Masses" also occur within this till. Vernon [1962] attempted to subdivide the Lower till into two units, using the Bedrock Masses horizon as the boundary between them. Where this horizon is absent, such a division is very difficult.

The lower part of the Lower till is dark grey, being nonweathered. The upper part is weathered and has a brownish-grey or buff color. Nielsen [1970] reports a few drill records which identify weathered zones within nonweathered till. This condition has also been observed by Hendry et al. [1986].

A distinct, stratified layer, named Lenzie Silts, which was deposited in a lacustrine environment, occurs above the Lower till. It consists of clay, silt and sand, and has a loess-like appearance [Horberg, 1952]. The layer, when present in outcrop, is quite noticeable ranging up to 12 m in thickness. It is stratified and lighter in color than the tills above and below. In boreholes, this zone is much more difficult to recognize. Where sandy, it may be recognized from electric logs, but otherwise is difficlt to differentiate from till.

The Upper till (Etzikom drift of Westgate [1968]), has a maximum thickness of about 40 m in the Lethbridge area [Nielsen, 1970]. Although some sand and gravel are present in the Upper till, such materials are fairly rare except at the base and top. When weathered, this till is buff, otherwise grey to bluish grey in color. Nielsen [1970] observed that the Upper till is not strongly jointed in outcrop and has a more massive appearance than do the deeper tills.

Although these till sheets have been identified in outcrop and in some testholes using electric logging, it has proven very difficult to impossible to identify these individual till sheets from cores, split spoon samples and drill cuttings. As a result, the division of the till deposits has been made on the basis of color in the field; this being the weathered and nonweathered till zones. The validity of this simple divison is verified by hydrogeologic and chemical differences between the till zones (discussed in later sections).

### 5.B.2.3.2.2 CHARACTERISTICS OF GLACIAL TILL

The most common colors of till are grey (5Y6/2, 5/2, 5/1) for the nonweathered till zones and brown (10YR5/2 or 6/3) for the weathered till zones.

Tills of southern Alberta are an unsorted admixture of local bedrock and rock material derived from the Canadian Shield and Paleozoic carbonate rocks from the rim of the Shield [Westgate, 1968; Pawluk and Bayrock, 1969]. Most tills are a clay loam to loamy texture [Westgate, 1968; Grisak et al., 1976; Hendry, 1983a]. The dominant clay mineral in the till is smectite with lesser amounts of illite, followed by kaolinite and chlorite [Hendry, 1981; Schwartz et al., 1982]. These local results are in keeping with the more regional results of Pawluk and Bayrock [1969].

Tills of southern Alberta have liquid limits varying from 22 to 48% and plasticity indexes from 5 to 25 [Pawluk and Bayrock, 1969; Hendry, 1981]. Pawluk and Bayrock [1969] attribute the wide spread in this data to the variability in the soluble salt content in the till, although variability in clay-mineral distribution is also of significance.

High resolution gamma ray logs were conducted by the author in piezometers completed in till in the Taber, Bow River and St. Mary River Irrigation Districts. These logs revealed the presence of numerous thin discontinuous sand layers in both the weathered and nonweathered till zones.

In the Vauxhall area, Hendry [1982] noted fracture systems within weathered till. The fracture networks are cubical with fracture spacings, or the distance between two sub-parallel vertical fractures, averaging 10 mm for small-scale fractures and from 20 mm to 635 mm for the large-scale fractures. Many of the fractures were lined with authigenic gypsum and organics. Free water was observed along many of the fractures. These observations concerning fracture development within the till are consistent with those made by others such as Williams and Farvolden [1969], Schwartz [1975], Grisak and Cherry [1975], Grisak [1975], Burnett [1982], Schwartz et al. [1982]. No fractures have been observed by the author in drill cuttings, split spoon samples or shelby tube samples from the grey nonweathered till; it appears to be massive but this massive nature has not been directly verified. No evidence of colmnar jointing in the lower grey till (Basal and Lower tills of the previous section) as observed in outcrops has been encountered.

The presence of large amounts of soluble salts in the weathered till zones (especially the dominant sodium sulfate salt) cannot be related to the much lower salt content of the underlying nonweathered till zones or bedrock [Hendry et al., 1986; Pawluk and Bayrock, 1969]. Hendry et al. [1986] attribute the higher salt content in the weathered till zone to the oxidation of reduced sulfur which was incorporated in the till during deposition and oxidized in the weathered zone during the past 11,000 years (see Section 5).

### 5.B.2.3.2.3 DISTRIBUTION OF TILLS IN THE IRRIGATION DISTRICTS

Within the Irrigation Districts of southern Alberta, till is a major surficial deposit. The distribution of till throughout most of the Irrigation Districts is presented in Figure 4 (map pocket) [Shetsen, 1981]. Based on this map, till comprises approximately 40% of the surficial geology in the irrigated areas represented. It is believed that this distribution is also typical of the irrigation districts not covered by this map.

### 5.B.2.3.3 Postglacial Deposits

As the last glacier retreated by ablation to the northeast, numerous temporary proglacial lakes formed where glacial meltwater was not free to drain away. These lakes rose until one or more meltwater channels formed to drain them. Since the glacial ice was retreating, these lakes tended to have only a short life span.

The distribution of lacustrine deposits in the Irrigation Districts are outlined in Figure 4 (map pocket). Lacustrine deposits cover about 60% of the land mass of the Irrigation Districts presented. Based on numerous borehole logs, the lacustrine deposits can be as thick as 12 m. The mean thickness of the lacustrine deposits can only be estimated; it appears to be less than 1 m. In Figure 4, the laucustrine deposits are divided into either a silt to clay or sand to silt textural group.

Minor surficial deposits observed in the Irrigation Districts include those of outwash and eolean origin (Figure 4). The eolean deposits, which are primarily silts and clays, formed from reworked lacustrine deposits after the drainage of the lacustrine lakes and prior to reestablishment of vegetal cover.

Outwash occurs as sheets composed largely of fine grained, well sorted sand [Shetsen, 1981]. Isolated bodies of sandy gravel and gravelly sand are present in places within the ice contact margins of the outwash plains, where they form minor hills of irregular shape.

## 5.B.3. HYDROGEOLOGY

### 5.B.3.1 Bedrock

A summary of most of the known data on the hydraulic conductivity of bedrock units in southern Alberta is presented on a formational basis in Table 3. Most of the calculated hydraulic conductivities presented in this table are from single well response tests.

The Milk River Formation is the most permeable formation (Table 3) and, as such, is the major bedrock aquifer for domestic and agricultural (livestock) water supplies. The recharge area for the aquifer is in the uplands in northern Montana and in southern Alberta where the formation outcrops or subcrops (Figure 2). The aquifer has a regional dip to the north and is confined above and below by the slowly permeable Colorado and Pakowki Formations (Table 3). From the area between Highway 61 to the South Saskatchewan River (Figure 2), extensive areas of flowing or once flowing wells completed in the Milk River Formation can be found. These occur most frequently in deeply incized existing or ancestral river channels where the piezometric surface in the aquifer is above ground surface.

The hydraulic head in the Bow Island sandstone of the Colorado Formation is less than that in the Milk River Formation [Schwartz et al., 1981]. Therefore, the potential not only exists for groundwater in the Milk River Formation to move upward, but downward into underlying formations.

Residence times in the Milk River aquifer are very long. In the recharge area the ages of porewater are a few thousand to tens of thousands of years old. In the vicinity of Taber and Bow Island (Figure 1) the water is as old as a few million years [International Atomic Energy Agency, 1986].

The Foremost and Oldman Formations (Belly River Group), and the St. Mary River Formation all have variable lateral hydraulic conductivities (Table 3). The variability reflects their broad range in lithology (from sandstone to bentonitic beds). On a formational scale the vertical hydraulic conductivity in the Belly River Group and St. Mary River Formation is similar to that of the Pakowki and Colorado Formations. The low vertical hydraulic conductivity in these units can be attributed to the presence of the bentonitic beds. These beds have hydraulic conductivities in the order of 1 x 10-10 ms-1 (Table 3). As a result, water in these formations moves along beds rather than across them. This low vertical hydraulic conductivity is in keeping with studies conducted by Bennett and Hendry [1986] at a shallow bedrock site on the Oldman Formation. At this site, irrigation caused a perched water table to form above a shallow, partially saturated bedrock.

Limited data on the Bearpaw Formation (Table 3) indicates that it has a low hydraulic conductivity. This is in keeping with its lithology.

The author is unaware of any hydraulic conductivity data for the Blood Reserve Formation or the Willow Creek or Porcupine Hills Formations. Based on lithologies, the Blood Reserve should have a high hydraulic conductivity (possibly similar to that of the Milk River Formation) and the Willow Creek should have a similar hydraulic conductivity to that of the St. Mary River Formation and the Belly River Group.

### 5.B.3.2 Surficial Deposits

The hydraulic conductivity and water movement in the Saskatchewan sands and gravels, tills, outwash and lacustrine deposits are discussed in this section. All available hydraulic conductivity data for these deposits are presented in Table 4.

#### 5.B.3.2.1 Saskatchewan Sands and Gravels

The Saskatchewan sands and gravels constitute the major surficial aquifer in southern Alberta. It supplies water for domestic as well as agricultural (livestock) uses. Nielsen [1971] reports that in some areas within the bedrock channels, interglacial outwash may be being mistaken for Saskatchewan sands and gravels.

Reported hydraulic conductivities (Table 4) are in the range of 6 x 10-5 to 5 x 10-6 ms-1. Observations of the coarse nature of exposed surfaces of this deposit tend to indicate a much higher hydraulic conductivity in some areas and a much lower hydraulic conductivity in other areas (due to cementation). Transmissivities for some of these channel deposits are reported by Alberta Environment and the Alberta Research Council. These values could not be obtained for this report.

The Saskatchewan sands and gravels have been cut by rivers in several places during the post glacial erosion. This has allowed the groundwater present in these deposits to drain laterally into the river systems thus producing partially saturated conditions in the Saskatchewan sands and gravels [Nielsen, 1970; Hendry, 1986a]. In these areas the overlying till has remained saturated. Artesian conditions exist in areas where partially saturated conditions do not occur.

#### 5.B.3.2.2 Glacial Till

##### 5.B.3.2.2.1 HYDRAULIC CONDUCTIVITY

A number of techniques have been applied to determine the hydraulic conductivity of the tills in southern Alberta. These include single well response tests, auger hole tests, constant

Table 3. Hydraulic conductivity values (ms-1) of bedrock formations of southern Alberta determined from single well response tests.

| Formation | Number of Tests | Range | Geometric Mean | SDF[a] |
|---|---|---|---|---|
| <u>Colorado</u> | | | | |
| Hendry [1986b][b] | 20 | 9 x 10-10 to 5 x 10-12 | 5 x 10-11 | 1.3 |
| Hendry [1986b] | 1 | -- | <10-10 | --- |
| <u>Milk River</u> | | | | |
| Schwartz et al. [1981] | -- | -- | 5 x 10-5 | --- |
| <u>Pakowki</u> | | | | |
| Hendry [1983] | 1 | -- | <10-10 | --- |
| Hendry [1986b] | 2 | 4 x 10-9 to 2 x 10-9 | -- | --- |
| <u>Foremost/Oldman</u> | | | | |
| Hendry [1983] | 60 | 2 x 10-5 to 2 x 10-10 | 2 x 10-8 | 1.2 |
| Hendry [1981] | 13 | 5 x 10-7 to <10-10 | 5 x 10-8 | --- |
| <u>Bearpaw</u> | | | | |
| Chan & Hendry [1985] | 2 | 2 x 10-9 to 1 x 10-9 | 2 x 10-9 | --- |
| <u>St. Mary River</u> | | | | |
| Chan & Hendry [1985] | 30 | 3 x 10-6 to 1 x 10-10 | 2 x 10-8 | --- |
| Schwartz et al. [1982] | 3 | 2 x 10-6 to 2 x 10-10 | 5 x 10-8 | 2.1 |

a standard deviation factor

b determined from vertical consolidation tests conducted on core samples

Table 4. Hydraulic conductivity values (ms-1) of surficial deposits of southern Alberta determined from single well response tests.

| Deposit | Number of Tests | Range | Geometric Mean | SDFa |
|---|---|---|---|---|
| <u>Lacustrine</u> | | | | |
| Hendry [1981] | 1 | -- | 1 x 10-8 | --- |
| Hendry [1981]b | -- | 4 x 10-5 to 1 x 10-6 | -- | --- |
| Burnett [1982] | -- | 1 x 10-5 to 1 x 10-6 | 5 x 10-6 | --- |
| Hendry & Buckland [1986]c | 29 | 5 x 10-6 to 9 x 10-7 | 2 x 10-6 | --- |
| Buckland et al. [1986]d | 10 | 5 x 10-7 to 2 x 10-8 | 2 x 10-7 | --- |
| Buckland et al. [1986]e | 5 | 1 x 10-6 to 2 x 10-7 | 5 x 10-7 | --- |
| <u>Outwash</u> | | | | |
| Burnett [1982] | 11 | 8 x 10-5 to 5 x 10-6 | 5 x 10-5 | --- |
| Hendry [1981] | 4 | 1 x 10-7 to 5 x 10-7 | 2 x 10-7 | --- |
| Robertson [1985] | 9 | 2 x 10-7 to 1 x 10-9 | 2 x 10-8 | 0.86 |
| Chan & Hendry [1985] | 4 | 6 x 10-7 to 6 x 10-9 | 2 x 10-8 | 0.44 |
| <u>Till</u> (<u>weathered</u>) | | | | |
| Schwartz et al. [1982] | 4 | 1 x 10-7 to 2 x 10-9 | 3 x 10-8 | 0.83 |
| Hendry [1983] | 26 | 1 x 10-7 to 2 x 10-9 | 2 x 10-8 | 1.04 |
| Burnett [1982] | 10 | 5 x 10-6 to 3 x 10-9 | 1 x 10-7 | --- |
| Hendry [1982] | 41 | 7 x 10-7 to 3 x 10-9 | 2 x 10-7 | --- |
| Robertson [1985] | 16 | 2 x 10-7 to 2 x 10-9 | 2 x 10-8 | 0.61 |
| <u>Till</u> (<u>nonweathered</u>) | | | | |
| Burnett [1982] | 29 | 8 x 10-8 to <10-10 | 2 x 10-9 | --- |
| Hendry [1982]f | 3 | 1 x 10-9 to 3 x 10-10 | <10-10 | --- |
| Robertson [1985] | 13 | 6 x 10-8 to 9 x 10-10 | 6 x 10-9 | 0.58 |
| Schwartz et al. [1982] | 3 | 1 x 10-5 to 1 x 10-7 | 5 x 10-7 | 1.15 |
| Hendry [1986]b | 3 | -- | <10-9 | --- |
| <u>Saskatchewan Sands and Gravels</u> | | | | |
| Burnett [1982] | 1 | -- | 6 x 10-5 | --- |
| Nielsen [1970]. | 1 | -- | 5 x 10-6 | --- |

a standard deviation factor
b constant-head permeameter tests on horizontal core samples
c auger-hole tests
d vertical conductivity based on drain drawdown near Nobleford
e vertical conductivity based on drain drawdown near Raymond
f consolidation tests
g results of pump testing

head tests, consolidation tests and pumping tests. The calculated hydraulic conductivities from these tests at some of the detailed study areas in southern Alberta are presented in Table 4.

From review of the geometric mean hydraulic conductivity for the two till zones in Table 4, it appears that the hydraulic conductivity of the weathered zone is greater than that of the non-weathered zone. Burnett [1982] reached this same conclusion based on single well response test data collected in his study area. More recent and detailed scrutiny of single well response test results by Hendry [1986a] and Robertson [1985] and by Chan and Hendry [1986] for an area in central Alberta (data not presented in Table 4) indicated that there was no statistical difference between the geometric mean hydraulic conductivities for each till zone. Hendry [1986a] and Robertson [1985] report geometric mean hydraulic conductivities from their single well response testing of 1.6 x 10-8 ms-1 (n = 46) and 1.4 x 10-8 ms-1 (n = 29), respectively.

The hydraulic conductivity values reported by Hendry [1986a] and Robertson [1985] as well as the other single well response test results presented in Table 4 are too high to represent the intergranular hydraulic conductivity of the till, which is estimated to be approximately 1 x 10-10 ms-1 [Hendry, 1982]. These values are either the result of fracturing and/or the presence of thin horizontal sand layers or lamallae.

Using a number of techniques to determine hydraulic conductivity, Hendry [1982] attributed the high hydraulic conductivity of the weathered till zone to a secondary hydraulic conductivity - that of fracturing. This same conclusion was reached by Burnett [1982].

The similarity between the hydraulic conductivities determined by single well response testing on weathered and nonweathered zones could lead one to presume that the high hydraulic conductivity of the nonweathered till is due to the presence of fracturing, although none have been observed in boreholes (Section 5.B.2.3.2). Pumping tests conducted by Hendry [1986a] (Table 4) on sand layers in the nonweathered till indicated that the vertical hydraulic conductivity of the nonweathered till is less than 1 x 10-9 ms-1. He postulated that the high hydraulic conductivities from the single well response test data is not the result of fracturing but reflects the hydraulic conductivity of sand streaks and layers present in the nonweathered till. This postulate has been verified by the author using high resolution gamma ray logging (Section 3.3.2). The fact that the single well response test results in the nonweathered till reflects the hydraulic conductivity of sand layers and streaks sheds some doubt on the findings of Hendry [1982] who states that the high hydraulic conductivity in the weathered zone is due to fracturing because sand layers were also observed from the gamma ray logging conducted in weathered till zones. The topic of fracture flow is discussed further in subsequent sections of this report.

5.B.3.2.2.2 HYDRAULIC GRADIENTS

A characteristic common to glacial tills in southern Alberta is a general decline in hydraulic heads with depth through the till [Nielsen, 1970; Burnett, 1982; Hendry, 1981 and 1986a; and Schwartz et al., 1982]. The decrease in hydraulic head with depth appears to be independent of whether the till is underlain by Saskatchewan sands and gravels or by less permeable bedrock.

Greater vertical hydraulic gradients have been observed in nonweathered till zones (15 to 20 m over 15 to 20 m thickness) than in weathered till zones (2 to 3 m over 5 to 10 m thickness) by Burnett [1982]. Similar trends have been noted by Hendry [1982 and 1986a]. The differences in hydraulic head between the two till zones can be used to indicate that the vertical hydraulic conductivity in the weathered till zone is greater than that in the underlying nonweathered till zone.

In locations where the Saskatchewan sands and gravels are partially saturated, perched water table conditions are observed in the tills [Nielsen, 1970; Hendry, 1986a]. The presence of perched water table conditions in the nonweathered till zones also reflect its low hydraulic conductivity.

The presence of outwash within the till can result in deviations from the trend to decreasing hydraulic head with depth depending on the position of the outwash within the groundwater flow regime. Areas of groundwater discharge (zones of soil salinization) represent another condition where vertical hydraulic gradients may differ from those outlined above. In these cases upward gradients may exist in the tills. Several geologic conditions can cause this reversal in gradients. Some of these are outlined by Hendry and Schwartz [1983].

Horizontal hydraulic gradients in the tills are much smaller than the vertical gradients. Horizontal gradients are in the order of 0.001 to 0.01 [Burnett, 1982; Hendry, 1981 and 1982]. The very low horizontal gradients may be less than the threshold gradient which is the minimum hydraulic gradient required to cause flow by exceeding the viscous frictional forces. In laboratory tests on clayey glacial materials, threshold gradients have been found to be important [Tavenas et al., 1983].

Water level responses to spring thaw or heavy precipitation events have been observed in piezometers completed in weathered till zones but not in piezometers completed in nonweathered till zones [Hendry, 1982]. This finding was used by Hendry as indirect evidence to support his conclusion that water movement in much of the weathered till zone is controlled by fracture flow whereas it is controlled by porous media flow in the nonweathered till zone.

5.B.3.2.2.3 TRITIUM

Tritium, which has a half life of 12.43 years, occurs in the hydrologic cycle from anthropogenic and natural sources. It is measured in tritium units (T.U.) where 1 T.U. is the equivalent of one tritium atom in 10(18) atoms of hydrogen. From 1953 to 1969 large amounts of tritium entered the hydrologic cycle in the northern hemisphere as a result of atmospheric testing of thermonuclear bombs. Prior to 1953 the natural tritium concentrations of precipitation were in the range 5 to 10 T.U., however, during thermonuclear testing the tritium concentrations of precipitation increased to several thousand T.U. Any waters which entered the subsurface environment prior to 1953 (and have not interacted with post-1953 waters) are characterized by a tritium concentration of less than 2 T.U. Waters which entered the subsurface environment after 1953 will have much higher tritium concentrations (up to thousands of T.U.). Thus, measurements of tritium concentrations can be used to provide information on residence times of subsurface waters.

Hendry [1983a] used the natural tritium concentrations of water samples distilled from unsaturated and saturated samples collected from the weathered till zone to show that fractures are transmitting post-1953 recharge water to depths within the weathered till. Additional tritium analyses were performed on water distilled from core samples collected from the weathered and non-weathered till zones by Hendry [1986a]. These tritium results indicated that some water movement in the weathered till zone is likely the result of fracture flow. The limited amount of tritium data on soil-water extracts of samples collected from the non-weathered till zone indicated that water movement in the non-weathered till zone is not via fracture flow but by intergranular seepage.

The tritium content of groundwater samples collected from the weathered till zone indicated that tritiated groundwater is present at depth in the weathered till zone [Hendry, 1982]. These findings are in keeping with the conclusions reached from soil-water extracts outlined above.

5.B.3.2.2.4 OXYGEN-18 AND DEUTERIUM

Oxygen-18 and deuterium are generally considered to be conservative groundwater tracers at low temperatures because they are not significantly affected by reactions with minerals in the subsurface environment. Because of this the stable isotopes of oxygen-18 and deuterium can be used to yield additional information on the relative ages of the porewaters in till.

Analytical results for oxygen-18 and deuterium are reported using the s (delta) notation and are expressed in units of per mille (o/oo) defined as:

$$so/oo - [(Rx - Rs) / Rs] \times 1000$$

where

$$R = 180/160 \text{ or } R = 2H/1H$$

and s and x refer to the standard and sample, respectively. The standard adopted for hydrologic studies is Standard Mean Ocean Water (SMOW).

Hendry [1986a] reported that the oxygen-18 in porewaters collected from the tills that he investigated decreased with depth from above -18 o/oo near the water table in the weathered till zone to approximately -23 o/oo at depth within the nonweathered till zone. Hendry stated that the oxygen-18 shift suggested that the porewaters in the nonweathered till zone originated under cooler climatic conditions than that in much of the weathered till zone and that a significant climatic shift occurred since the porewater entered the nonweathered till zone. The last major climatic shift was during the retreat of the last continental glaciers (approximately 13,000 years ago). If this was the case, porewater in the nonweathered till is older than 13,000 years whereas the porewater in the weathered till is younger than 13,000 years, and, as evidenced by the tritium data, younger than 30 years old in some cases.

Oxygen-18 and deuterium in precipitation are linearly correlated by a meteoric water line which can be defined for each area [Craig, 1961]. When points do not fall on this line the water sample has generally undergone evaporation, condensation, mixing with waters of nonmeteoric origin or biological transformations. Precipitation and surface water data collected from southern Alberta (n = 8) by Hendry [1986a] fall on or near the Craig [1961] meteoric line. Although this limited amount of data cannot be used to conclusively state that precipitation data for southern Alberta falls on the Craig meteoric water line, it is in keeping with data collected in southwestern Alberta by Wallick et al. [1984].

Results of oxygen-18 and deuterium analyses conducted on groundwaters from the weathered and nonweathered till zones by Hendry [1986a] are presented in Figure 5. These results are in keeping with those oxygen-18 results described above; negative oxygen-18 and deuterium values are obtained from porewaters collected from the nonweathered till zone. The oxygen-18 and deuterium results from porewaters from the weathered till zone are typically more positive although they are more variable than those from the nonweathered till zone.

Based on Figure 5, Hendry [1986a] concluded that much of the precipitation in the past underwent evaporation before entering the groundwater regime in the till zones. A similar conclusion was reached by Freeman [1986] for groundwaters of the Ross Creek Irrigation District. These findings were not unexpected because

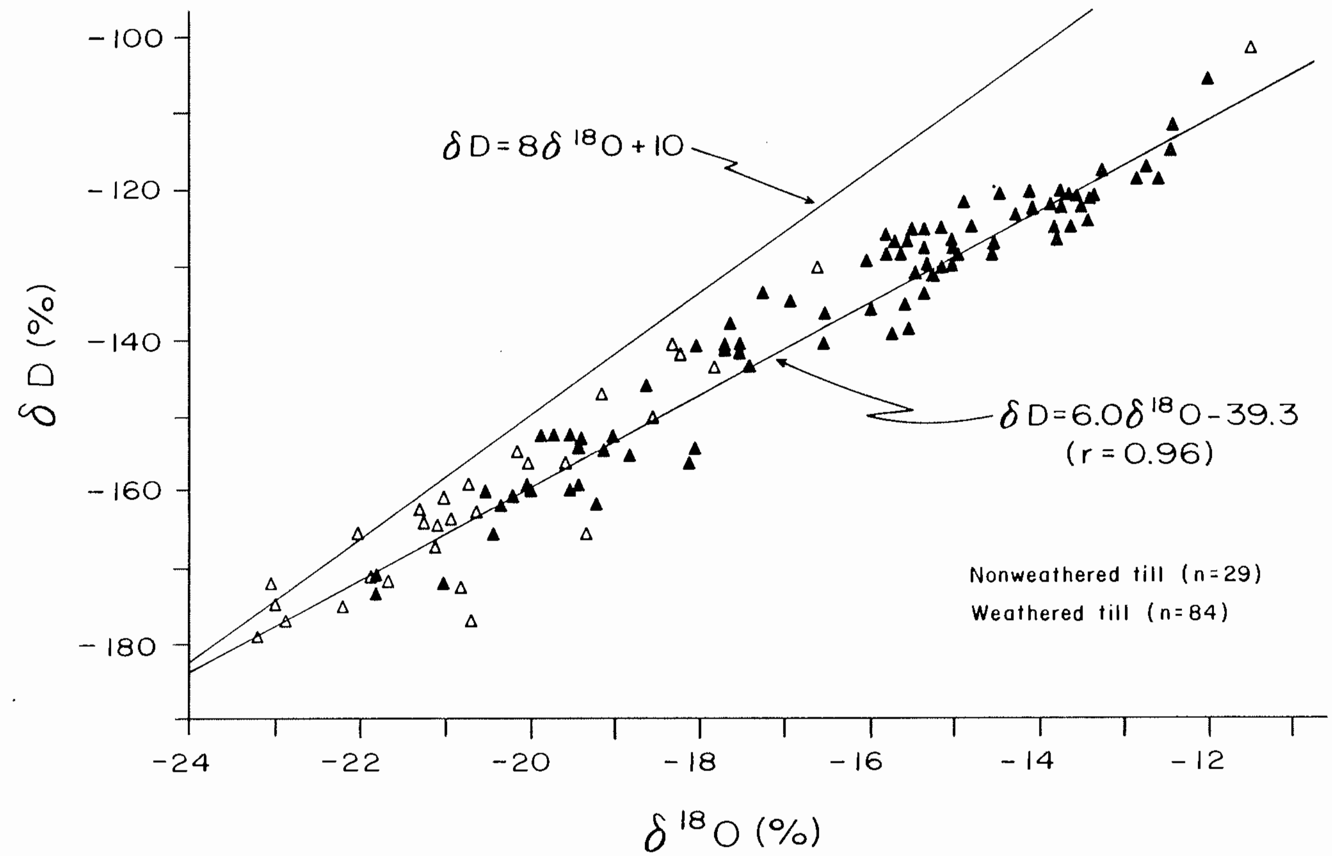


Figure 5. Oxygen-18 vs. deuterium of groundwaters collected from the till zones.

these areas are semiarid and have been semiarid for much of the past 10,000 years [Hendry et al., 1986]. Evapotranspiration has generally exceeded precipitation in southern Alberta. An alternate hypothesis is that the groundwater in the weathered till zone could have undergone, and may still be undergoing evaporation. The implication of this hypothesis is discussed in a subsequent section of the report.

#### 5.B.3.2.2.5 CARBON-14

Carbon-14 decay ages for two groundwater samples from the nonweathered till zone of 28,000 and 29,000 years B.P. were reported by Hendry [1986a] If the dilution of carbon-14 by additional inorganic carbon was corrected for, the ages of the porewaters would likely be 10,000 to 15,000 years old. These findings verify the ages implied by the oxygen-18 and deuterium data of Hendry [1986a]. Additional unpublished carbon-14 ages on porewater collected from the nonweathered till zone by the author range from 25,000 to 30,000 years B.P. These values are also in keeping with those outlined above.

Unpublished carbon-14 ages obtained from near the bottom of the weathered till zone by the author range from 8,000 to 10,000 years B.P. If these ages were corrected for dilution with inorganic carbon, the ages would likely be about 5,000 years old. These findings are also in keeping with the oxygen-18 and deuterium data of Hendry [1986a].

### 5.B.3.2.3 Outwash

Despite the low hydraulic conductivity of the till, groundwater is nevertheless obtained by farmers from outwash deposits located within it. Most of these wells are marginal producers [Nielsen, 1971]. The majority of hydraulic conductivity data for outwash deposits is from near the surface (Table 4). As expected, the hydraulic conductivity of the outwash deposits are very variable. These deposits are also of limited extent [Nielsen, 1971].

### 5.B.3.2.4 Lacustrine

The lacustrine materials which typically overlie the till exhibit variable hydraulic conductivities (Table 4). The variability can be attributed to textural changes (Section 3.3.3). It is the opinion of the author that the laminated or thinly bedded nature of these deposits produce a vertical hydraulic conductivity which is less than the horizontal hydraulic conductivity reported in Table 4. This is verified by the work of Sommerfeldt et al. [1983] in the Bow River Irrigation District. They concluded that the fine texture of some layers severely inhibited water vertical movement.

## 5B.4 CHEMISTRY OF GROUNDWATERS

### 5.B.4.1 Bedrock Formations

A statistical summary of the results of chemical analyses performed on groundwater samples collected from the bedrock formations which are important to this study are presented in Table 5. This data is plotted in Figure 6a. Limited chemical data is presented for Pakowki and Milk River Formations in this table. No additional groundwater chemistry data are known to exist for the Pakowki Formation. Additional instrumentation is presently being installed and groundwater samples collected and analyzed by the Groundwater Section of Alberta Agriculture. Because the groundwater chemistry in this formation changes spatially, the chemistry presented in Table 5 reflects the chemistry of the north central part of the Formation.

The groundwater chemistry of the bedrock formations fall into four chemical categories. The first, which is sodium-bicarbonate rich waters, is representative of the Colorado Formation. The second, which is sodium-chloride rich waters, is representative of the Milk River Formation. The Bearpaw Formation, which contains sodium-bicarbonate-sulfate rich waters, is the third category. The fourth category is sodium-sulfate rich waters. This category represents groundwater from the Oldman, Foremost, St. Mary River and Pakowki Formations.

As indicated by Chan and Hendry [1985] and Hendry [1983b], groundwaters from weathered zones in the bedrock have higher salt contents than those from the underlying nonweathered bedrock zones. Although not proven, this is in keeping with the findings for the weathered and nonweathered tills presented by Hendry et al. [1986].

### 5.B.4.2 Surficial Deposits

A statistical summary of the results of chemical analyses on groundwater samples collected from surficial deposits are presented in Table 6 and summarized in Figure 6b. The dominant anion in groundwaters from these deposits is sulfate. The dominant cation is sodium.

Groundwaters collected from lacustrine and surficial outwash deposits exhibit varying degrees of salinity. The variability can be attributed to their location within flow systems. Higher salt levels are usually associated with salinized areas (discharge areas).

The weathered till zone contains more salt than the nonweathered till zone. Hendry et al. [1986] concluded that the dissolved species in the nonweathered till zone reflect that of the underlying bedrock and that the greater salt contents in the groundwaters of the weathered till zone are the result of oxidation of

Table 5. Summary of chemical analyses (mgL-1) performed on groundwater samples collected from bedrock formations.

| Formation | No. of Anal-yses | EC (dSm-1) | HCO3 | CL | SO4 | Mg | Ca | Na |
|---|---|---|---|---|---|---|---|---|
| <u>Oldman</u> | | | | | | | | |
| Hendry et al. [1986] | 6 | ---- | 885a<br>(116)b | 202<br>(138) | 1777<br>(605) | 55<br>(66) | 64<br>(80) | 1154<br>(331) |
| <u>Foremost</u> | | | | | | | | |
| Hendry [1983]c | 23 | 9.9<br>(10.3) | 964<br>(506) | 124<br>(216) | 3996<br>(4424) | 525<br>(725) | 240<br>(184) | 1561<br>(1637) |
| <u>Bearpaw</u> | | | | | | | | |
| Chan and Hendry [1985] | 8 | 1.6<br>(0.9) | 537<br>(342 ) | 25<br>(39) | 389<br>(283) | 47<br>(47) | 48<br>(48) | 294<br>(260) |
| <u>St. Mary River</u> (<u>weathered</u>) | | | | | | | | |
| Chan and Hendry [1985] | 7 | 7.9<br>(1.2) | 592<br>(232) | 96<br>(28) | 3842<br>(1268) | 673<br>(275) | 361<br>(200) | 1262<br>(460) |
| <u>St. Mary River</u> (<u>nonweathered</u>) | | | | | | | | |
| Chan and Hendry [1985] | 28 | 3.5<br>(2.8) | 500<br>(317) | 35<br>(35) | 1138<br>(1297) | 66<br>(121) | 58<br>(102) | 644<br>(621) |
| <u>Pakowki</u> | | | | | | | | |
| Hendry [1986b] | 1 | 1.2 | 372 | 14 | 476 | 48 | 25 | 299 |
| <u>Milk River</u> | | | | | | | | |
| Hendry [1986b]d | 1 | 5.6 | 842 | 1375 | 10 | 8 | 4 | 1287 |
| <u>Colorado</u> | | | | | | | | |
| Hendry [1986b] | 2 | 0.7 | 226 | 96 | 113 | 19 | 105 | 37 |

a arithmetic mean
b standard deviation
c summary includes chemical analyses from both weathered and nonweathered bedrock
d chemistry of sample presented was collected south of Taber, Alberta

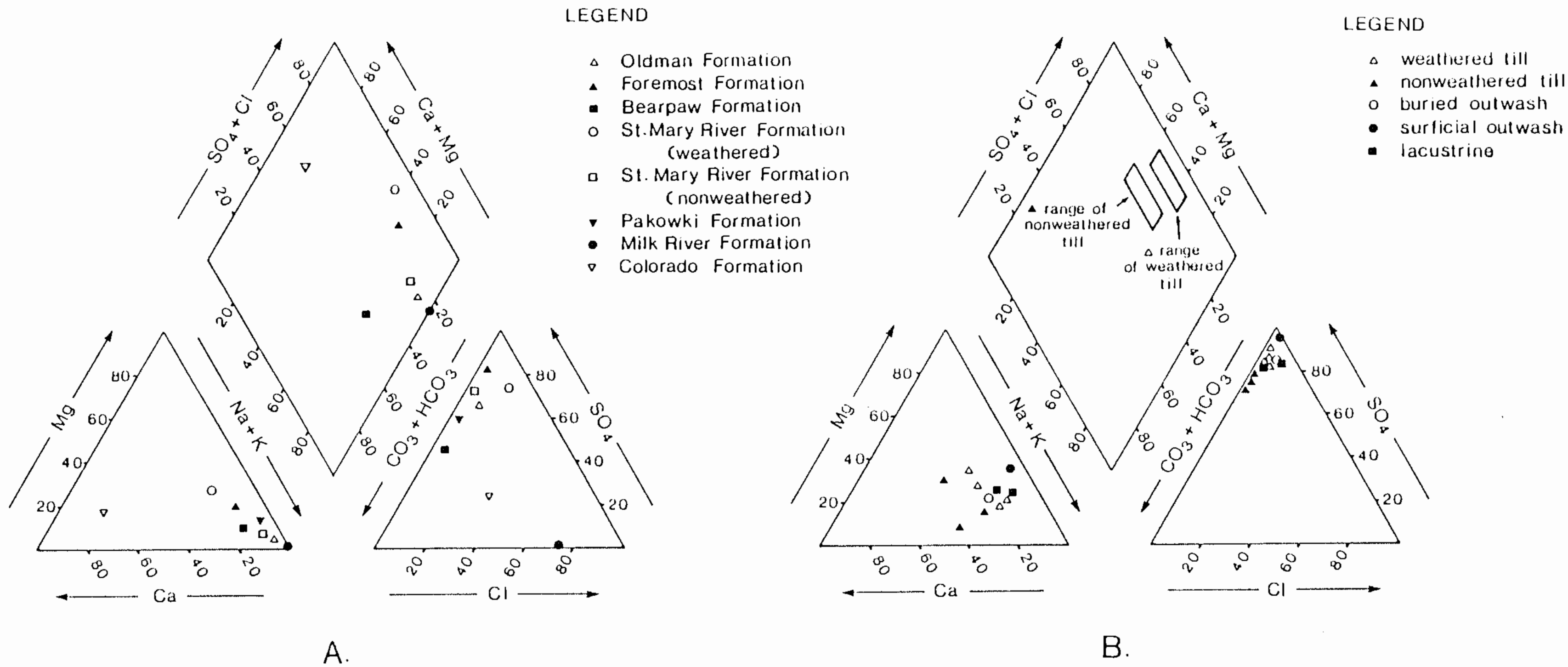


Figure 6. Piper diagrams of mean ionic concentrations. (a) bedrock formations and (b) surficial deposits (means of individual study areas are presented)

Table 6. Summary of chemical analyses (mgL-1) performed on groundwater samples collected from surficial deposits.

| Deposit | No. of Anal-yses | EC (dSm-1) | HCO3 | CL | SO4 | Mg | Ca | Na |
|---|---|---|---|---|---|---|---|---|
| <u>Lacustrine</u> | | | | | | | | |
| Hendry [1983] | 2 | 16.1a | 1135 | 390 | 7877 | 1437 | 383 | 2759 |
| Pike-Glover [1982] | 5 | 4.1 (4.8)b | 421 (122) | 64 (96) | 2209 (2997) | 363 (420) | 162 (144) | 761 (1021) |
| <u>Till</u> (<u>weathered</u>) | | | | | | | | |
| Hendry et al. [1986] | 34 | ---- ---- | 732 (256) | 117 (121) | 5293 (2213) | 731 (214) | 405 (108) | 1915 (1030) |
| Hendry [1983] | 19 | 7.2 (9.0) | 732 (201) | 181 (128) | 3780 (2056) | 772 (258) | 457 (86) | 1156 (997) |
| Pike-Glover [1982] | 7 | 6.1 (2.5) | 824 (281) | 163 (103) | 4582 (2056) | 583 (247) | 391 (140) | 1729 (811) |
| Robertson [1985] | 11 | 6.9 (2.4) | 537 (134) | 202 (184) | 3703 (1974) | 874 (462) | 403 (94) | 924 (481) |
| <u>Till</u> (<u>nonweathered</u>) | | | | | | | | |
| Hendry et al [1986] | 4 | ---- ---- | 1025 (146) | 188 (280) | 2402 (1009) | 198 (137) | 749 (958) | 1138 (457) |
| Pike-Glover [1982] | 11 | 3.7 (2.3) | 708 (293) | 28 (21) | 1585 (1316) | 223 (173) | 236 (174) | 582 (413) |
| Robertson [1985] | 10 | 4.3 (0.5) | 720 (92) | 67 (43) | 2253 (490) | 462 (151) | 415 (88) | 444 (76) |
| <u>Outwash</u> | | | | | | | | |
| Hendry [1983]c | 2 | 25.7 | 1049 | 450 | 15082 | 3571 | 415 | 5057 |
| Pike-Glover [1982]d | 7 | 6.9 (3.1) | 506 (223) | 124 (89) | 3108 (1306) | 473 (184) | 433 (148) | 1138 (669) |

a arithmetic mean
b standard deviation
c surface outwash
d outwash in weathered till

reduced sulfur and concommitant dissolution of carbonates and sodium exchange on clays.

The chemistry of groundwater collected from the buried outwash in the weathered till zone (Table 6 and Figure 6b) reflects that of the surrounding weathered till. Although no data is available, the chemistry of groundwater from outwash contained within the nonweathered till zone should reflect the chemistry of the non-weathered till which encloses it.

## 5.B.5. GROUNDWATER MOVEMENT IN THE TILL

Water movement in tills of southern Alberta is not fully understood at present. The movement of water in the till is a function of, among other things, the surficial topography. In this report only groundwater movement under relatively flat lying lands are discussed. Flat lying lands are typical of the irrigated areas in southern Alberta.

As outlined in previous sections of this report, water movement in the shallow weathered till appears to occur along fractures, whereas in the deeper weathered till and nonweathered till water movement is through the till matrix material. This is evidenced by visual observations, water level responses and the results of isotopic analyses, however, this observation is not obvious from results of hydraulic conductivity determinations. Best estimates of hydraulic conductivities for the weathered and nonweathered till zones are 1 x 10(-8) and 1 x 10(-10) ms-1, respectively.

An estimate of the vertical groundwater velocity through the nonweathered tills was made by Hendry [1986a] using an estimated hydraulic conductivity of 1 x 10(-10) ms-1 [Hendry, 1982], a porosity of 0.35, and vertical hydraulic gradients of 0.2 to 0.7. Estimated velocities ranged from 20 to 60 m per 10,000 years. From these calculations, the porewaters in the nonweathered till should be younger than 10,000 years. This differs from the findings of the isotope data. If oxygen-18, deuterium and carbon-14 data are correct, the vertical hydraulic conductivity of the non-weathered till could be even less than 1 x 10(-10) ms-1.

Using the mean hydraulic conductivities presented above and the hydraulic gradient data presented in Section 4.2.2.2 one can estimate the vertical movement of water in the nonweathered till zone and lateral water movement in the weathered till zone. Assuming the vertical hydraulic conductivity to be 1 x 10(-10) ms-1 and the vertical hydraulic gradient to be 1.0, the downward water movement through the nonweathered till zone should not exceed 0.3 cm yr-1. If the lateral hydraulic conductivity of the weathered till zone is 1 x 10(-8) ms-1 and the lateral hydraulic gradients range from 0.01 to 0.001, lateral water movement in the weathered till zone should range from 0.03 to 0.3 cm yr-1. These hand calculations indicate that the quantity of water migrating through the tills is very small.

To define and characterize groundwater movement through the till under the irrigated lands in southern Alberta further, Frind and Matanga [1981] defined a vertical cross section oriented parallel to the general flow direction in the study area described in Hendry [1982] and Hendry et al. [1986] and performed mathematical modeling of groundwater flow paths using stream function theory. The cross section, which is 10 kilometres long, is bounded by an irrigation canal in the south and the Bow River (Figure 1) in the north. The model simulations indicate that groundwater flow in the weathered till zone is characterized by a number of small local flow systems which recharge and discharge at the water table. The simulations also indicate that there is no effective hydraulic connection from the weathered till zone through the nonweathered till zone to the deeper regional flow system in the bedrock. This deeper system discharges into the Bow River. Consequently, there appears to be no effective mechanism for recharge to the river from the water table within the cross section, with the exception of the area immediately adjoining the river. It follows from these simulations that there is little chance of irrigation water applied at this site discharging to the river and that the salts dissolved in the weathered till during irrigation will essentially remain in the weathered till where they will be continually moved about within the confines of the local flow systems. This conclusion is in keeping with chemical analyses of samples of weathered and nonweathered till performed by Hendry et al. [1984 and 1986] at the same study area. They did not find any difference between nitrogen and sulfur concentrations in samples of weathered and nonweathered till. If lateral water movement through the weathered till zone or vertical water movement through the nonweathered till zone was occurring, the weathered till would be depleted in salts (i.e., nitrate and sulfate).

If the above hydrogeologic interpretation is correct and insignificant quantities of water migrate laterally through the weathered till zone or vertically through the underlying nonweathered till zone, the amount of recharge to the groundwater regime must be offset by evapotranspiration. The oxygen-18 and deuterium data (Section 4.2.2.4) collected from the weathered till zone can be used to corroborate this statement. Research on the topic of recharge and evapotranspiration is being conducted in southern Alberta at present.

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CHAPTER 5.C.

# COMPARISON OF HYDROGEOLOGY OF IRRIGATED LANDS IN SOUTHERN ALBERTA, CANADA, AND HYDROGEOLOGY OF THE CENDAK AREA, SOUTH DAKOTA

by

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DEPARTMENT OF WATER AND NATURAL RESOURCES
DIVISION OF GEOLOGICAL SURVEY

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CONTENTS



TABLE

## 5.C.1
## BEDROCK

Thick sequences of pre-Cretaceous rocks, ranging in age from Precambrian to Jurassic (in southern Alberta), and from Precambrian to Permian (in CENDAK area), are present in both the CENDAK area and southern Alberta. However, they are not important to the objectives of this study.

The Dakota Formation-Inyan Kara Group in the CENDAK area and the Milk River Formation in Alberta are sandstone aquifer units present in the lower parts of the Cretaceous that are used extensively as water supplies in both areas. The geometric mean hydraulic conductivity of the Milk River is 5E-05 m/sec (5E-03 cm/sec). Hydraulic conductivity of the Dakota-Inyan Kara is unknown. Flowing conditions were present over large portions of both areas but in Alberta flowing conditions are now present primarily in the topographic low areas associated with present or ancestral drainages. The geometric mean hydraulic conductivities of the upper confining layers range from 2E-08 m/sec (2E-06 cm/sec) to <1E-10 m/sec (1E-08 cm/sec) in Alberta. The hydraulic conductivity of the Pierre Shale, the uppermost layer of the confining unit ranges from 1.7E-10 to 1.9E-12 cm/sec about 35 miles west of the CENDAK area, and there is no reason to believe that these values would be different within the study area.

Ground water from bedrock is high in chemical constituents in both areas although it is used extensively for domestic and stock watering. Primary chemical constituents in water from the Dakota are sulfate, chloride, sodium, and calcium, and primary chemical constituents of water from the Milk River Formation are sodium, chloride, and bicarbonate.

In both areas, erosion during late Teritary to early Pleistocene time carved major east-west drainage channels into the predominantly shale sediments.

## 5.C.2
## GLACIAL DRIFT

Glacial drift is thickest along axes of major bedrock channels and thinner on interflue areas in both CENDAK and Alberta areas. The drift of both areas contain a mixture of local bedrock types and rock material derived from the Canadian Shield and Paleozoic carbonates from the rim of the Shield.

In Alberta, there is one early Wisconsin drift and three late Wisconsin drifts deposited between 24,000 and 13,000 years ago. In the CENDAK area, there is possibly one early Wisconsin drift, and probably two late Wisconsin drifts which were deposited between 22,000 and about 11,000 years ago.

Till is ubiquitous throughout the irrigated lands in southern Alberta and the CENDAK area, although locally thin lacustrine deposits, outwash, alluvium, or windblown deposits may overlie the till. In bulk composition the tills of Alberta generally contain a higher proportion of non-marine shale, however, this factor apparently is not significant when comparing the overall physical and hydrologic characteristics of tills from the two areas (table 1). This conclusion is contrary to that of Lee and others (1962) who stated that only till derived primarily from shale of non-marine origin could be successfully irrigated in southern Alberta, Canada.

Till of both areas is gray to dark-gray where unweathered and various shades of brown where weathered. Fractures are not noticeable in unweathered till, however the weathered till is highly fractured. Table 1 compares other physical and hydrologic characteristics of till from both areas.

In both the CENDAK area and southern Alberta, the hydraulic conductivity of weathered till is several orders of magnitude higher than that of unweathered till. This difference is attributed to the presence of fractures in the weathered till in both geographic areas. In addition, vertical hydraulic gradients in weathered till are much smaller than in unweathered till in both geographic areas.

The salt content of waters from the weathered till is much greater than the salt content of unweathered till waters in both CENDAK and Alberta. This difference in chemical makeup of weathered till waters versus unweathered till waters also indicates that flow of ground water from the weathered till into the unweathered till is insignificant.

**Table 1. Physical and hydrologic characteristics of till**

W = weathered till
U = unweathered till
NA = No data available

| | CENDAK | SOUTHERN ALBERTA |
|---|---|---|
| Clay mineral content | Smectite (highest)<br>Illite<br>Kaolinite and chlorite | Smectite (highest)<br>Illite<br>Kaolinite and chlorite |
| Liquid limit | 34 and 35 percent | 22 to 48 percent |
| Plasticity index | 16 and 17 percent | 5 to 25 percent |

Table 1 -- continued.

| | CENDAK | SOUTHERN ALBERTA |
|---|---|---|
| Texture | Clay loam<br>Gravel 2-5 percent<br>Sand 31-34 percent<br>Fines 62-67 percent | Clay loam to loam |
| Vertical gradients | W: min = (-) 0.928<br>max = 1.196<br>ave = 0.065<br>U: min = (-) 2.000<br>max = 4.645<br>ave = 0.652 | Hydraulic gradients greater in unweathered than in weathered till. 2 to 3 m over 5 to 10 m thickness in weathered till versus 15 to 20 m over 15 to 20 m thickness in unweathered till. |
| Horizontal gradients | W: 8 ft/mile (1.5E-03 ft/ft) Regional gradient<br>U: NA | Gradient range in tills 0.001 to 0.01; much lower than vertical gradients |
| Vertical hydraulic conductivity | Range of geometric means<br>W: 3.4E-08 cm/sec to 1.9E-04 cm/sec<br>U: 3.8E-09 cm/sec to 5.5E-06 cm/sec | Range of geometirc means<br>W: 2E-06 to 2E-05 cm/sec<br>U: <1E-08 cm/sec to 5E-05 cm/sec |
| Lateral hydraulic conductivity | W: Geometric mean is 1.3E-05<br>U: NA | W: NA<br>U: NA |
| Tritium content | W: Indicates fracture flow of post-1953 water<br>U: Indicates non-fracture flow of post-1953 water | W: Indicates fracture flow of post-1953 water<br>U: Indicates non-fracture flow of post-1953 water |
| O-18 | W: data inconclusive<br>U: data inconslusive | W: Indicates water is younger than 13,000 years<br>U: Indicates water originated under cooler climatic conditions. Probably more than 13,000 years ago |

Table 1 -- continued.

| | CENDAK | SOUTHERN ALBERTA |
|---|---|---|
| O-18 vs. deuterium | W: data inconclusive<br>U: data inconclusive | W: Indicates water underwent evaporation<br>U: Indicates water underwent less evaporation than weathered till water |
| Carbon-14 dating of water | Carbon-14 dating of water from weathered till zone indicates recent recharge water present. Carbon-14 dating of water from unweathered till zone indicates water greater than 8,000 to 11,000 years old. | Carbon-14 dating of water from bottom of weathered till zone indicates age of about 5,000 years before present. Carbon-14 dating of water from unweathered till indicates age range of 10,000 to 15,000 years before present |
| Water chemistry | W: EC = 5289 umhos/cm<br>TDS = 5199 mg/L<br>Dominant ions =<br>Na = 562 mg/L<br>SO4 = 3039 mg/L<br>U: EC = 3982 umhos/cm<br>TDS = 3601 mg/L<br>Dominant ions =<br>Na = 487 mg/L<br>SO4 = 1909 mg/L | W: Range of arithmetic means<br>EC = 6100 - 7200 umhos/cm<br>Dominant ions =<br>Na = 924 - 1915 mg/L<br>SO4 = 3703 - 5293 mg/L<br>U: Range of arithmetic means<br>EC = 3700 - 4300 umhos/cm<br>Dominant ions =<br>Na = 444 - 1138 mg/L<br>SO4 = 1585 - 2402 mg/L |

The major nonbedrock aquifer in southern Alberta is the Saskatchewan Gravels, a nonglacial deposit. In the CENDAK area buried glacial outwash deposits are the major aquifers. Thus, a direct comparison cannot be made between these units. The limited information on outwash in Alberta and CENDAK shows highly variable hydraulic conductivities. Water quality within the outwash is also highly variable, depending mostly on local conditions, but in general, it is of better quality than that contained in weathered or unweathered till. Carbon-14 age dating of water from buried outwash in the CENDAK area ranged from 4,890 to 26,500 years before present. In Alberta, many of the outwash wells are "marginal producers." It can be inferred from the two previous statements that recharge to the buried outwash through unweathered till is very low in both areas. However, significant recharge can occur where weathered till overlie outwash, where the buried outwash is hydraulically connected to other permeable glacial deposits, or from bedrock aquifers.

Lacustrine deposits overlie till in about 4 percent of the CENDAK area and about 60 percent of southern Alberta. The texture ranges from clay to sand in both areas, thus a wide range of hydraulic conductivities are reported. Maximum thickness is reported to be about 35 feet in both areas, however, the estimated mean thickness in Alberta is less than 3 feet. Average thickness of lacustrine deposits in the CENDAK area is unknown but is thought to be greater than 3 feet.

Minor deposits of windblown material occur in both areas, however, no data are available for comparison.

The physical characteristics of the geologic deposits (shale and till) severely limit ground-water movement in both geographic areas. Detailed studies have provided data indicating that very little of the water penetrating below the root zone (recharge water) is dissipated by downward flow. Additionally, the available information strongly indicates that lateral flow will not account for dissipation of this water. Thus, the main avenue of dissipation is upwards.

## 5.C.3 REFERENCES CITED

Lee, J. K., Maierhofer, C. R., Langley, M. N., Maletic, J. T., and Woltersdorf, D. B., 1962, Survey of drainage experience in Canada as related to irrigation development in the Oahe and Garrison Diversion Units of the Missouri River Basin Project in North and South Dakota: Memorandum to Assistant Commissioner Palmer, U.S. Bureau of Reclamation, dated October 2, 1962.

CHAPTER 6.A.

# AGRICULTURE AND IRRIGATION IN CENDAK

by

SOUTH DAKOTA
DEPARTMENT OF WATER AND NATURAL RESOURCES
DIVISION OF PROJECT AND COMMUNITY DEVELOPMENT

1987

CONTENTS



TABLE



APPENDICES

## 6.A.1
## INTRODUCTION

South Dakota is more dependent on agriculture than any state in the country. Twenty percent of South Dakota's total income is credited directly to farming and ranching. This compares to a national average of 3 percent, and 10 to 15 percent in neighboring states like Iowa and Nebraska.

The climate in South Dakota is semiarid and annual precipitation can be quite erratic. The State experiences regular periods of drought and the rain that does fall is often either insufficient or untimely from a crop perspective. During such dry periods, the State's ranchers must sell major portions of their livestock herds due to inadequate feed supplies and, consequently, the economic impact is severe. For example, in 1970 South Dakota ranked 38th in the country in per capita income; and in 1973, with high cattle prices, the State ranked 21st. In 1976, however, as a result of a severe drought, South Dakota ranked 49th in per capita income. It has taken the State's farmers and ranchers several years to recover from the 1976 drought and such recovery has been hampered by a number of dry years since then including 1980 and 1985.

In order to provide for stable crop production and to avoid the adverse economic impacts caused by droughts, South Dakota farmers have turned to irrigation on a limited basis. The Belle Fourche and the Angostora Irrigation Projects in western South Dakota were completed in 1914 and 1953, respectively. However, most irrigation in the State has been developed since the 1950's on an individual basis or in conjunction with the formation of small irrigation districts (2,000 to 3,000 acres) consisting of less than a dozen landowners. Only limited irrigation development has taken place in the State due to lack of funding, a very conservative farming ethic and limited supplies of good quality water.

In spite of various limitations, there are approximately 500,000 acres currently under irrigation in the State. Such irrigation has been developed primarily in the eastern part of the State where relatively good quality ground water is available, and in the central part of the State where annual precipitation is often insufficient for stable crop production. Table 1 shows growth of irrigation in those counties in which the proposed CENDAK project is to be developed. Of these totals, current estimates are that about 40,000 acres are under irrigation within the actual CENDAK boundary.

Table 1

**Irrigated Acres By County**

| | 1970 | 1972 | 1974 | 1976 | 1978 | Irrigated Acres as % of total Farmland 1978 |
|---|---|---|---|---|---|---|
| Beadle | 5,412 | 2,867 | 6,869 | 13,699 | 17,653 | 2.3% |
| Faulk | 104 | 104 | 104 | 104 | 104 | <0.1% |
| Hand | 1,903 | 1,008 | 2,415 | 4,817 | 6,207 | 0.7% |
| Hughes | 4,011 | 2,124 | 5,091 | 10,152 | 13,083 | 3.6% |
| Hyde | 168 | 89 | 212 | 423 | 545 | 0.1% |
| Spink | 5,747 | 3,044 | 7,294 | 14,549 | 18,749 | 2.0% |
| TOTAL | 17,345 | 9,236 | 21,985 | 43,744 | 56,341 | 1.4% |

Source: Bureau of the Census 1978

Table from U.S. Bureau of Reclamation report, CENDAK FINAL LAND CLASSIFICATION REPORT, prepared by Camp Dresser and McKee Inc., Denver, Colorado.

The irrigators within the CENDAK area have been irrigating for as long as 25 years with very minimal, if any, artificial drainage. These irrigators continue to report good success with their systems in terms of both crop yields and lack of water table or salt build-up problems. This conclusion is substantiated by results of interviews with irrigators as reported in appendix A.

## 6.A.2 SURFACE-WATER QUALITY

Irrigators in the most western part of the project area (Hughes County) primarily utilize the Missouri River as a surface water source and in the eastern part of the area (Beadle County) the James River is the primary source. Landowners in the remainder of the area generally use ground water for irrigation. Water quality in the Missouri River is generally good. Information from the USGS station near Pierre shows that total dissolved solids (TDS) concentrations average about 490 milligrams per liter (mg/L). The sodium-adsorption-ratio averages about 2. Based on the U.S. Department of Agriculture classification system, this water would be rated C2/C3-S1 (medium to high salinity, low sodium) for irrigation use.

Minor and trace constituent concentration ranges and means for the Missouri River at Pierre are listed below. The data are from the United States Bureau of Reclamation (1986).

| | Range (mg/L) | Mean (mg/L) |
|---|---|---|
| Selenium | 0.000-0.002 | 0.001 |
| Iron | 0.000-1.000 | 0.126 |
| Manganese | 0.000-0.120 | 0.031 |
| Nitrogen, Nitrite plus Nitrate (as N) | 0.000-0.092 | 0.134 |

Water-quality records for the James River are available from 1949-1952 and 1956 to present. Daily water temperatures and specific conductance were available from 1956-1970 and 1971 to present. From these water-quality records, the following TDS values are presented.

James River at Huron

Mean TDS in mg/L

| | | | |
|---|---|---|---|
| January | 1,150 | July | 660 |
| February | 1,370 | August | 710 |
| March | 820 | September | 750 |
| April | 510 | October | 820 |
| May | 610 | November | 840 |
| June | 660 | December | 950 |

Water quality in the James is related to flows. During high flows, TDS at Huron average between 500-700 mg/L. In late summer and winter, TDS sometimes exceeds the State drinking water standard of 1,000 mg/L. Available data on minor and trace constituent concentrations for the James River at Huron are:

| | Range (mg/L) | Mean (mg/L) |
|---|---|---|
| Selenium | 0.001-0.0150 | 0.0074 |
| Arsenic | 0.001-0.0030 | 0.0021 |
| Cadmium | 0.000-0.0030 | 0.0013 |
| Copper | 0.000-0.0170 | 0.0036 |
| Iron | 0.010-0.0900 | 0.0251 |
| Lead | 0.000-0.0210 | 0.0040 |
| Manganese | 0.001-0.0300 | 0.0095 |
| Mercury | 0.000-0.0005 | 0.0003 |
| Nitrogen, Nitrite plus Nitrate (as N) | 0.000-2.8000 | 0.4746 |

Information for major tributaries is generally available from the late 1950's to the present. These streams support peak flows of up to 1,000 ft3/s during spring runoff, but characteristically do not convey water between July and February most years. Flows vary annually between 1-130 ft3/s.

## 6.A.3 GROUND WATER

Substantial portions of the project area are underlain by ground-water aquifers (Hedges and others, 1985) in glacial deposits. The general distribution of these aquifers are shown on figure 17, Chapter 5A of this report. Although these aquifers are illustrated as being composed of continuous, interconnected aquifer units, detailed testing has shown that local occurrences and hydraulic continuity are highly variable, particularly in Hyde and Hand Counties where the aquifers occur as lenses within the till. The depth of wells in the project area range from 60 to 227 feet.

In Chapter 5A of this report the aquifer units were grouped into surficial aquifers, buried unconfined aquifers and buried confined aquifers. The mean total dissolved solids content of water from each of these groups varied between 1,200 and 1,300 mg/L, thus indicating no significant difference in water quality. Locally, water quality in individual aquifer management units may vary significantly as shown by Meyer and Bardwell (1983). Their data show that the mean total dissolved solids in individual aquifer management units in the project area range from 583 to 2,199 mg/L. The mean of the major and minor chemical constituents also vary by individual aquifer management units.

## 6.A.4
## TYPES OF CROPS

While corn and wheat are the predominant crops produced within the CENDAK project area, the involved farmers also plant such crops as soybeans, sorghum, oats, barley, sunflowers, and rye. A breakdown of crop production (both dryland and irrigated) is presented as appendix B.

## 6.A.5
## IRRIGATION STANDARDS

South Dakota statutes and regulations specify that State water permits for irrigation shall not exceed the rate of one-cubic-feet-per-second for each 70 acres and the volume of water diverted shall not exceed two acre-feet/acre, although certain exceptions can be made if soil conditions so dictate. The State further requires the completion of a soil-water compatibility analysis in accordance with State regulations prior to acting on a water right permit application. The specific soil-water compatibility requirements are presented as appendix C.

## 6.A.6
## IRRIGATION PRACTICES

The South Dakota DWNR, during March - May, 1986, conducted on-site farm interviews with 15 irrigators in order to gather information regarding their irrigation practices, success and problems. The sample group of 15 landowners collectively irrigate about 5,000 acres, and such land has been irrigated for at least 6 and as long as 30 years.

Overall, irrigators reported favorable results in terms of both crop yields and lack of drainage problems. If it is assumed that the landowners questioned provide a representative sample of conditions and experiences, then the following conclusions can be made from these farm interviews:

1. The irrigators interviewed primarily utilize individual systems withdrawing water from surficial area aquifer units, the Missouri River or the James River. The quality of the ground-water supplies used for irrigation generally exceeds 1,000 TDS, while the quality of James River water generally is within 500-1,000 TDS. None of the involved irrigators have installed artificial drainage.

2. All irrigators responding to the farm interviews in the CENDAK area submit soil samples on an annual basis to an appropriate private or public entity for analysis to monitor any potential salinity or soil deficiency problems. In spite of the poor quality water used for

irrigation and the absence of artificial drainage, the irrigators reported no appreciable salinity or water-table build-up problems. In fact, a number of irrigators observed an overall improvement of soil conditions due to irrigation operations.

3. The irrigated till lands commonly consist of an upper layer (10' to 50') of low permeability weathered till and a lower layer (50' - 125') of virtually impermeable unweathered till. The soils irrigated in the area generally may be described as loam, silt loam and silty clay loam.

4. While the annual water application will vary with natural precipitation, crop and soil types, review of irrigation records from 1968 to 1983 indicate that the irrigators apply an average of 8 inches to 16 inches per year and usually limit any one application to no more than 1 inch. While a collective water management system is not in place at this time, the involved irrigators have gained sufficient knowledge and experience to operate sprinkler systems in a relatively efficient manner. In particular, the irrigators attempt to avoid excessive applications in the spring and early summer in order to take advantage of natural precipitation events.

5. The irrigators generally follow agricultural extension service recommendations regarding the use of fertilizers, pesticides, and insecticides.

6. The irrigators interviewed reported crop yields of approximately 140 bushels per acre of corn, 5 tons per acre for alfalfa, and 40 bushels per acre for beans as compared to approximately 45 bushels per acre of corn, 2 tons per acre for alfalfa, and 20 bushels per acre for beans for dryland yields.

The individual responses obtained from the farm interviews are presented as appendix A, with supporting information from South Dakota DWNR water rights records.

## 6.A.7
## REFERENCES CITED

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Meyer, M., and Bardwell, L., 1983, Evaluation of ground-water resources, eastern South Dakota and upper Big Sioux River, South Dakota and Iowa, Task 5: Water quality suitability by aquifer for drinking, irrigation, livestock watering and industrial use, vol. 1, draft final report: South Dakota Department of Water and Natural Resources.

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# APPENDIX A

## On-site farm interviews with irrigators in the CENDAK area

Buell Slepikas (Beadle County)
33-112N-61W

CENDAK Irrigation Survey

| Crop | Years Irrig. | Acres Irrig. | Yields[1] | Water Applied | Applic. Freq. | Applic. Amount | Insecticide | Applic. Amount | Herbicide | Applic. Amount | Fertilizer | Applic. Amount | Applic. Time | Plant Pop. | Soil Type | Water Table Build-up | Water Holding Capacity | Infilt. Rate | Pumps& Motors | Wildlife Impacts |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 26 | | | | | | | | | | | | | | | | | | | |
| Corn | | | | | | | | | | | | | | | | | | | | |
| 1981 | | 65 | 130 bu | 16" | 10 days | 2" | | | Lasso | 3 qt/A | 160-34-0 | | Preplant at planting | 26,500 | | None | | | 1800 gph 64 kw 100-125 kw/hr 4 acveinches/un | Improved |
| 1982 | | 130 | 130 bu | 9" | 10 days | 2" | | | Lasso | 3 qt/A | 160-34-0 | | Preplant at planting | 26,500 | | | | | | |
| 1983 | | 65 | 130 bu | 9" | 10 days | 2" | | | Lasso | 3 qt/A | 160-34-0 | | Preplant at planting | 26,500 | | | | | | |
| 1984 | | 130 | 130 bu | 9" | 10 days | 2" | | | Lasso | 3 qt/A | 160-34-0 | | Preplant at planting | 26,500 | | | | | | |
| 1985 | | 130 | 115 bu | 7" | 10 days | 2" | | | Lasso | 3 qt/A | 140-34-0 | | Preplant at planting | 26,500 | | | | | | |
| Alfalfa | | | | | | | | | | | | | | | | | | | | |
| 1981 | | 65 | 6 tons | 17" | 10 days | 2" | | | | | None | | | | | | | | | |
| 1982 | | 65 | 6 tons | 12" | 10 days | 2" | | | | | None | | | | | | | | | |
| 1983 | | 65 | 6 Tons | 11" | 10 days | 2" | | | | | None | | | | | | | | | |
| 1984 | | 65 | 6 tons | 11" | 10 days | 2" | | | | | None | | | | | | | | | |
| 1985 | | 65 | 4 tons | 4" | 30 days | 2" | | | | | None | | | | | | | | | |
| Beans | | | | | | | | | | | | | | | | | | | | |
| 1981 | | 130 | 40 bu | 12" | | | | | Lasso | 4 qt/A | | | | | | | | | | |
| 1982 | | 65 | 40 bu | 7" | | | | | Lasso | 4 qt/A | | | | | | | | | | |
| 1983 | | 130 | 40 bu | 7" | | | | | Lasso | 4 qt/A | | | | | | | | | | |
| 1984 | | 65 | 40 bu | 7" | | | | | Lasso | 4 qt/A | | | | | | | | | | |
| 1985 | | 65 | 30 bu | 6" | | | | | Lasso | 4 qt/A | | | | | | | | | | |

George Broer (Beadle Co.)
25-109N-62W

## CENDAK Irrigation Survey

| Crop | Years Irrig. | Acres Irrig. | Yields¹ | Water Applied | Applic. Freq. | Applic. Amount | Insecticide | Applic. Amount | Herbicide | Applic. Amount | Fertilizer | Applic. Amount | Applic. Time | Plant Pop. | Soil Type | Water Table Build-up | Water Holding Capacity | Infilt. Rate | Pumps¹ Motors | Wildlife Impacts |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Corn | 5 | | | | | | | | | | | | | | | | | | | |
| 1981 | | | | | | | Same @ 1984 | | | | Same @ 1984 | | | | Hand-Bonilla Silt-loams | | 0.12-0.22 I/In | 0.6-2.0 I/Hr | 1300 GPM | |
| 1982 | | | | | | | | | | | | | | | | | | | | |
| 1983 | | | | | | | 101# Furodan | | 3 qt of Lasso with fertilizer per acre | | 85-100# $NH_3$ | side dresses in spring | | 25,000 | | | | | | |
| 1984 | | 120 | 120 | | | | 7#/A Lasso II @ planting time | | | | Anhydrous Ammonia 289% A of 28% N | | | 19,500-20,000 | | | | | | |
| 1985 | | | | 4 days June 4 days July 8 days Aug. | | | | | | | | | | | | | | | | |
| Alfalfa | | | | | | | | | | | | | | | | | | | | |
| 1981 | | 160 | 3 cuts | | | | | | | | | | | | silty loam | | | | | |
| 1982 | | | | | | | | | | | | | | | | | | | | |
| 1983 | | | | | | | | | | | 100# of 0-45-0 spring after 1st cutting | | | | | | | | | |
| 1984 | | | | | | | | | | | | | | | | | | | | |
| 1985 | | 66 | | | | | | | | | 100# of actual 18-46-0 | | | | | | | | | |
| Beans | | | | | | | | | | | | | | | | | | | | |
| 1981 | | | | | | | | | | | | | | | | | | | | |
| 1982 | | 70 | 45 | | | | | | 2 qt. of Lasso per acre | | | | | | | | | | | |
| 1983 | | | | | | | | | | | | | | | | | | | | |
| 1984 | | | | | | | | | | | | | | | | | | | | |
| 1985 | | | | | | | | | | | | | | | | | | | | |

Dennis Meyer (Beadle Co.)
SE¼ 17-110-62
SW¼ 15-110-62

CENDAK Irrigation Survey

| Crop | Years Irrig. | Acres Irrig. | Yields[1] | Water Applied | Applic. Freq. | Applic. Amount | Insecticide | Applic. Amount | Herbicide | Applic. Amount | Fertilizer | Applic. Amount | Applic. Time | Plant Pop. | Soil Type | Water Table Build-up | Water Holding Capacity | Infilt. Rate | Pumps' Motors | Wildlife Impacts |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 15 | | | | | | | | | | | | | | | | | | | |
| Corn | | | | | | | | | | | | | | | | | | | | |
| 1981 | | 270 | 130 | 8" | | | | 5#/Acre | Lasso | 2 1/2 #/A | | Preplant 150-200 #/N 40-50 # P | | | | | | | | |
| 1982 | | | 130 | 8" | | | | | | | | 40-50 # P | | | | | | | | |
| 1983 | | | 130 | 8" | | | | | | | | 40-50 # P | | | | | | | | |
| 1984 | | | 130 | 8" | | | | | | | | 40-50 # P | | | | | | | | |
| 1985 | | | 130 | 4" | | | Furadan | 2 1/2 #/A | | | | 40-50 # P | | | | | | | | |

Melvin (Dick) Puffer (Beadle Co.)
SE17-113N-62W
NE20-113N-62W

CENDAK Irrigation Survey

| Crop | Years Irrig. | Acres Irrig. | Yields[1] | Water Applied | Applic. Freq. | Applic. Amount | Insecticide | Applic. Amount | Herbicide | Applic. Amount | Fertilizer | Applic. Amount | Applic. Time | Plant Pop. | Soil Type | Water Table Build-up | Water Holding Capacity | Infilt. Rate | Pumps' Motors | Wildlife Impacts |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 5 | | | | | | | | | | | | | | | | | | | |
| Corn | | | | | | | | | | | | | | | | | | | | |
| 1981 | | 144 | 130 | Pierre | | | Counter & Lorsban | 7#/A | Lasso-Atrizine | 39#s/Acre | 150# N 50# Ph | | With herbicide May | | Houdek-Prosper (Heavy Loam) | .7 foot build-up | 0.16-0.22 In/in | 0.6-2.0 In/hr | Beadle Electric | Waterfowl improved |
| 1982 | | 144 | 180 | Pierre | | | Counter & Lorsban | | Lasso-Atrizine | 39#s/Acre | 150# N 50# Ph | | With herbicide May | | | | | | | |
| 1983 | | 144 | 180 | Pierre | | | Counter & Lorsban | | Lasso-Atrizine | 39#s/Acre | 150# N 50# Ph | | With herbicide May | | | | | | | |
| 1984 | | 144 | 130 | Pierre | | | Counter & Lorsban | | Lasso-Atrizine | 39#s/Acre | 150# N 50# Ph | | With herbicide May | | | | | | | |
| 1985 | | 144 | 180 | Pierre | | | Counter & Lorsban | | Lasso-Atrizine | 39#s/Acre | 150# N 50# Ph | | With herbicide May | | | | | | | |
| Alfalfa | | | | | | | | | | | | | | | | | | | | |
| 1981 | | 90 | 4 cuttings | Pierre | | | | | | | 80# PH/A | | June (40#) Aug. (40#) | | | | | | | |
| 1982 | | 90 | | Pierre | | | | | | | 80# PH/A | | | | | | | | | |
| 1983 | | 90 | | Pierre | | | | | | | 80# PH/A | | | | | | | | | |
| 1984 | | 90 | | Pierre | | | | | | | 80# PH/A | | | | | | | | | |
| 1985 | | 90 | | Pierre | | | | | | | 80# PH/A | | | | | | | | | |

John Mortimer (Beadle Co.)
22-113N-62W

CENDAR Irrigation Survey

| Crop | Years Irrig. | Acres Irrig. | Yields[1] | Water Applied | Applic. Freq. | Applic. Amount | Insecticide | Applic. Amount | Herbicide | Applic. Amount | Fertilizer | Applic. Amount | Applic. Time | Plant Pop. | Soil Type | Water Table Build-up | Water Holding Capacity | Infilt. Rate | Pumps[1] Motors | Wildlife Impacts |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Corn | 32 | | | | | | | | | | | | | | | | | | | |
| 1981 | | | | | | | | | | | | | | | Beadle | None. No salts, no flooding the root zone, irrigation better every year. Started flood irrigation in 1954. Good water management key, cannot afford to put on too much $H_2O$, too costly. Water according to crop needs. | I/In 0.19-0.22 | I/Hr 0.6-2.0 | Beadle Electric 75 HP | Improved 27' W.T. no drawdown |
| 1982 | | | | | | | | | | | | | | | | | | | | |
| 1983 | | | | | | | | | | | | | | | | | | | | |
| 1984 | | | | | | | | | | | 225# 20/20 | | | | | | | | | |
| 1985 | | | | | | | | | | | 225# 20/20 | | | | | | | | | |
| Alfalfa | | | | | | | | | | | | | | | | | | | | |
| 1981 | | 90 | 4 cuts | | | | | | | | | | | | | | | | | |
| 1982 | | 90 | 4 cuts | | | | | | | | | | | | | | | | | |
| 1983 | | 90 | 4 cuts (winter kill sheep turned in) | | | | | | | | | | | | | | | | | |
| 1984 | | | | | | | | | | | | | | | | | | | | |
| 1985 | | | | | | | | | | | | | | | | | | | | |
| Oats | | | | | | | | | | | | | | | | | | | | |
| 1981 | | | | | | | | | | | | | | | | | | | | |
| 1982 | | | | | | | | | | | | | | | | | | | | |
| 1983 | | | | | | | | | | | | | | | | | | | | |
| 1984 | | 27 | 92 | Once | | | None | | None | | 27 | None | | | | | | | | |
| 1985 | | | | | | | | | | | | | | | | | | | | |

Trevor Bixler (Spink Co.)
5-114N-62W

CBNDAK Irrigation Survey

| Crop | Years Irrig. | Acres Irrig. | Yields[1] | Water Applied | Applic. Freq. | Applic. Amount | Insecticide | Applic. Amount | Herbicide | Applic. Amount | Fertilizer | Applic. Amount | Applic. Time | Plant Pop. | Soil Type | Water Table Build-up | Water Holding Capacity | Infilt. Rate | Pumps[2] Motors | Wildlife Impacts |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 9 | | | | | | | | | | | | | | | | | | | |
| Corn | | | | | | | | | | | | | | | | | | | | |
| 1981 | | 540 | 135-140 | | | | Purodan | | Atrizine (1 gal) | | | 150# N<br>40# PH | | | Beadle #7<br>(with<br>10 CMS) | Drains<br>better than<br>before<br>irrigation.<br>No salts or<br>flooding of<br>root zone. | | | 3 wells<br>1 well<br>supplies<br>8" 60 HP<br>-2 75 HP | |
| 1982 | | 540 | 135-140 | | | | | | | | | 150# N<br>40# PH | | | | | | | | |
| 1983 | | 540 | 135-140 | | | | | | | | | 150# N<br>40# PH | | | | | | | | |
| 1984 | | 540 | 135-140 | | | | | | | | | 150# N<br>40# PH | | | | | | | | |
| 1984 | | 540 | 135-140 | | | | | | | | | 150# N<br>40# PH | | | | | | | | |

Floyd Kopfman (Beadle Co.)
33-109N-63W

CBNDAK Irrigation Survey

| Crop | Years Irrig. | Acres Irrig. | Yields[1] | Water Applied | Applic. Freq. | Applic. Amount | Insecticide | Applic. Amount | Herbicide | Applic. Amount | Fertilizer | Applic. Amount | Applic. Time | Plant Pop. | Soil Type | Water Table Build-up | Water Holding Capacity | Infilt. Rate | Pumps[1] Motors | Wildlife Impacts |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 25 | | | | | | | | | | | | | | | | | | | |
| Corn | | | | | | | | | | | | | | | | | | | | |
| 1981 | | 140 | 140 | 10 in | | 2 in | Lorsban | 6 # | Atrazine | 2 # | | | | | | | | | | |
| 1982 | | 140 | 142 | 10 in | | 2 in | Lorsban | 6 # | Atrazine | 2 # | | | | | | | | | | |
| 1983 | | 140 | 135 | 10 in | | 2 in | Lorsban | 6 # | Atrazine | 2 # | | | | | | | | | | |
| 1984 | | 100 | 138 | 6 in | | 2 in | Lorsban | 6 # | Atrazine | 2 # | | | | | | | | | | |
| 1985 | | 202 | 145 | 6 in | | 2 in | Lorsban | 6 # | Atrazine | 2 # | | | | | | | | | | |
| Alfalfa | | | | | | | | | | | | | | | | | | | | |
| 1981 | | 80 | 5T/acre | 16 in | | 3.25 | | | | | | | | | | | | | | |
| 1982 | | 80 | 5T/acre | 16 in | | 3.25 | | | | | | | | | | | | | | |
| 1983 | | 80 | 5T/acre | 16 in | | 3.25 | | | | | | | | | | | | | | |
| 1984 | | 80 | 5T/acre | 16 in | | 3.25 | | | | | | | | | | | | | | |
| 1985 | | | | | | | | | | | | | | | | | | | | |

Larry Nielson (Spink County)
SW¼ 4-114N-64W

CENDAK Irrigation Survey

| Crop | Years Irrig. | Acres Irrig. | Yields¹ | Water Applied | Applic. Freq. | Applic. Amount | Insecticide | Applic. Amount | Herbicide | Applic. Amount | Fertilizer | Applic. Amount | Applic. Time | Plant Pop. | Soil Type | Water Table Build-up | Water Holding Capacity | Infilt. Rate | Pumps¹ Motors | Wildlife Impacts |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 30 | | | | | | | | | | | | | | | | | | | |
| Corn | | | | | | | | | | | | | | | | | | | | |
| 1981 | | 300 | 130 | | | | Furadan | 8#/A | Lasso Bladex | 2 qt. ea | N 200<br>P 60<br>K 30 | | At planting or side dress | 22,000 | Hecla (fine sandy loam) | Temporary pit build up in spring | | | 75 HP electric 800-1000 | Better deer habitat |
| 1982 | | 300 | 130 | | | | Counter | 8#/A | Lasso Bladex | 2 qt. ea | 700<br>80<br>30 | | At planting or side dress | 22,000 | Hecla (fine sandy loam) | Soluble Salt 0.5-0.8 mhos/cm | | | | |
| 1983 | | 300 | 130 | | | | Furadan | 8#/A | Lasso Bladex | 2 qt. ea | 700<br>60<br>30 | | At planting or side dress | 22,000 | Hecla (fine sandy loam) | Soluble Salt 0.5-0.8 mhos/cm | | | | |
| 1984 | | 360 | 150 | | | | Lorsban | 8#/A | Lasso Bladex | 2 qt. ea | 200<br>60<br>30 | | At planting or side dress | 25,000 | Hecla (fine sandy loam) | Soluble Salt 0.5-0.8 mhos/cm | | | | |
| 1985 | | 360 | 130 | | | | Furadan | 8#/A | Lasso Bladex | 2 qt. ea | 200# N<br>60# P<br>30# K | | At planting or side dress | 25,000 | Hecla (fine sandy loam) | Soluble Salt 0.5-0.8 mhos/cm | | | | |
| Barley | | | | | | | | | | | | | | | | | | | | |
| 1981 | 3 | | | | | | | | | | | | | | | | | | | |
| 1982 | | | | | | | | | | | | | | | | | | | | |
| 1983 | | 65 | 50 | | | | None | | None | | 25N<br>25P | | | 2 Bu/Acre | | | | | | |
| 1984 | | 65 | 80 | | | | None | | None | | 25N<br>25P | | | 2 Bu/Acre | | | | | | |
| 1985 | | 65 | 80 | | | | None | | None | | 26N<br>36P | | | 2 Bu/Acre | | | | | | |
| Beans | | | | | | | | | | | | | | | | | | | | |
| 1981 | | 65 | 50 | | | | None | | Lasso | 2 qt/A | 10N - 35P | | | 1 Bu/Acre | | | | | | |
| 1982 | | 32 | 20 | | | | | | Lasso | 2 qt/A | | | | 1 Bu/Acre | | | | | | |
| 1983 | | 65 | 20 | | | | | | Treflan | 2 qt/A | | | | 1 Bu/Acre | | | | | | |
| 1984 | | 100 | 40 | | | | | | Sonolan | 2 qt/A | | | | 1 Bu/Acre | | | | | | |
| 1985 | | 130 | 25 | | | | | | Sonolan | 2 qt/A | 10N - 34P | | | 1 Bu/Acre | | | | | | |

Tim Binger (Beadle Co.)
S8' 31-115-64

CENDAK Irrigation Survey

| Crop | Years Irrig. | Acres Irrig. | Yields[1] | Water Applied | Applic. Freq. | Applic. Amount | Insecticide | Applic. Amount | Herbicide | Applic. Amount | Fertilizer | Applic. Amount | Applic. Time | Plant Pop. | Soil Type | Water Table Build-up | Water Holding Capacity | Infilt. Rate | Pumps[2] Motors | Wildlife Impacts |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 27 | | | | | | | | | | | | | | | | | | | |
| Corn 1981 | | 225 | 140 | | | | 8 1/2 #/Acres Counter | | 29#s Lasso 29#s Atrizine | | 150# N 100# 10-34-0 | | Preplant & side dress | 26-27,000 | very light sandy soil | None | Average | Fast | 1,400 gpm (2) 75 HP electric pumping static level @ 100' aquifer to 100 | |
| 1982 | | 225 | 140 | | | | 8 1/2 #/Acres Counter | | 29#s Lasso 29#s Atrizine | | 150# N | | Preplant & side dress | 26-27,000 | | | | | | |
| 1983 | | 225 | 155 | | | | 8 1/2 #/Acres Counter | | 29#s Lasso 29#s Atrizine | | 100# 10-34-0 150# N | | Preplant & side dress | 26-27,000 | | | | | | |
| 1984 | | 225 | 140 | | | | 8 1/2 #/Acres Counter | | 29#s Lasso 29#s Atrizine | | 150# N 100# 10-34-0 | | Preplant | 26-27,000 | | | | | | |
| 1985 | | 225 | 140 | | | | 8 1/2 #/Acres Counter | | 29#s Lasso 29#s Atrizine | | 150# N 100# 10-34-0 | | Preplant | 26-27,000 | | | | | | |

Bruce McNeill (Spink County)
14-114N-65W

CENDAK Irrigation Survey

| Crop | Years Irrig. | Acres Irrig. | Yields[1] | Water Applied | Applic. Freq. | Applic. Amount | Insecticide | Applic. Amount | Herbicide | Applic. Amount | Fertilizer | Applic. Amount | Applic. Time | Plant Pop. | Soil Type | Water Table Build-up | Water Holding Capacity | Infilt. Rate | Pumps[2] Motors | Wildlife Impacts |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 27 | | | | | | | | | | | | | | | | | | | |
| Corn 1981 | | 260 acres | 125 Bu/A | | | | Furadan/ Lorsban | | | | 150# N/180# 10-34-0 | | At planting | 23,000 | Sandy loam | No Water build-up or salt problems. | | | 2-75 HP pumps @ 5.50 GPM cost of irrigation is $3,000 per pump a year from Spink Ble. | |
| 1982 | | 260 acres | 125 Bu/A | | | | Furadan/ Lorsban | | | | 150# N/180# 10-34-0 | | At planting | 23,000 | Sandy loam | No water build-up or salt problems. | | | | |
| 1983 | | 260 acres | 125 Bu/A | | | | Furadan/ Lorsban | | Lasso/ Atrizine | | 150# N/180# 10-34-0 | | At planting | 23,000 | Sandy loam | No water build-up or salt problems. | | | | |
| 1984 | | 260 acres | 125 Bu/A | | | | Furadan/ Lorsban | | Lasso/ Atrizine | | 150# N/180# 10-34-0 | | At planting | 23,000 | Sandy loam | No water build-up or salt problems. | | | | |
| 1985 | | 260 acres | 125 Bu/A | | | | Furadan/ Lorsban | | Lasso/ Atrizine | | 150# N/180# 10-34-0 | | At planting | 23,000 | Sandy loam | No water build-up or salt problems. | | | | |

Max Conkey (Hand Co.)
7-113N-66W

CENDAK Irrigation Survey

| Crop | Years Irrig. | Acres Irrig. | Yields[1] | Water Applied | Applic. Freq. | Applic. Amount | Insecticide | Applic. Amount | Herbicide | Applic. Amount | Fertilizer | Applic. Amount | Applic. Time | Plant Pop. | Soil Type | Water Table Build-up | Water Holding Capacity | Infilt. Rate | Pumps' Motors | Wildlife Impacts |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 5 | | | | | | | | | | | | | | | | | | | |
| Corn | | | | | | | | | | | | | | | | | | | | |
| 1981 | | 240 | 130 | May | 15 days | 2.4" | 5#/acre | Lasso & | 2 1/2-3 | 200# N/acre | | | Preplant | | Houdek- | No | 0.13-0.21 | 0.2-2.50 | See Below | More wildlife than |
| | | | | June | 20 days | 3.2" | | Atrex | #/acre | | | | | | Bonilla | | I/Hr | I/In | | before irrigation |
| | | | | July | 20 days | 3.2" | | | | | | | | | | | | | | |
| | | | | Aug. | 15 days | 2.4" | | | | | | | | | | | | | | |
| 1982 | | 240 | | July | 3 days | 0.5" | | | | | 200# | | | | | | | | | |
| | | | | Aug. | 25 days | 7.5" | | | | | | | | | | | | | | |
| 1983 | | 240 | | June | 8 days | 6.3" | | | | 200# | 50# PH | | Preplant | | | | | | | |
| | | | | Aug. | 25 days | 7.4" | | | | | | | | | | | | | | |
| 1984 | | 240 | | May | 3 days | 0.9" | | | | | | | | | | | | | | |
| | | | | July | 18 days | 6.1" | | | | | | | | | | | | | | |
| | | | | Aug. | 20 days | 6.1" | | | | | | | | | | | | | | |
| 1985 | | | | | | | | | | | 200# N | 50# PH | Preplant | | | | | | | |
| | | | | | | | | | | | 200# N | | | | | | | | | |
| | | | | | | | | | | | | | | 40 HP w/traveling gun | | | 105 HP pivot w/trveling gun | | | 50 HP Pivot |
| | | | | | | | | | | | | | 1981 | 5,600 kwh | | | | 118,080 kwh | | 55,360 kwh |
| | | | | | | | | | | | | | 1982 | 2,560 kwh | | | | 62,720 kwh | | 17,440 kwh |
| | | | | | | | | | | | | | 1983 | 1,440 kwh | | | | 30,720 kwh | | 20,480 kwh |
| | | | | | | | | | | | | | 1984 | 2,720 kwh | | | | 41,760 kwh | | 18,880 kwh |
| | | | | | | | | | | | | | 1985 | 6,800 kwh | | | | 71,040 kwh | | 28,000 kwh |
| Alfalfa | | | | | | | | | | | | | | | | | | | | |
| 1981 | | 35 | 3 cuts | May | 12 days | 1.5" | | | | | | | | | | | | | | |
| | | | | June | 9 days | 1.1" | | | | | | | | | | | | | | |
| | | | | July | 6 days | 0.7" | | | | | | | | | | | | | | |
| | | | | Aug. | 6 days | 0.7" | | | | | | | | | | | | | | |
| 1982 | | 35 | 3 cuts | June | 6 days | 0.7" | | | | | | | | | | | | | | |
| | | 30 | | June | 3 days | 0.4" | | | | | | | | | | | | | | |
| | | | | Aug. | 3 days | 0.4" | | | | | | | | | | | | | | |
| 1983 | | 35 | 3 cuts | Aug. | 3 days | 0.4" | | | | | | | | | | | | | | |
| 1984 | | 35 | 3 cuts | July | 3 days | 0.4" | | | | | | | | | | | | | | |
| 1985 | | | | | | | | | | | | | | | | | | | | |
| Oats | | | | | | | | | | | | | | | | | | | | |
| 1981 | | 30 | | May | 7 days | 0.5" | | | | | | | | | | | | | | |

Randy Schultz (Hand Co.)
SE1/4 Sec 5 114-66
E1/2 Sec 29 115-66

CENDAK Irrigation Survey

| Crop | Years Irrig. | Acres Irrig. | Yields[1] | Water Applied | Applic. Freq. | Applic. Amount | Insecticide | Applic. Amount | Herbicide | Applic. Amount | Fertilizer | Applic. Amount | Applic. Time | Plant Pop. | Soil Type | Water Table Build-up | Water Holding Capacity | Infilt. Rate | Pumps[2] Motors | Wildlife Impacts |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 5 | | | | | | | | | | | | | | | | | | | |
| Corn | | | | | | | | | | | | | | | | | | | | |
| 1981 | | 115 | 120 | 13.26" | | 1.02" | Lorsban | 7 # | Lasso<br>Blade X | 1.5 qt.<br>1.1 pts | 200# N<br>60# P<br>90# K | | Preplant & Tassling | 28,000 | Sandy loam | 3 ' rise | I/In<br>0.13-0.21 | I/Hr<br>0.80-2.50 | $18 per acre demand<br>149,280 @ .03 | |
| 1982 | | 150 | 120 | 6.8" | | 1.09" | Counter<br>Furadan | 8#<br>10# | '' | '' | 200# N<br>60# P<br>10# K | | | | | | | | 65,760 @ .03 | |
| 1983 | | | | | | | | | | | | | | | | | | | 6,400 @ .03 | |
| 1984 | | 130 | 115 | 5.8 | | 1.22 | Furadan | 20# | '' | '' | 200# N<br>60# P<br>10# K | | | | | | | | 21,600 @ .03 | |
| 1985 | | 130 | 100 | 5.3 | | 1.15 | None | | 2-4D | 1 qt. | '' | | | | | | | | 27,520 @ .0175 | |
| Alfalfa | | | | | | | | | | | | | | | | | | | | |
| 1981 | | 50 | 3 cuts | 9.8" | | | | | | | 80# P | | April | | | | | | | |
| 1982 | | | | | | | | | | | | | | | | | | | | |
| 1983 | | | | | | | | | | | | | | | | | | | | |
| 1984 | | | | | | | | | | | | | | | | | | | | |
| 1985 | | | | | | | | | | | | | | | | | | | | |
| Wheat | | | | | | | | | | | | | | | | | | | | |
| 1981 | | 130 | 50 | 4.15" | | 1." | None | | 2-4D | | | | | | | | | | | |
| 1982 | | | | | | | | | | | | | | | | | | | | |
| 1983 | | | | | | | | | | | | | | | | | | | | |
| 1984 | | | | | | | | | | | | | | | | | | | | |
| 1985 | | | | | | | | | | | | | | | | | | | | |
| Sunflowers | | | | | | | | | | | | | | | | | | | | |
| 1981 | | | | | | | | | | | 125# N 40# P | | Preplant | 32,000 | Sandy loam | | | | | |
| 1982 | | 65 | 1200# | 6.8" | | 1.09" | Parathion | 1 qt | Treflan | 2 qts | | | | | | | | | | |
| 1983 | | | | | | | | | | | | | | | | | | | | |
| 1984 | | | | | | | | | | | | | | | | | | | | |
| 1985 | | | | | | | | | | | | | | | | | | | | |

Jim Paulstich (Hyde County)
NE¼ 7-114N-71W

CENOAK Irrigation Survey

| Crop | Years Irrig. | Acres Irrig. | Yields[1] | Water Applied | Applic. Freq. | Applic. Amount | Insecticide | Applic. Amount | Herbicide | Applic. Amount | Fertilizer | Applic. Amount | Applic. Time | Plant Pop. | Soil Type | Water Table Build-up | Water Holding Capacity | Infilt. Rate | Pumps[1] Motors | Wildlife Impacts |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Corn | 10 | | | | | | | | | | | | | | | | | | | |
| 1981 | | | | | | | | | | | | | | | Clay loam | | | | | Great increase in production feed and cover |
| 1982 | | 118 | 100-130 | 6 in | 3 days | 1 in | None | | Lasso<br>Bladex | 1 qt<br>2 qt | Actual 50 N<br>35 P | | Preplant<br>& Planter | 20,000 | | None | | | | |
| 1983 | | | | | | | | | | | | | | | | | | | | |
| 1984 | | | | | | | | | | | | | | | | | | | | |
| 1985 | | 130 | 100 | 8 in | 3 days | 1 in | None | | Lasso Band | 6 lb | Actual 130 N<br>45 P 20 Sulfer | | Preplant<br>& Planter | 17,000 | | None | | | | |
| Alfalfa | | | | | | | | | | | | | | | | | | | | |
| 1981 | | | | | | | | | | | | | | | Clay loam | | | | | Great increase in production feed and cover |
| 1982 | | 160 | 6 ton | 20 | 10 days | 5 in | Spray | hoppers | | | Actual 25 P | | Fall | | | None | | | | |
| 1983 | | | | | | | | | | | | | | | | | | | | |
| 1984 | | 80 | 7 ton | 15 | 18 days | 5 in | | | | | Actual 40 P | | Fall | | | None | | | | |
| 1985 | | 140 | 7 ton | 20 | 14 days | 5 in | | | | | Actual 45 P | | Spring | | | None | | | | |
| Milo | | | | | | | | | | | | | | | | | | | | |
| 1981 | | | | | | | | | | | | | | | | | | | | |
| 1982 | | | | | | | | | | | | | | | | | | | | |
| 1983 | | | | | | | | | | | | | | | | | | | | |
| 1984 | | 80 | 100 Bu | 6 in | 14 days | 3 in | | | | | 0-Alfalfa ground | | | | Clay loam | None | | | | |
| 1985 | | | | | | | | | | | | | | | | | | | | |

Johnson (Hughes Co.)
SW¼-14-112-79

CENOAK Irrigation Survey

| Crop | Years Irrig. | Acres Irrig. | Yields[1] | Water Applied | Applic. Freq. | Applic. Amount | Insecticide | Applic. Amount | Herbicide | Applic. Amount | Fertilizer | Applic. Amount | Applic. Time | Plant Pop. | Soil Type | Water Table Build-up | Water Holding Capacity | Infilt. Rate | Pumps[1] Motors | Wildlife Impacts |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Corn | 3 | | | | | | | | | | | | | | | | | | | |
| 1981 | | | | | | | | | | | | | | | | No build-up, no silting,<br>no root zone flooding. | | | | Seems like we have more than we ever had. |
| 1982 | | | | | | | | | | | | | | | | | | | | |
| 1983 | | 132 | 130 | | If no rain approx. 1 1/2 to 2" per wk. | 14-15 in per year. Usually 1" applications. | None | | Lasso Bladx combo | 2 qt<br>1 1/2 qt approx | 140# N<br>50# P | preplant about $60 $65/A | | 28,000 | | | | | | |
| 1984 | | 132 | 0 (Hail) | | | | | | | | | | | 28,000 | | | | | | |
| 1985 | | 132 | 90 (Hail) | | | | | | | | | | | 28,000 | | | | | | |

Ed Niece (Hughes Co.)
22-112N-79W

CENDAK Irrigation Survey

| Crop | Years Irrig. | Acres Irrig. | Yields[1] | Water Applied | Applic. Freq. | Applic. Amount | Insecticide | Applic. Amount | Herbicide | Applic. Amount | Fertilizer | Applic. Amount | Applic. Time | Plant Pop. | Soil Type | Water Table Build-up | Water Holding Capacity | Infilt. Rate | Pumps[1] Motors | Wildlife Impacts |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 8 | | | | | | | | | | | | | | | | | | | |
| Corn | | | | | | | | | | | | | | | | | | | | |
| 1981 | | | 170 | | | | | | 1/3 Atrizine<br>1/3 Bladex<br>1/3 Lasso | | | | | | Clay loam | None | | | $55.67 /Acre O&M | |
| 1982 | | 821 | 170 | | | | | | | | | | | | | | | | | |
| 1983 | | | 170 | | | | | | | | | | | | | | | | | |
| 1984 | | | 170 | | | | | | | | | | | | | | | | | |
| 1985 | | | 170 | 14.5" | | | | | 1 qt Atrizine<br>1 qt Plus of Lasso<br>1 qt Bladex | | 190# N<br>30# K<br>49# P | | | 30,000 | | | | | | |

# APPENDIX B

Crop production

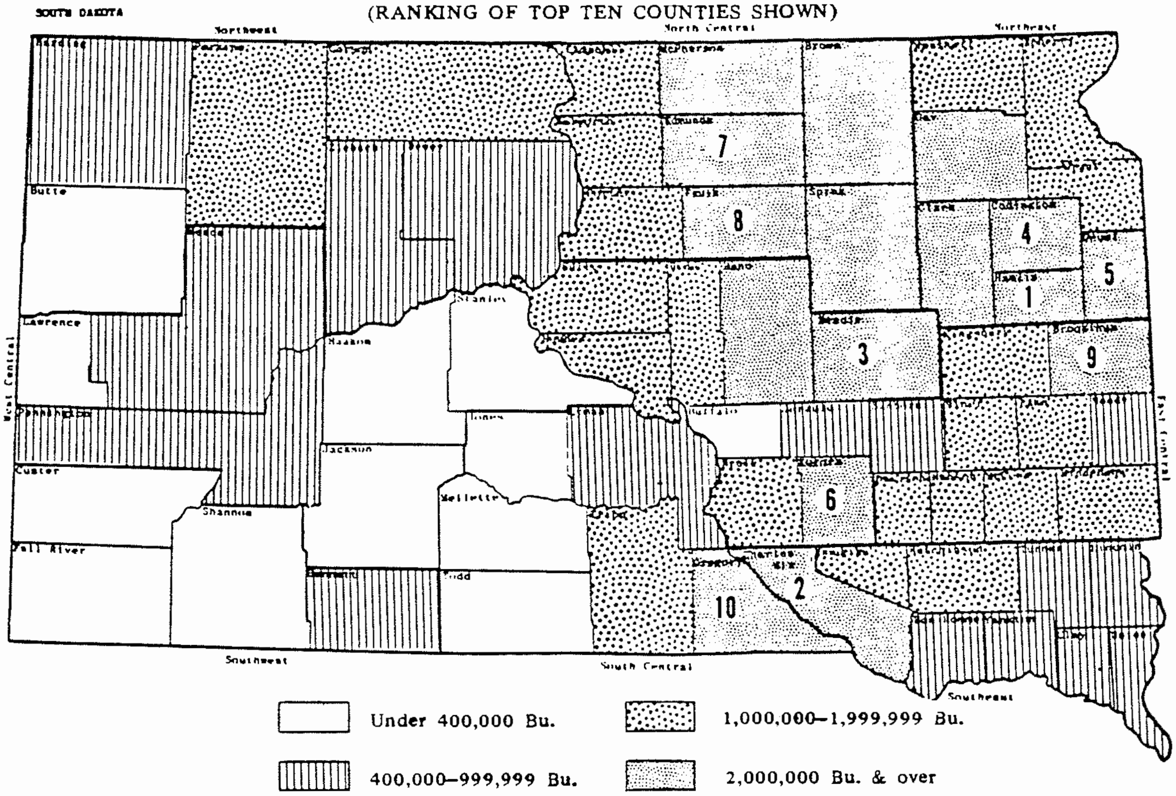
Maps of crop production for South Dakota

Tables of crop production for CENDAK area

# PRODUCTION BY COUNTIES

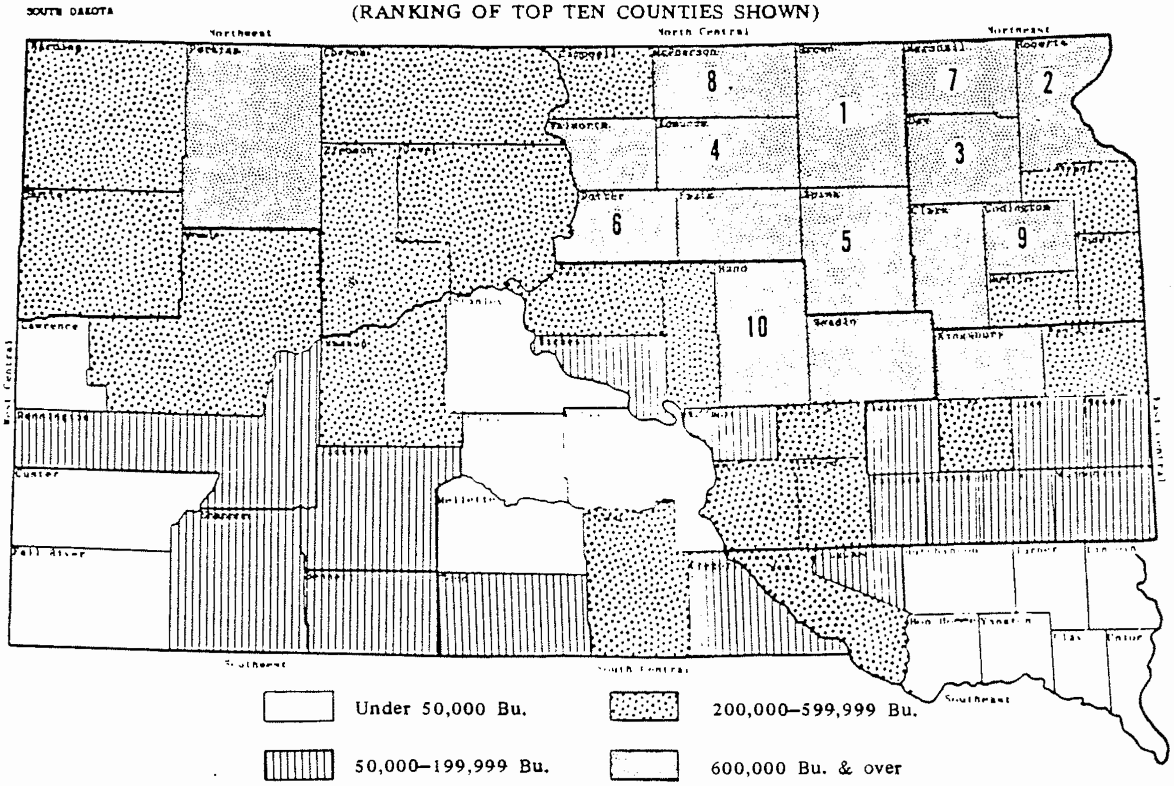
## OATS, SOUTH DAKOTA, 1984

(RANKING OF TOP TEN COUNTIES SHOWN)




## BARLEY, SOUTH DAKOTA, 1984

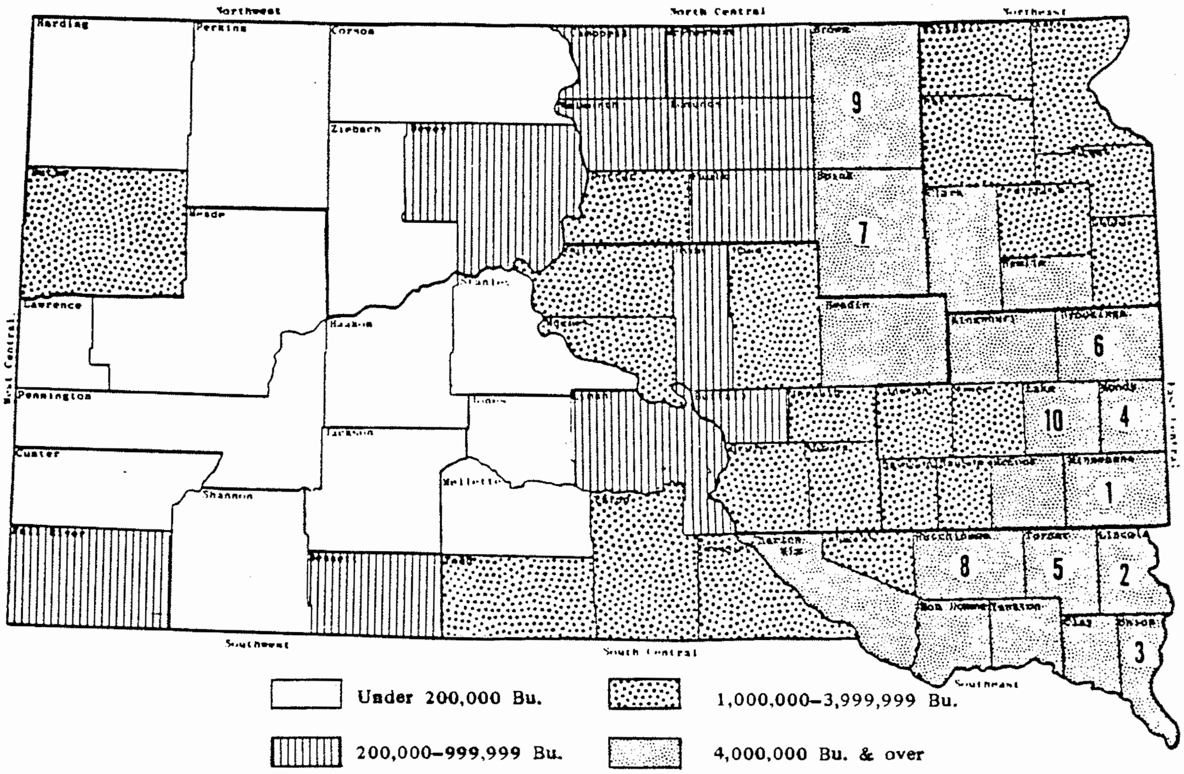
(RANKING OF TOP TEN COUNTIES SHOWN)



# PRODUCTION BY COUNTIES

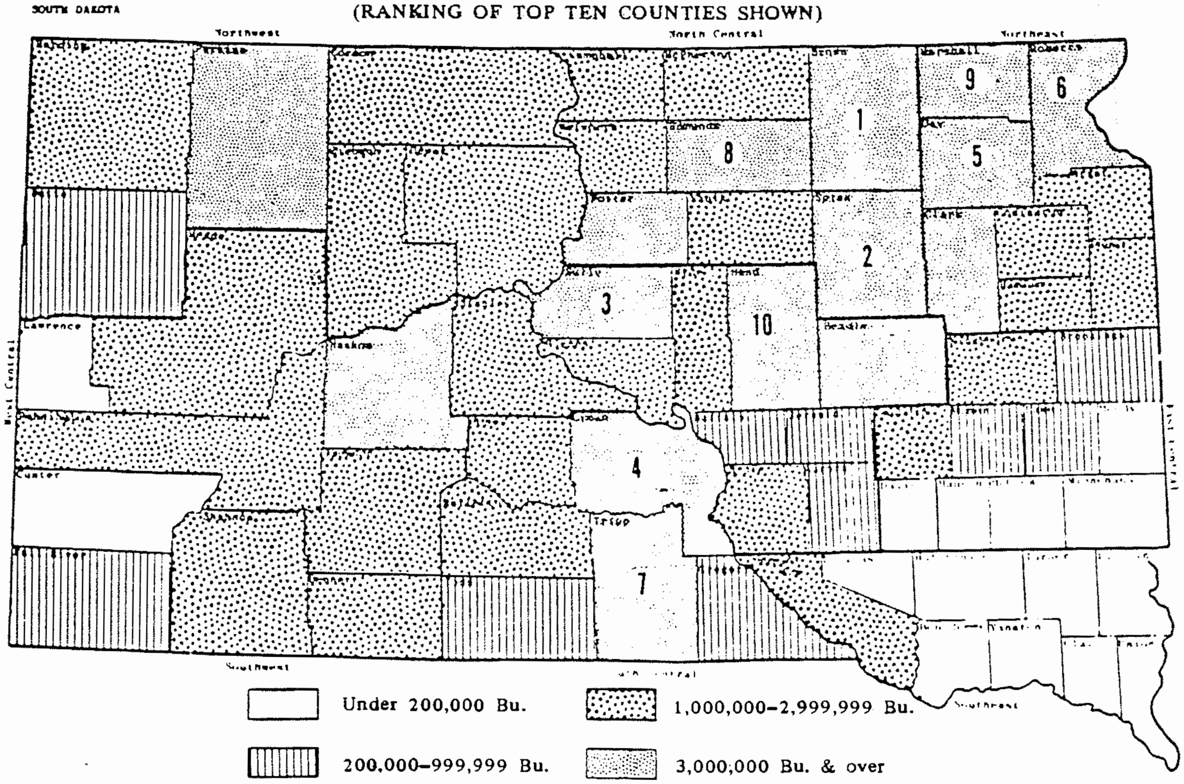
## CORN FOR GRAIN, SOUTH DAKOTA, 1984

(RANKING OF TOP TEN COUNTIES SHOWN)




## ALL WHEAT, SOUTH DAKOTA, 1984

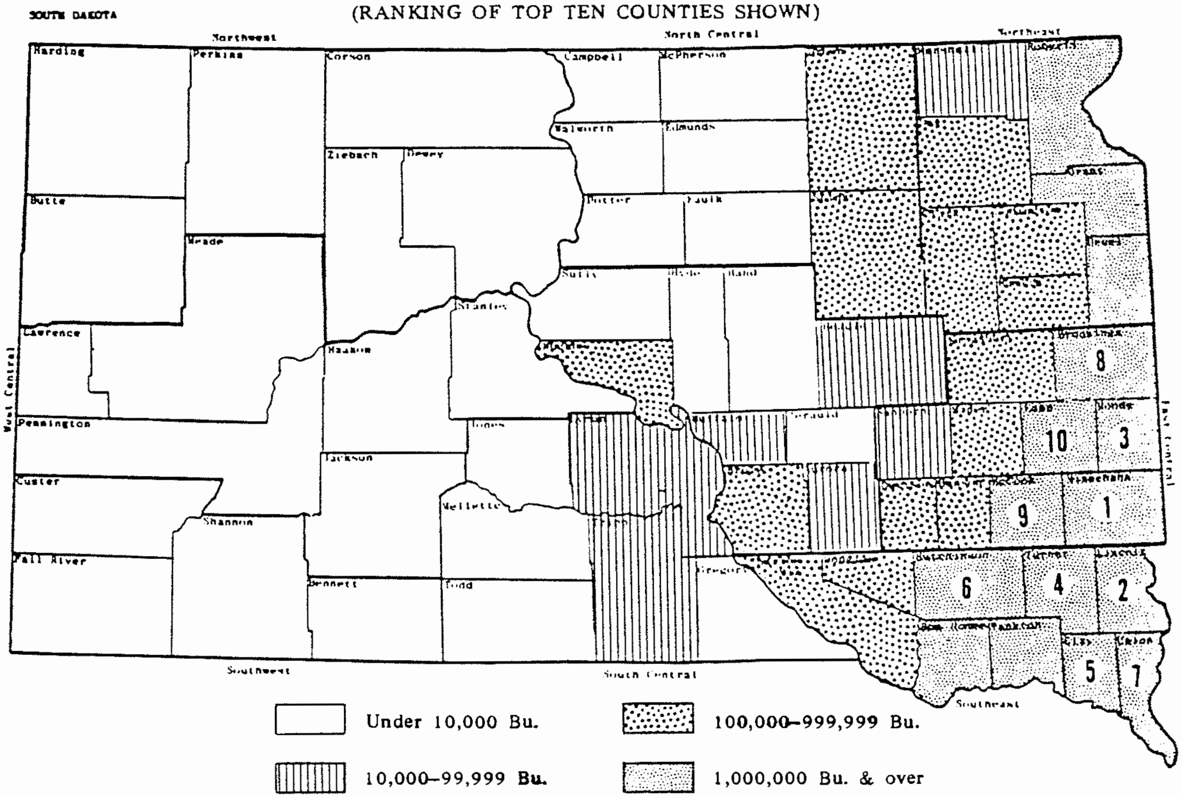
(RANKING OF TOP TEN COUNTIES SHOWN)



# PRODUCTION BY COUNTIES

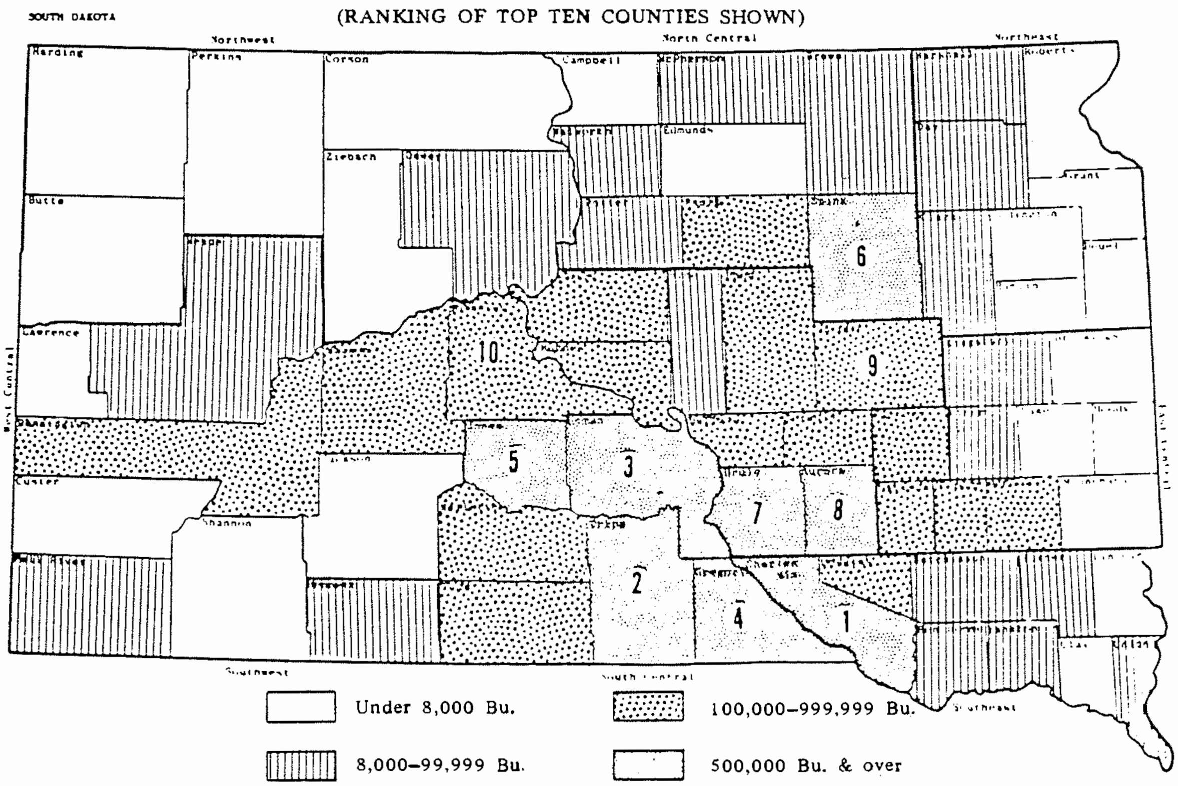
## SOYBEANS, SOUTH DAKOTA, 1984

(RANKING OF TOP TEN COUNTIES SHOWN)




## GRAIN SORGHUM, SOUTH DAKOTA, 1984

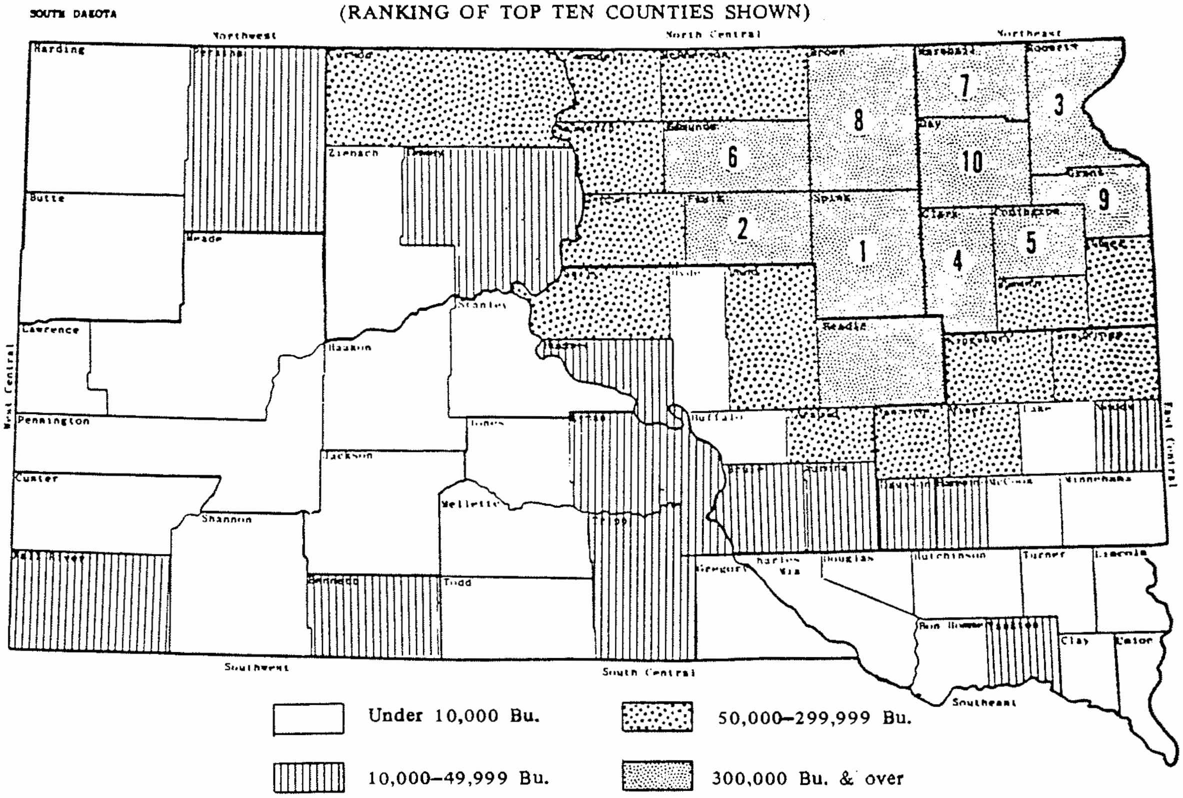
(RANKING OF TOP TEN COUNTIES SHOWN)



# PRODUCTION BY COUNTIES

## RYE, SOUTH DAKOTA, 1984

(RANKING OF TOP TEN COUNTIES SHOWN)




## FLAXSEED, SOUTH DAKOTA. 1984

(RANKING OF TOP TEN COUNTIES SHOWN)

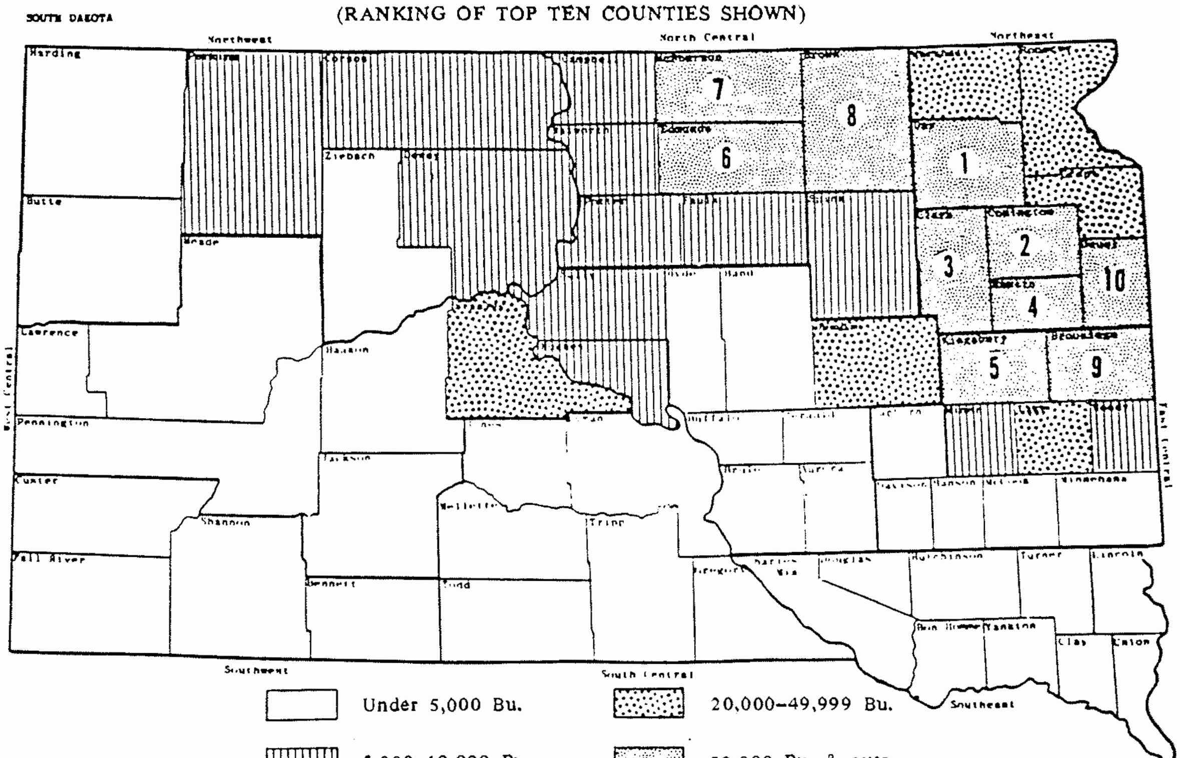


TABLE OF CROP PRODUCTION BY COUNTY

CORN FOR GRAIN
(Bushels)

| CENDAK COUNTIES | 1975 | 1976 | 1977 | 1978 | 1979 | 1980 | 1981 | 1982 | 1983 | 1984 | 10-year Average |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Faulk | 376,500 | 32,500 | 448,400 | 696,000 | 1,031,000 | 181,000 | 209,000 | 233,000 | 471,000 | 607,000 | ---------- |
| Spink | 1,608,300 | 118,000 | 3,267,000 | 5,033,000 | 6,168,000 | 2,375,000 | 2,372,000 | 4,778,000 | 3,925,000 | 7,015,000 | ---------- |
| Beadle | 1,109,900 | 89,100 | 2,039,400 | 3,199,000 | 4,740,000 | 1,441,000 | 3,200,000 | 5,973,000 | 2,792,000 | 6,146,000 | ---------- |
| Hand | 396,900 | 29,600 | 942,300 | 1,338,000 | 2,552,000 | 445,000 | 1,150,000 | 2,020,000 | 1,259,000 | 2,155,000 | ---------- |
| Hughes | 413,300 | 40,400 | 798,600 | 1,509,000 | 1,445,000 | 345,000 | 2,530,000 | 1,738,000 | 1,014,000 | 1,917,000 | ---------- |
| Hyde | 136,400 | 12,300 | 153,100 | 115,000 | 158,000 | 31,000 | 206,000 | 215,000 | 170,000 | 389,000 | ---------- |
| CENDAK Counties Totals | 4,041,300 | 321,900 | 7,648,800 | 11,890,000 | 16,094,000 | 4,818,000 | 9,667,000 | 14,957,000 | 9,631,000 | 18,229,000 | 9,729,800 |
| CENDAK Unit Totals * (474,000 Acres) | 719,351 | 57,298 | 1,361,486 | 2,116,420 | 2,864,732 | 857,604 | 1,720,726 | 2,662,346 | 1,714,318 | 3,244,762 | 1,731,904 |
| CENDAK Unit % of U.S. | .0124 | .0009 | .0209 | .0291 | .0361 | .0129 | .0212 | .0323 | .0411 | .0424 | .025 |

* Based on CENDAK's 474,000 acres representing approximately 17.8 percent of the cropland in the six county CENDAK area.

ALL WHEAT
(Bushels)

| CENDAK COUNTIES | 1975 | 1976 | 1977 | 1978 | 1979 | 1980 | 1981 | 1982 | 1983 | 1984 | 10-year Average |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Faulk | 1,360,100 | 327,700 | 2,090,000 | 1,332,800 | 1,364,200 | 1,164,600 | 1,601,200 | 1,963,200 | 2,067,200 | 2,793,000 | ---------- |
| Spink | 3,649,300 | 1,553,900 | 6,549,000 | 3,867,900 | 4,614,600 | 4,467,600 | 4,944,600 | 5,360,000 | 4,335,000 | 6,675,000 | ---------- |
| Beadle | 1,021,300 | 320,600 | 1,765,700 | 1,266,400 | 1,398,100 | 1,930,500 | 1,728,900 | 2,589,900 | 2,135,900 | 3,212,000 | ---------- |
| Hand | 1,434,700 | 339,400 | 1,355,200 | 1,425,100 | 1,277,500 | 2,263,000 | 2,723,400 | 2,723,400 | 2,651,700 | 3,761,000 | ---------- |
| Hughes | 1,052,600 | 283,700 | 1,018,400 | 1,005,300 | 1,026,200 | 1,273,900 | 2,283,000 | 2,442,000 | 2,248,000 | 2,769,000 | ---------- |
| Hyde | 289,400 | 112,300 | 579,300 | 436,000 | 317,000 | 272,400 | 975,000 | 1,220,000 | 1,393,000 | 1,673,000 | ---------- |
| CENDAK Counties Totals | 8,807,400 | 2,937,600 | 13,357,600 | 9,333,500 | 9,997,600 | 11,372,000 | 14,256,100 | 16,298,500 | 14,830,800 | 20,883,000 | ---------- |
| CENDAK Unit Totals * (474,000 Acres) | 1,567,717 | 522,893 | 2,377,653 | 1,661,363 | 1,779,573 | 2,024,216 | 2,537,586 | 2,901,133 | 2,639,882 | 3,717,174 | 2,172,919 |
| CENDAK Unit % of U.S. | .074 | .024 | .116 | .094 | .083 | .085 | .091 | .105 | .109 | .143 | .094 |

* Based on CENDAK's 474,000 acres representing approximately 17.8 percent of the cropland in the six county CENDAK area.

TABLE OF CROP PRODUCTION BY COUNTY

SOY BEANS
(Bushels)

| CENDAK COUNTIES | 1975 | 1976 | 1977 | 1978 | 1979 | 1980 | 1981 | 1982 | 1983 | 1984 | 10-year Average |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Faulk | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | ---------- |
| Spink | 0 | 0 | 0 | 0 | 45,600 | 64,500 | 67,000 | 101,000 | 236,700 | 583,000 | ---------- |
| Beadle | 0 | 0 | 3,100 | 0 | 14,300 | 53,400 | 49,000 | 60,000 | 73,000 | 92,400 | ---------- |
| Hand | 0 | 0 | 2,300 | 0 | 0 | 5,300 | 0 | 0 | 0 | 0 | ---------- |
| Hughes | 0 | 0 | 28,500 | 55,000 | 106,000 | 0 | 38,000 | 56,300 | 0 | 100,000 | ---------- |
| Hyde | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | ---------- |
| CENDAK Counties Totals | 0 | 0 | 33,900 | 55,000 | 165,900 | 123,200 | 154,000 | 217,300 | 309,700 | 775,400 | ---------- |
| CENDAK Unit Totals * (474,000 Acres) | 0 | 0 | 6,034 | 9,790 | 29,530 | 21,930 | 27,412 | 38,679 | 55,127 | 138,021 | 32,652 |
| CENDAK Unit % of U.S. | 0 | 0 | .0003 | .0005 | .001 | .001 | .001 | .002 | .003 | .007 | .002 |

* Based on CENDAK's 474,000 acres representing approximately 17.8 percent of the cropland in the six county CENDAK area.

SORGHUM
(Bushels)

| CENDAK COUNTIES | 1975 | 1976 | 1977 | 1978 | 1979 | 1980 | 1981 | 1982 | 1983 | 1984 | 10-year Average |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Faulk | 25,900 | 800 | 19,800 | 50,300 | 12,900 | 10,800 | 35,000 | 25,200 | 29,300 | 150,200 | ---------- |
| Spink | 326,000 | 36,300 | 344,400 | 3,800 | 94,100 | 191,800 | 412,000 | 374,000 | 202,000 | 779,000 | ---------- |
| Beadle | 290,300 | 11,900 | 138,900 | 168,800 | 86,000 | 165,000 | 223,000 | 674,000 | 353,000 | 457,700 | ---------- |
| Hand | 170,400 | 0 | 121,200 | 401,100 | 320,000 | 226,800 | 404,000 | 405,000 | 701,000 | 224,800 | ---------- |
| Hughes | 139,000 | 0 | 104,100 | 397,000 | 31,000 | 60,000 | 149,000 | 190,000 | 77,500 | 177,900 | ---------- |
| Hyde | 152,900 | 0 | 125,000 | 115,500 | 21,000 | 28,000 | 173,000 | 90,000 | 67,000 | 61,400 | ---------- |
| CENDAK Counties Totals | 1,104,500 | 49,000 | 853,400 | 1,136,500 | 565,000 | 682,400 | 1,396,000 | 1,758,200 | 1,429,800 | 1,851,000 | ---------- |
| CENDAK Unit Totals * (474,000 Acres) | 196,601 | 8,722 | 151,905 | 202,297 | 100,570 | 121,467 | 248,488 | 312,960 | 254,504 | 329,478 | 192,699 |
| CENDAK Unit % of U.S. | .026 | .001 | .018 | .028 | .012 | .021 | .028 | .037 | .052 | .038 | .026 |

* Based on CENDAK's 474,000 acres representing approximately 17.8 percent of the cropland in the six county CENDAK area.

TABLE OF CROP PRODUCTION BY COUNTY

OATS
(Bushels)

| CENDAK COUNTIES | 1975 | 1976 | 1977 | 1978 | 1979 | 1980 | 1981 | 1982 | 1983 | 1984 | 10-year Average |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Faulk | 1,598,700 | 30,000 | 1,969,300 | 1,456,600 | 1,011,200 | 254,800 | 530,000 | 2,158,000 | 2,793,000 | 2,387,000 | ---------- |
| Spink | 1,985,200 | 150,000 | 2,493,200 | 1,689,600 | 1,405,700 | 760,000 | 674,000 | 2,050,000 | 2,361,000 | 2,093,000 | ---------- |
| Beadle | 2,518,900 | 61,300 | 2,534,200 | 2,762,400 | 2,130,900 | 1,285,000 | 850,000 | 2,694,000 | 2,125,000 | 3,166,000 | ---------- |
| Hand | 1,629,400 | 5,900 | 1,782,700 | 1,584,000 | 1,123,000 | 613,000 | 688,000 | 1,635,000 | 1,488,000 | 2,072,000 | ---------- |
| Hughes | 343,600 | 9,200 | 584,300 | 553,400 | 643,500 | 20,300 | 541,800 | 814,000 | 781,000 | 1,056,000 | ---------- |
| Hyde | 526,800 | 0 | 801,500 | 505,200 | 209,000 | 54,000 | 559,000 | 801,000 | 925,000 | 1,182,000 | ---------- |
| CENDAK Counties Totals | 8,602,600 | 256,400 | 10,165,200 | 8,551,200 | 6,523,300 | 2,987,100 | 3,842,800 | 10,152,000 | 10,473,000 | 11,956,000 | ---------- |
| CENDAK Unit Totals * (474,000 Acres) | 1,531,263 | 45,639 | 1,809,406 | 1,522,114 | 1,161,147 | 531,704 | 684,018 | 1,807,056 | 1,864,194 | 2,128,168 | 1,308,466 |
| CENDAK Unit % of U.S. | .240 | .008 | .240 | .267 | .220 | .116 | .134 | .305 | .391 | .451 | .236 |

* Based on CENDAK's 474,000 acres representing approximately 17.8 percent of the cropland in the six county CENDAK area.

BARLEY
(Bushels)

| CENDAK COUNTIES | 1975 | 1976 | 1977 | 1978 | 1979 | 1980 | 1981 | 1982 | 1983 | 1984 | 10-year Average |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Faulk | 364,700 | 40,700 | 768,300 | 654,800 | 387,800 | 262,400 | 570,000 | 628,000 | 928,000 | 1,012,000 | ---------- |
| Spink | 873,800 | 81,400 | 1,475,200 | 1,043,000 | 806,000 | 659,000 | 693,000 | 992,000 | 997,000 | 1,427,000 | ---------- |
| Beadle | 258,000 | 38,400 | 538,700 | 562,000 | 553,300 | 322,600 | 245,300 | 524,000 | 420,000 | 722,000 | ---------- |
| Hand | 86,200 | 17,200 | 639,000 | 630,000 | 566,100 | 288,700 | 504,900 | 511,000 | 635,000 | 1,037,000 | ---------- |
| Hughes | 55,700 | 2,300 | 78,000 | 151,000 | 74,800 | 13,800 | 39,000 | 29,400 | 36,300 | 52,200 | ---------- |
| Hyde | 40,000 | 5,500 | 222,700 | 198,000 | 148,400 | 75,600 | 170,000 | 176,000 | 343,000 | 351,000 | ---------- |
| CENDAK Counties Totals | 1,678,400 | 185,500 | 3,720,900 | 3,238,800 | 2,536,400 | 1,622,100 | 2,222,200 | 2,860,400 | 3,359,300 | 4,601,200 | ---------- |
| CENDAK Unit Totals * (474,000 Acres) | 298,755 | 33,019 | 662,320 | 576,506 | 451,479 | 288,734 | 395,552 | 509,151 | 597,955 | 819,014 | 463,249 |
| CENDAK Unit % of U.S. | .079 | .009 | .155 | .127 | .118 | .080 | .084 | .099 | .118 | .137 | .101 |

* Based on CENDAK's 474,000 acres representing approximately 17.8 percent of the cropland in the six county CENDAK area.

TABLE OF CROP PRODUCTION BY COUNTY

SUNFLOWERS
(Pounds)

| CENDAK COUNTIES | 1975 | 1976 | 1977 | 1978 | 1979 | 1980 | 1981 | 1982 | 1983 | 1984 | 10-year Average |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Faulk | 0 | 0 | 2,635,000 | 2,310,000 | 14,704,000 | 12,459,000 | 10,224,000 | 14,423,000 | 10,013,000 | 12,111,000 | ---------- |
| Spink | 0 | 0 | 25,654,000 | 34,857,000 | 133,062,000 | 83,648,000 | 67,225,000 | 75,561,000 | 51,448,000 | 54,462,000 | ---------- |
| Beadle | 0 | 0 | 760,000 | 2,200,000 | 13,305,000 | 6,975,000 | 7,820,000 | 17,702,000 | 9,879,000 | 31,579,000 | ---------- |
| Hand | 0 | 0 | 810,000 | 1,400,000 | 13,424,000 | 18,460,000 | 19,770,000 | 29,510,000 | 19,936,000 | 32,176,000 | ---------- |
| Hughes | 0 | 0 | 0 | 640,000 | 10,199,000 | 1,964,000 | 3,220,000 | 9,787,000 | 9,240,000 | 11,685,000 | ---------- |
| Hyde | 0 | 0 | 0 | 0 | 2,325,000 | 700,000 | 542,000 | 4,750,000 | 4,235,000 | 9,322,000 | ---------- |
| CENDAK Counties Totals | 0 | 0 | 29,859,000 | 41,407,000 | 187,019,000 | 124,206,000 | 108,801,000 | 151,733,000 | 104,751,000 | 151,335,000 | 89,911,100 |
| CENDAK Unit Totals * (474,000 Acres) | 0 | 0 | 5,314,902 | 7,370,446 | 33,289,382 | 22,108,668 | 19,366,578 | 27,008,474 | 18,645,678 | 26,937,630 | 16,003,976 |
| CENDAK Unit % of U.S. | 0 | 0 | .019 | .019 | .046 | .059 | .043 | .051 | .058 | .072 | .045 |

* Based on CENDAK's 474,000 acres representing approximately 17.8 percent of the cropland in the six county CENDAK area.

RYE
(Bushels)

| CENDAK COUNTIES | 1975 | 1976 | 1977 | 1978 | 1979 | 1980 | 1981 | 1982 | 1983 | 1984 | 10-year Average |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Faulk | 492,700 | 164,000 | 244,000 | 570,000 | 347,000 | 272,000 | 289,000 | 477,000 | 914,000 | 1,297,000 | ---------- |
| Spink | 326,200 | 178,000 | 323,000 | 654,000 | 460,000 | 447,000 | 229,000 | 482,000 | 1,289,000 | 1,433,000 | ---------- |
| Beadle | 317,200 | 36,000 | 152,000 | 425,000 | 341,000 | 130,000 | 88,000 | 277,700 | 414,000 | 377,300 | ---------- |
| Hand | 95,100 | 10,400 | 30,000 | 108,000 | 130,000 | 26,000 | 14,200 | 52,000 | 195,000 | 141,000 | ---------- |
| Hughes | 43,900 | 4,600 | 0 | 22,000 | 97,000 | 19,500 | 13,200 | 27,000 | 32,300 | 23,400 | ---------- |
| Hyde | 22,400 | 4,200 | 0 | 52,000 | 29,000 | 5,000 | 17,000 | 26,400 | 40,000 | 0 | ---------- |
| CENDAK Counties Totals | 1,297,500 | 397,200 | 749,000 | 1,831,000 | 1,404,000 | 899,500 | 650,400 | 342,100 | 2,884,300 | 3,271,700 | ---------- |
| CENDAK Unit Totals * (474,000 Acres) | 230,955 | 70,702 | 133,322 | 325,918 | 249,912 | 160,111 | 115,771 | 60,894 | 513,405 | 582,363 | 244,335 |
| CENDAK Unit % of U.S. | 1.45 | .47 | .81 | 1.35 | 1.14 | 1.00 | .64 | .31 | 1.89 | 1.80 | 1.18 |

* Based on CENDAK's 474,000 acres representing approximately 17.8 percent of the cropland in the six county CENDAK area.

# APPENDIX C

## Soil-water compatibility requirements

# ARTICLE 12:08

## IRRIGATION SOIL-WATER COMPATIBILITY



## CHAPTER 12:08:01

## GENERAL PROVISIONS



12:08:01:01 Definitions. Terms used in this article mean:

( 1) "Adequate internal drainage", internal drainage which is sufficient to prevent plant toxicity without degradation to the soil;

( 2) "Adjusted sodium adsorption ratio," "Adjusted SAR," or "Adj. SAR," the calculated sodium hazard of irrigation water, taking into account the tendency of the water in question to deposit lime in the soil or to dissolve lime from soil minerals:

$$\text{adj.SAR} = \frac{Na^+}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}} \cdot [1 + (8.4 - pHc)] \quad ;$$

( 3) "Commission," the state conservation commission;

( 4) "Division", division of conservation, South Dakota department of agriculture;

( 5) "Permit approved with requirements," an application in which soil-water compatibility or land capability, or both, show that potential adverse effects may exist under continual irrigation;

( 6) "Electrical conductivity," the ability of an aqueous solution to conduct an electrical current; an index of the salt content of an aqueous solution;

( 7) "Empirical factor," a factor used in the consideration of climatic soil weathering effects for Adj. SAR. - Adj. SAR. x 0.7;

( 8) "Exchangeable Sodium Percentage" the exchangeable sodium in the soil as a percent of all cations held by the soil;

( 9) "Inadequate water quality data," data that have less than four water analyses from the aquifer to be used for irrigation;

(10) "Internal soil drainage," the movement of water through the soil profile escaping past the bottom of the root zone;

(11) "pHc," a theoretical, calculated pH of irrigation water in equilibrium with calcium carbonate;

(12) "Production well," a fully developed well designed to provide water to an irrigation system;

(13) "Sodium absorption ratio" or "SAR," a mathematical ratio comparing the sodium to calcium plus magnesium of irrigation water or a soil solution. It describes the sodium hazards to the surface of a soil to which the water is applied:

$$SAR=\frac{Na^{+}}{\sqrt{\frac{Ca^{2+}+Mg^{2+}}{2}}};$$

(14) "Sodium," a positively charged ion that tends to attach itself to the clay fraction of a soil particle which in excess is detrimental to soil structures;

(15) "Sodium percentage," the chemical equivalent content of sodium ions compared to the chemical equivalent content of all cations of a solution; as applied to a soil;

(16) "Soil extract," an aqueous solution of distilled water leached through a soil sample under suction. The resulting solution provides for the measure of soluble cations and anions in the soil sample;

(17) "Soil-water compatibility," a term descriptive of the relative degree of success derived from the application of certain waters on specific soil types;

(18) "Test hole," an exploratory drilled hole which is drilled to learn the characteristics of the various strata encountered below the earth's surface;

(19) "Test well," a well cased so that a screen is placed into a water bearing aquifer for use in obtaining a water sample and monitoring the static water; and

(20) "Tile drainage," land drainage by means of series of buried perforated pipe lines laid at a specified depth and grade.

Source:
General Authority: SDCL 46-5-6.7.
Law Implemented: SDCL 46-5-6.7.

12:08:01:02 Pumping methods. To insure that a water sample obtained from a test hole or test well is representative of the water to be used in irrigation, a test hole or test well shall be pumped for not less than six hours immediately before taking the sample.

Source: 5 SDR95, Transferred from §12:08:03:03
General Authority: SDCL 46-5-6.7.
Law Implemented: SDCL 46-5-6.2, 46-5-6.3

12:08:01:03 Water sampling techniques and labeling. All water samples shall be at least one pint and shall be taken in a clean container. A label on the container shall contain the following information:

(1) Name of the applicant;
(2) Name of the individual who took the sample;
(3) Date and time of the sampling; and
(4) The legal description of the sample location.

Source: Transferred from §§12:08:03:04 and 12:08:03:05
General Authority: SDCL 46-5-6.7
Law Implemented: SDCL 46-5-6.3

12:08:01:04 Soils information. Soils information is a soil map and a detailed narrative description of that map along with other interpretative data sheets as they appear in the published soil survey by the soil conservation service or as provided by a professional soil classifier.

Source:
General Authority: SDCL 46-5-6.7
Law Implemented: SDCL 46-5-6.3

12:08:01:05 Water analysis requirements. The analysis of water samples shall be conducted in a laboratory that is certified by the United States environmental protection agency as of July 1, 1985.

Source: Transferred from 12:08:05:04
General Authority: SDCL 46-5-6.7
Law Implemented: SDCL 46-5-6.3

12:08:01:06 Soil analysis requirements. The analysis of soils shall be conducted in a laboratory approved by the United States department of agriculture to receive soil samples as of July 1, 1985.

Source:
General Authority: SDCL 46-5-6.7
Law Implemented: SDCL 46-5-6.3

# CHAPTER 12:08:02

## APPLICATION PROCEDURES



12:08:02:01 Application requirements. Repealed.

12:08:02:02 Processing of application, Transferred to §12:08:02:04

12:08:02:03 Content of application. The applicant for a soil-water compatibility permit shall file a correctly filled out application with the division of conservation on a form furnished by the division. To complete the application, the applicant shall file soils information as defined in §12:08:01:04 and a laboratory analysis of the waters to be used for irrigation. The water must meet requirements for representative samples in chapter 12:08:03. The division may request additional information as required to make its determination.

Source:
General Authority: SDCL 46-5-6.7
Law Implemented: SDCL 46-5-6.2, 46-5-6.3.

12:08:02:04 Processing of application. All applications shall be mailed to the Water Resources Institute, Brookings, South Dakota, 57007, for an initial evaluation. The institute shall mail the application with the initial evaluation to the division for further action. The division shall process applications within 60 days after receiving the completed application from the Water Resources Institute.

Source: Transferred from 12:08:02:02
General Authority: SDCL 46-5-6.7
Law Implemented: SDCL 46-5-6.2

## CHAPTER 12:08:03

## REPRESENTATIVE WATER SAMPLES

Section



12:08:03:01 Groundwater. Groundwater samples submitted to the division shall be taken from the aquifer that is to be used in irrigation. Such water samples will be considered representative when they have been obtained from the well to be used for water production or test wells which lie within a 2,000-foot radius of the well. However, the test well must lie within a 660-foot radius of the well to be used for water production if there is conflicting or inadequate water quality data within the area.

Source:
General Authority: SDCL 46-5-6.7
Law Implemented: SDCL 46-5-6.2

12:08:03:01.01 Commission waiver. The commission may waive the 2,000-foot radius requirement in §12:08:03:01 upon a finding by the commission that the depth of the aquifer, the water quality data from the aquifer, depth of the wells in the area known to be in the aquifer, and well logs indicate that water quality in the aquifer is stable throughout the aquifer in that area.

Source: Transferred from 12:08:03:06
General Authority: SDCL 46-5-6.7
Law Implemented: SDCL 46-5-6.3

12:08:03:02 Surface waters. Surface water samples are required in all cases, except when certified water quality data is available from samples taken within the 12 months immediately preceding the application.

Source:
General Authority: SDCL 46-5-6.7
Law Implemented: SDCL 46-5-6.2, 46-5-6.3

12:08:03:03 Pumping methods. Transferred to §12:08:01:02.

12:08:03:04 Water sampling techniques. Transferred to §12:08:01:03.

12:08:03:05 Labeling of the water sample. Transferred §12:08:01:03.

12:08:03:06 Commission waiver. Transferred to §12:08:03:01.01.

12:08:03:07 Notice of well locations. Repealed.

12:08:03:08 Dry draw. If an application is made for a dry draw at a time during the year when a water sample cannot be obtained, the division shall process the application and the applicant shall submit a water sample for analysis when water is available during the irrigation season.

Source:
General Authority: SDCL 46-5-6.7
Law Implemented: SDCL 46-5-6.2, 46-5-6.3

12:08:03:09 Additional points of diversion. An application for the amendment of an existing water permit for one or more additional points of diversion does not require a soil-water compatibility approval if the application is for no additional water and no additional lands and the proposed point is within a 2,000-foot radius of the original well and is in the same aquifer.

Source:
General Authority: SDCL 46-5-6.7
Law Implemented: SDCL 46-5-6.2, 46-5-6.3

# CHAPTER 12:08:04

## SOIL-WATER COMPATIBILITY STANDARDS



12:08:04:01 Soil-water compatibility standards. The following soil-water compatibility standards shall be used to determine whether or not the permit application is granted:

WATER QUALITY STANDARDS
FOR SOUTH DAKOTA IRRIGATION WATERS
AS REVISED ____________

MAXIMUM ALLOWABLE SALINITY* (EC $10^6$) AND SODIUM (SAR) VALUES
PERMISSIBLE FOR WATERS

| Soil texture families | | ADJUSTED SAR OF WATER *** | 40 inches or less to more permeable material** ECx$10^6$ | 40 inches to 72 inches to more permeable material** ECx$10^6$ | 20 inches to 60 inches to less permeable material** ECx$10^6$ |
|---|---|---|---|---|---|
| Sandy | Sand | 17.0 | 3000 | 3000 | 3000 |
| | Mixed | <8.5 | 2800 | 2500 | 2000 |
| | | 8.5-11.5 | 2500 | 2300 | 1700 |
| | | 11.5-16.0 | 2200 | 2000 | 1400 |
| Coarse Loamy | | <8.5 | 2600 | 2200 | 1800 |
| Coarse silty | | 8.5-11.5 | 2300 | 1900 | 1300 |
| | | 11.5-16.0 | 1900 | 1500 | 1100 |
| Fine loamy | | <8.5 | 2100 | 1900 | 1700 |
| Fine silty*** | | 8.5-11.5 | 1800 | 1600 | 1200 |
| Clayey | | <8.5 | 1900 | 1700 | 1500 |
| Fine, very fine | | 8.5-11.5 | 1700 | 1500 | 1100 |

For waters having more than 10 milliequivalents per liter of calcium and more than 10 milliequivalents per liter of sulfate, add 400 micromhos to all categories.

*The $ECx10^6$ values are based on 12 inches or less of average rainfall during the normal growing season. For each additional 2 inches of rainfall during this period, the permissible $ECx10^6$ values may be increased by 200 for all categories.

**Permeable material is defined as soil texture of loam, silt loam, silt, or coarser material.

***The adjusted sodium adsorption ratio has been corrected to consider an empirical factor for the soil weathering effects.

****Soils of the fine loamy and fine silty textural families with the solum of silt, silt loam, or loam and coarser may be considered in the coarse loamy and coarse silty category.

+These standards are subject to revision within two years after adoption and every 2 years thereafter as more research becomes available.

Source:
General Authority: SDCL 46-5-6.7
Law Implemented: SDCL 46-5-6.5

12:08:04:01:01 Water quality standards for boron in irrigation waters. The maximum allowable boron concentration permissible in water for irrigation use is 3.0 ppm for all soils.

Source: Transferred from 12:08:04:03
General Authority: SDCL 46-5-6.7
Law Implemented: SDCL 46-5-6.5

12:08:04:02 Slope consideration. The percent of slope allowed for the irrigation of specific soil types shall be determined by the recommendations stated in the Irrigation Guide for South Dakota, 1978 edition, pages S-13 to S-40, inclusive.

Source:
General Authority: SDCL 46-5-6.7
Law Implemented: SDCL 46-5-6.5

Reference: Irrigation Guide for South Dakota 1978 edition, pages S-13 through S-40, inclusive, United States Department of Agriculture, Soil Conservation Service. Copies may be obtained from the Soil Conservation Service, 200 4th St. SW, Huron, South Dakota 57350-2475. Cost may vary per page. All Soil Conservation District offices have the publication on file for public use.

12:08:04:03 Boron standards for irrigation waters. Transferred to §12:08:04:01.01.

12:08:04:04 Internal drainage. The division shall review the soils interpretative data sheets to evaluate the natural internal drainage capabilities of the soil and shall use these sheets in the estimation of internal drainage under the proposed irrigation regime. If in the opinion of the division the internal drainage is not adequate and cannot be addressed through the use of management practices, the permit shall be denied.

Source: Transferred from 12:08:05:03
General Authority: SDCL 46-5-6.7
Law Implemented: SDCL 46-5-6.5

# CHAPTER 12:08:05

## APPLICATION STANDARDS



<u>12:08:05:01 Standards for issuing an approved permit</u> Applications meeting the following table of standards shall be granted an approved permit:

| | |
|---|---|
| Electrical conductivity | Less than 1400 micromhos/cm |
| Adjusted sodium adsorption ratio | Less than 5.0 |
| Surface texture (A horizon) | Loam, silt loam, silt, or coarser |
| Subsurface material (B or C horizon, or both) | Loam, silt loam, silt, or coarser |

The area to be irrigated may not contain more than 15 percent of those soil types which do not meet these standards, slopes may not be greater than 9 percent, and internal drainage must be adequate.

<u>Source:</u>
<u>General Authority:</u> SDCL 46-5-6.7
<u>Law Implemented:</u> SDCL 46-5-6.5

<u>12:08:05:01.01 Standards for issuing an approved with requirements permit.</u> Applications meeting the following standards may qualify for a permit approved with requirements:

The area to be irrigated may not contain more than 25 percent of soils generally not suited to irrigation and areas where slopes are greater than 9 percent or drainage is inadequate, unless those areas can be removed from the proposed project or the applicant can provide plans for the management of the areas which are considered adequate, by the Division and subject to the approval of the Conservation Commission.

<u>Source:</u>
<u>General Authority:</u> SDCL 46-5-6.7
<u>Law Implemented:</u> SDCL 46-5-6.5

<u>12:08:05:02 Maximum allowable limits for all permits.</u> The standards in the following table are the maximum allowable limits of salt and sodium buildup in

the profile at the root zone (upper 12 inches of the soil profile) at the beginning of the growing season. They become applicable upon the issuing of a soil-water compatibility permit by the division or the commission.

The maximum allowable limits are as follows:

| | |
|---|---|
| Saturation extract electrical conductivity | 3000 micromhos/cm |
| Exchangeable sodium percentage | 8 percent |

Source:
General Authority: SDCL 46-5-6.7
Law Implemented: SDCL 46-5-6.5, 46-5-6.6

12:08:05:03 Internal drainage required. Transferred to §12:08:04:04.

12:08:05:04 Laboratory analysis. Transferred to §12:08:01:05.

12:08:05:05 Disapproval of an application. If the division disapproves an application for a soil-water compatibility permit, the applicant may request a hearing before the commission.

The commission shall follow the procedures set forth in SDCL 1-26 for a contested case hearing.

Source:
General Authority: SDCL 46-5-6.7
Law Implemented: SDCL 46-5-6.6

# CHAPTER 6.B.

# AGRICULTURE AND IRRIGATION

# IN SOUTHERN ALBERTA

by

U.S. Bureau of Reclamation
Engineering and Research Center
Denver, Colorado

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CONTENTS



TABLES

## 6.B.1
## INTRODUCTION

Agriculture is one of the primary industries in the Alberta Province today. The southern region of Alberta, one of the principal agricultural producing areas of Canada, is generally described as lying east of the Rocky Mountains and west of the Alberta-Saskatchewan border and extending north of the Canada-United States border a distance of approximately 125 miles. It is located in an area between 100 degrees and 114 degrees west longitude and 49 degrees and 52 degrees north latitude. This area encompasses a major portion of the 10,000 square mile Oldman River Basin, which is composed of three major river systems - tThe Bow, the Oldman, and the St. Mary. Southern Alberta has a total land area of approximately 15 million acres. Of this total, about 6 million acres or 40 percent comprise improved farmland - 1.2 million acres irrigated and the remaining 4.8 million acres nonirrigated. At present, irrigated lands comprise about 20 percent of the improved farmland and roughly 8 percent of the total surface area of southern Alberta.

As early as 1898, irrigation was developed in southern Alberta by the Alberta Irrigation Company. However, the main era of irrigation development occurred at the turn of the century when the railroad companies began larger developments on tracts of land that had been granted to them by the government as incentives to construct the railroad. These large projects - one near Lethbridge, a part of the present St. Mary Project, and two other projects located north of the Bow River between Calgary and Medicine Hat which later became the Eastern and Western Irrigation Districts - were developed in this manner. During this same period, a large irrigation project was developed on the southside of the Bow River which was later to become the Bow River Irrigation District.

Since the beginning of organized irrigation in Alberta, in 1900, the area of land irrgated has increased steadily (table 1). The assessed acreage (table 2) is more than the irrigated acreage. This reflects climatic and economic conditions. In seasons of low rainfall and in times of good economic conditions more land is irrigated than in other times.

These irrigation districts were organized into quasi-municipal bodies which operate under the legislative authority of the Alberta Irrigation Act of 1968. Each district elects a board of directors, independently manage their affairs and levy and collect water fees under the Alberta Resources Act. Each district is licensed to divert specific amounts of water.

Since water project development first began in the area, water management, irrigation, drainage and cultivation practices have been developed in response to the unique climatic and soil conditions of the area.

Table 1

**Area of land aotually irrigated in Alberta over the years**

| Irrigation District | Head-quarters Location | Acres Irrigated | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 1930 | 1940 | 1950 | 1960 | 1970 | 1975 | 1980 | 1985 |
| Aetna | Cardston | ---- | ---- | ---- | 440 | 2,523 | 2,400 | 2,500 | 2,933 |
| Bow River | Vauxhall | 31,207 | 37,906 | 36,508 | 71,392 | 77,580 | 98,332 | 134,493 | 174,087 |
| Eastern | Brooks | 89,913 | 146,211 | 180,000 | 189,761 | 199,729 | 179,095 | 212,524 | 244,763 |
| Leavitt | Cardston | ---- | ---- | 2,500 | 1,542 | 4,523 | 4,430 | 4,476 | 3,664 |
| Lethbridge Northern | Lethbridge | 70,007 | 72,492 | 78,721 | 71,006 | 49,783 | 70,859 | 95,979 | 114,635 |
| Magrath | Magrath | 5,167 | 3,700 | 3,500 | 5,000 | 5,000 | 6,000 | 8,000 | 13,000 |
| Mountain View | Mountain View | ---- | 3,000 | 3,300 | 2,789 | 2,789 | 3,000 | 2,900 | 3,184 |
| Raymond | Raymond | 7,000 | 13,000 | 12,000 | 15,200 | 15,000 | 21,500 | 19,137 | 36,286 |
| Ross Creek | Irrine | ---- | ---- | ---- | 200 | 1,000 | 600 | 600 | 700 |
| St. Mary River | Lethbridge | 67,004 | 75,766 | 77,674 | 179,477 | 134,982 | 175,883 | 251,914 | 305,560 |
| Taber | Taber | 19,322 | 21,391 | 21,864 | 29,448 | 50,094 | 44,606 | 63,202 | 70,133 |
| United | Glenwood | 5,847 | 10,500 | 9,758 | 16,536 | 15,019 | 4,952 | 12,607 | 12,620 |
| Western | Strathmore | 41,570 | 20,134 | 23,100 | 12,000 | 15,000 | 34,036 | 43,986 | 49,666 |
| TOTAL | | 337,031 | 404,973 | 448,925 | 594,791 | 573,022 | 641,693 | 852,318 | 1,031,231 |

Table 2

**Assessed acres of irrigated land in Alberta**

| Irrigation District | Year Organized | Assessed Acres | | | |
|---|---|---|---|---|---|
| | | 1970 | 1975 | 1980 | 1985 |
| Aetna | 1945 | 6,673 | 3,081 | 3,104 | 3,399 |
| Bow River | 1909* | 23,783 | 131,764 | 164,889 | 185,034 |
| Eastern | 1935 | 199,729 | 212,982 | 229,110 | 246,658 |
| Leavitt | 1944 | 4,523 | 4,430 | 4,477 | 4,460 |
| Lethbridge Northern | 1920 | 89,360 | 108,106 | 112,562 | 118,883 |
| Magrath | 1898** | 8,506 | 8,871 | 10,797 | 14,218 |
| Mountain View | 1920 | 3,719 | 3,720 | 3,710 | 3,710 |
| Raymond | 1898** | 20,847 | 26,920 | 33,681 | 44,990 |
| Ross Creek | 1949 | 2,068 | 2,068 | 1,776 | 1,319 |
| St. Mary River | 1898** | 197,540 | 252,019 | 293,126 | 328,065 |
| Taber | 1919 | 57,484 | 62,692 | 70,368 | 73,063 |
| United | 1920 | 33,353 | 33,358 | 33,544 | 33,854 |
| Western | 1944 | 44,006 | 45,311 | 76,029 | 85,698 |
| TOTAL | | 691,591 | 895,322 | 1,037,173 | 1,143,349 |

* Bow River Irrigation District increased 94,000 acres in 1974 with the amalgamation of the Bow River Irrigation District and the Bow River (Federal) Project.

** Originally the Magrath, Raymond, and St. Mary River projects were known as the Lethbridge Section CPR. The St. Mary River Irrigation District as now known was not formed until 1968.

## 6.B.2
## TYPES OF CROPS

The irrigated lands of southern Alberta perform a significant role in Canadian agriculture. Southern Alberta comprises a total land area of over 15 million acres including 11 million acres of farmland of which 1.1 million acres were classified as irrigable and about 1.2 million acres are presently irrigated. A study by Thiessen and Smith (1981) indicated that the farmlands of southern Alberta were distributed among 8,188 farms, classified as follows: dairy, 4 percent; cattle, 31 percent; hogs, 2 percent; poultry, 1 percent; wheat, 29 percent; small grains, 18 percent; other field crops, 5 percent; mixed farms, 6 percent; and other types, 4 percent. Table 3 lists the area planted to various crops and the estimated gross value of the crops grown on irrigated lands in 1979. This area had a total estimated gross crop value of $220.8 million and an average gross return of about $540/ha.

A number of economists have attempted to simulate the value of crops grown under dryland conditions to arrive at a comparison of returns from drylands to those of irrigated lands in this region. Thiessen and Smith (1981) estimated the average gross return from simulated dryland crops to be $88.75/ha. Other estimates of the average gross return from simulated dryland farming have varied from $75 to $115/ha, depending on the area for which the estimate was made (Anderson, 1978; Hobbs, 1970).

Considerable variation in cropping patterns occurs between areas and from year-to-year within this region. A study of selected sites in the southern Alberta area by Thiessen and Smith (1981) revealed that the following crops had been planted: 51 percent grain, 31 percent forage, and 18 percent speciality crops as shown in table 3.

**Table 3. Acreage and value of irrigated crops, southern Alberta, 1979.**

| Crop | Area * (ha) | Estimated Gross Value ** ($ 1,000) |
|---|---|---|
| Wheat | 89,100 | 34,700 |
| Oats | 7,600 | 2,375 |
| Barley | 80,500 | 31,841 |
| Flax | 9,400 | 4,890 |
| Other grain | 14,000 | 5,330 |

Table 3 -- continued.

| Crop | Area * (ha) | Estimated Gross Value ** ($ 1,000) |
|---|---|---|
| Rapeseed | 26,800 | 13,909 |
| Sugarbeets | 13,100 | 24,356 |
| Potatoes | 4,600 | 9,117 |
| Peas | 4,400 | 8,872 |
| Beans | 5,826 | 5,039 |
| Carrots | 100 | 197 |
| Miscellaneous vegetables | 600 | 946 |
| Hay and alfalfa | 91,000 | 39,205 |
| Alfalfa and grass seed | 2,600 | 2,450 |
| Green feed | 3,000 | 1,108 |
| Pasture | 34,900 | 25,850 |
| Nursery | 200 | 624 |
| Lawn turf | 300 | 1,038 |
| Summerfallow | 8,900 | ------ |
| Miscellaneous | 2,000 | 723 |
| TOTAL | 408,100 | $220,842 |

* Rounded to the nearest 100 ha (Thissen and Smith, 1981)
** In Canadian dollars

Because of the major influence of the saline tills upon crop production throughout the region, no discussion of cropping patterns would be complete without considering salt tolerances of various plants. Although cropping decisions cannot be based entirely on salt tolerances of plants, apart from yields and other economic factors, it has become a very important consideration in deciding what crops to plant in a specific area.

Studies by Maas and Hoffman (1977) and Holm (1982) showed that, across the salinity gradient, barley yields were higher than those of oats, wheat, and other cereal grains. Since barley showed highest yields under saline conditions, a number of varieties have been tested. While not always providing highest yields, the Bonanza variety was the most resistant to salinity.

Of the oilseeds, sunflowers outperformed all others under higher levels of salinity, followed by safflower. Rapeseed was classified to be tolerant (T) of salinity of the oilseeds being studied. As a result of these studies, the following classifications of crop salinity tolerances were noted: Fairway Crested Wheatgrass and Tall Wheatgrass were tolerant (T); barley (forage), ryegrass (perennial), and wheat were moderately tolerant (MT); and alfalfa and corn were sensitive.

Stanley/SLN Consulting (1978) found that salt-sensitive crops experienced significant crop yield decreases at moderate levels of soil salinization. Alfalfa, beans, broadbeans, cabbage, carrots, cloves, corn, cucumber, flax, lettuce, onion, pepper, potato, radish, and tomato crops experienced 30 percent or greater reductions in yields when soil salinity equaled or exceeded 4 mmhos/cm. On moderately saline soils (4.8 mmhos/cm), speciality crops (vegetables and potatoes) suffered yield losses of 50 percent or more; yield losses for alfalfa were 50 percent; and yield losses of wheat were 40 percent in the Oldman Basin. Barley, soybean, salt-tolerant grasses, and sugar beets were grown in the Oldman Basin without significant yield reductions on soils having salinities of 4 to 8 mmhos/cm.

## 6.B.3
## IRRIGATION PRACTICES

Salinity and drainage have been identified as two of the main problems facing agriculture in this region today. For the most part, these conditions result from documented complex mixes of some or all of the following: (1) The types of soils, including heavy, fine textured soils (clay-loam and clay soils) which restrict lateral and vertical water migration; (2) improper balances or excesses of salts and minerals contained in soil parent materials and in irrigation water, including return flows; (3) the existence of a glacial till (in which some cases, is underlain by marine shale resulting in saline soil) or hardpan located near the surface of the soil which impedes the vertical movement of water; (4) improperly constructed canals, resulting in water seepages; (5) poorly designed field layouts for efficient irrigation, resulting in excessive water use and/or losses; (6) mismanagement of water, either overirrigation or underirrigation (more typical of this area); (7) improper scheduling of water applications; (8) improper cropping decisions, (inconsistent with existing salinity and drainage conditions); and (9) climate conditions, including precipitation, temperature, humidity, and wind. The remainder of this chapter will focus on salinity and drainage problems and their impact on agriculture in southern Alberta, along with various water management practices (both irrigation and drainage) which have been developed to deal with these problems.

## 6.B.3.1
## Amounts of Water Applied

The objective of irrigation as a practice, is to provide a suitable amount of moisture in the soil for plant growth to occur. The water should be applied uniformly and distributed evenly over the surface of the soil. In subhumid and semiarid regions, the amount applied should be less than the amount needed to bring the crop root zone to field capacity so as to reserve soil-water storage capacity for rainfall. Overirrigation that causes deep percolation and leaching of soil nutrients should be avoided. Underirrigation that causes plant stress and results in the accumulation of salts in the upper soil should also be prevented.

The amount of water to apply depends on the stage of plant growth, on the salt tolerance of a specific crop, and on the acceptable level of salinity, in terms of prevailing water, soil, crop, and economic conditions. In the early stages of plant development, it is desirable to irrigate the soil to "field capacity" only to a depth just beyond the rooting zone. In order to sustain the long-term productivity of the soil, extra irrigation water may need to be applied periodically to leach out excess salts and maintain a favorable salt balance in the root zone. However, snowmelt and spring rains will usually provide sufficient deep percolation for leaching and salt balance in southern Alberta.

The amount of irrigation water to be applied varies substantially throughout the region depending on conditions. Cereals require most of their water during the root- and grain-forming stages. In southern Alberta, irrigation of grains can cease after about July 20 without a significant yield loss. However, alfalfa will grow vigorously over the entire summer if cut and watered regularly. Therefore, as long as the alfalfa plant is large, and the weather is warm and sunny, its moisture use will be high.

In an evaluation of a center pivot irrigation system in the Oldman River Basin, Pohjakas (1977-1980) measured actual water applications by farmers over a period of 4 years. The actual quantities of water applied to various crops, and the percent this represented of their total water requirements, were as follows: alfalfa, 6.7 inches (27 percent); wheat, 4.48 inches (25 percent); barley, 2.68 inches (16 percent); corn silage, 5.64 inches (45 percent). Water deficits for the above crops ranged from a low of 136 mm (5 inches) for barley to a high of 223 mm (9 inches) for alfalfa.

Other reports (Schaack, 1985) show overall water application amounts in southern Alberta ranging from about 6 to 15 inches, depending on the crop irrigated, natural precipitation, and other pertinent conditions.

The effectiveness of irrigation water management and avoidance of water losses is often referred to by engineers as "irrigation efficiency." Irrigation efficiency is commonly used to describe the ratio of water stored in the soil during an irrigation season relative to the volume of water delivered to the field. Overall efficiency of an irrigation system is the product of three basic components, as follows:

1. Storage Efficiency - the volume of water delivered from a reservoir to the delivery system, as a percentage of the volume of water diverted from the stream flow to the storage reservoir.

2. Water application efficiency (also known as "Farm efficiency") - the volume of water transpired by plants, plus the volume that evaporated from the soil, plus the volume necessary to maintain a favorable salt balance in the soil, as a percentage of the total volume of water delivered to the farm.

3. Water conveyance efficiency. The volume of water delivered at the farm headgate, by an open or closed conveyance system, as a percentage of the total volume of water delivered to the conveyance system at the supply source.

In a study of 10 different districts within the Oldman River Basin, Massland (1978) found that conveyance efficiencies ranged from a low of 40 percent in the United, Aetna, Mountain View, and Leavitt Irrigation Districts to a high of 77 percent in the St. Mary and Eastern Irrigation Districts. Farm efficiencies ranged from a low of 35 percent in the Magrath, Aetna, Mountain View and Leavitt Irrigation Districts to a high of 58 percent in the Taber Irrigation District. Stanley/SLN Consulting (1978) predicted that, if optimum methods and practices were employed, the irrigation systems in southern Alberta could conceivably be improved to attain a conveyance efficiency of 85 percent and a farm efficiency of 80 percent over a period of years. In another study of efficiencies in the Lethbridge Irrigation District between 1968 and 1978, McKenzie (1982) observed a conveyance efficiency to be 60 percent and the farm efficiency to be 44 percent.

Management of irrigation water (on farm and in the distribution system) in Alberta is perceived to be a very critical element in minimizing drainage problems. Although there are some exceptions, most irrigators in Alberta utilize efficient irrigation techniques including the concept of deficit irrigation (frequent irrigations which do not exceed available soil moisture holding capacity) which minimizes deep percolation and water table buildup. This practice has diminished salinity in the root zone of the soil profile; as stated previously, the salinity concentration in the root zone has generally decreased in the irrigated areas of southern Alberta. Providing lining in canals and laterals with excessive leakage also helps to reduce water-table buildup.

### 6.B.3.2
### Quality of Water Applied

The quality of the irrigation water in southern Alberta is 300-500 ppm TDS which is excellent. Some water which is reused and/or pumped from groundwater is of lower quality but is still very satisfactory for irrigation purposes.

Traditionally, one of the most important indices of continued successful irrigation is the maintenance of a salt balance in the soil. The accumulation of excessive soluble salts may occur in soils as water is removed through evaporation and transpiration and sufficient leaching does not take place. Since soluble salts must not be allowed to accumulate to toxic levels in the root zone, they must be removed by some form of water management and either stored in the soil profile below the root zone or returned as drainage to the stream from which the irrigation water was withdrawn. Generally speaking, the rate at which salts accumulate in irrigated soils is slower in humid and subhumid regions (such as CENDAK and southern Alberta) than in arid and semiarid regions because a larger portion of the water crops need is provided by rain.

Among other things, the following factors affecting salinity have been identified: (1) the presence of initial soil salts; (2) the existing salt content and ion concentration in irrigation waters; (3) the dissolution of soluble salts, such as lime and gypsum; (4) the ratio of water, both from precipitation and irrigation, applied to soil in relation to the evapotranspiration rate; (5) the efficiency of the soil in leaching salts; (6) the type and efficiency of the irrigation system; (7) uniformity of distribution and infiltration of irrigation water; (8) the height of the water table; (9) field capacity and drainage effectiveness; and (10) the physical characteristics of the soil (including texture, stratification, density, etc.) which affect the vertical and lateral movement of soil water.

To sustain optimum growth, the salt concentration in the root zone must be maintained below a specific salt level, depending on the crop and the desired yield. As a general rule, salinity levels in excess of 1,000 mg/L are usually undesirable for agriculture. Based on a review of the existing scientific literature, water quality, is not a general problem in the southern Alberta region at this particular time. This is probably due to the fact that surface waters are of excellent quality. However, with the expansion of irrigation and increased recycling of water throughout the region, salt concentration in the water might rise in the future.

In 1979 Oosterveld, et al. studied the transfers of water, salt, and nutrients into, within, and out of the Bow River Irrigation District. He observed that the salt content of the water in the Little Bow River was higher than in the Bow River and that the water quality along a 98 km canal system was essentially constant from one end to the other. Total dissolved and suspended matter in the return flow ranged from a low of 22.4 mg/L at one of the Hays drains to 300.6 mg/L at one of the Vauxhall drains, which consistently showed the poorest water quality.

The water used for irrigation in the 54,000 - acre Bow River Irrigation District of Alberta from 1974-1976 was of excellent quality. About 87 percent of the return flow came from high quality surface sources, including runoff from flood irrigation and spill water from canals and reservoirs. Of the three blocks studied in the district, only one had a net outflow of salt for a 2-year period.

According to Oosterveld, the results of this study are reasonably representative of the range of conditions found in the other irrigation districts of southern Alberta. In general, it was stated that few irrigation areas of North America with similar soil conditions have a salt index (averaging from 300-500 p/m per year) as low as that of southern Alberta.

### 6.B.3.3
### Methods of Application

At the time irrigation was first introduced in southern Alberta, it consisted predominantly of surface irrigation. In the surface method, water is applied directly to the soil at the ground level and flows by gravity over the surface, using border dikes, border ditches, and contour ditches. The border dike is the most common form of surface or flood irrigation used in this area - accounting for almost one-third of the irrigation systems (Thiessen and Smith, 1981).

Over the past 25 years, there has been a major shift from surface flooding to sprinkler irrigation. In southern Alberta today, about 76 percent or 912,000 acres of the approximate 1.2 million acres of irrigated land is under sprinkler irrigation of which about 50 percent is irrigated by the side wheel method and 50 percent by the pivot method (Schaack, 1985).

The types of sprinkler irrigation systems used range from hand-move systems to fully automatic center-pivot systems. A recent design of center pivot systems directs the water downward at relatively low pressure which reduces evaporation losses and results in lower total energy requirements than the high pressure large nozzle units.

Studies of surface and sprinkler irrigation efficiencies by R. C. McKenzie (1982) revealed that center pivots used to irrigate crops in the Lethbridge and Medicine Hat areas had very little shut down time due to crop water requirements and shortness of season. A center pivot irrigating one circle must operate all but 15 days for cereals and all but 5 days for hay in order to provide sufficient water for plant growth during the growing season. A center pivot was found to provide 5.5 mm of water daily when irrigating one circle and 3.9 mm for two circles. Normal consumptive water use by cereals and forage crops is from 6-7 mm per day during the peak of the growing season. This results in a water deficit, unless stored soil water or summer rainfall is available to the plants.

Wheel roll systems with two 400-meter (1/4 mile) lines per 160 acres are capable of meeting the irrigation requirements of cereals if the system is fully utilized, but are not capable of meeting the irrigation requirements of hay. Wheel roll system with 4 lines are seldom used except for potatoes and sugar beets. A wheel roll system with 2 lines on 160 acres irrigated 3.7 acres at one set and provided 0.36 inches/hour at 75-80 percent efficiency. Under this method cereals and hay received about half of the amount of irrigation needed for optimum growth (McKenzie, 1982).

From this study of irrigation efficiencies it was concluded that:

1. Alfalfa hay which is deep rooted received near optimum irrigation when it was irrigated twice;

2. Cereals that were irrigated once did not receive sufficient moisture at the beginning and at the end of the growing season;

3. Water tables appeared to be a problem and were contributing to salinity in about one-third of the fields studied;

4. A center-pivot system was estimated to function 85 percent of the time; while a wheel roll system was estimated to function 95 percent of the time;

5. Many crops which were irrigated by pivots and wheel rolls did not receive sufficient irrigation water and suffered from moisture stress and salinity-induced moisture stress;

6. Sprinkler systems did not provide sufficient water for many crops at peak use times;

7. Wet saline areas were very difficult to cross with both center pivot and wheel roll sprinkler systems which accounted, in part, for the failure by farmers to irrigate fields adequately;

8. Most cereal crops which received surface irrigation using border dikes only once during July suffered from moisture stress and salinity-induced moisture stress early in the growing season;

9. If cereals were surface irrigated more than once during the season, this increased the risk of high water tables and more salinity;

10. Farmers using surface irrigation seldom put irrigation ditches in their cereal fields until after weed spraying in early July and by that time the crop had already gone through the stages where it is most sensitive to salinity;

11. Installation of canal lining, drainage, and automation systems were recommended as measures by which to improve irrigation, but not before consideration of costs and returns.

From this study it was generally concluded that greater awareness of water management, soil salinity, and crop tolerance for various salts should assist in developing solutions to minimize some of the problems that constantly confront farmers throughout this area.

## 6.B.3.4
## Canal Systems

The original water conveyance system in this area consisted mostly of open, unlined earth canals which followed the contours of the lands. These canals were mostly located along hill sides with side slopes steeper than 2 horizontal to 1 vertical, resulting in substantial seepage potential (Paterson and Harber, 1980). To avoid excessive seepage problems, it has been stated that canals should not have been constructed on hill sides with slopes which exceeded 3 horizontal to 1 vertical.

Although dryland salinity problems predated the development of irrigation, the first salinity on irrigated land was observed shortly after the turn of the century, or about 15 years after irrigation was first introduced in the area (Vander Pluym, 1982). At the time, erosion protection along canals and ditches was inadequate, resulting in seepage, salinity, siltation, and weed problems which resulted in higher maintenance costs and lower conveyance efficiencies.

Prior to 1958, water conservation and seepage from irrigation canals were not major concerns in southern Alberta. Water was generally available in adequate quantities and at low cost so that water conservation was not a determining factor in stressing the need for canal lining. However, with the passage of time and expansion of irrigation the gradual buildup of saline and akaline soil conditions along irrigation canals resulted in the introduction of drainage systems and canal seepage control measures.

There was greater incentive for seepage control measures with the continued rise in land values and when some of the landowners filed crop-loss claims against irrigation districts due to seepage. As the conditions of water loss and soil salinity became more prevalent considerations in water management programs throughout the area and various methods and materials for lining canals were tested and adopted.

Preliminary investigations often included borings to determine the types of soil in the area to be traversed by the canal, down to the level of excavation. Porous materials, such as gravel and sand, were avoided whenever possible.

### 6.B.3.4.1
### Types of Lining

To avoid water losses, canals have been lined with earth, concrete, or flexible membrane lining materials. The first attempts at lining irrigation canals in this area involved the use of polyethylene membranes of 0.14 to 0.20 mm (5 to 8 mil) thickness. Between 1958 and 1972, 200 km (124 miles) of canals were lined with buried membranes. These liners were generally effective in reducing water losses, provided there was no physical damage to the membrane. Physical damage to buried membrane lining has resulted from a loss of cover due to erosion, livestock punctures, and external hydrostatic pressures. Also, considerable damage was suspected to have been caused by equipment and machinery during installation and maintenance operations. In recent years, heavier, more durable polyethylene membranes (0.5 mm or 20 mil thickness) have been used for canal linings. To remain effective, buried membrane linings are often protected from physical damage through the use of non-erosive cover materials (Thiessen and Smith, 1981). Buried membrane linings do not, however, control weed growth and silting as effectively as concrete and, therefore, maintenance costs are not reduced significantly by this type of lining.

According to Thiessen and Smith (1981), unreinforced concrete lining has been installed in 275 km (175 miles) of irrigation canals since 1966. Concrete lining is put in place by mechanical slip form methods at 75 mm thickness, using 1.5 horizontal to 1.0 vertical side slopes.

In addition to controlling water losses and reducing maintenance costs related to aquatic and canal bank weed growth, concrete linings in large irrigation canals enable a higher velocity of water flow and permit the cross-sectional area of the channel to be reduced in size and "drops" to be omitted. The main disadvantage of concrete lining is the potential for cracking which occurs with foundation shrinkage, freeze-thaw action, and swelling and hydrostatic pressure on the side slopes. These problems may result from frost action, excessive moisture in the soil, lack of compaction prior to placement, high ground water, or a change in soil loading conditions. Due to extensive deterioration, the use of unreinforced concrete lining has almost entirely been discontinued.

An investigation and inventory of concrete-lined canals in the area was performed by Underwood, McLellen and Associates in May, 1979. A total of 207 km (128 miles) of concrete-lined canals within four different irrigation districts were categorized by the extent and causes of cracking. Although the extent of cracking was high, not all cracks represented total failure of the lining. It was found that cracks and displacement up to one-half thickness of the lining may be tolerable and may be repaired using a bituminous-based filler. A well compacted foundation prepared to support the concrete lining also provided a relatively impermeable layer to water penetration.

Buried pipe distribution systems have also been used but are normally limited to canals having maximum capacities of 3 m3/s due to high installation costs. The most common materials used in buried pipe systems are polyethlene and preset reinforced concrete pipe.

The advantages of buried pipes include reduced evaporation loss, safety, least disturbance of land surface, elimination of weed problems, and relatively low maintenance costs. According to Thiessen and Smith (1981), approximately 90 km (56 miles) of buried pipe irrigation supply systems were installed between 1971 and 1981. In 1978, a typical installation consisted of 800 m (2,640 feet) of 558 mm (22.3 inches) diameter reinforced concrete pipe. At that time the cost of installation ranged from $67 per lineal meter for concrete to $57 per lineal meter for polyethylene pipe.

Research is ongoing to develop and evaluate the effectiveness of a variety of new methods and materials for use in lining canals. In addition to pipelines, polyethylene membranes and compacted earth, the following types of materials are being tested: soil sealants, sulphur, reinforced concrete, fiberglass and fiberglass with polyester, aluminum, butyl rubber, PVC, prefabricated asphalt sheeting, hot spray-on asphalt, fabric, and a number of others (Schaack, 1985).

### 6.B.3.4.2
### Seepage Problems

Of the total 6 million acres of agricultural land, 10 to 12 percent (120,000 to 140,000 acres) of the 1.2 million acres of irrigated land and 10 to 12 percent (480,000 to 575,000 acres) of the 4.8 million acres of nonirrigated farmland are affected by some degree of salinity and drainage problems. It has been estimated that 80 percent (about 100,000 acres) of the salinity problems on irrigated lands are due to canal seepage and that about 30,000 acres of the irrigated farm lands are being adversely affected by water table buildup (Vander Pluym, 1982).

Soil and water conditions and good irrigation management likely contribute to the less-than-anticipated drainage and salinity problems in this area. Deficit irrigation of land, good quality irrigation water, leaching from precipitation and snow-melt, along with the low infiltration rates of the predominantly heavy soils minimizes deep percolation losses and/or salt buildup. In addition, much of this area has moderate topographic relief with a well defined system of natural, relatively deep drainage channels situated below irrigated lands. It was observed, for example, that the river at Lethbridge is more than 100 feet below the irrigated areas.

Saline seeps, which are increasing in size and severity, are one of the major soil problems in this area today. Saline seeps refer to saline soils which develop on both irrigated and nonirrigated lands. They can be identified by the formation of a salt crust on the soil surface, a reduction in crop yields, the presence of salt tolerant vegetation, and a saturated soil zone during at least part of the year.

Factors responsible for the development of saline seeps include soil type, soil stratification, geology, subsurface salt reservoirs, climate and cultural practices. Saline seeps are caused and sustained by recharge areas located upslope from discharge areas. In the recharge area, water resulting from a summer-fallow field, a pond, drifted snow, or a leak in an irrigation canal will cause deep percolation. This water which is in excess of plant water requirements and the water-holding capacity of the soil combines with the groundwater. Lateral flow downslope then begins through one or more permeable layers. Consequently, the water table begins to rise on the downslope portion of the landscape. If the water table rises to within 1 meter of the surface, the groundwater, including soluble salts, may move to the surface through capillary action to form a saline seep. As the water evaporates in the discharge area, salts accumulate in the root zone of the soil.

## 6.B.3.4.3
## Reclamation of Seepage Lands

The reclamation of seepage lands depends to a large extent upon the prevailing conditions of the lands and soils to be reclaimed. The most common form of reclamation is generally to install some type of drainage system to intercept the supply of groundwater to the seep, followed by the application of a sufficient amount of water to the saline area to leach excess salts from the root zone. For large seeps, it may be necessary to also install a drainage system within the seep area to alleviate the problem before normal irrigation can be resumed.

## 6.B.3.5
## Irrigated Land Salinity

In southern Alberta, some soils with glacial till near the surface (150 cm or less) have been irrigated successfully over the past 70-80 years. In most regions, soils like these would be considered unsuitable for irrigation because they are difficult to drain artificially when salinization and waterlogging occur (Maierhofer, 1956).

According to Stanley/SLN Consulting Limited (1978), the salinity problems in this area are very serious and they estimated that about 174,500 acres of land, including nonirrigated and irrigated land, have salinized root zones in the districts of the Oldman River Basin. They reported that the most critical salinization of root zones has occurred in the Magrath and Raymond Irrigation Districts, followed by the Taber, Leavitt, and St. Mary River Irrigation Districts. High salt concentrations often occur at surface and subsurface outlets, such as springs, seepages at breaks in slopes and deposits, and in natural low areas which may act as evaporation ponds.

Stanley/SLN Consulting Limited (1978) also observed that poorly-scheduled irrigation (deficit) and underirrigation are common in the Oldman Basin and cause root-zone salinization in two ways: by concentrating the salts in the irrigation water and inducing capillary rise of saline groundwater.

However, some scientists and engineers believe that the formation of a high water table and salinization have been slow to occur in the Oldman Basin for a number of reasons, including:

1. Initial water tables may have been quite deep when irrigation started.

2. The irrigated acreage has expanded rather slowly.

3. The period of high evapotranspiration is relatively short (about 2-3 months), resulting from relatively short growing seasons and low temperatures.

4. Some spring rainfall and melting winter snows percolate through the soil profile.

5. The weathered tills contain two types of fractures - small and large - providing some permeability to the groundwater flow system; thereby, preventing the formation of perched water table conditions and buildup of soluble salts in the soil zone and resulting in natural drainage for existing flows underground.

6. Intergranular and fracture flow are accounting for some lateral and vertical movement of water, both above and below the water table.

7. Some of the areas which have developed salinity problems have been reclaimed through good management practices (water scheduling, deep plowing, etc.).

8. Although the topography of this area is moderately flat, some fairly deep incised waterways throughout the area provide good surface drainage and likely some amount of subsurface drainage.

9. The generally low infiltration rate of the relatively compact, heavy soils prevents overirrigation and deep percolation.

10. Deficit irrigation - the general practice in this area, which consists of applying less irrigation water than the water holding capacity of the soil, results in minimum deep percolation losses. It was stated during one field investigation that deep percolation (beyond 6 feet in depth) is an average of about 11 centimeters (4 inches) per year and that salt content of the soil profile generally decreases over time.

11. Migration of ground water to the freezing front.

A study by Chang and Oosterveld (1981) of the effects of long term (25-60 years) irrigation on soil salinity at 13 selected sites which were representative of the soil types of much of the irrigated land in southern Alberta, revealed that total soluble salts in the root zone of the soil profile were either reduced or unchanged at all sites except one.

A number of studies (Chang and Oosterveld, 1981) confirm the fact that although soils underlain by tills in this area have low permeability, the soils apparently have sufficient drainage to prevent waterlogging and soil salinization under normal irrigation procedures. Also, there was sufficent water from precipitation and irrigation to leach salts from the soil zone. The only sites where any increase in salinity occurred had very low initial salt contents and the salinity level that had occurred under normal irrigation was well below the level at which the most salt sensitive plants are affected. Although the sodium-absorption-ratio (SAR) increased slightly, the amounts were too low to affect permeability.

In another study of eight sites in the Bow River Irrigation District near Vauxhall, Alberta, Sommerfeldt and Oosterveld (1977) found that if the till occurred at a depth of 150 cm or more and good management practices were followed, salinity did not appear to be a major problem. When the till was between 120 cm and 150 cm, careful management was necessary to prevent salinization. Subsurface tills (90 cm or more in depth) did not necessarily limit internal drainage of irrigated soils, provided surplus water was not introduced by seepage or irrigation mismanagement. If the till was within 60 cm of the surface, continued irrigation under present management practices was questionable. It was determined that 45 percent of the irrigable lands in this district had till within 90 cm of the surface.

The above studies emphasize the fact that tills found at shallow depths of 90 cm or less cannot be classified as nonirrigable without hydrogeologic investigations to determine whether the till is weathered or unweathered, the amount of fracturing that exists and the hydraulic conductivity of the soil.

### 6.B.3.6
### Dryland Salinity

Under the original native vegetation, tall grasses and trees covered the higher rainfall areas, while short grasses covered the semiarid lands. These plants formed a climax prairie vegetation in response to climatic conditions, especially moisture, and became part of a hydrological and ecological balance in which soil moisture and precipitation were most nearly utilized. Grasses having a relatively long growing season and a moderately - high consumptive-use requirement, generally maintained groundwater levels sufficiently low to minimize the upward flow of salts through capillary action. The balance between consumptive use and water storage in the soil and precipitation resulted in a net downward movement of salts without raising the water tables. Consequently, deep percolation and salinization were non-existent, except for a few very wet years.

With the introduction of extensive agriculture to southern Alberta nearly a century ago, large acreages of land were brought into crop production. Cereal crops replaced more and more of the native vegtation, which upset the ecological balance. The introduction of summerfallow as a water conservation measure added to the problem by increasing the opportunity for water to percolate past the root zone. Water-table and soil salinity buildups occurred in downslope areas and where bedrock was shallow on hillside locations (see section 6.B.3.4.2. "Seepage Problems" for additional discussion).

A number of technical experts (Pohjakas, 1982) have indicated that the magnitude of the dryland salinity problem in southern Alberta today is major. In the dryland farming areas alone, more than a half million acres are affected by saline seeps and/or other related salinity problems. Of even greater concern, is the fact that this acreage is estimated to be increasing at an average annual rate of 10 percent. The total annual loss of net revenue from saline seepage was estimated to be about $90 per acre or $202 per ha.

The recommended practices for controlling saline seeps include (1) limiting the amount of water that percolates below the root zone by annual cropping (or flexcropping) or by use of deep rooted periennials like alfalfa, (2) surface drainage to eliminate depressions that serve as recharge areas for seeps located lower on the landscape, and (3) subsurface drainage to intercept the percolating soil water in or above the discharge area.

Flexcropping is a cultural system designed for nonirrigated lands whereby annual crops are planted on lands that might otherwise be fallowed when enough stored soil water is available in the spring so as to provide a good probability that a crop can be produced with the addition of expected growing-season precipitation.

## 6.B.3.7
## Leaching Requirement

Leaching requirement is the quantity of water, over and above that amount needed to meet the evapotranspiration requirements, which must be passed through the root zone to keep soil salinity within the limits of crop tolerance. The leaching requirement is greater for salt sensitive crops than for salt tolerant crops. The principle of salt balance requires that the amount of salt brought with the irrigation water must be removed from the root zone by deep percolation or in the drainage water. The usual means of controlling soil salinity is to maintain net downward flow of water in the root zone by employing appropriate irrigation management and, if necessary, by providing the proper drainage system. However, the leaching of salts from the root zone need not be accomplished with every irrigation in subhumid and semiarid regions because natural rainfall contributes to the leaching process.

Salinity is generally associated with the soil, but soluble salts move within the soil solution. Since the soil is the medium through which the water moves, the physical properties of the soil (such as permeability, cracks, texture and structure) significantly influence the flow process and leaching efficiency. The distribution and accumulation or removal of salts can be controlled by water management.

As mentioned previously, the key element in the success of irrigated agriculture in southern Alberta is good water management. It includes a combination of deficit irrigation (application amounts that bring the soil-water content to less than the available water-holding capacity of the soil so as to maintain storage capacity for natural rainfall), uniform and efficient application of irrigation water, and control of canal seepage. The success of good water management in the reduction of soil salinity has been reflected in the following studies.

Chang, et al. (1982) showed that after 50 years of normal irrigation there had been sufficient leaching to reduce the total soluble salt content in the soil root zone of two farms located near Tilley, Alberta. Oosterveld, et al. (1979) observed the salt balance in two different irrigation basins in southern Alberta - one irrigated with sprinklers and the other with the flood method. This study revealed that 11.7 tons of soluble salts per acre were moved below the root zone using sprinkler irrigation, while 13.7 tons of soluble salts per acre were moved below the root zone using flood irrigation.

Chang and Oosterveld (1981) conducted a study at 13 selected sites within four major irrigation districts - Eastern, Bow River, St. Mary River, and Magrath. Of these sites, 10 had been irrigated for a period of 60 years or more and three had been irrigated for about 25 years. Soil textures of these sites ranged from sandy loam to clay. Under normal irrigation, the total soluble salts in the soil profiles were either reduced or unchanged. After long-term irrigation at all sites except one, the magnitude of reduction in salts of soil profiles was directly related to the initial salt content and ranged between 0 percent and 82 percent of the original content. The SAR (sodium-absorption-ratio) decreased in the subsoil at all of the sites and long-term irrigation did not salinize the soils at any of these sites. Because of the wide range of soils throughout the study areas, it was concluded that the sites were moderately representative of the range of irrigated lands found throughout the southern Alberta region and that good water management practices were effective in controlling soil salinity.

From these studies and others regarding the leaching requirement of soluble salts, it became evident that irrigation management and drainage are interdependent and both require careful planning for successful sustained irrigation.

## 6.B.4
## ARTIFICIAL DRAINAGE

### 6.B.4.1
### Types of Artificial Drainage Systems

Estimates and data vary considerably on the amount of land affected by salinity and drainage problems in southern Alberta. However, the general consensus of opinion is that about 12 percent (144,000 acres) of the irrigated land has drainage and/or salinity related problems and about 80 percent (110,000 acres) of these drainage problems are attributed to canal seepage. The remainder of the affected land (34,000 acres) is being adversely affected by water-table buildup due to deep percolation from irrigation.

The majority of the measures taken to alleviate drainage problems principally consist of instituting good management practices, and installing drainage systems and canal lining. Research is ongoing to develop and evaluate the most feasible lining types. Nonreinforced concrete lining, which has been used previously, has been discontinued due to extensive and rapid deterioration. Reinforced concrete, pipelines, fiberglass, aluminum, butyl rubber, PVC, fabric, etc., are being used and/or tested for feasibility.

Drains have been constructed to remedy drainage problems for about 15,000 to 20,000 acres throughout the 1.2 million acre irrigated area. In general, it has been found in southern Alberta that drain installation is usually more economical than lining canals. An example given by Canadian experts shows that the cost of lining was $250,000 (C) versus $25,000 (C) for drain installation to reclaim 40 acres of land. It was also noted that most drainage problems have developed from 5-10 years after the beginning of irrigation.

Drain installation has increased in recent years despite the fact that farmers totally finance this activity as opposed to rehabilitation work on distribution facilities which is financed on an 86-14 (Province-district) basis. The primary reasons farmers desire drains are to improve trafficability and yield, in that order.

Most drains have been constructed at depths of 4-5 feet by plow without a gravel envelope. About half of the drain tube is installed with a nylon sock. Drain spacings are normally in the 50-100 foot range, with plot size averaging 20 acres. The cost for installed drains is $1-$2 per linear foot. Research work has been conducted in southern Alberta to determine optimum spacing, drain depth, drain design, location, and general configuration. The results of this work are presented in "Subsurface Drainage Guidelines for Irrigated Alberta" No. 83-004, March 1985.

Minimal data are available on the sustained satisfactory operation of the installed drains and the quality and quantity of the drain effluent. Studies have shown, however, that for 50 plus years the total salt content has actually decreased in the upper 6 feet of the soil profile. Salts are apparently being stored in the profile at depths greater than 6 feet where they are not detrimental to crop production.

Considering the soil conditions in southern Alberta, drainage problems have not developed nearly to the degree expected. Soils with low permeabilities and shallow barrier depths usually have poor natural drainage and thus have high artificial drainage requirements.

High quality irrigation water (300-500 ppm TDS), good irrigation management practices, and generally heavy topsoils with low infiltration rates all likely contribute to the minimal drainage problems encountered. It appears that very little deep percolation results from irrigation as most applications are less than the water-holding capacity of the soil. Therefore, most deep percolation results principally from precipitation and snowmelt, except for very heavy rainfall events that may occur occasionally during the irrigation season when the soil profile is at its full or near full water holding capacity.

## 6.B.5
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# CHAPTER 6.C.

# COMPARISON OF AGRICULTURE AND IRRIGATION IN SOUTHERN ALBERTA AND CENDAK

by

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CONTENTS

## 6.C.1
## INTRODUCTION

Irrigation of glacial till soils has been an ongoing process since about 1900 in southern Alberta and since about 1960 in the central South Dakota (CENDAK) area. Since these areas and soils are perceived to be similar in nature, comparisons have been made to project potential problems and successes encountered in Canada to South Dakota. Most of these comparisons have been verbal, fragmented, and inconsistent and not of a comprehensive nature. Chapter 6 of this report describes conditions under irrigated agriculture in these areas and the problems encountered particularly from a drainage viewpoint which is a major concern (due to the relatively low permeability of glacial till soils) and the emphasis of this report.

Following is a summary comparison of Chapter 6 "Agriculture" for the CENDAK and southern Alberta areas from an irrigated agriculture viewpoint with emphasis on the effects of past irrigation and related drainage problems and conditions.

## 6.C.2
## LOCATION

### 6.C.2.1
### Alberta (Canada)

The irrigated portion of southern Alberta lies east of the Rocky Mountains and west of the Alberta - Saskatchewan border and extends north of the Canadian-United States border a distance of about 125 miles. It is located within 100 degrees and 114 degrees west longitude and 49 degrees and 52 degrees north latitude. It encompasses a major portion of the Oldman River Basin which is composed of three river systems - the Bow, the Oldman, and the St. Mary.

### 6.C.2.2
### CENDAK (South Dakota)

The CENDAK project is located in east central South Dakota, east of the Missouri River and extends eastward to about Huron, South Dakota. The CENDAK area is located about 350 miles south and 600 miles east of the irrigated area in southern Alberta.

## 6.C.3
## IRRIGATION DEVELOPMENT AND IRRIGATED AREA

### 6.C.3.1
### Alberta (Canada)

Irrigation development began around 1900 in this area and by 1977 over 980,000 acres had been developed. At the present time about 1.2 million acres are being irrigated. Most of the irrigation works which provide water to these areas are administered by 13 irrigation districts.

### 6.C.3.2
### CENDAK (South Dakota)

Most irrigation in South Dakota has been developed since 1950, either on an individual basis or as irrigation districts. There are about 500,000 acres presently being irrigated. Most of this land is located in eastern and central South Dakota. About 40,000 acres are presently being irrigated by center pivot systems in the proposed CENDAK project area and most of this development has occurred since 1960.

## 6.C.4
## IRRIGATION PRACTICES AND SYSTEM EFFICIENCIES

### 6.C.4.1
### Alberta (Canada)

The general irrigation practice in this area is to apply less water per irrigation than required to reach the water holding capacity of the root zone, which minimizes deep percolation losses (optimum irrigation). A 4-year study of center pivot systems showed the actual water applied to crops was as follows: alfalfa 6.7 inches, wheat 4.5 inches, barley 2.7 inches, and corn silage 5.6 inches. Water deficits for these crops ranged from a low of 5 inches for barley to a high of 9 inches for alfalfa. Other studies show water application to range from 6 (cereals) to 15 (alfalfa) inches annually depending on conditions and crops. About 76 percent of the land is irrigated by sprinker system (50 percent sidewheel and 50 percent center pivot) and 24 percent by surface gravity method.

Studies on conveyances and farm efficiencies in Alberta showed that conveyance efficiencies range from a low of 40 percent to a high of 77 percent and farm efficiencies range from 35 to 58 percent. There are about 7,000 miles of canals and laterals in Alberta to serve the approximate 1.2 million acres. About 170 miles were concrete lined between 1958 and 1972. From 1971 to 1981 about 56 miles of pipelines have replaced open ditches in the system. It has been reported that the practice of installing drains is more economically feasible than lining canals.

### 6.C.4.2
### CENDAK (South Dakota)

Due to the generally heavy soils in this area with low infiltration rates,the amount of water applied per irrigation is also quite low (generally 1 inch). This practice helps to minimize percolation losses (optimum irrigation).

As reported by a sample survey of CENDAK area irrigators, 8 to 16 inches of water is applied per year depending on effective precipitation and other conditions. Irrigation efficiencies are not specifically known, but are estimated to be in the range of 65-75 percent. The distribution system (canals and laterals) for the CENDAK area will be lined in the reaches that have potential excessive leakage. Toe drains will also be used in lieu of lining where practical to reduce costs.

Most of the land (40,000 acres) in this area is presently being irrigated with pivot systems and it is expected that most land developed in the future will use this method.

## 6.C.5
## WATER QUALITY

### 6.C.5.1
### Alberta (Canada)

The quality of the irrigation water in southern Alberta is 300-500 ppm total dissolved solids (TDS). In some areas where reuse occurs, the quality is somewhat poorer but still of high quality for irrigation.

### 6.C.5.2
### CENDAK (South Dakota)

The water to be used for irrigation will be from the Missouri River which has a quality about 500 mg/L TDS. The quality of the ground water exceeds 1,000 ppm TDS while the quality of the James River water during the irrigation season varies from 500-1,000 ppm TDS.

## 6.C.6
## SALINITY PROBLEMS AND ARTIFICIAL DRAINAGE

### 6.C.6.1
### Alberta (Canada)

In general, salinity and drainage problems have developed on about 10-12 percent of the approximate 1.2 million acres of irrigated land. However, there are numerous estimates of lands affected by drainage problems ranging from 10 to 35 percent.

Eighty percent of these problems are generally attributed to canal seeage. Artificial drains have been constructed to remedy problems on about 15,000 to 20,000 acres throughout this area. Drains are financed by the farmers, whereas rehabilitation work on the distribution system is cost shared on an 86 percent (province), 14 percent (district) basis. The primary reasons farmers install drains are for trafficability and yield, in that order.

A study of the effects of long-term irrigation on soil salinity within the southern Alberta region generally revealed that total soluble salts in the soil profiles were either reduced or unchanged. However, efforts in recent years have increased to rectify identified drainage and salinity problems.

### 6.C.6.2
### CENDAK (South Dakota)

Virtually no artificial drains have been installed in the 40,000 acres presently being irrigated in the CENDAK area. Some irrigators monitor salinity and other soil conditions by periodic testing of soil samples and this testing has not revealed a salinity buildup on these lands.

## 6.C.7 SUMMARY

In general, the physical characteristics and water-management practices in southern Alberta and the CENDAK areas are quite similar. Therefore, it is reasonable to expect, based on this comparison, that drainage problems encountered will also be similar, assuming that good water-management practices are followed in the CENDAK area.