Open File Report 86-3
December, 1986

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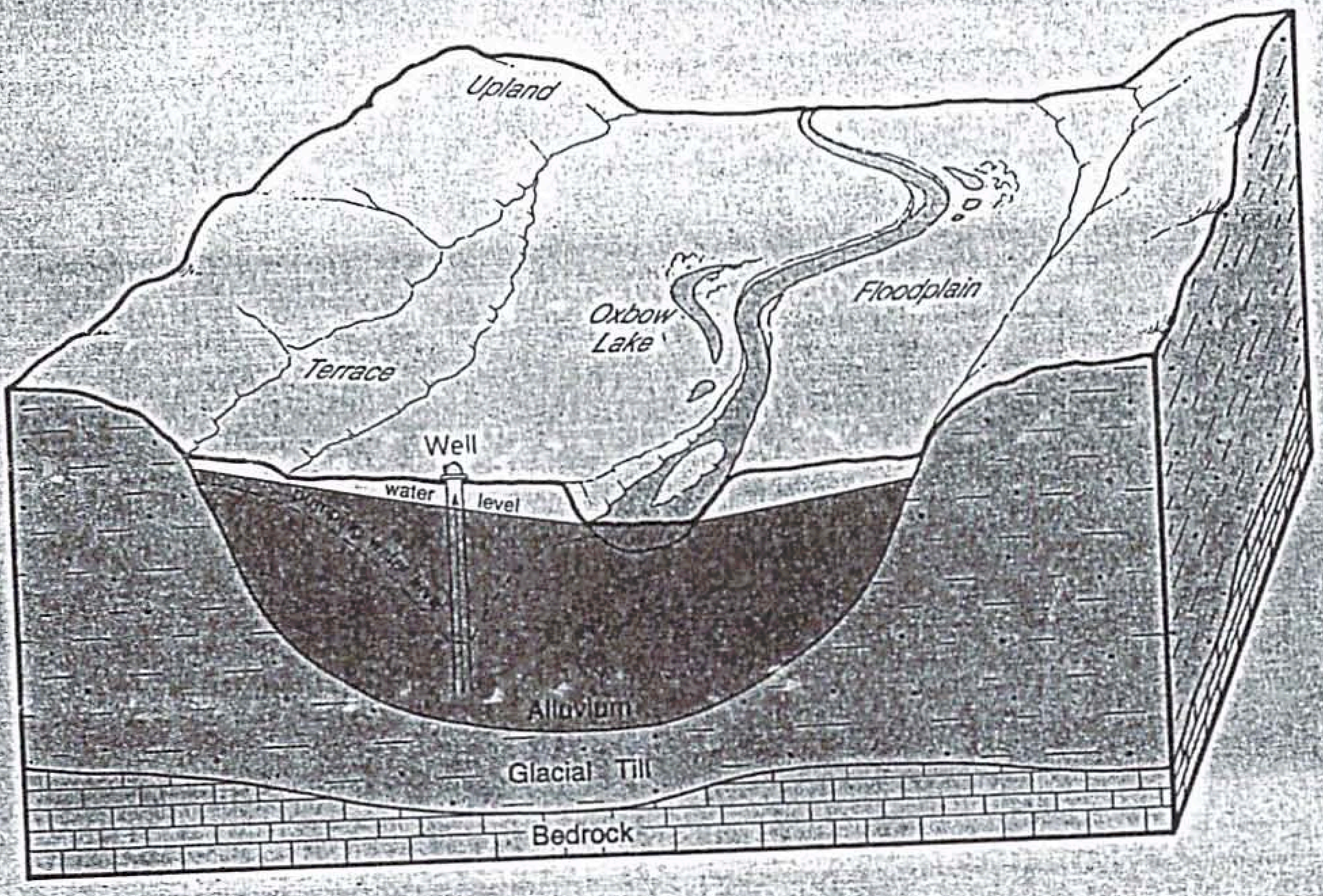
Carol A. Thompson

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ACKNOWLEDGEMENTS

This study was partially funded by the U.S. Environmental Protection Agency.

Seismic data was collected by Calvin Cumerlato, Joost Korpel, Dave Thomann, Mark Morton, and Stephen Ales. Darwin Evans and Mike Tietgen installed the wells for the project and collected water samples. Additional sampling assistance was given by Roger Bruner, Donivan Gordon, Jean Prior, and Paul VanDorpe.

The Office of the State Climatologist provided timely delivery of climatologic data.

The University Hygienic Laboratory has provided excellent support. They performed all the water quality analytical work and provided answers to many questions which arose during the study. The special efforts of Roger Splinter, John Kempf, Nancy Hall, and Jack Kennedy are appreciated.

Data entry was done by Steve Gates, Lynette Siegley and Nancy Hancock. Cathy Scherer and John Schmidt both wrote programs for water data analysis and plotting. Graphics were prepared by Kay Irelan and Pat Lohmann.

Bob Libra, George Hallberg, Roger Bruner, and Don Gordon have provided ideas and valuable discussion throughout the course of this research.

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## EXECUTIVE SUMMARY

A study of the alluvial aquifers of the Ocheyedan and Little Sioux River valleys from the Minnesota border south to the Woodbury-Monona County line was conducted to provide information on water availability and water quality.

The geologic history of the alluvial valleys is complex. A major change in the drainage area and course direction of the Ocheyedan and Little Sioux Rivers occurred as a result of disruption by Wisconsinan glaciations.

Seismic refraction surveys were used to define the thickness and extent of the alluvial deposits within these valleys. Nineteen traverses covering a total of 25 miles were done during the summers of 1983 and 1984. The alluvial valley floors are commonly wide and flat. The thickness of the alluvial deposits ranges from less than 10 feet (3 m) to 90 feet (27 m) and averages about 25 feet (7.5 m). Characteristically, the alluvial materials consist of highly stratified, fine to coarse gravel units with occasional fine-sand lenses. Cut-and-fill sequences are common. On late Wisconsinan terraces the alluvial sequence is often capped by a coarse gravel unit. Older terraces along the Little Sioux are loess-mantled and the fluvial deposits are fine-textured. Often these terraces are not hydraulically connected to the present alluvial aquifer.

Recharge to the alluvial system occurs primarily from infiltration of precipitation. Most recharge occurs during the early spring and fall. In summer, evapotranspiration losses exceed precipitation, and groundwater levels usually decline. During most of the year, alluvial groundwater discharges to the streams, supplying as much as 70 percent of annual stream flow. As groundwater levels decline, flow to the stream diminishes and stream levels fall. Flow-duration and low-flow data show that low flows are expected to recur frequently on the Ocheyedan and Little Sioux Rivers, particularly in the upper reaches.

Transmissivities calculated from pumping test data range from 30,000 to 800,000 gpd/ft. In most of the Ocheyedan Valley, transmissivities of 200,000 gpd/ft are not uncommon. Only small drawdowns occur because of the highly transmissive nature of the aquifer. Water in storage in the Ocheyedan alluvial system is estimated to be at least 2.4 billion gallons.

Water levels were measured monthly and ranged from one foot above ground level to 18 feet below ground level. Most wells varied an average of five feet during the course of this study. Water table gradients are low, varying between .001 (5 ft/mi) to .005 (26 ft/mi). Vertical gradients are generally low, being within measurement error of zero. Two wells, however, show strong upward gradients of .01 to .14. Gradients in the aquifer appear to control the migration of contaminants.

A total of 31 observation wells were installed in the Ocheyedan-Little Sioux alluvial system. These were sampled monthly for nitrate and bacteria with a few wells being analyzed for pesticides. The groundwater can be classified as slightly alkaline freshwater with calcium and magnesium the dominant cations and bicarbonate the major anion. The results of the nitrate monitoring have shown that although nitrate levels are not excessively high, extensive areal contamination has occurred. Nitrate levels vary temporally and generally increase in response to increased infiltration. Pronounced vertical stratification of nitrate has been found, with nitrate levels decreasing with depth. Highest concentrations are generally found in the upper 10 feet (3 m) of the saturated zone. Tritium dating has shown that this

stratification may be age-related with older water in the lower zones. However, even in these lower zones tritium is present, indicating at least some of the water must be less than 30 years old.

There are some locations where nitrate is consistently not detected. Denitrification is suspected as the mechanism for nitrate losses in these areas. Denitrification is the transformation of nitrate to nitrogen gas which is then lost to the atmosphere. The greatest potential for denitrification occurs in oxygen deficient, water-saturated soil with an available supply of biodegradable carbon. Conditions favorable for denitrification exist at some places in the alluvium.

High bacteria levels were seen in almost all wells sampled. Much of this bacterial contamination may result from leakage or contamination introduced during sampling. Fecal coliform contamination at one well suggests that some migration of bacteria through the aquifer can occur.

Five different pesticide compounds were detected. Highest concentrations were found in surface waters, although all concentrations detected were below acute toxicity levels. Most pesticides were detected in the early summer months, after field application. Atrazine was the only compound detected during fall sampling.

The largest amount of water presently allocated is for irrigation followed by municipal, rural water system, livestock, and rural-domestic use. Adequate water is available during most seasons to meet current needs and to support projected future increases. Further degradation in water quality could limit certain uses of this water resource.

# INTRODUCTION

Study of alluvial aquifers in Iowa by the Geological Survey Bureau began in 1981 in order to obtain detailed information on the nature and potential of these important resources. Although many Iowa municipalities, rural water distribution systems, irrigators, and rural residents draw water from alluvial systems, little specific information is available concerning their development potential or limitations. In several regions of the state, alluvial systems are the only source of good quality water, and competition for alluvial water supplies is increasing.

## Study Objectives

The program's objectives are to evaluate the thickness, geology, and hydrology of the alluvial systems associated with major streams, and to evaluate their water-producing potential in terms of yield and water quality. Specific objectives were to: 1) determine the geometry of the alluvial valley: depth and width of alluvium; 2) investigate the geology: nature of the overlying materials, substrate composition, and nature of alluvial sediments; 3) evaluate surfacewater hydrology: relationships between surfacewater and groundwater, and flow-duration characteristics; 4) evaluate groundwater hydrology: water level variations, aquifer parameters, and quantity of water in storage; 5) evaluate the quality of water in the aquifer both spatially and through time; 6) estimate water withdrawals from the aquifer and projected increases; and 7) assess potential for future resource development.

## Physiographic Setting

The Rock River is located in northwest Iowa on the Northwest Iowa Plains (Figure 1; Prior, 1976). The topography of the Northwest Iowa Plains in this region is the product of Pre-Illinoian glaciations and subsequent erosion. The landscape is gently rolling with a well-defined network of streams.

The study area includes the alluvial plains and terraces which border the river. These plains are broad, nearly flat valley floors adjacent to the rivers and are characterized by low relief and poor drainage. Terraces which are present along the valley margins of the present alluvial plains are remnants of former floodplains. The uplands are mantled with loess. The drainage area of the Rock River where it enters the Big Sioux River is 1688 square miles.

## Climatic Setting

The climate of Iowa and that of the project area can be characterized as humid continental. Summers are usually hot and humid, and winters are cold and relatively dry. Summer weather is influenced by air flows which bring warm, moisture-laden air to the state from the south and west. The winter period is dominated by cold, dry Canadian air.

Mean annual temperatures in the project area range from about 48°F in the southern counties to 46°F in the northern counties. The growing season, the period between spring thaw and fall freeze, extends from about the 5th of May to the 30th of September. Within given years, temperature extremes can vary from winter lows of less than -20°F to summer highs above 100°F.

Normally, precipitation in the project area averages 26 inches annually.

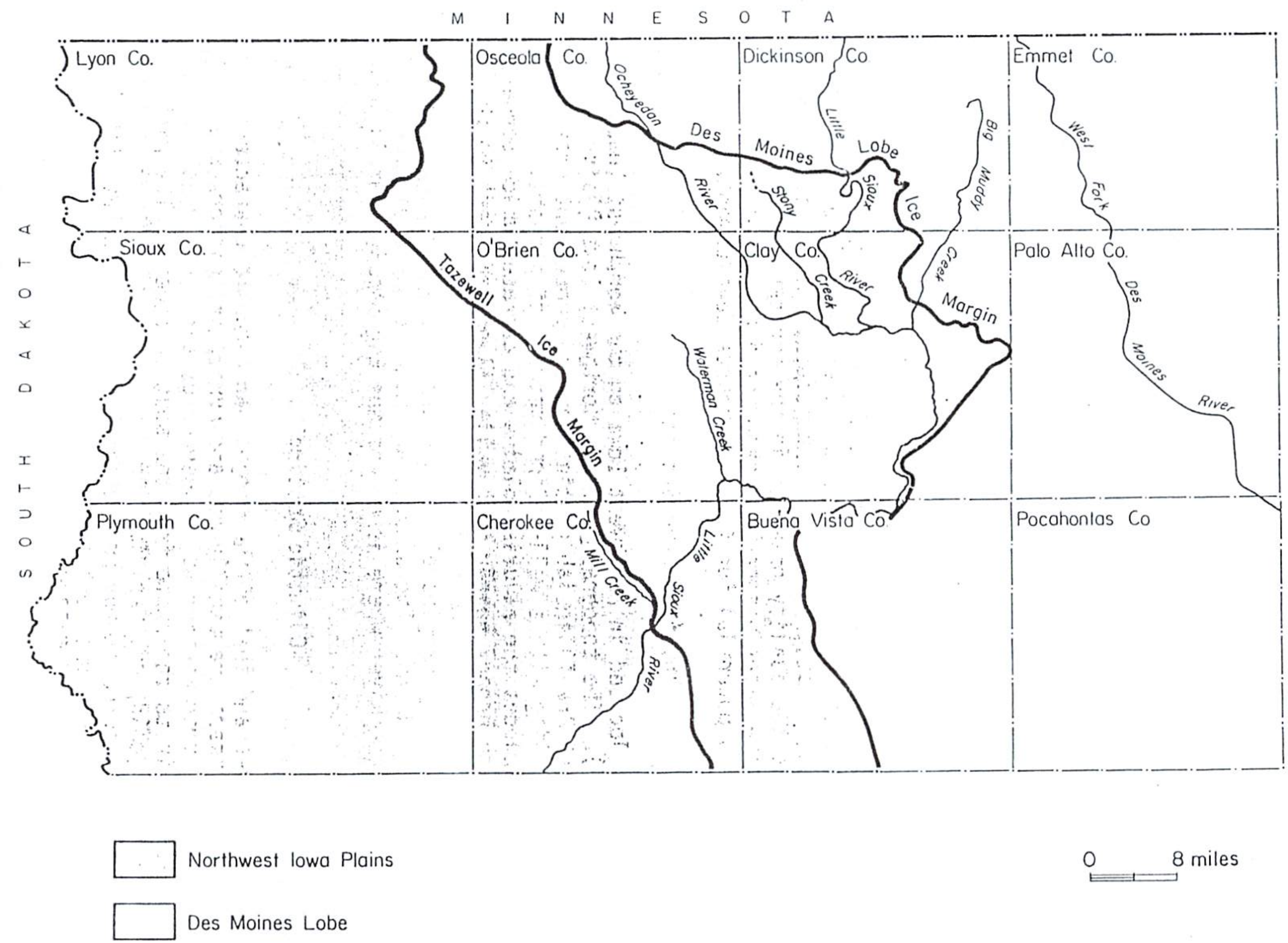



Figure 1. Drainage and physiographic provinces.

square miles, and its drainage area above the city of Cherokee is 2,128 square miles. The total drainage area of the Little Sioux above its entry into the floodplain of the Missouri River is 2,718 square miles.

### Climatic Setting

The climate of Iowa and that of the project area can be characterized as humid continental. Summers are usually hot and humid, and winters are cold and relatively dry. Summer weather is influenced by air flows which bring warm, moisture-laden air to the state from the south and west. The winter period is dominated by cold, dry Canadian air.

Mean annual temperatures in the project area range from about 49°F in the southern counties to 46°F in the northern counties. The growing season, the period between spring thaw and fall freeze, extends from about the 5th of May to the 5th of October. Within given years, temperature extremes can vary from winter lows of less than -20°F to summer highs above 100°F.

Normally, precipitation in the project area ranges between 25 and 28 inches annually. Northwest counties are drier; east and southeast counties are wetter. During most years in the project area, about 75 percent of all precipitation, about 20 inches, occurs during the growing season. Normally, June is the wettest month and January the driest. Average seasonal snowfall ranges from 32 to 38 inches.

### Geologic History and Setting

Previous work on the geology of the rivers in the study area has been done by Macbride (1901), Carman (1915), Pedersen and Lohnes (1963), and Hoyer (1980). The Ocheyedan and Little Sioux drainages have changed as a result of multiple Wisconsinan glaciations. Before the Des Moines Lobe glaciation, 14,000 years before present (YBP), what is now the Little Sioux River above Spencer was a tributary of the Ocheyedan River. At the time, the Ocheyedan formed the headwaters of a river which drained easterly to the Mississippi River. During the same period the Little Sioux was less extensive and actually headed in the Mill Creek drainage in O'Brien County.

As the ice which formed the Des Moines Lobe advanced southward, it dammed the Ocheyedan. This ice dam caused a large lake to form in the area north and west of the city of Spencer. Glacial Lake Spencer persisted until its water overflowed the dam and cut the present Little Sioux River valley in Clay and Buena Vista Counties between the communities of Gillett Grove and Peterson. The river valley in this area is narrow and steep, almost canyon-like. Figure 2 shows the sequence of events leading to the development of the present Little Sioux River system.

The alluvial deposits of the Ocheyedan and Little Sioux Rivers are underlain by relatively thick sequences of glacial materials. Cretaceous sandstones and shales are the uppermost bedrock in the study area.

## GEOLOGICAL INVESTIGATIONS

### Data Collection

A preliminary phase of this project included a compilation of the avail-

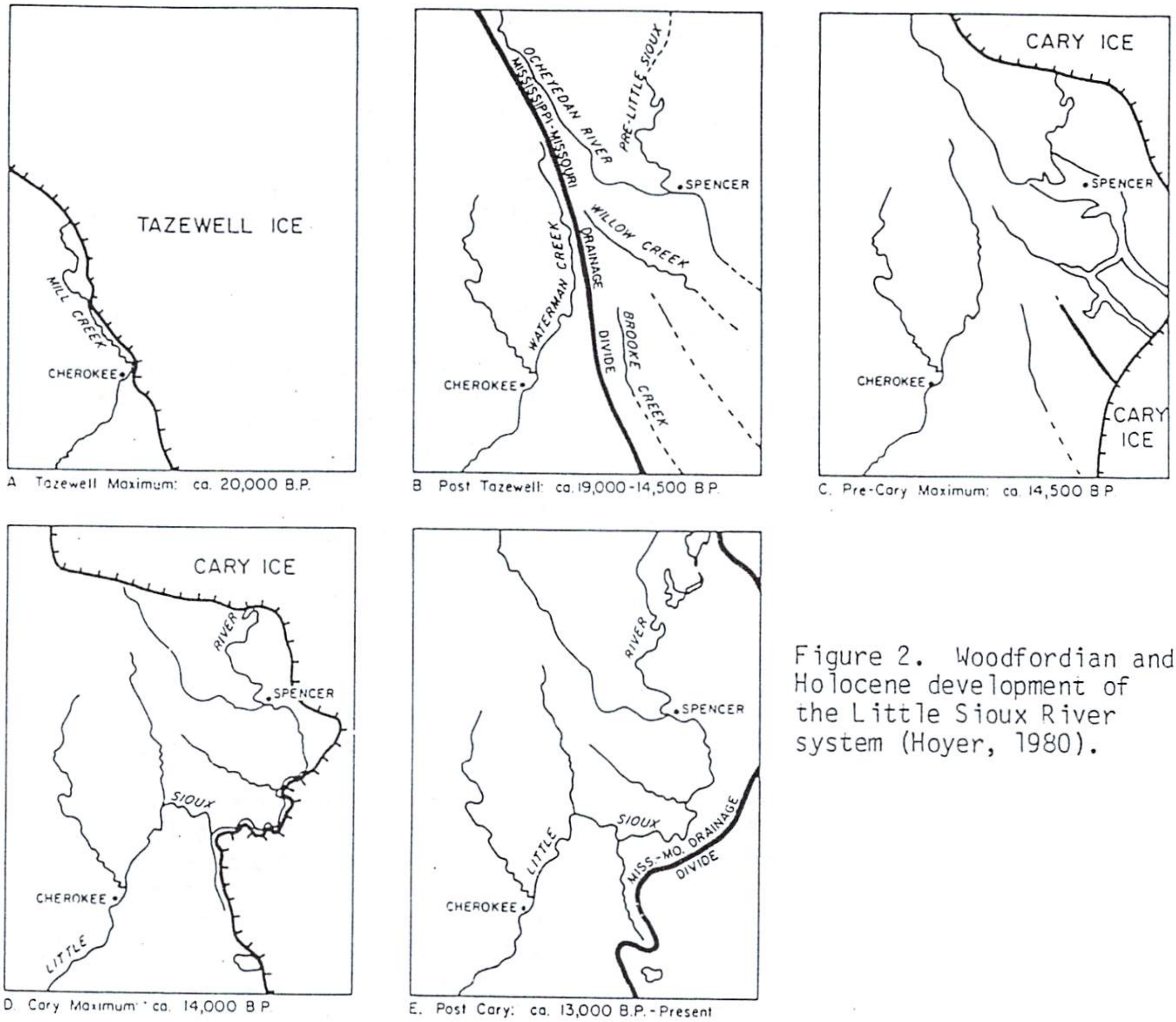



Figure 2. Woodfordian and Holocene development of the Little Sioux River system (Hoyer, 1980).

able geologic data. To evaluate the hydrologic potential of an alluvial aquifer, its boundaries (width and depth) must be known. Well logs on file at the Geological Survey Bureau were examined for information about the alluvial systems under investigation. These data were supplemented with information obtained from Department of Transportation bridge borings and sand and gravel pit tests. Other information was obtained from test well borings into the alluvium for rural water district, municipal, and industrial users. The available data is contained in Appendix A of the Open-File Data Report (Thompson, 1986).

Modern county soil survey maps, prepared by the USDA Soil Conservation Service, were used to determine subsoil lithologies and where possible, depths to these materials. Till-derived (glacial) soils were generally found on the uplands and valley side-slopes, and they mark the lateral boundary of alluvial materials. The soil maps proved very useful in areas where the valley margins were subtle and not easily located. The area of glacial Lake Spencer, west of the city of Spencer, was partially delineated with the help of the soil maps. These maps also were useful in ascertaining the presence of "benched" terraces, which are terraces with thin sand and gravel over glacial deposits. Normally they are not suitable aquifers and are not hydraulically connected to the main alluvial aquifer. They were delineated on soil maps by recognition of till-derived soils along terrace scarps.

In a few areas existing geologic data were adequate, but in most areas, limited data were available on which to predict resources. In order to reconstruct aquifer geometry, especially in areas where thickness of the alluvium can vary greatly, additional lateral and vertical control was needed. Seismic refraction surveys were conducted to supplement available information. Test holes were then drilled to obtain additional detail in areas targeted by the seismic work. A description of the field methods, along with results of the refraction work, can be found in Appendix B of the Open-File Data Report (Thompson, 1986).

## Results and Discussion

A total of 370 seismic spreads were run at 19 different locations covering a linear distance of approximately 25 miles. Figures 3 and 4 show the locations of each traverse.

Borings were drilled at 47 sites along the Ocheyedan-Little Sioux alluvial system. All borings were drilled with a mud-rotary unit. At 19 different sites, a total of 31 wells, including nine multi-level completions, were installed. The wells were cased with 2-inch, schedule 40 PVC pipe which was slotted at intervals selected for sampling. Well and test-hole locations are shown in Figures 5 and 6, and well descriptions can be found in Table 1. Lithologic descriptions of the materials encountered are given in Appendix C of the Open-File Data Report (Thompson, 1986).

The Ocheyedan River valley exhibits several distinct changes in character along its different reaches. The valley from the Minnesota border to south of the community of Ocheyedan is narrow and somewhat poorly defined. The alluvial deposits are thin, less than 10 feet thick, and discontinuous. A noticeable increase in valley width occurs at the edge of the Des Moines Lobe near Ocheyedan. From this former ice margin to the community of Everly the valley is a broad, flat outwash plain. The alluvial materials here lie on early Woodfordian (Tazewell) glacial deposits. Alluvial sands and gravels underlie the valley floor and are water saturated. Rotary drilled samples generally show 0-5 feet of sandy, silty topsoil, underlain by occasional silty clay layers, over fine sand and coarse to very coarse gravel alluvium, over glacial till. Boulder layers are sometimes present at the base of the sand and gravel. Figure 7 shows generalized stratigraphic sections for both upland and valley sections in the study area.

The Upper Little Sioux on the Des Moines Lobe flows through a narrow, incised valley with discontinuous sand and gravel deposits up to 20 ft thick. Beyond the terminus of the Des Moines Lobe near Milford, the valley becomes much wider and an extensive sloping terrace is present. The deposits comprising the terrace range from 10 to 80 feet in thickness and are composed of fine to medium

SEISMIC TRAVERSE LOCATIONS

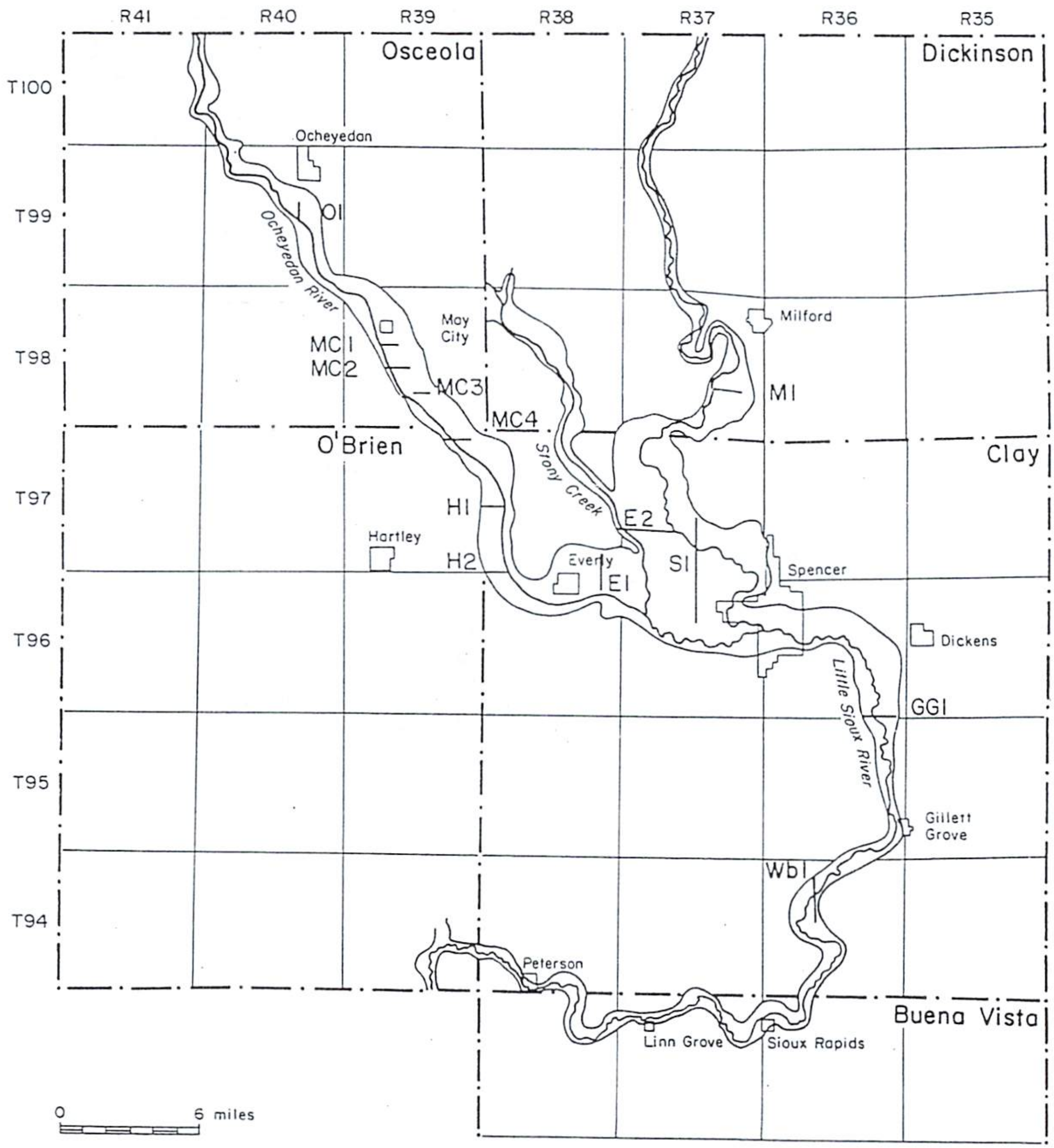



Figure 3. Seismic traverse locations: Ocheyedan and Upper Little Sioux.

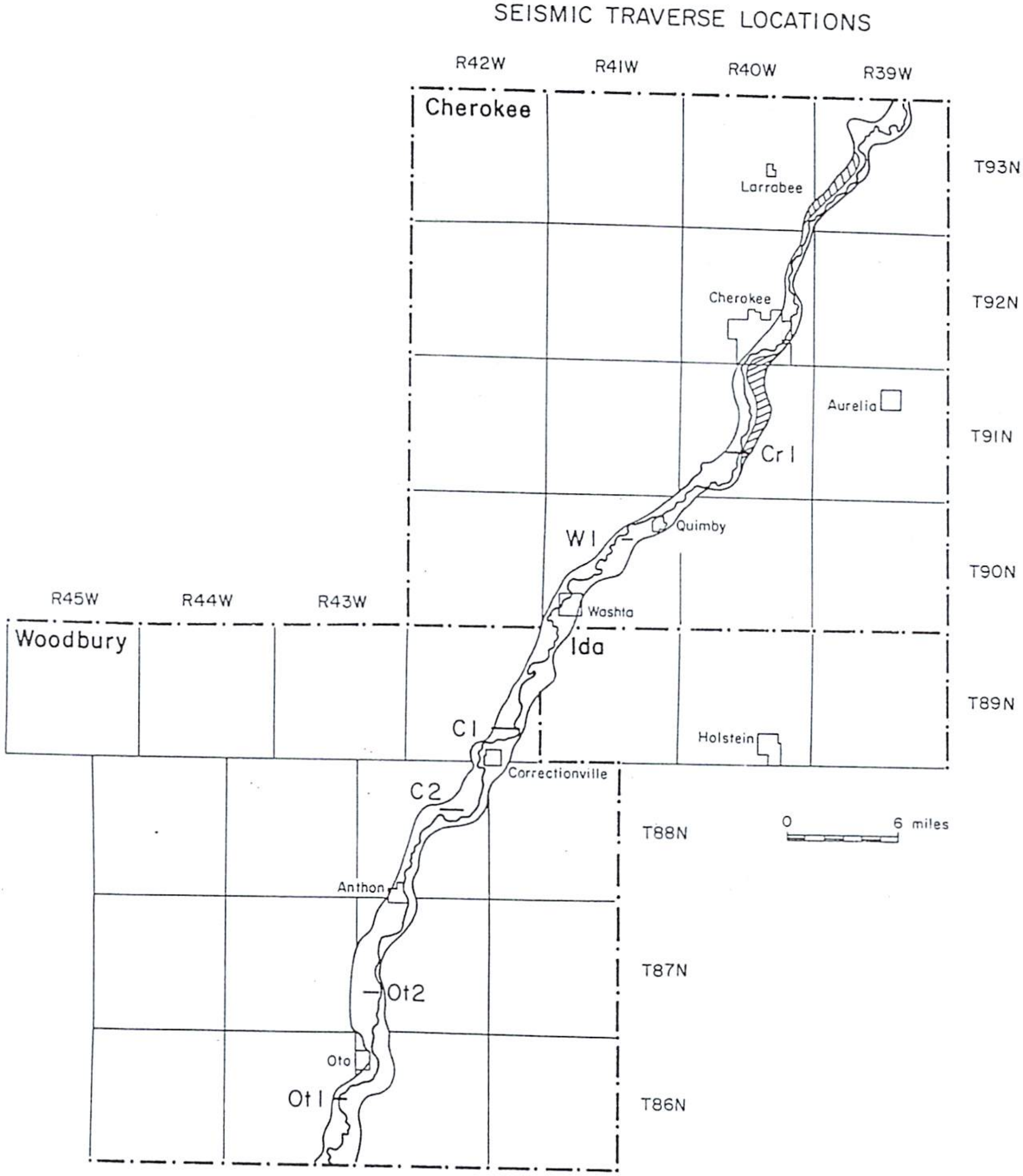



Figure 4. Seismic traverse locations: Lower Little Sioux. Hatchured areas represent terraces.

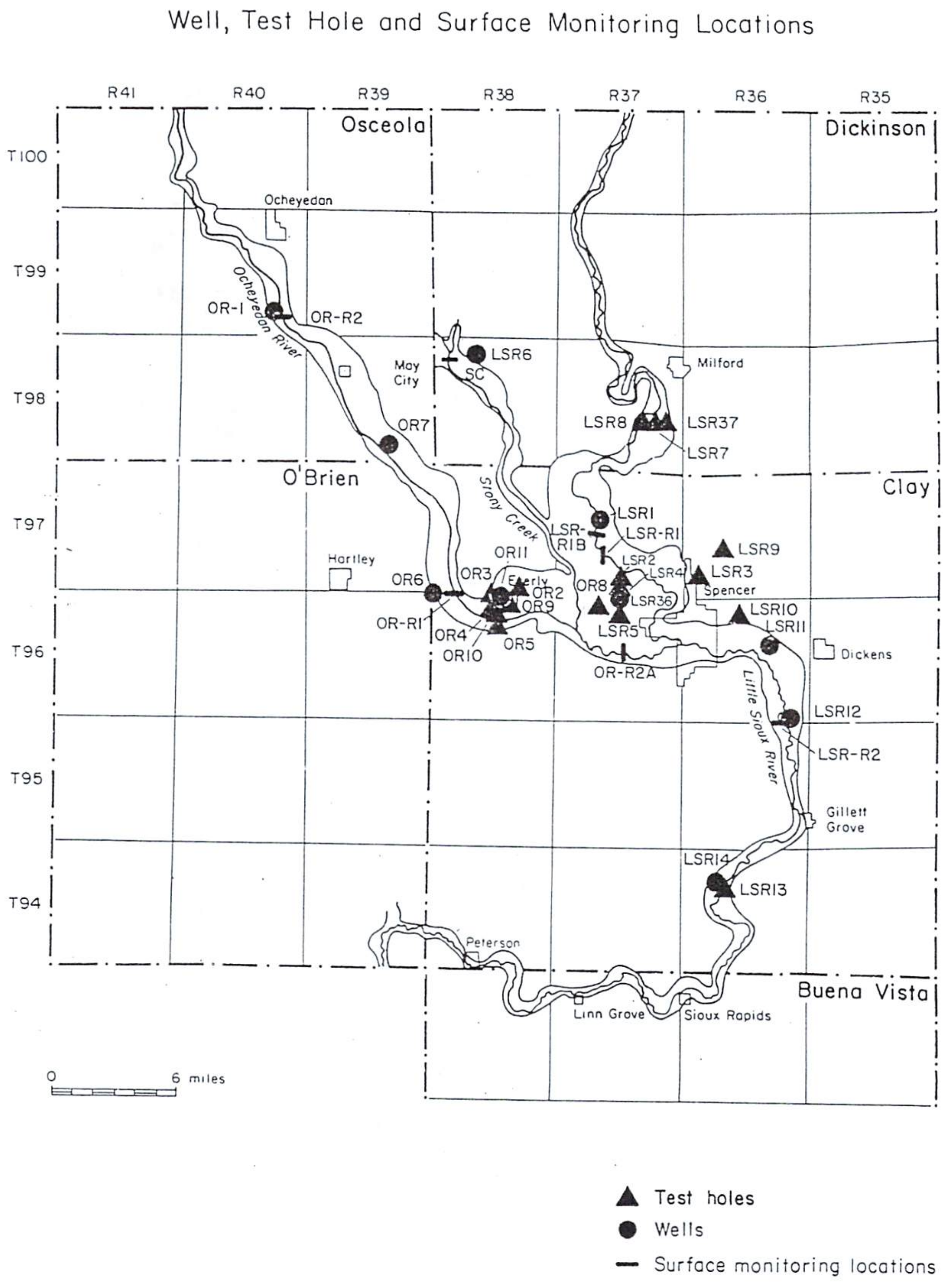



Figure 5. Well and test-hole locations: Ocheyedan and Upper Little Sioux.

Well, Test Hole and Surface Monitoring Locations

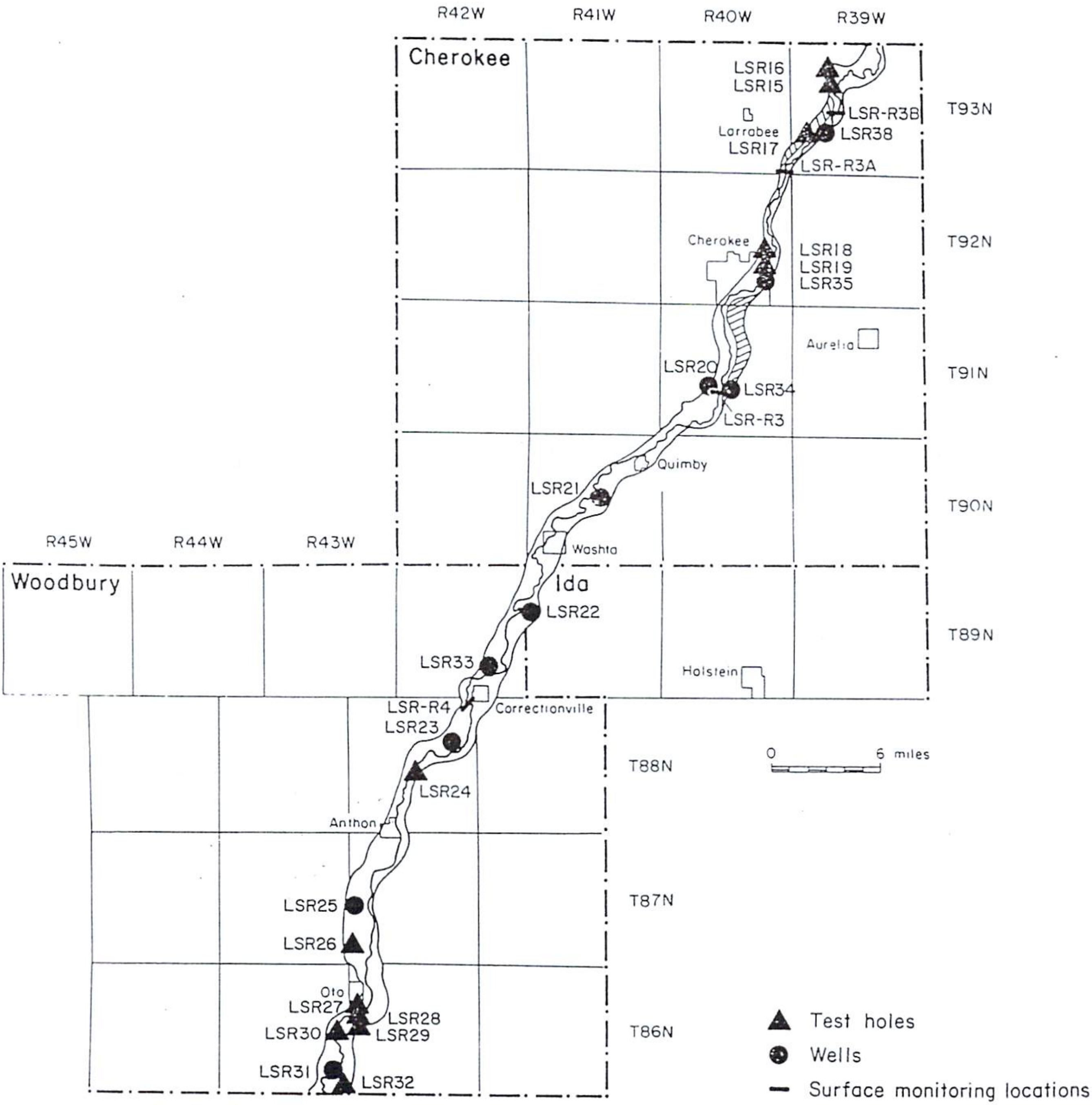



Figure 6. Well and test-hole locations: Lower Little Sioux. Hatchured areas represent terraces.

Table 1. Summary of Well and Test-Hole Information.

| Well No. | Elevation (ft. above mean sea level) | Screened Interval (ft) | Substrate Lithology | Thickness of Sand & Gravel (ft) | Depth to Sand & Grav (ft) |
|---|---|---|---|---|---|
| OR1-U | 1435.8 | 7-9 | Till | 66 | 1 |
| OR1-M | 1453.6 | 26-30 | | | |
| OR1-L | 1453.4 | 54-58 | | | |
| OR7-U | 1402.1 | 6-7 | Till | 13 | 5 |
| OR7-L | 1402.4 | 12.5-16 | | | |
| OR6 | 1372.8 | 16-19 | | 16 | 5 |
| OR2 | 1356.0 | | Clay | 10 | 6 |
| OR3 | 1365.0 | | Till | 24 | 6 |
| OR11-U | 1364.8 | 10-13 | Clay | 13 | 3 |
| OR11-L | 1364.6 | 26-30 | Clay/Till | 5 | 19 |
| OR9 | 1355.0 | | Till | 9 | 4 |
| OR4 | 1352.0 | | Till | 4 | 9 |
| OR5 | 1350.0 | | Till | 17 | 10 |
| OR10 | 1355.0 | | Till | 29 | 14 |
| LSR6 | 1419.1 | 11-18 | Till | 15 | 4 |
| LSR7 | 1400.0 | | Clay | 20 | 5 |
| LSR8 | 1370.0 | | Till | 8 | 4 |
| LSR1-U | 1352.5 | 16-17 | Clay | 17 | 3 |
| LSR1-L | 1352.3 | 85-90 | Till | 40 | 54 |
| LSR2 | 1340.0 | | Till | 10 | 4 |
| LSR4 | 1337.0 | | Till | 37 | 5 |
| LSR36-U | | 6-8 | Clay | 20 | 5 |
| LSR36-L | | 21-24.5 | | | |
| OR8 | 1340.0 | | Till | 21 | 6 |
| LSR5 | 1337.0 | | Till | 23 | 4 |
| LSR9 | 1338.0 | | Till | 0 | |
| LSR3 | 1336.0 | | Till | 10 | 27 |
| LSR10 | 1312.0 | | Till | 26 | 31 |
| LSR11 | 1301.8 | 14.5-16.5 | Till | 14 | 3 |
| LSR12 | 1294.3 | 17-19 | Till | 9 | 11 |
| LSR14 | 1281.1 | 22-28 | Till | 17 | 14 |
| LSR15 | 1208.0 | | | | |
| LSR16 | 1209.0 | | Clay/Shale | 53 | 28 |
| LSR38-U | 1193.9 | 23.5-28.5 | Clay/Shale | 32 | 19 |
| LSR38-L | 1193.7 | 44-50 | | | |
| LSR17 | 1225.0 | | Till | 26 | 6 |
| LSR18 | 1218.0 | | Till | 8 | 4 |
| LSR19 | 1190.0 | | Clay | 3 | 5 |
| LSR35-U | 1179.7 | 20.5-22.5 | Till | 36 | 18 |
| LSR35-M | 1179.4 | 30.5-37.5 | | | |
| LSR35-L | 1179.2 | 50-52 | | | |
| LSR34-U | 1208.9 | 17.5-19 | Clay/Till | 19 | 0 |
| LSR34-L | 1208.7 | 53-63 | Till | 15 | 50 |
| LSR20-U | 1156.4 | 20-23 | Till | 31 | 20 |
| LSR20-L | 1156.2 | 42-48 | | | |

Table 1. Continued

| Well No. | Elevation (ft. above mean sea level) | Screened Interval (ft) | Substrate Lithology | Thickness of Sand & Gravel (ft) | Depth to Sand & Gravel (ft) |
|---|---|---|---|---|---|
| LSR21 | 1164.9 | 12-13 | Till | 8 | 5 |
| LSR22 | 1146.7 | 23-26 | Till | 20 | 8 |
| LSR33 | 1136.9 | 24-25.5 | Till | 11 | 15 |
| LSR23 | 1131.6 | 28-31 | Till | 33 | 0 |
| LSR24 | 1107.0 | | Till | 24 | 30 |
| LSR25 | 1090.3 | 19-24 | Till | 21 | 3 |
| LSR26 | 1100.0 | | Till | 15 | 27 |
| LSR27 | 1082.0 | | Shale | 35 | 33 |
| LSR28 | 1096.0 | | Till | 25 | 19 |
| LSR29 | 1132.0 | | Clay | 15 | 35 |
| LSR30 | 1075.0 | | Sandstone | 50 | 30 |
| LSR31 | 1073.2 | 34-37.5 | | 7 | 34 |
| LSR32 | 1076.0 | | Sandstone | 49 | 26 |

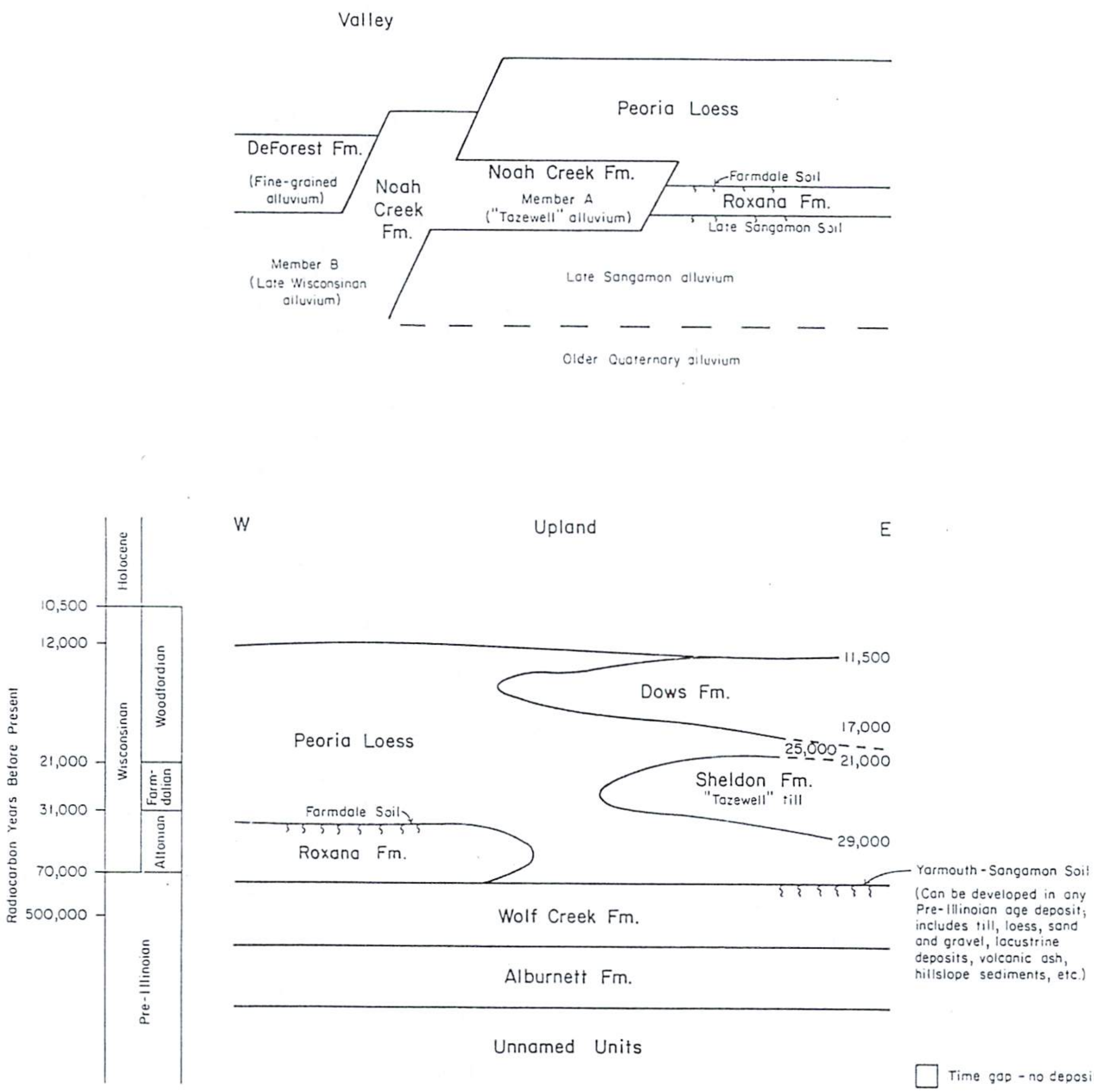



Figure 7. Generalized stratigraphy in the study area.

sands and coarse to very coarse gravels. Silty and sandy clays, up to 20 feet in thickness, are intermixed at several locations. Thicker deposits of silty, sandy clays (70 feet) were found on a terrace near the outlet of Lake Okoboji. Perhaps these are lake sediments deposited when the lake was at maximum size. The gradient of the modern stream valley is less than that of the terraces. These terraces merge with the stream valley near Spencer. The present day floodplain of the Little Sioux in this reach is narrow and incised below the terraces. Alluvial deposits are thin consisting of 0-10 feet of alluvial silts and clays overlying 5 to 10 feet of sand and gravel which rest on glacial till.

The Ocheyedan Valley at Everly and the Little Sioux Valley north of Spencer open into the basin of former Lake Spencer. Figure 8 is a map modified from Hoyer (1980) showing the probable distribution of outwash and lake sediments. Seismic findings and drilling results from this study have confirmed the pattern shown in Figure 8. West of Spencer, the lake sediments are dominated by glaciofluvial sands and gravels, with occasional lenses of fine-textured lacustrine sediments. North and northeast of Spencer, fine-textured, laminated lake sediments have been found. These sediments sometimes overlie previously deposited outwash sands and gravels which are up to 25 feet thick.

From Gillett Grove to Peterson, the Little Sioux River flows in a narrow, deep valley bordered by high terraces. This is the area where the river cut a new channel when its original course east to the Mississippi was blocked by ice. Few alluvial deposits are preserved along this segment of the valley. The terraces are benched above the present floodplain and are dry.

West of Peterson, the Little Sioux intersects the Waterman Creek drainage. Waterman Creek, along with Mill Creek further downstream, formed the original headwaters of the downstream portion of the Little Sioux River (see Figure 2). Four terrace levels are present in this reach of the valley, and these extend to Cherokee. While the terrace deposits contain thick gravel sequences, 10 to 35 feet, they are benched above the present floodplain and generally are dry. The floodplain, although narrow, also contains thick sequences of sand and gravel (10 to 50 feet). Occasionally, these are covered by alluvial fan deposits from the adjacent valley walls. These alluvial fans consist of up to 20 feet of silty clay which overlie coarser sand and gravel alluvium. The alluvial fan deposits were formed during the Holocene (approximately 10,000 to 5,000 YBP).

At the intersection with Mill Creek, the Little Sioux Valley leaves the area affected by Wisconsinan glaciation and continues onto the Southern Iowa Drift Plain. Pre-Illinoian age glacial deposits (600,000 YBP or older) underlie the alluvial deposits in this region. The valley is straight and wide with loess-capped uplands. Hills developed in deep loess become more pronounced downstream and along the Missouri River valley. Five terrace levels (Hoyer, 1980) are recognizable between Cherokee and Anthon. South of Anthon only one terrace level can be seen. Terrace deposits near Correctionville show a sequence typical for these terraces. Coarse sands and gravels/cobbles are present and are characterized by trough cross-bedding and cut-and-fill sequences along with planar and cross-bedded coarse sand and pebble layers. The entire sequence is capped with a coarse gravel layer 3 to 8 feet thick. The oldest terrace is loess-covered, with 5 to 40 feet of loess present. Terraces at the higher elevations within the valley are generally dry, but lower terraces are partially saturated. The gradients of successively younger terraces decrease downstream. Floodplain deposits range from 10 to 50 feet thick and are overlain by silty clays up to 30 feet thick. These clays may correlate with the fan deposition discussed in the preceding paragraph and may represent Holocene valley filling.

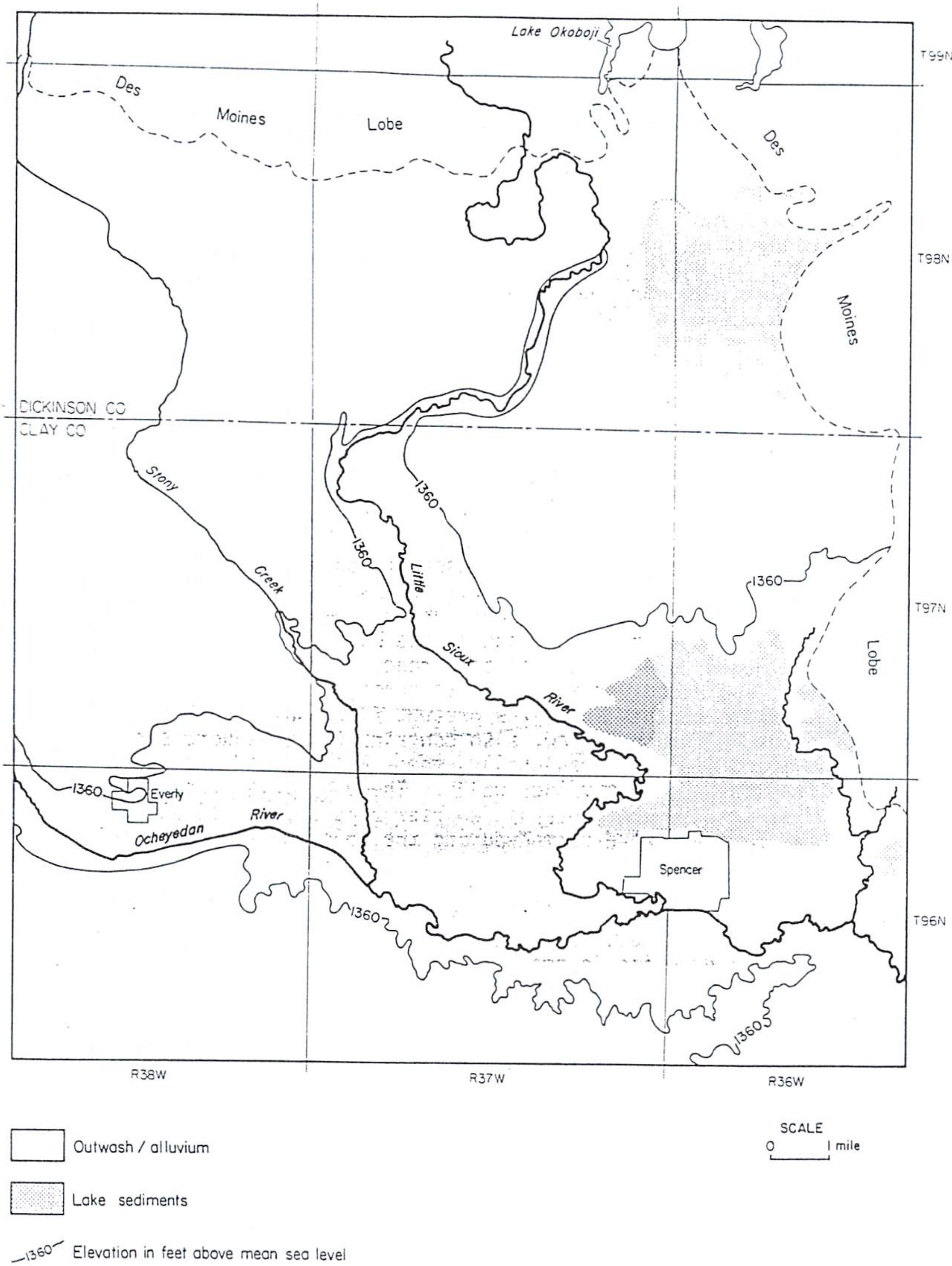



Figure 8. Glacial Lake Spencer (modified from Hoyer, 1980).

A series of isopach maps, which define the thickness of the sand and gravel deposits along each reach of river, are located in Appendix I. The thickness of alluvial material along with water level measurements can be used to calculate the saturated thickness of the aquifer.

## SURFACEWATER RESOURCES

Streamflow data are available for several gaging stations along the Ocheyedan-Little Sioux Rivers. The stations in the study area are listed in downstream order in Table 2. Data for these stations were statistically analyzed to evaluate the hydrologic characteristics of the river and the role of groundwater discharge in maintaining flow.

The flow characteristics of streams are a function of weather, vegetative cover, topography, and geology. Water discharged by streams derives from precipitation and snowmelt, and the discharge of groundwater. Normally, highest stream discharges occur in the spring and early summer, then gradually decrease over the balance of the growing season. The decrease is caused by increased evapotranspiration during the peak growing months. Withdrawals and discharges from power plants and municipal water works also cause variations in streamflow, which are especially noticeable at low discharges. The day-to-day variation in streamflow can be shown by streamflow hydrographs--plots of discharge versus time. For evaluating streamflow variability over longer periods of time, statistical methods are used to characterize such parameters as flow duration, low-flow frequency, and baseflow recession. These methods use historical streamflow data to characterize a stream's flow regime.

The flow response of a stream, as mentioned earlier, depends on many factors but particularly on the intensity and duration of precipitation events, and on the physical characteristics of the stream's watershed. Streams having well integrated, efficient drainage networks have very rapid flow responses to rainfall events. Conversely, if the drainage network is poorly integrated, the result of a particular precipitation event is attenuated, and peaks on the stream's hydrograph are modulated or suppressed.

The Ocheyedan River has a somewhat poorly integrated drainage network as does the upper portion of the Little Sioux. Here the tributary streams are short and the uplands are undulating with numerous swales which trap surface runoff. In this reach, overland flow is diminished and groundwater contribution to streamflow becomes more important. Below Gillett Grove, the river is entrenched and the uplands are drained by numerous streams which collect surface runoff and deliver it to the Little Sioux. In the vicinity of Cherokee this trend becomes very pronounced as the drainage basin narrows and has sharp divides and steep valley walls.

### Streamflow Variability

#### Flow Duration

Flow-duration curves are used to assess the variability of streamflow, and to compare the flow characteristics of one drainage area with another. Flow-duration curves show the percentage of time that a given flow is equalled or exceeded. The flow duration curve is plotted from long-term flow records and does not represent the distribution of yearly flow, but rather is indicative of the long-term average. A steeply sloping duration curve denotes a highly

Table 2. Streamflow-gaging stations on the Ocheyedan - Little Sioux Rivers

| Station No. | Station Name | Drainage Area (sq. mi.) | Station Type | Years of Record |
|---|---|---|---|---|
| 06-6045-10 | Ocheyedan River near Ocheyedan | 73.5 | Partial low-flow | Intermittent |
| 06-6047.00 | Ocheyedan River near May City | 226 | Partial low-flow | Intermittent |
| 06-6050.00 | Ocheyedan River near Spencer | 426 | Complete record | 10/77 - present |
| 06-6049.00 | Stony Creek near Everly | 81.6 | Partial low-flow | Intermittent |
| 06-6039.00 | Little Sioux River near Milford | 333 | Partial low-flow | Intermittent |
| 06-6051.00 | Little Sioux River at Spencer | 990 | Complete record<br>Partial low-flow | 1936 - 42 |
| 06-6056.00 | Little Sioux River at Gillett Grove | 1334 | Complete record | 1958 - 73 |
| 06-6058.50 | Little Sioux at Linn Grove | 1548 | Complete record | 10/72 - present |
| 06-6061.00 | Little Sioux River near Sutherland | 1803 | Partial low-flow | Intermittent |
| 06-6064.00 | Little Sioux River at Cherokee | 2173 | Partial low-flow | Intermittent |
| 06-6066.00 | Little Sioux River near Correctionville | 2500 | Complete record | 6/36 - present |

variable stream--one whose flow is largely controlled by surface runoff. Flat sloping curves indicate that streamflow is significantly supplemented by base flow, i.e., groundwater discharge. The slope at the lower end of the duration curve indicates the relative contribution of baseflow in maintaining streamflow during low-flow periods. A flat slope shows that streamflow is essentially supported by groundwater discharge. In contrast, a steep lower end indicates that groundwater discharge is negligible and not capable of maintaining streamflow.

Flow-duration curves were constructed for the Ocheyedan and Little Sioux gaging stations using computer programs available from the U.S. Geological Survey (Figure 9). June-September curves are shown as this is the critical demand period for water and also eliminates the effects of ice on winter low flows. The curves for Correctionville and Linn Grove are relatively steep indicating large contributions from surface runoff. The curves for the Ocheyedan and Little Sioux Rivers at Spencer show flattening at the lower ends of the duration curves indicating significant groundwater contributions. This is true to a lesser degree for the Little Sioux at Gillett Grove. Data for the two Spencer stations, however, represent only a short time period (six years) and thus the inflection of lower end of the duration curves may be statistically biased.

## Low-Flow Frequency

Iowa law limits the withdrawal of surfacewater during periods of low stream flow. The 84 percent duration flow for the growing season (April-September) is the approximate regulated, protected flow for Iowa streams. When the flow is less than the 84 percent duration flow, water cannot be withdrawn for consumptive purposes.

Withdrawals from wells for consumptive purposes in unconsolidated aquifers adjacent to streams are subject to restrictions based on distance of the well from the stream, the drainage area of the stream, and the stream's low-flow characteristics. Withdrawals from a stream draining 50 or more square miles or from wells in an alluvial aquifer within 1/8 mile of the stream are regulated by the protected flows discussed earlier. Withdrawals from alluvial wells located between 1/8 and 1/4 mile (1320 feet) from a stream are regulated by the seven-day, one-in-ten year low flow (7Q10). This is the lowest average flow for seven consecutive days that is expected to occur on the average of once in 10 years. If the stream discharge falls to these levels, regulated consumptive water withdrawals from the unconsolidated aquifer, within the prescribed distances, must cease. Municipal, household, ordinary livestock, and domestic uses are exempted under these rules. Table 3 lists the 84 percent duration flows and the 7Q10 flows at selected points along the rivers. The values for Linn Grove and Gillett Grove stations were derived by correlation with the longer period station at Correctionville. Values for stations above the confluence were calculated from a regional correlation equation derived by the U.S.G.S. Protected flows at other points are established when the need arises by comparison of streamflow data and basin characteristics.

Water developments that are based on withdrawals from streams or from wells regulated by protected flows, require attention to other low-flow characteristics. At gaging sites with adequate historical records, 20 to 30 years, daily flow data can be statistically analyzed to more clearly characterize the duration and frequency of low streamflows. These values are of particular importance in determining the long-term ability of a stream to sustain given rates of withdrawal. They also can be used to predict the frequency and

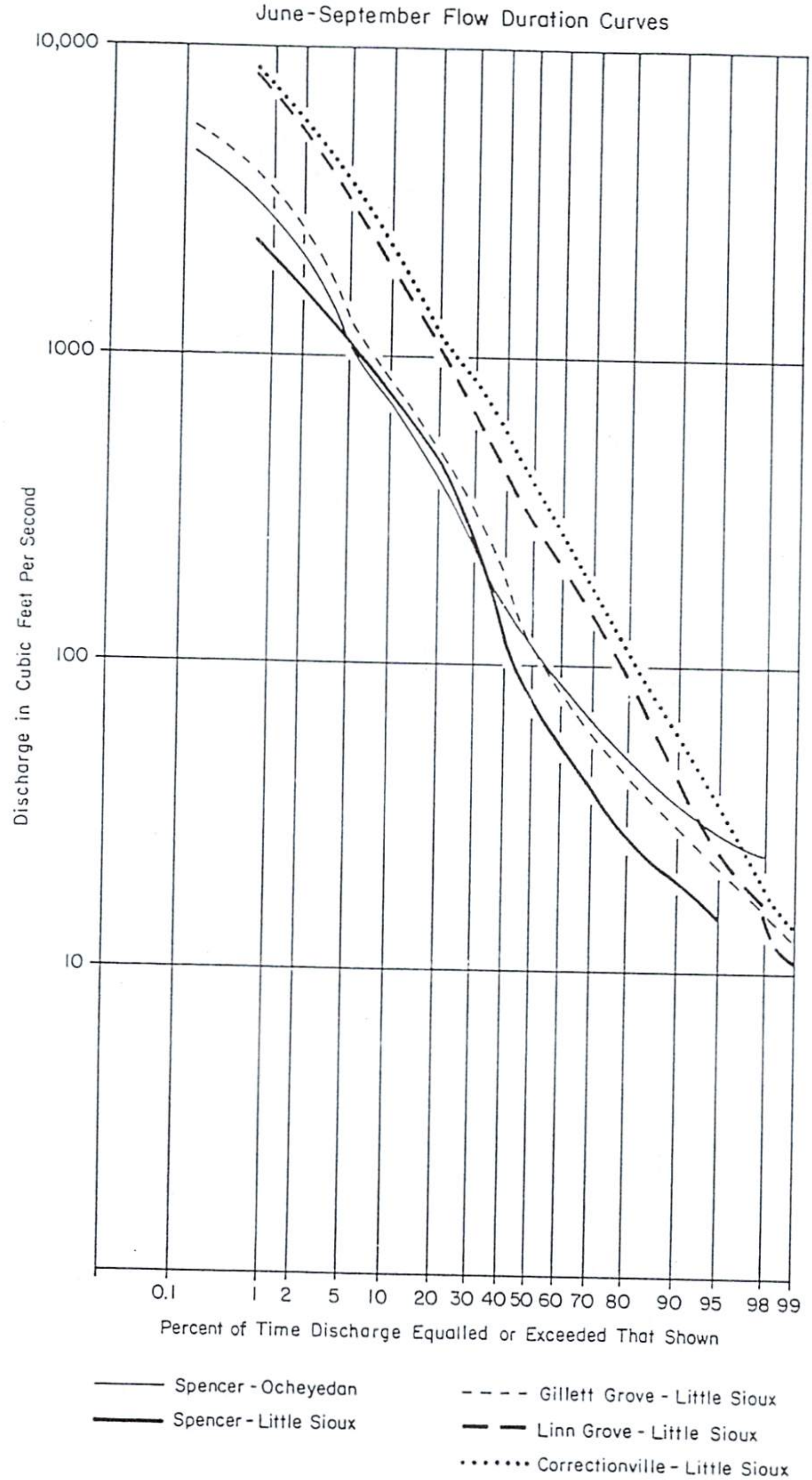



Figure 9. Flow-duration curves.

Table 3. Low-Flow Values

| Station | 84% Duration Flow (cfs) | 7Q10 (cfs) Annual | 7Q10 (cfs) June/Sept |
|---|---|---|---|
| Ocheyedan River, May City | 6.4 | 1.3 | |
| Ocheyedan River, Spencer | 12.0 | 4.5 | 20.3 |
| Stony Creek, Everly | 2.6 | 0.2 | |
| Little Sioux River, Milford | 1.5 | 0.3 | |
| " Spencer | 28.0 | 5.8 | 11.8 |
| " Gillett Grove | 47.0 | 7.1 | 13.9 |
| " Linn Grove | 42.0 * | 8.1 | 18.6 |
| " Sutherland | 64.0 | 9.4 | |
| " Cherokee | 81.0 | 13.0 | |
| " Correctionville | 106.0 * | 14.2 | 22.5 |

* As listed in the Code of Iowa

duration of potential supply interruptions and the frequency of low flows which might trigger withdrawal restrictions imposed to protect in-stream flow. Table 4 presents low-flow data for five gaging sites in the study area. The flows listed in the table are those anticipated to occur at the given recurrence intervals and for a specified number of consecutive days. These values are based on the statistical probability of events occurring as recorded in historical streamflow records. Values in Table 4 are different from those in Table 3 because no corrections were made for stations with short periods of record. For example, Table 4 indicates that for the Ocheyedan River at Spencer, the lowest flow anticipated to occur once in ten years for seven consecutive days (7Q10) is 0 cfs--no flow. Such conditions would be critical for a power plant requiring an uninterrupted supply of cooling water or a municipal sewage plant discharging wastewater. In the latter case, the waste load allocations of receiving streams are set, in part, by flow conditions at 7Q10. In simple terms, wastewater discharged into streams with recurrent, extremely low flows must receive a much higher level of treatment before being discharged. This fact adds significantly to the cost of treatment plant construction and to its normal operating costs.

Table 4. Magnitude and frequency of low flows: Ocheyedan and Little Sioux Rivers.

Station 06-6050.00, Ocheyedan River, Spencer

| Recurrence interval in years | ANNUAL 3 | 7 | 14 | 30 | 60 | 90 | 120 | 183 | JUNE-SEPTEMBER 3 | 7 | 14 | 30 | 60 | 90 | 120 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Lowest average flow, in cu. ft./sec., for indicated period in consecutive days | | | | | | | | | | | | | | |
| 2 | 18.4 | 19.3 | 20.0 | 22.1 | 24.9 | 35.9 | 44.9 | 56.5 | 34.9 | 36.9 | 39.6 | 46.9 | 78.0 | 169 | 272 |
| 5 | 2.0 | 2.1 | 2.1 | 2.3 | 1.2 | 6.4 | 12.1 | 19.7 | 23.4 | 24.6 | 26.1 | 31.4 | 53.1 | 80.9 | 148 |
| 10 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 2.2 | 5.8 | 11.8 | 19.2 | 20.3 | 21.4 | 25.9 | 43.5 | 51.0 | 103 |
| 20 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.8 | 3.1 | 7.9 | 16.5 | 17.6 | 18.2 | 22.3 | 36.8 | 33.4 | 73.8 |

Station 06-6051.00, Little Sioux River, Spencer

| Recurrence interval in years | ANNUAL 3 | 7 | 14 | 30 | 60 | 90 | 120 | 183 | JUNE-SEPTEMBER 3 | 7 | 14 | 30 | 60 | 90 | 120 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Lowest average flow, in cu. ft./sec., for indicated period in consecutive days | | | | | | | | | | | | | | |
| 2 | 12.9 | 13.5 | 13.5 | 14.8 | 17.1 | 21.2 | 25.9 | 34.7 | 22.4 | 26.1 | 29.7 | 42.8 | 84.5 | 99.0 | 151 |
| 5 | 9.4 | 9.8 | 9.9 | 10.6 | 11.4 | 14.3 | 16.8 | 20.2 | 13.8 | 14.8 | 15.2 | 16.9 | 28.8 | 35.5 | 61.4 |
| 10 | 8.2 | 8.5 | 8.8 | 9.2 | 10.0 | 12.4 | 14.5 | 16.8 | 11.7 | 11.8 | 11.7 | 11.5 | 16.8 | 21.6 | 40.5 |
| 20 | 7.4 | 7.7 | 8.0 | 8.4 | 9.3 | 11.4 | 13.2 | 15.0 | 10.6 | 10.1 | 9.9 | 8.8 | 10.9 | 14.7 | 29.4 |

Station 06-6056.00, Little Sioux River, Gillett Grove

| Recurrence interval in years | ANNUAL 3 | 7 | 14 | 30 | 60 | 90 | 120 | 183 | JUNE-SEPTEMBER 3 | 7 | 14 | 30 | 60 | 90 | 120 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Lowest average flow, in cu. ft./sec., for indicated period in consecutive days | | | | | | | | | | | | | | |
| 2 | 18.5 | 19.5 | 21.2 | 26.1 | 35.6 | 43.7 | 53.0 | 76.1 | 37.7 | 39.3 | 42.8 | 48.6 | 70.7 | 127 | 259 |
| 5 | 9.5 | 9.5 | 10.9 | 13.9 | 18.8 | 23.3 | 27.3 | 36.7 | 18.9 | 20.0 | 22.4 | 25.5 | 37.9 | 58.1 | 125 |
| 10 | 6.7 | 6.7 | 7.7 | 10.0 | 13.1 | 16.7 | 19.3 | 24.5 | 12.8 | 13.9 | 16.0 | 19.2 | 29.0 | 40.8 | 84.8 |
| 20 | 5.0 | 5.0 | 5.7 | 7.6 | 9.7 | 12.7 | 14.5 | 17.4 | 9.2 | 10.3 | 12.2 | 15.6 | 23.8 | 31.3 | 61.3 |

Station 06-6058.50, Little Sioux River, Linn Grove

| Recurrence interval in years | ANNUAL 3 | 7 | 14 | 30 | 60 | 90 | 120 | 183 | JUNE-SEPTEMBER 3 | 7 | 14 | 30 | 60 | 90 | 120 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Lowest average flow, in cu. ft./sec., for indicated period in consecutive days | | | | | | | | | | | | | | |
| 2 | 45.2 | 45.7 | 47.9 | 56.4 | 67.6 | 85.9 | 104 | 140 | 90.2 | 95.9 | 105 | 139 | 220 | 332 | 586 |
| 5 | 9.2 | 9.9 | 10.6 | 13.2 | 17.0 | 20.9 | 29.3 | 44.0 | 33.6 | 35.5 | 38.8 | 57.2 | 84.1 | 110 | 193 |
| 10 | 3.4 | 3.9 | 4.2 | 5.5 | 7.9 | 9.7 | 15.0 | 23.9 | 17.7 | 18.6 | 20.4 | 32.5 | 45.7 | 56.5 | 95.5 |
| 20 | 1.4 | 1.7 | 1.8 | 2.5 | 4.1 | 5.0 | 8.6 | 14.4 | 9.7 | 10.2 | 11.3 | 19.3 | 26.0 | 31.2 | 49.8 |

Station 06-6066.00, Little Sioux River, Correctionville

| Recurrence interval in years | ANNUAL 3 | 7 | 14 | 30 | 60 | 90 | 120 | 183 | JUNE-SEPTEMBER 3 | 7 | 14 | 30 | 60 | 90 | 120 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Lowest average flow, in cu. ft./sec., for indicated period in consecutive days | | | | | | | | | | | | | | |
| 2 | 53.3 | 54.9 | 58.4 | 66.8 | 83.6 | 112 | 136 | 182 | 103 | 110 | 122 | 160 | 264 | 390 | 629 |
| 5 | 21.4 | 22.8 | 24.9 | 28.4 | 36.6 | 49.3 | 59.9 | 75.8 | 36.3 | 40.2 | 46.3 | 60.8 | 99.9 | 159 | 259 |
| 10 | 13.0 | 14.3 | 15.9 | 18.1 | 24.0 | 32.4 | 39.3 | 46.8 | 20.9 | 22.9 | 27.3 | 36.0 | 57.9 | 97.8 | 156 |
| 20 | 8.5 | 9.6 | 10.9 | 12.5 | 17.0 | 23.0 | 27.8 | 31.0 | 11.9 | 14.1 | 17.5 | 23.1 | 36.2 | 64.9 | 101 |

## Groundwater and Surfacewater Relationships

Interactions between a stream and aquifer affect the distribution of water, as well as the slope of the water table. Groundwater travels very slowly while surfacewater typically flows at a rate of 1 to 10 ft./sec. Precipitation events rapidly impact stream levels, and with time the effects are transferred to the aquifer by bank seepage. The amount of water transferred between the stream and the aquifer depends on the hydraulic conductivity of the stream bed, on the water-table gradient, and on the permeability or hydraulic conductivity of the aquifer materials.

A hydrograph can be divided into two components: direct surface runoff and groundwater flow. Direct surface runoff responds rapidly to precipitation events and is primarily responsible for the peaks on a hydrograph. Groundwater contributions supply most of streamflow during rainless periods. Since groundwater moves slowly, baseflow contributions display a slower response than surface runoff. Figure 10 is an idealized hydrograph showing the components of surface runoff and baseflow. Integration of the separate areas under these curves provide the relative volume contributions of each component. The rapid increase in streamflow in response to rainfall may reverse the hydraulic gradient between a stream and the groundwater system. Normally, an alluvial aquifer will discharge to a stream. Occasionally, during a rainfall event, stream levels will rise rapidly causing the level of the stream to be higher than the surrounding water table. Water then flows from the stream to the aquifer. As stream levels decrease, the gradients again reverse and groundwater discharges to the stream. This temporary storage of water in the aquifer is termed "bank storage," and can have a pronounced effect on hydrograph shape. Streams with little bank storage characteristically have hydrographs with large steep-sided peaks. Streams with significant bank-storage capacity have lower hydrograph peaks and less steep recession curves. This is shown schematically in Figure 11.

The Little Sioux and Ocheyedan Rivers north of Gillett Grove have considerable bank-storage capacity. The stream hydrograph for Correctionville also suggests that some bank-storage capacity exists in the lower reach of the Little Sioux.

The hydrograph records for the gaging stations were separated into surface and baseflow components using the method developed by the Institute of Hydrology (1980). Daily discharges are grouped into sets of five and the minimum flow is chosen. The selected minima are then sequentially evaluated in groups of three. If 0.9 of the mid-value in the group is less than its preceding and succeeding values, it is considered a baseflow turning point. The turning points are plotted on the daily discharge graph and connected to form the baseflow hydrograph. Integration of the areas under the baseflow and daily discharge curves, over the period of record, results in volumes that are used to calculate an average baseflow percentage. These percentages are presented in Table 5.

The average baseflow, which represents the percentage of groundwater discharging to the stream, appears to be highest above Spencer on the Ocheyedan. This would be expected from the geology, as the stream flows over a thick, extensive, highly productive aquifer in this area. However, as discussed before, the length of time that data has been collected at the Spencer gage is relatively short (six years) and is not adequate for long-term flow analysis. This is also true for data from the Linn Grove and Gillett Grove stations and may account for the ranges being small and having relatively high values. During

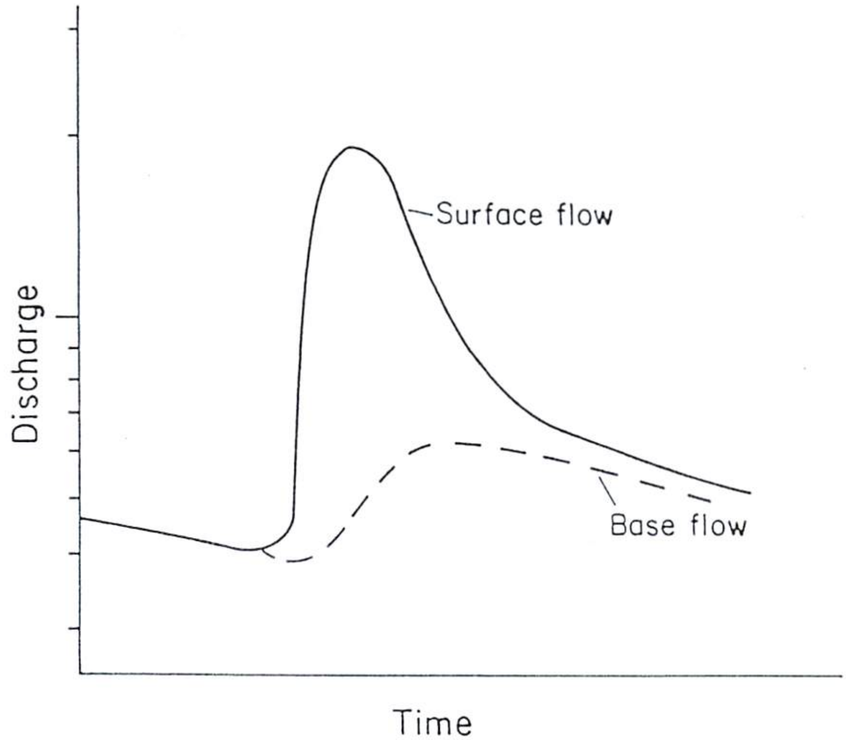



Figure 10. Idealized hydrograph illustrating the relative relationships of surface runoff and groundwater flow.

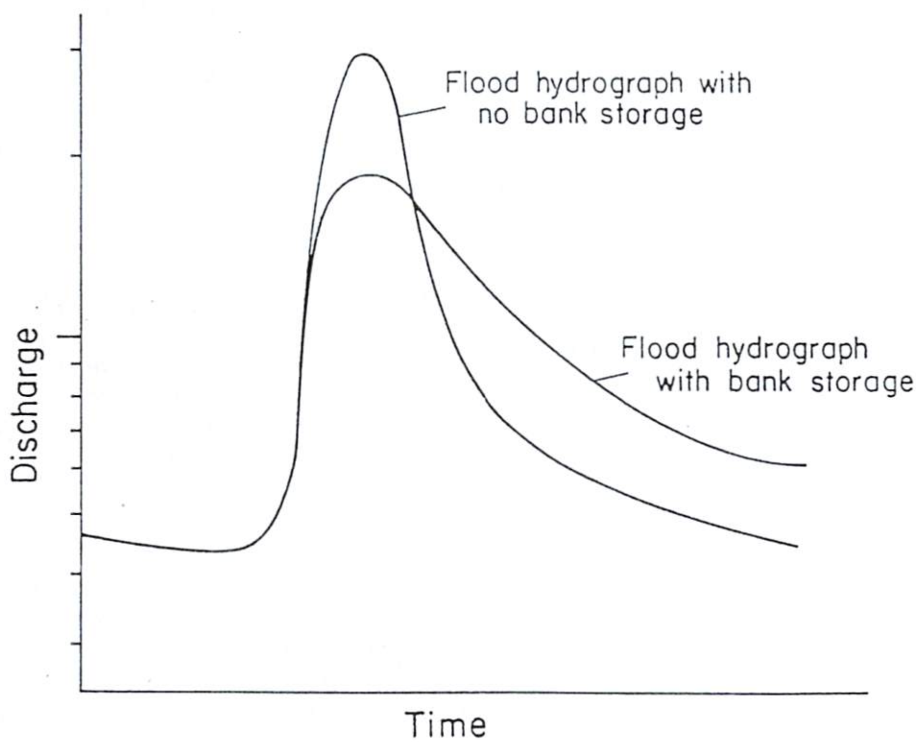



Figure 11. Idealized hydrograph showing the effects of bank storage.

Table 5. Baseflow Percentages.

| Station | Average | Range |
| --- | --- | --- |
| Ocheyedan River near Spencer | .62 | .45 - .75 |
| Little Sioux River at Gillett Grove | .51 | .53 - .69 |
| Little Sioux River at Linn Grove | .59 | .51 - .69 |
| Little Sioux River near Correctionville | .57 | .29 - .97 |

extended drought periods alluvial groundwater levels can fall to a point at which no discharge to the stream occurs and baseflow percentages are reduced.

Baseflow recession curves define the relationship between baseflow discharge and time. The principal use of these curves is to forecast low flows, especially during the growing season when most low flows occur and when water demand is highest. The curves provide estimates of normal streamflow recession rates, providing that no appreciable precipitation occurs during the period. The reliability of the curves decreases after about 20 days and depends, in part, on the variability of streamflow and groundwater discharge. Figure 12 shows the curves developed for the study area gaging stations.

## GROUNDWATER RESOURCES

Earth materials that store, transmit, and yield useable quantities of water to wells are called aquifers. The sands and gravels which comprise the alluvial aquifer of the Little Sioux and Ocheyedan Rivers originated as stream deposits laid down during and subsequent to the melting of the Des Moines Lobe glacier. The saturated sand and gravel is unconfined, meaning that it is not overlain by material which retards the downward flow of water. In a few areas a thin layer of clay is present, but this is not laterally persistent.

The top of the alluvial aquifer is defined as the water table and is the level to which water will freely rise in a well or open hole. The surface of the associated stream defines the water table at that point. The water table generally slopes from the higher ground towards the stream, although this can be reversed during high stream stages. The source of groundwater in the alluvial system is precipitation which infiltrates through the soil. Groundwater levels thus change noticeably throughout the year in response to precipitation and evaporation, and are highest in late spring and fall. Another source of groundwater in the alluvial system is seepage from streams which cut through the aquifer. Pumping wells will result in lowering of the water table (static water level) and will induce infiltration from the river.

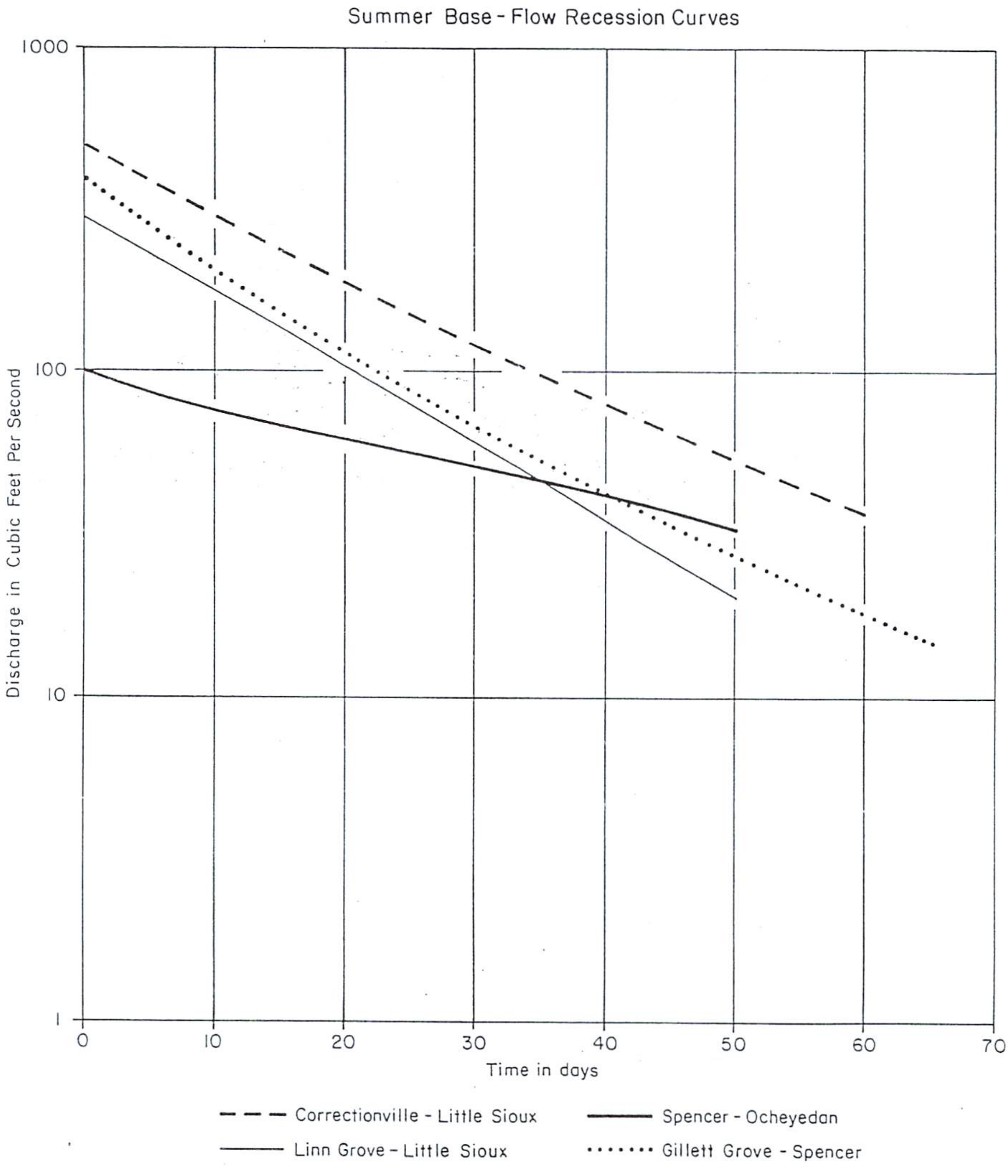



Figure 12. Baseflow recession curves.

Figure 13 shows how groundwater levels are affected by pumping. When a well is pumped, water is withdrawn from storage in the immediate vicinity of the well. As pumpage continues, more water is withdrawn from storage over larger areas. Water levels may eventually be lowered below the stream surface causing influent seepage from the stream, which recharges the aquifer. The rate and area over which water levels decline depends on the aquifer boundaries, the infiltration rates of the stream bed, and the hydrogeologic properties of the aquifer.

Hydrogeologic properties which are necessary to define the water resources potential of an aquifer are specific yield (Sy), hydraulic conductivity (K) and transmissivity (T). Specific yield is defined as the volume of water yielded for a specific area and for a specific drop in the water table. It is a dimensionless quantity. Thus, if an unconfined aquifer releases 2 acre-feet of water over an area of 20 acres with a drop in the water table of 1 foot, the specific yield would be 0.1. Hydraulic conductivity is defined as the volume of water that will move through a specific area at a specific gradient for a specific length of time. It is measured in units such as feet/sec or gallons per day/square foot. Hydraulic conductivity is related to the velocity of water moving through the sediment and the slope of the water table. Transmissivity is similar to hydraulic conductivity but considers the volume of the aquifer. It is defined as $T = Kb$ where b is thickness of the aquifer and is measured in gallons per day/foot or square feet/day.

Several pumping tests were conducted in the upper reaches of the study area as part of the development of rural water systems. Table 6 summarizes the information from these pumping tests. The transmissivity values are high even for sands and gravels. This may be the result of a variety of factors. The observation wells may not be completed at the same depth as the pumping

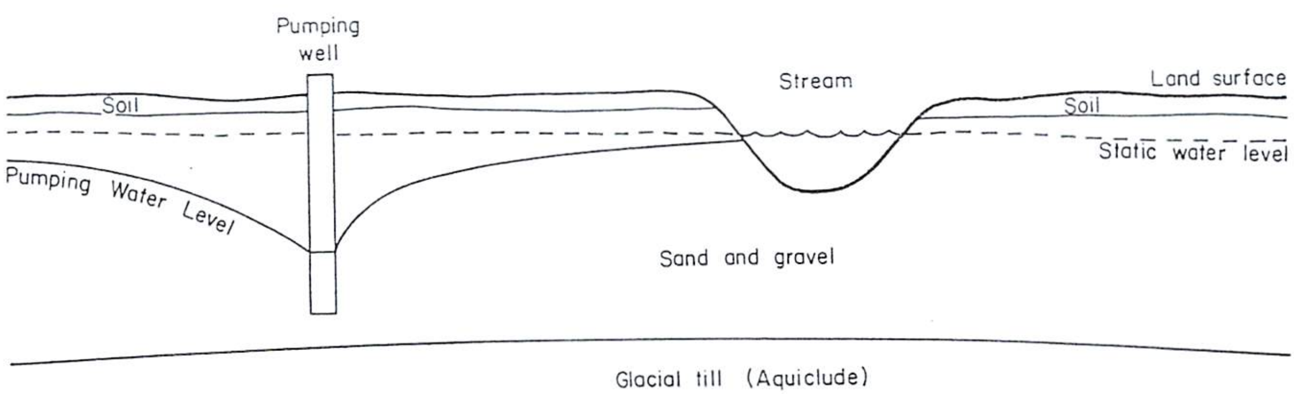



Figure 13. Schematic diagram showing relationship between static and pumping water levels.

Table 6. Hydrogeologic properties of alluvial wells: Ocheyedan and Little Sioux Rivers.

| | | T (gpd/ft) | | S | | | Permeability (gpd/ft2) | Specific Capacity (gpd/ft) |
|---|---|---|---|---|---|---|---|---|
| | | Range | Avg. | Range | Avg. | Thickness (ft.) | Avg. | |
| Osceola-O'Brien RWS North Unit | Dirks | 360,000-700,000 | 500,000 | 0.0001-0.03 | 0.008 | 42 | 12,000 | 65 |
| | Harms | 180,000-790,000 | 510,000 | 0.0003-0.04 | 0.02 | 37 | 14,000 | 34 |
| | Caawe | 200,000-650,000 | 425,000 | 0.0001-0.05 | 0.004 | 37 | 11,500 | 44 |
| | Rossman | 140,000-310,000 | 230,000 | 0.002 -0.04 | 0.02 | 37 | 6,200 | 30 |
| | Speck | 112,000-370,000 | 208,000 | 0.001 -0.1 | 0.06 | 30 | 7,000 | 32 |
| | Anderson | 100,000-290,000 | 180,000 | 0.0001-0.1 | 0.04 | 31 | 5,800 | -- |
| Clay Co. RWS | #1 | 171,000-240,000 | 200,000 | | | 31 | 6,500 | 150 |
| | #2 | 125,000-310,000 | 220,000 | | | 35 | 6,300 | 33 |
| | #3 | 26,000-190,000 | 132,000 | | | 26 | 5,100 | 30 |
| | #4 | 81,000-195,000 | 133,000 | | | 25 | 5,300 | 35 |
| Everly | | 34,000-43,000 | 39,000 | | | | | |
| Corn Belt Power | | 96,000-106,000 | 101,000 | 0.08-1.4 | 1.1 | | | |
| Spencer | | 200,542 | | .0005 | | | | |
| Oseola-O'Brien RWS South Unit | #1 | 100,000-330,000 | 220,000 | | | 29 | 7,600 | 30 |
| | #2 | 270,000-410,000 | 340,000 | | | 34 | 10,000 | 60.5 |
| | #3 | 190,000-670,000 | 330,000 | | | 24.5 | 13,500 | 21 |

wells; recharge of the pumped water may have occurred during the pump test; and/or the saturated thickness was not constant during the test. Also, there may be a high degree of connection between the aquifer and the river which would allow recharge of the aquifer. However, no recharge effects were seen on the drawdown curves. The variability of the numbers is a reflection of the variability of the aquifer and its geology. Low specific yields signify semi-confined conditions and probably indicate the presence of silts and clays overlying the sand and gravel. Lithologic changes such as the presence of silt can occur over a short distance in an alluvial sequence. Often the floodplain adjacent to the river will be covered with a Holocene silt, while further away from the river, the sands and gravels may be immediately below the soil.

The total volume of groundwater in storage can be estimated from the areal extent of the aquifer, the average saturated thickness, and the average specific yield. As an example, the storage in the Ocheyedan alluvial system in Osceola County would be:

$$\text{Area} \times \text{Saturated Thickness} \times \text{Specific Yield} \times \text{Conversion Factor} = \text{Storage}$$

$$530 \text{ million sq. ft.} \times 30 \text{ ft.} \times .02 \times 7.48 \text{ gallons/ft}^3 = 2.4 \text{ billion gallons}$$

This translates to 2 acre-inches of water in storage per acre. This is a conservative figure. If a higher specific yield were applied, which would be reasonable for an alluvial system, then the amount of water in storage would increase. Variations in the saturated thickness will also affect the amount of water in storage. During drought, the water table drops, decreasing the saturated thickness and decreasing the amount of water in storage. In wet years, the reverse occurs.

The rate at which water moves through an alluvial aquifer and the path that it takes is dependent on both geologic features and the gradient or slope of the water table. Geologic factors include the nature of the materials in the aquifer, their bedding patterns and thickness, and the size and arrangement of the particles comprising the unit. In alluvial systems, the geology of the aquifer is highly variable and difficult to characterize. The numbers presented here are a general guide to the availability of water. Potential sites for well development need to be evaluated by test drilling and pumping to determine the specific aquifer characteristics at that site.

## Water Levels

Water levels were measured from August, 1985 to August, 1986 at all well and river locations. All locations were surveyed to obtain more accurate estimates of water-table position. Water-level data are presented in Appendix D of the Open-File Data Report (Thompson, 1986).

Groundwater levels ranged from approximately one foot above to 18 feet below ground level during the course of this study. Water levels varied in any one well by a maximum of 10.7 feet although most wells varied an average of five feet. Water levels in alluvial systems are controlled by infiltration and correspond with effective precipitation. In drier years, particularly drought years, declining water levels will reduce the saturated thickness, affecting the amount of water in storage and possibly affecting water quality.

Surfacewater levels varied up to seven feet over the time of this study. Streams are dependent on groundwater discharge to maintain flow. During prolonged drought, the upper reaches of these streams, particularly the Ocheyedan, will go dry.

Water-table gradients measured over the study area ranged from .001 (5ft/mi) to .005 (26 ft/mi). Flow in the aquifer is towards the river and slightly downvalley. Six of the multi-level completions (nested well sets) are in the same aquifer, and are not separated by clays or other retarding layers. Two of these show strong upward gradients ranging from .01 (52 ft/mi) to .14 (72 ft/mi). The other four well sets show low gradients within measurement error of zero. One nested set was observed to go from zero gradient to a low downward gradient during a period of recharge. Vertical gradients may influence water quality in the aquifer. Some examples of this were seen during the course of this research. At one well, strong upward gradients exist, and no nitrate or pesticide contamination has ever been measured at this site. At another well site, nitrates and pesticides were found in the middle well of a nested set when downward vertical gradients were present.

## Streamflow Depletion

As previously discussed, gradients in alluvial aquifers normally slope toward streams. The groundwater discharged to streams is called baseflow. During times of high river stages, the gradients may reverse and the river will discharge to the aquifer. Another mechanism which will cause streamflow to be diverted to an aquifer is pumping. The reduction of streamflow caused by groundwater withdrawal is streamflow depletion. Streamflow depletion has two components, although not necessarily separable: a) that induced directly from the stream, and b) that intercepted enroute to the stream. A method described by Jenkins (1968) was used to evaluate streamflow depletion for the Little Sioux and Ocheyedan systems. The method computes the percentages of depletion attributable to pumpage using the distance of the pumping from the stream, the rate and duration of pumping, and assumed values of specific yield and transmissivity. Figures 14 and 15 show the graphs developed to provide a basis for predicting stream depletion effects along the Little Sioux and Ocheyedan systems.

Both graphs result from using a transmissivity value of 200,000 gpd/ft (26,600 $ft^2/d$). The upper curves are for a specific yield of 0.01 and the lower for 0.1. Stream depletion is expressed as a percentage (the total volume of water from the stream divided by the total volume pumped from the well). Table 7 shows the rate of stream depletion (i.e., the actual cfs being taken/diverted from the stream) for a well pumping at 700 gpm. The rate of stream depletion increases with time of pumping and decreases with distance from the river.

The assumptions that the Jenkins' model are based on are the same as those used in the pumping test analysis and are as follows:

1) Transmissivity is constant over time; i.e., drawdown is negligible compared to saturated thickness.
2) The aquifer is isotropic, homogenous, and semi-infinite in areal extent.
3) The stream is straight and fully penetrates the aquifer.
4) The stream and aquifer are hydraulically connected.
5) The pumping rate is steady.
6) The well is open to the full thickness of the aquifer.

Field conditions never match the idealized assumptions. In the case of assumption (1), T can vary, and therefore streamflow depletion will vary.

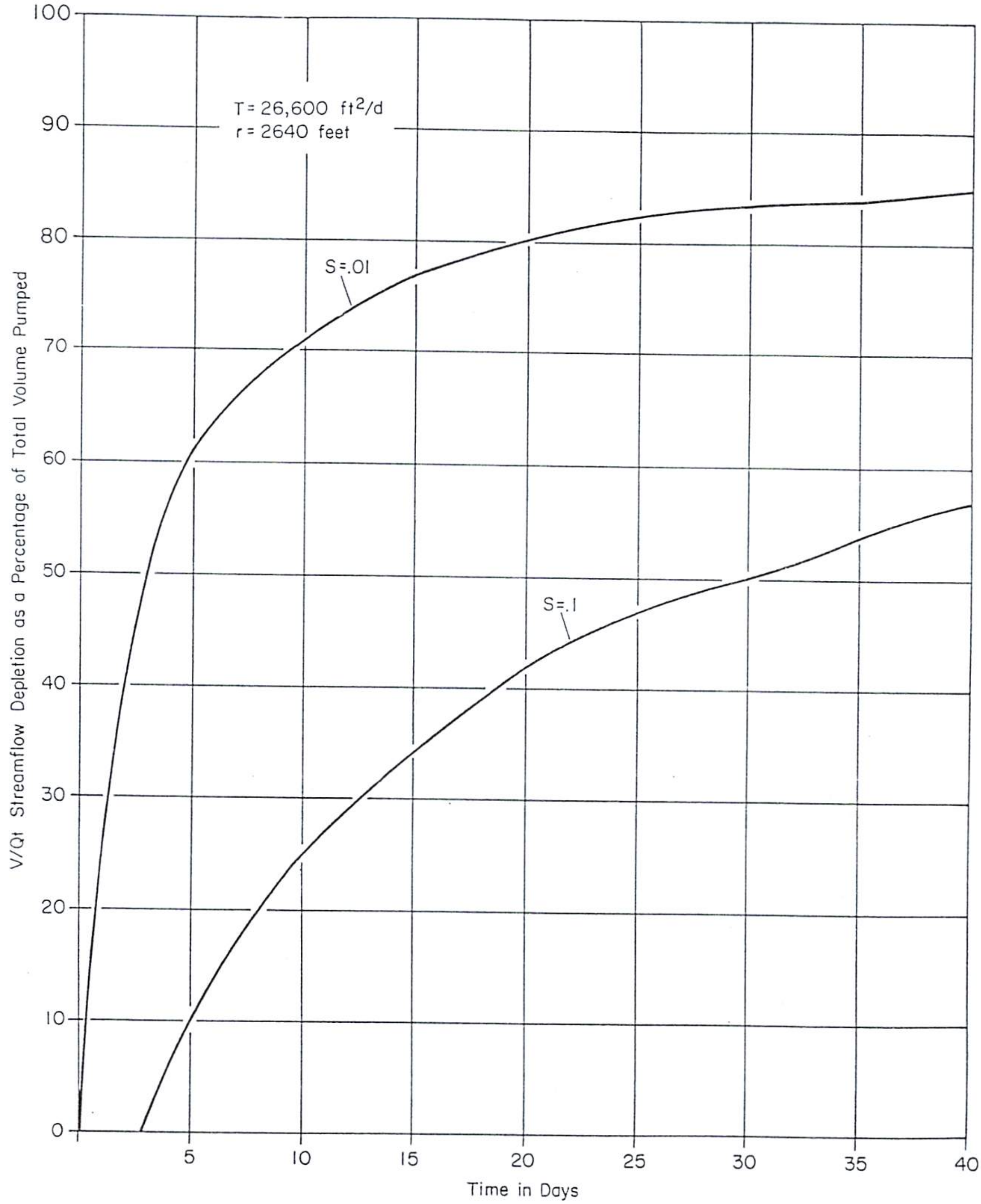



Figure 14. Streamflow depletion curves: time vs. depletion.

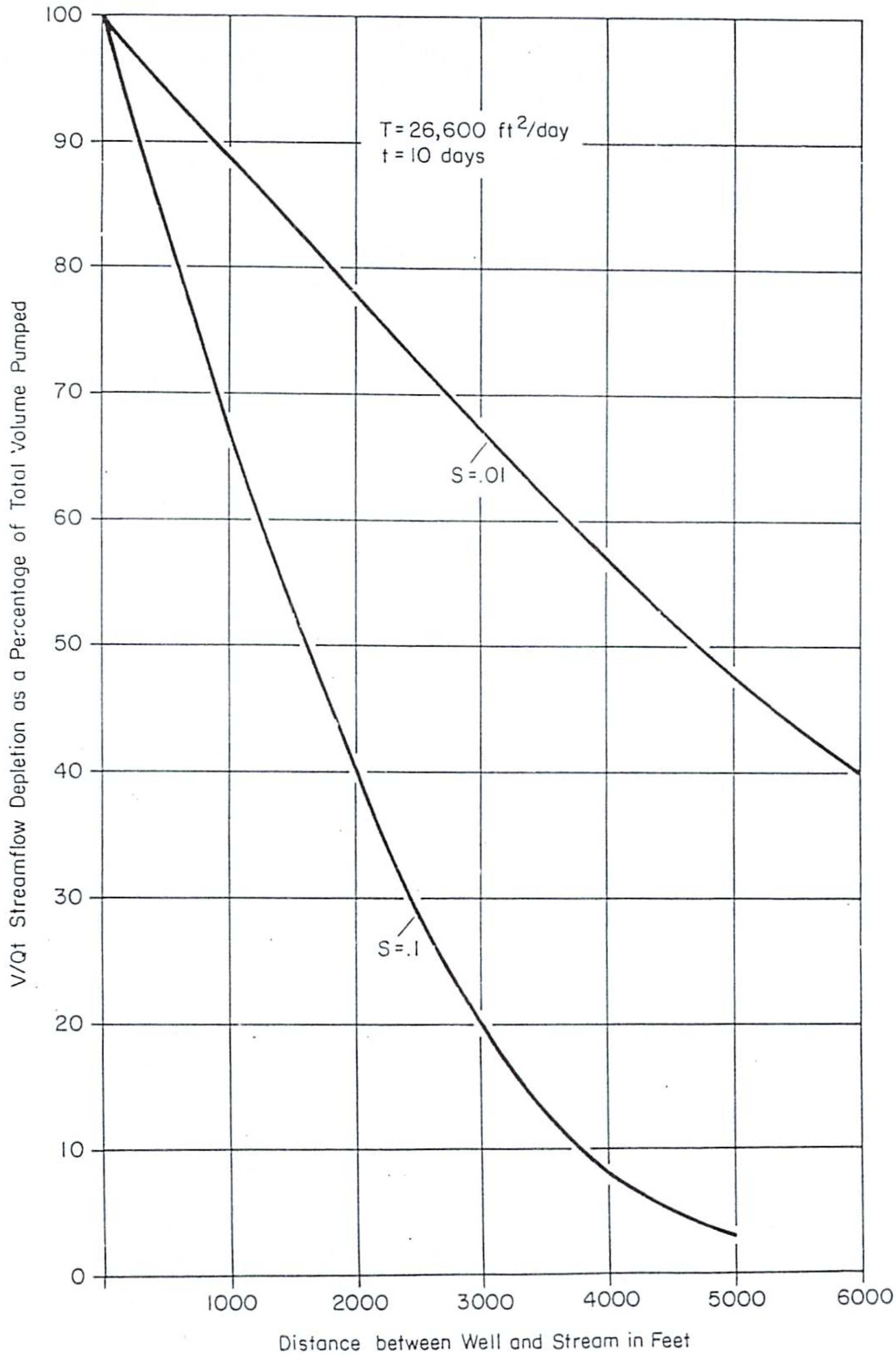



Figure 15. Streamflow depletion curves: distance vs depletion.

Table 7. Streamflow depletion calculations. Assumptions are: constant transmissivity (T) of 26,600 $ft^2$/day and a constant pumping rate (Q) of 700 gpm. Distance from the pumping well to the river (r) is constant for the first three columns while time is varied. Time is then constant over the second three columns as r is varied. Caculations are for two different specific yield(s).

T = 26,600 $ft^2$/d
Q = 700 gpm

| | r = 2640 feet | | | t = 10 days | |
|---|---|---|---|---|---|
| t (days) | S = 0.01 v/Qt (cfs) | S = 0.1 v/Qt (cfs) | r (feet) | S = 0.01 v/Qt cfs) | S = 0.1 v/Qt (cfs) |
| 1 | 0.4 | 0 | 1000 | 1.4 | 1.0 |
| 3 | 0.8 | 0.1 | 2000 | 1.2 | 0.6 |
| 5 | 1.0 | 0.2 | 3000 | 1.0 | 0.3 |
| 10 | 1.1 | 0.4 | 4000 | 0.9 | 0.1 |
| 20 | 1.2 | 0.6 | 5000 | 0.8 | 0.05 |
| 30 | 1.3 | 0.8 | 6000 | 0.6 | 0 |

Assumption (2) has more ramifications. The aquifer is neither isotropic, homogeneous, nor semi-infinite. Impermeable boundaries, such as those corresponding to the valley wall, cause stream depletion effects to be larger. The non-homogeneous nature of the aquifer leads to non-homogeneity of the aquifer constants. T and S can vary throughout the aquifer. The graphs are useful, however, as a general guide to the effects of stream depletion.

## WATER QUALITY

Background groundwater quality data were obtained from the University Hygienic Lab (UHL), from the Department of Natural Resources, Environmental Protection Division, and from the files of rural water systems and municipalities. This data is contained in Appendix E of the Open-File Data Report (Thompson, 1986).

From the existing major-ion data, groundwater can be classified as slightly alkaline freshwater with calcium and magnesium as the dominant cations and bicarbonate the dominant anion. Total dissolved solids are usually less than 1000 mg/l and the water is characteristically hard. A few of the wells show objectionable iron (Fe) concentrations indicating that the gravels are iron-rich in some localities.

Spencer municipal wells 1, 2, 3, and 4, all 45 feet deep, have a higher dissolved solids content than is typical for most alluvial wells in the area. The wells show higher calcium, magnesium, manganese, sulfate and iron, and lower nitrate concentrations. These concentrations can be explained by the geology in the vicinity. The wells are near the eastern edge of glacial Lake Spencer, an area where laminated lake clays occur. If there are clay lenses present, the clay would provide a source for mineral enrichment and would also act as a barrier to the downward movement of surface related contaminants such as nitrate.

Nitrate contamination of the shallow groundwater is a significant problem. It is well documented in Iowa that wells at depths of less than 50 feet (15 m) are highly susceptible to contamination. A cursory examination of recorded information on wells has shown that more than 25 percent of all wells in northwest Iowa are completed at depths of less than 100 feet (30 m) (Figure 16). The actual percentage of shallow wells is probably much higher as the data evaluated are heavily biased toward deep wells completed in Cretaceous sandstones. Potential water quality problems in the region are increased by cropping practices. In most counties of northwest Iowa over 60 percent of the land is in row crops, primarily corn and soybeans, receiving chemical applications (Figure 17). In a few counties more than 80 percent of the land is row-cropped. Most areas along the alluvial valleys are intensively farmed.

Figure 18 shows the percentage of water samples from private wells less than 100 feet deep which exceeded the nitrate recommended maximum contaminant level (MCL) of 45 mg/l $NO_3$ (10 mg/l $NO_3$-N). Of the private alluvial wells in Appendix E, 50 percent exceeded the recommended limit on nitrate. Many municipal supplies, particularly in northwest Iowa, have also exceeded the nitrate MCL (Figure 19).

Background surfacewater quality data show a wide range of nitrate values from 0 to 37 mg/l $NO_3$ (0-8.3 mg/l $NO_3$-N). Organic nitrogen averages around 2 mg/l as N. Ammonia and nitrite-nitrogen concentrations are generally low. Fecal coliform concentrations also show a wide variation from <10 to 16,000 organisms per 100 ml.

Previous studies in Iowa (McDonald and Splinter, 1982; Hallberg et al, 1984) have shown that regional increases in nitrate levels in groundwater and surfacewater occurred in direct relation to the increased use of nitrogen fertilizers. In Iowa the statewide average nitrogen fertilization rate for corn has increased from 45 lbs-N/ac (50 kg-N/ha) in 1964, to 143 lbs-N/ac (160 kg-N/ha) in 1984 (Hallberg, 1986). For soybeans the rate has increased from 4 lbs-N/ac (4.5 kg-N/ha) in 1964, to 23 lbs-N/ac (26 kg-N/ha) in 1984. Nitrate concentrations in public water supplies in northwest Iowa have risen steadily over the past thirty years (Figure 20).

Previous investigations along the Des Moines River in north-central Iowa (Thompson, 1984) have shown that significant vertical stratification of nitrate does occur. In order to investigate the distribution of contaminants within the aquifer, nested wells were installed (Figure 21). In general, one well was set into the top of the aquifer near the water table, one near the middle, and one at the bottom of the aquifer. Wells were constructed of 2-inch PVC pipe with slotted intervals ranging from two to four feet.

Water quality sampling was done monthly on 31 wells at 19 sites and 10 surfacewater sites. Shortly after monitoring began, one well and one surfacewater site were dropped for construction reasons. In addition, several surfacewater sites were replaced in the early phase of the monitoring. Complete information and results for each monitoring well can be found in Appendix II of this report.

The wells were purged with a submersible pump before each sampling. Three casing-volumes were removed which has proven more than adequate to stabilize temperature and conductivity values and to assure a representative sample. Samples were collected with a PVC bailer. Prior to sample extraction all equipment was rinsed with a 75 percent ethyl-alcohol solution.

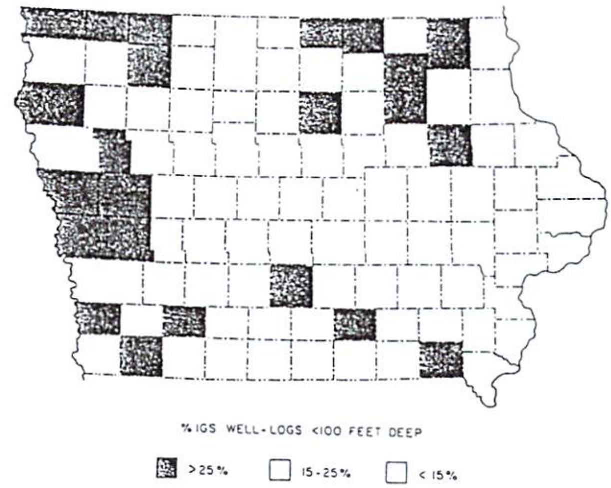



Fig. 16. Percentage of wells in Iowa less than 100 ft deep, by county. (Data from G.S.B. files.)

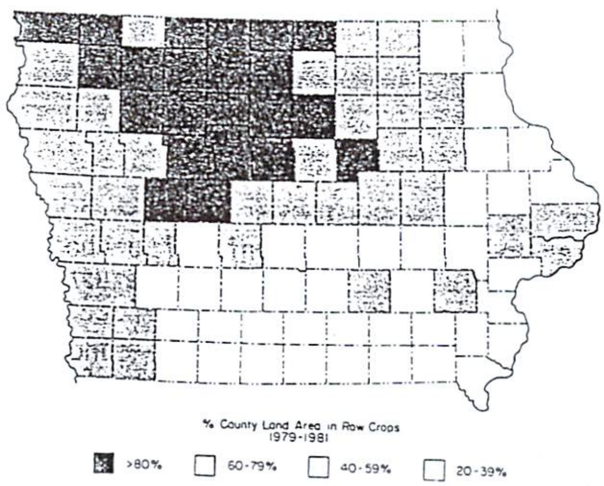



Fig. 17. Average percent of land area in corn and soybeans, by county, 1979-1981. (Data from Iowa Dept. of Ag., Crop and Livestock Rept. Serv.)

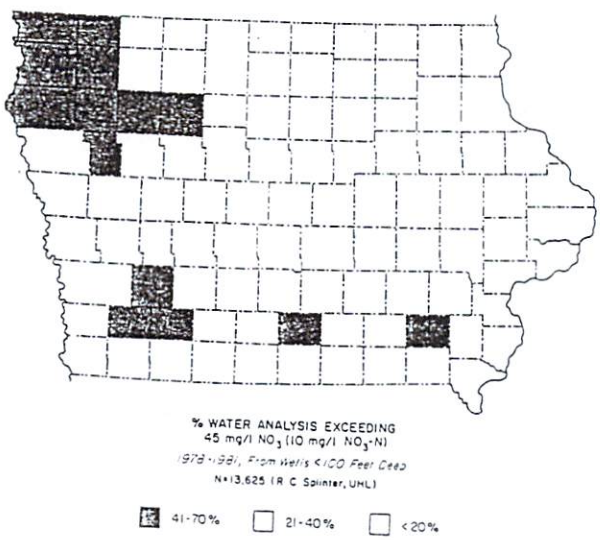



Fig. 18. Percent of water samples, by county, exceeding the nitrate MCL, from private wells less than 100 feet (30 m) deep; analayzed by UHL between 1978-1981. N = 13,625; 28 percent of all samples exceeded the MCL. (Data from Roger Splinter, UHL, pers. commun.)

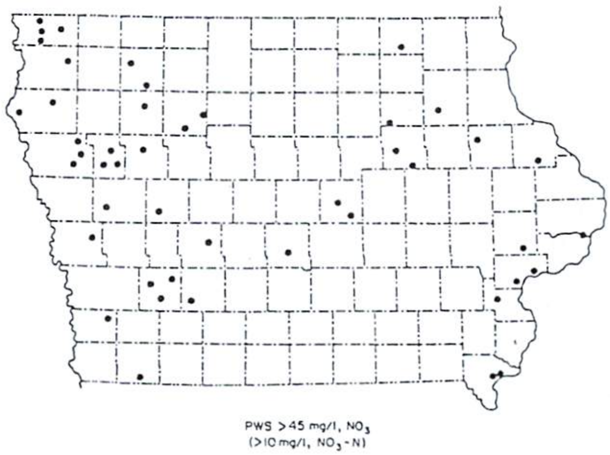



Fig. 19. Public water supplies which have exceeded the nitrate maximum contaminant level of 10 mg $NO_3$-N (45 mg/l $NO_3$) since 1980. (From Hallberg, 1985.)

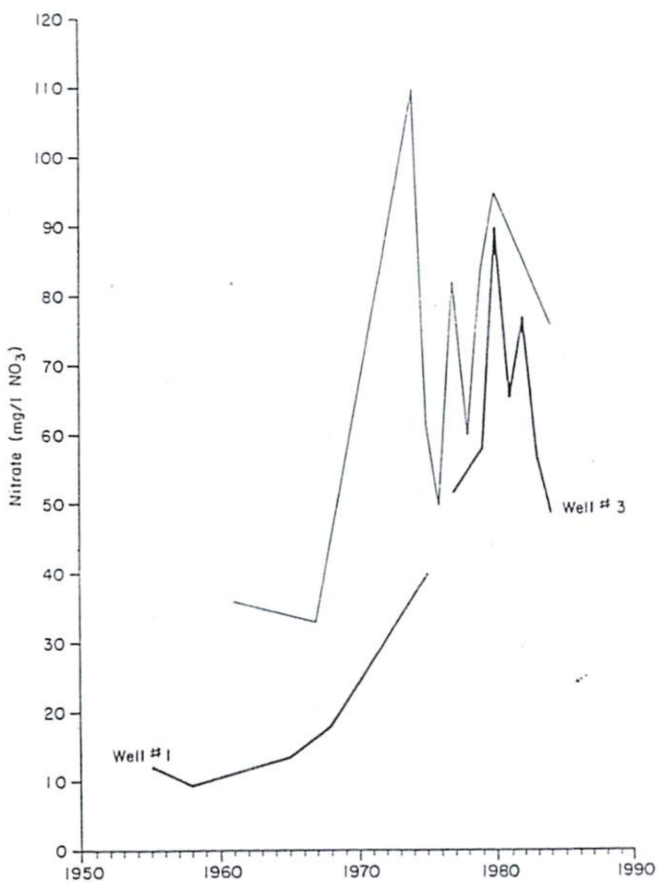



Fig. 20. Nitrate concentrations through time from public water supply wells in northwest Iowa. Light line - Rock River basin. Dark line - Ocheyedan-Little Sioux basin.

## Field Analyses

Parameters measured in the field included temperature, conductivity, pH, and dissolved oxygen. Temperature was measured with a standard laboratory thermometer. Conductivity was measured using a Fisher Model 152 conductivity meter. Specific conductance was measured in micromhos/cm, automatically corrected to 25°C.

SCHEMATIC OF NESTED WELL DESIGN

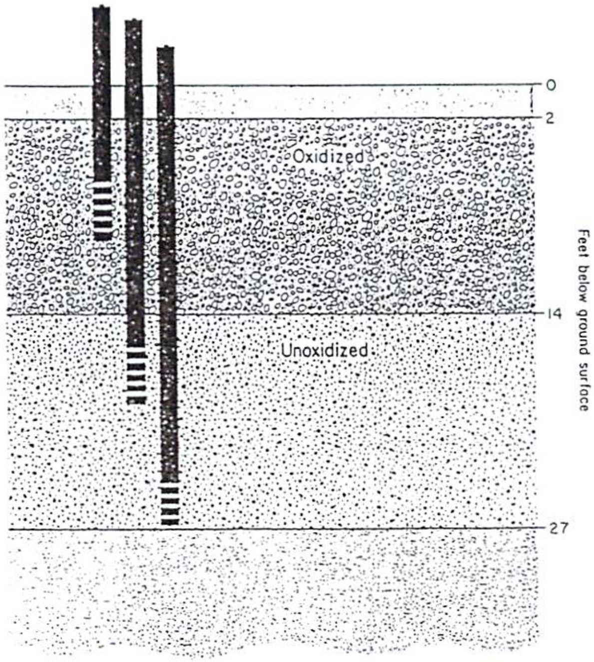



Fig. 21 Schematic diagram of nested monitoring wells.

A Sargent-Welch pH meter, Model 2050, coupled with a glass combination electrode utilizing Thalomid intervals was used to determine pH of the sample. Temperature compensation was automatic.

Dissolved-oxygen measurements were made using a YSI Model 57B dissolved-oxygen meter and a self-stirring BOD bottle probe. Samples were collected in standard BOD bottles and were measured in mg/l. Additional dissolved-oxygen measurements were made within 24 hours using the azide modification of the Winkler method.

## Chemical Analyses

All chemical analyses of water samples were performed by the University Hygienic Laboratory (UHL) using standard analytical methods. Details of the analytical procedures may be obtained from UHL. All samples were refrigerated until delivery to UHL.

### Nitrate

Nitrates were analyzed using EPA method 353.2 (EPA, 1983) with minor modifications. This is the standard cadmium-reduction method for nitrate/nitrite analysis. Results are reported as milligrams per liter nitrate (mg/l, $NO_3$).

### Bacteria

Total coliform bacteria were determined using the most probable number (MPN) method, in accord with EPA standard methods (EPA, 1978). The data are reported as the statistical MPN of total coliform individuals per 100 ml of water. The MPN classes are 0, 2.2, 5.1, 9.2, 16, and 16+. Any value above 0 is considered unsatisfactory and any value >2.2 is considered unsafe. Fecal coliforms were analyzed by the MPN method as well.

### Pesticide Analysis

Pesticide concentrations in the water samples were analyzed by standard gas-chromatographic column methods, following EPA guidelines (EPA, 1982). Prior to 1986 all samples were analyzed by gas chromotography using a split injection system with dual capillary columns and electron capture detection. Each sample showing a positive was also analyzed with packed columns using a nitrogen-phosphorus detector. Beginning in 1986 all samples were analyzed by gas chromotography using a split injection and two capillary columns with two nitrogen-phosphorus detectors. Results are reported as micrograms per liter (µg/l). Detection limits vary for individual pesticides, and with other water constituents (miscellaneous organic compounds) which may interfere with the chromatographic peaks.

### Organic Carbon

Total organic carbon was analyzed using a Dohrman TOC analyzer. Samples are acidized to remove inorganic carbon and purged with nitrogen gas. Results are reported in mg/l.

## Results of Nitrate Monitoring

Results of the nitrate monitoring in the Ocheyedan-Little Sioux alluvial system show that extensive areal contamination has occurred, though nitrate concentrations are not excessively high (Table 8). Nitrate was detected at 18 of the 19 well sites and at all surfacewater sampling sites. Fifty-two percent (226/438) of the samples collected showed detectable concentrations of nitrate; however, only six percent (27/438) of the samples exceeded the nitrate MCL.

The distribution of nitrate is not constant and shows a high degree of both areal and temporal variability. Individual wells at a single site ranged from <5 to 172 mg/l $NO_3$ (<1 to 38.2 mg/l $NO_3$-N) over a twelve-month period. Of the 30 wells sampled, only six always had nitrate present and none of these were consistently over the nitrate MCL. Samples from streams in the area displayed similar patterns over time.

Figure 22 shows the temporal trends in nitrate levels in three wells and two rivers located in different areas of the system. Although different in magnitude, the similarity in timing of changes illustrates the responsiveness of the system to hydrologic events. The primary mechanism for the movement of nitrate from the surface to groundwater is by infiltration of precipitation and snowmelt.

The distribution of nitrate is also variable over the study area. A maximum variation of 11 to 172 mg/l $NO_3$ (2.4-38.2 mg/l $NO_3$-N) was measured at closely spaced wells during a single sampling period. The nitrate concentration at any one sampling location at any given time reflects a complex interaction among the hydrogeologic properties of the aquifer, the nature of surficial materials and their hydraulic properties, precipitation patterns and intensities, land-use and chemical application patterns, and the exact portion of the aquifer flow system that is tapped by the well. Variability in chemical concentrations is to be expected.

Table 8. Nitrate Monitoring results: Ocheyedan-Little Sioux alluvial system.

| Location | Screened Interval | Jun 19 1985 | Jul 15-16 1985 | Aug 19-20 1985 | Sept 10-12 1985 | Oct 15-18 1985 | Nov 12-14 1985 | Dec 24-27 1985 | Jan 20 1986 | Feb 19-20 1986 | Mar 19-21 1986 | Apr 14-16 1986 | May 20-22 1986 | Jun 17-19 1986 | Jul 22-24 1986 | Aug 19-21 1986 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| OR-1U | 7-9 | 53 | -- | 40 | 40 | 41 | 45 | 11 | <5 | 43 | 31 | <5 | 67 | 55 | 50/50 | 33 |
| 1M | 26-30 | 47 | -- | 30 | 6 | <5/<5/<5 | <5 | <5 | 6 | 49 | 19 | 58 | 36 | 24/22 | 16 | 14 |
| 1L | 54-58 | <5 | -- | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 |
| OR-R2 | SURFACE | 20 | -- | <5 | 33 | 33 | 21 | -- | -- | 22 | -- | -- | 22/22 | 33 | 25 | 6 |
| OR-7U | 6.5-7.5 | <5 | -- | <5 | <5 | <5 | <5 | -- | <5 | <5/<5 | <5 | <5 | <5 | <5 | <5 | <5 |
| 7L | 13-16.5 | <5 | -- | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 |
| OR-6 | 16.5-19.5 | 59 | -- | 75 | 52 | 33 | 7 | 38/40 | 33/48 | 67 | 58 | 8 | 18 | 26/22 | 57 | 41 |
| OR-R1 | SURFACE | 31 | -- | 5 | D/C | | | | | | | | | | | |
| OR-11U | 10-13 | -- | -- | 71 | <5 | 9 | 26/24 | <5 | <5 | 43 | 25 | 9/7 | <5 | <5 | 20 | 20/24 |
| 11L | 26-30 | -- | -- | <5 | <5 | <5 | 5 | <5 | <5 | <5 | <5 | <5 | <5/<5 | <5 | <5 | <5 |
| OR-R2A | SURFACE | -- | -- | -- | 38 | 39 | 31 | -- | -- | 19 | -- | -- | 42 | 42 | 30 | 13 |
| LSR-6 | 11-18 | -- | 25 | 7 | 13 | 8 | 12/12 | <5/<5 | <5/<5 | <5 | <5 | <5 | 15 | 7/7 | 5 | 11 |
| SC | SURFACE | -- | -- | -- | -- | 32 | -- | -- | -- | -- | -- | -- | -- | 43 | -- | -- |
| LSR-R1B | SURFACE | 30 | -- | <5 | 25 | 37 | 28 | -- | -- | -- | -- | -- | 25 | 24 | 19 | 6 |
| LSR-1U | 16-17 | 41 | -- | 64 | 68 | 6 | 11 | 27/34 | 6 | 67/64 | 46 | 24 | 24 | -- | <5/12 | 6 |
| 1L | 85-90 | <5 | -- | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 |
| LSR-36U | 6.6-8 | -- | -- | 18 | -- | 9 | <5 | -- | <5 | <5 | 12 | 35 | 6/6 | 10 | 6 | <5 |
| 36L | 22-25.5 | -- | -- | <5 | -- | <5 | <5/<5 | -- | <5 | -- | <5 | 33 | <5 | <5 | <5 | <5 |
| LSR-11 | 15.5-18 | -- | 20 | <5 | <5 | <5/<5/<5 | <5 | <5/<5 | <5 | <5 | <5 | <5 | <5 | -- | <5/<5 | <5 |
| LSR-R2 | SURFACE | -- | 28 | 5 | D/C | | | | | | | | | | | |
| LSR-12 | 17-19 | -- | <5 | <5 | D/C | | | | | | | | | | | |
| LSR-14 | 22-28 | -- | 32 | 10 | 15 | 16 | <5 | 15 | <5/<5 | 16 | -- | 6 | 10 | 9/6 | 10 | 6 |
| LSR3RB | SURFACE | -- | -- | -- | 26 | 38 | 27 | -- | -- | -- | -- | -- | -- | 33 | 23 | 10/10 |
| LSR-38U | 23.5-29.5 | -- | -- | <5 | <5 | <5 | <5 | -- | -- | -- | -- | -- | <5 | <5 | <5 | <5 |
| 38L | 44-50 | -- | -- | <5 | <5 | <5 | <5 | -- | -- | -- | -- | -- | <5 | <5 | <5 | <5 |
| LSR-35U | 20.5-22.5 | -- | -- | <5 | 26 | 10 | 23/21 | <5 | <5 | 40 | 17 | 8/<5 | 16 | 22 | 13 | 26 |
| 35M | 35.5-37.5 | -- | -- | 33 | 36 | 26 | 8 | 25 | 24 | 32/30 | 25 | 31 | 17 | 17 | 18/24 | 19 |
| 35L | 50-52 | -- | -- | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 |
| LSR-34U | 17.5-19 | -- | -- | 9 | <5 | 13 | 9 | <5 | <5 | 8 | <5 | <5 | 32/32 | 10 | <5 | 37 |
| 34L | 53 -63 | -- | -- | <5 | <5 | <5/<5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 |
| LSR-R3 | SURFACE | -- | 33 | 6 | -- | 39 | 31 | -- | -- | -- | -- | -- | 32/31 | 38 | 24 | 11 |
| LSR-20U | 20-23 | -- | 11 | <5 | <5 | <5 | <5 | <5 | <5 | 9 | <5 | <5 | <5 | <5/<5 | <5 | <5 |
| 20L | 42-48 | -- | 11 | <5 | <5 | <5/<5/<5 | <5 | <5 | <5 | <5/<5 | <5 | <5 | <5 | <5 | <5 | <5 |
| LSR-21 | 12-13 | -- | 172 | 8 | 92 | 54 | 54 | -- | <5 | 78 | <5 | <5 | 40 | 59 | 48/40 | 25/36 |
| LSR-22 | 23-26 | -- | 57 | 33 | 24 | 14 | 19 | 48 | 34 | 49 | 25 | 27 | 45 | 19 | 24 | 26 |
| LSR-33 | 24-25.5 | -- | -- | 17 | 16 | 9 | 9 | 13 | 11 | 22 | 19 | 17 | 9 | 8 | 6 | 12/8 |
| LSR-4R | SURFACE | -- | -- | -- | 28 | 38 | 31 | -- | -- | 30 | -- | -- | 34 | 38 | 25 | 11 |
| LSR-23 | 28-31 | -- | 18 | <5 | <5 | <5/<5 | 5 | <5 | <5 | <5 | <5 | <5/<5 | <5/<5 | <5 | <5 | <5 |
| LSR-25 | 19-24 | -- | -- | <5 | 11 | 6 | <5 | <5/<5 | <5 | <5 | <5/<5 | <5 | 6 | 8 | 23 | 8 |
| LSR-31 | 34-37.5 | -- | -- | 58 | 57 | 44 | <5/<5 | 24 | 8 | 49/48 | 42 | 34/27 | 16 | 29 | 52 | 26/34 |

D/C - Discontinued

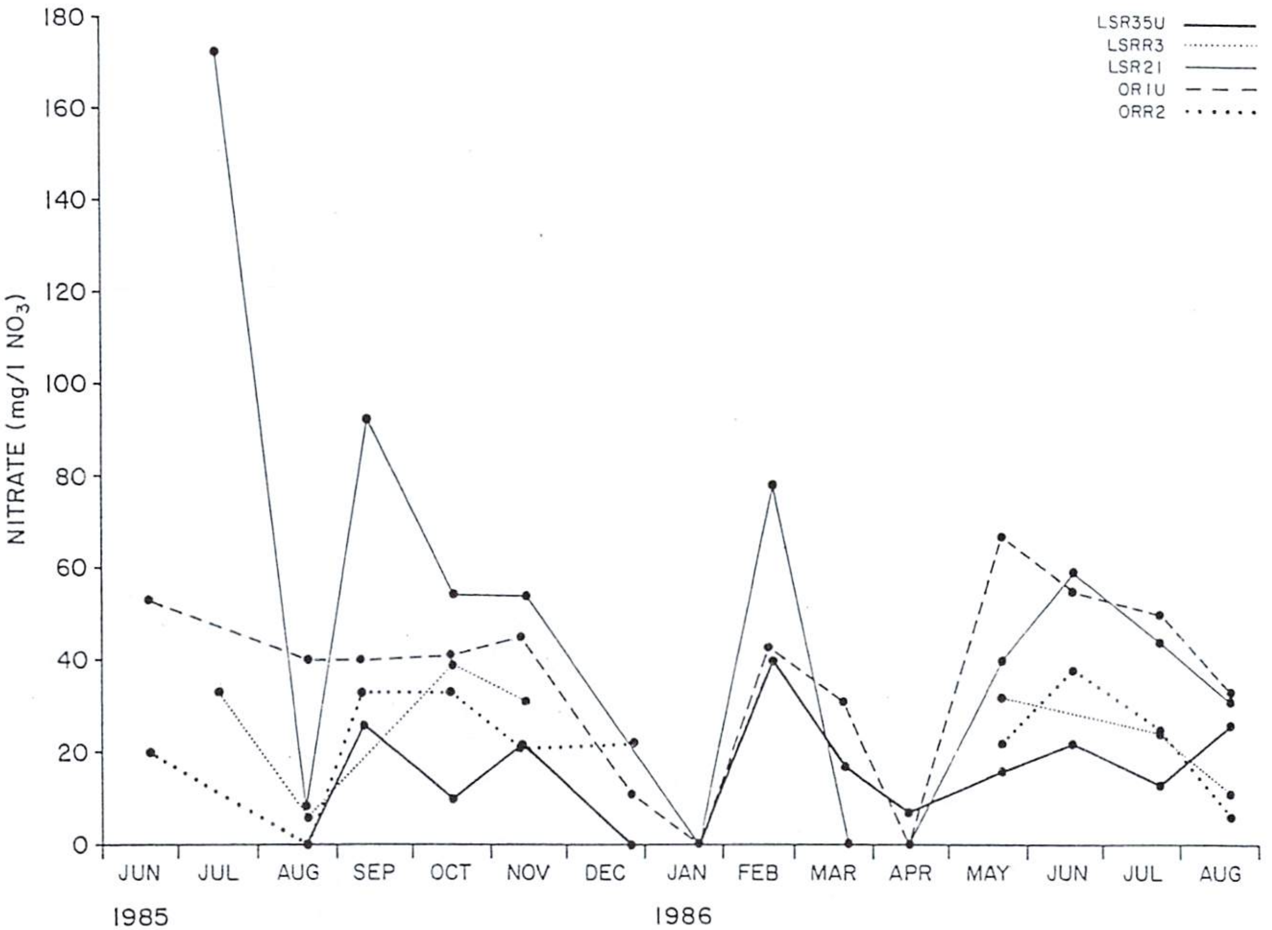



Figure 22. Temporal trends in nitrate levels in surfacewater and groundwater in the Ocheyedan-Little Sioux alluvial system.

## Vertical Distribution of Solutes

Nested piezometers were used to study the vertical distribution of solutes. Previous studies have shown an inverse relationship between nitrate concentration and depth (Wehtje et al., 1983; Hendry et al., 1983; Thompson, 1984). Table 9 shows average nitrate concentration versus average depth below water table.

For the nine sets of nested wells in this study area, six showed decreases in nitrate with depth; nitrate was never detected at two sites; and at the remaining site, nitrate concentrations were variable and unpredictable.

This decline in nitrate with depth may be caused in part by the flow system within the aquifer. If vertical transport rates are low, nitrate may remain in the upper part of the aquifer. Measurements of water levels for the nested wells in this study do indicate low to non-existent vertical gradients. Horizontal gradients, although low, are sufficient to promote lateral transport. The layered, anisotropic sedimentary patterns present may also favor lateral flow and limited vertical dispersion.

Tritium ($^3H$) is a radioactive isotope of hydrogen with a half-life of 12.4 years. Natural tritium levels are low (10-15 tritium units), but atomic testing during the mid-1950s and 1960s introduced large amounts of tritium in-

Table 9. Average nitrate concentration with depth.

| Average Depth Below Water Table | # Sites | # Samples | Average $NO_3$ (mg/l) |
|---|---|---|---|
| 0-10 | 9 | 118 | 19.3 |
| 10-20 | 13 | 153 | 11.8 |
| 20-30 | 3 | 40 | 6.5 |
| >30 | 6 | 63 | 0.2 |

to the atmosphere. The current tritium content of precipitation is approximately 15 to 30 tritium units, based on analyses from tile drainage and shallow wells. Assuming no mixing of recharge water and assuming an input value for current precipitation, a straight-line decay curve can be used to estimate groundwater age. Waters introduced into the aquifer prior to the 1950s, and not mixed with other water, would currently have very low to non-detectable tritium levels. Recharge water from the mid-sixties would have current tritium levels of 250 to 500 T.U.

Complicating this simple dating process is the fact that the tritium content of precipitation varies on a seasonal basis; spring rains being higher in tritium than fall or winter precipitation. Also, mixing of water of different ages does occur and will change the tritium content. Despite this, useful estimates can still be obtained.

Tritium analyses were done on one nested-well site in the Ocheyedan alluvial system. The lower and upper wells had tritium values of 31 and 32 T.U. The middle zone had a tritium value of 20 T.U. The difference in tritium values is not significant and could be attributed to seasonal variation. It is not possible to determine the exact age of the water, but it can be assumed that it is all of very recent origin. The tritium content of the middle zone is close to that currently observed in very shallow wells and tile lines. This may indicate a zone of preferential flow. This is, in part, supported by the chemical data. Pesticides were found only in the middle well along with occasional high nitrates.

Additional tritium analyses were done on nested sites in other alluvial systems. Lowest tritium values occur in the upper zones (18 to 21 T.U.) and increase with depth (40-70 T.U.). This would support the idea of a stratified aquifer, with age increasing with depth. Since measurable tritium levels exist in the lower parts of all the alluvial systems sampled, at least some of the water must be less than 30 years old. Thus, the stratification observed may be only a function of time. Slow migration of chemical contaminants in the aquifer may lead to deterioration of the lower zone in the future.

In most of the nested well sites, the nitrate concentrations declined to <5 mg/l $NO_3$ (<1 mg/l $NO_3$-N) below the uppermost piezometer. Other studies have also noted sharp declines in nitrate concentrations just below the water table (Hendry et al., 1983; Thompson, 1984; Trudell et al., 1986). This decline has been attributed to denitrification occurring in the aquifer.

Denitrification is the transformation of nitrate to nitrogen gas by denitrifying bacteria. These facultative bacteria use nitrate in place of oxygen for respiration. Necessary conditions include an anaerobic environment and a supply of organic carbon which is used as a food source (Rolston, 1981).

Denitrifying bacteria have been found at depths up to 50 meters in the unsaturated zone of carbonate aquifers, but denitrification does not occur in this oxidizing situation (Whitelaw and Rees, 1980). Soils at some sites where nitrates have not been found are poorly drained and calcareous to the surface, indicating limited leaching and probably continual saturation. The greatest potential for denitrification occurs in oxygen-deficient, water-saturated soil (Rolston, 1981). Soil cores from sites where denitrification is suspected often exhibit organic matter dispersed through the matrix, and gleyed soil colors which indicate conditions suitable to the reduction of free iron oxide.

Decreases in dissolved oxygen also were noted in most nested well sets. In addition, at sites where no nitrate was present even at the water table, dissolved-oxygen concentrations were correspondingly low. Table 10 shows the correlation between nitrate concentrations and dissolved-oxygen levels. Low concentrations of nitrate are associated with low dissolved-oxygen levels. Using oxygen levels as a surrogate for reducing conditions, it would seem that overall, little nitrogen is found in the reducing environment. In order to reduce the effects caused by stratification in the aquifer, only the shallow wells were considered (Table 10). Again low oxygen levels are associated with low nitrate concentrations. The absence of nitrate in the reducing environment may result from denitrification or from a lack of nitrification activity. Ammonia nitrogen is also low in these situations, which does not preclude volatilization of this form.

The denitrification process is dependent on an available supply of biodegradable organic carbon. Average total organic carbon (TOC) concentrations in well waters range from .5 to 2 mg/l (Maier et al., 1976). Concentrations of TOC in Iowa alluvial groundwaters range from 1.4 to 2.6 mg/l. If the total amount of carbon available could be assimilated, a total of 5.8 to 10.7 mg/l of $NO_3$ could be denitrified. Thus, to maintain continuous denitrification, a renewable carbon source is needed.

Changes in the concentration of several chemical constituents should theoretically be seen if denitrification is occurring. An increase in bicarbonate accompanied by a slight decrease in pH would be expected in addition to low dissolved-oxygen levels. Such chemical trends have been documented in other field studies in similar geologic environments (Trudell et al., 1986).

Alkalinities measured in the nested wells show no consistent trend nor any increases that could be associated with denitrification processes. The pH values also show no predictable patterns. This is not surprising in view of the vertical distribution of piezometers. Closer spacing of piezometers, probably in the range of 1 to 2 feet (0.3-0.6 m), would be necessary to determine if denitrification is responsible for decline of nitrate with depth.

Although not conclusively proven, dentrification is probably an important factor in reducing nitrate loads to the groundwater over portions of the alluvial system. The capacity of the denitrification system, however, is not known. Further research is needed to determine whether continued increases in nitrate levels will overload the system.

## Bacterial Monitoring

Historically, bacterial contamination of groundwater has not been thought to be a problem. The filtering action of the soil and the low concentrations of organic nutrients in groundwater have been seen as evidence that bacteria could not reach and/or would not survive in the groundwater environment. Many researchers believe that bacteria are introduced during well drilling or by

Table 10. Dissolved Oxygen versus Nitrate

| $NO_3$ (mg/l) | N | Mean D.O (mg/l) |
|---|---|---|
| | For All Depths | |
| <5 | 57 | 0.88 |
| 5-45 | 51 | 2.93 |
| >45 | 11 | 5.47 |
| | Depths Less than 10 feet | |
| <5 | 16 | 0.46 |
| 5-45 | 22 | 3.25 |
| >45 | 6 | 4.98 |

seepage along a well casing and do not migrate through an aquifer. Reneau and Pettry (1975) investigated the movement of coliform bacteria from septic tank effluent through three sandy soils and found little migration of bacteria from the drainfield. Their conclusion was that bacteria would not be likely to move into the groundwater.

Recently, however, several studies have shown that bacteria can be present and active at considerable depths in the subsurface. Dockins et al. (1980) found sulfate-reducing bacteria at depths from 10 to 260 meters. Whitelow and Rees (1980) found nitrate-reducing and ammonia-oxidizing bacteria at depths up to 50 meters. Over $10^6$ organisms per gram of dry soil were found in a shallow water-table aquifer at depths up to five meters (Wilson et al., 1983). Stetzenbach et al. (1986) sampled deep well water (150 m) and were able to grow a large number of bacteria in a low-nutrient medium.

It was not possible to look at all types of bacteria in this study. Instead, water samples from wells in the monitoring network were analyzed monthly for total coliform bacteria by the most probable number method (MPN) (Table 11). The coliform group is defined as "all of the aerobic and facultative anaerobic, gram-negative, nonspore forming, rod-shaped bacteria that ferment lactose with gas formation within 48 hours at 35°C" (Rand et al., 1976). Coliform bacteria are not a health problem themselves, but their occurrence may indicate the presence of other bacteria which can cause health problems. Even small amounts of bacteria in drinking water are considered unsatisfactory.

Previous studies in Iowa (Hallberg and Hoyer, 1982; Hallberg et al., 1983; Thompson, 1984) have documented bacterial contamination of groundwater. Sixty-six percent (220/332) of the samples collected in this study showed coliform levels greater than 2.2. Chlorination of all monitoring wells was done immediately after installation. However, some wells showed consistently high MPN

Table 11. Bacteria monitoring results: Ocheyedan - Little Sioux alluvial system.

| | Location | Screened Interval | Jun 19 1985 | Jul 15-16 1985 | Aug 19-20 1985 | Sept 10-12 1985 | Oct 15-18 1985 | Nov 12-14 1985 |
|---|---|---|---|---|---|---|---|---|
| 1 | OR-1U | 7-9 | 2.2 | | 16+ | 16+ | 16+ | 16 |
| 2 | 1M | 26-30 | 5.1 | | 0 | 16 | 0/2.2/2.2 | 2.2 |
| 3 | 1L | 54-58 | 0 | | 0 | 5.1 | 0 | 9.2 |
| 4 | OR-7U | 6.5-7.5 | 16+ | | 16+ | 9.2 | 2.2 | 0/2.2 |
| 5 | 7L | 13-16.5 | 16+ | | 5.1 | 9.2 | 5.1 | 2.2 |
| 6 | OR-6 | 16.5-19.5 | 0 | | 0 | 16+ | 16+ | 16+ |
| 7 | OR-11U | 10-13 | | | 2.2 | 16+ | 16+ | 16+/16+ |
| 8 | 11L | 26-30 | | | 16+ | 16+ | 16+ | 5.1 |
| 9 | LSR-6 | 11-18 | | 0 | 0 | 9.2 | 2.2 | 2.2/2.2 |
| 10 | LSR-1U | 16-17 | 16 | | 5.1 | 2.2 | 16 | 16+ |
| 11 | 1L | 85-90 | 9.2 | | 5.1 | 0 | 16+ | 9.2 |
| 12 | LSR-36U | 6.6-8 | | | 5.1 | | 0 | 0 |
| 13 | 36L | 22-25.5 | | | 0 | | 0 | 9.2/5.1 |
| 14 | LSR-11 | 15.5-18 | | 16+ | 16+ | 5.1 | 16+/9.2/16+ | 0 |
| 15 | LSR-12 | 17-19 | | | 16+ | D/C | | |
| 16 | LSR-14 | 22-28 | | 16+ | 5.1 | 16+ | 2.2 | 9.2 |
| 17 | LSR-38U | 23.5-29.5 | | | 16+ | 16+ | 5.1 | 0/ 2.2 |
| 18 | 38L | 44-50 | | | 16+ | 16+ | 16+ | 16+ |
| 19 | LSR-35U | 20.5-22.5 | | | 16+ | 16+ | 2.2 | 9.2/16+ |
| 20 | 35M | 35.5-37.5 | | | 2.2 | 16+ | 16+ | 16+ |
| 21 | 35L | 50-52 | | | 16 | 16+ | 16+ | 9.2 |
| 22 | LSR-34U | 17.5-19 | | | 16+ | 16+ | 16+ | 16+ |
| 23 | 34L | 53-63 | | | 16+ | 16+ | 5.1/9.2 | 0 |
| 24 | LSR-20U | 20-23 | | 16+ | 16+ | 16+ | 16+ | 16+ |
| 25 | 20L | 42-48 | | 16+ | 0 | 16+ | 16+/16+/16+ | 2.2/2.2 |
| 26 | LSR-21 | 12-13 | | 0 | 0 | 5.1 | 0 | 5.1 |
| 27 | LSR-22 | 23-26 | | 5.1 | 0 | 16+ | 16+ | 16 |
| 28 | LSR-33 | 24-25.5 | | | 0 | 16+ | 16 | 9.2 |
| 29 | LSR-23 | 28-31 | | 0 | 0 | 16+ | 16+/16+ | 16 |
| 30 | LSR-25 | 19-24 | | | 16+ | 16+ | 16+ | 16+/2.2 |
| 31 | LSR-31 | 34-37.5 | | | 0 | 16 | 16 | 5.1/9.2 |

D/C - Discontinued

Table 11. Continued.

| | Jan 20 1986 | Feb 19-20 1986 | | Apr 14 1986 | May 21 1986 | Jun 18 1986 | | Jul 23 1986 | Aug 20 1986 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 9.2 | 5.1 | OF | 16 | 9.2 | 16 | OF | 16+/16+ | 16+ |
| 2 | 0 | 0 | OF | 16+ | 5.1 | 16+/16 | OF | 16+ | 16+ |
| 3 | 0 | 0 | | 16 | 0 | 16+ | | 16+ | 16+ |
| 4 | 0 | 2.2/0 | | 5.1 | 0 | 16 | | 2.2 | 16+ |
| 5 | 0 | 0 | | 0 | 0 | 5.1 | | 0 | 16+ |
| 6 | 0/0 | 0 | | 0 | 2.2 | 16+/16+ | | 16 | 16+ |
| 7 | 0 | 9.2 | OF | 5.1/2.2 | 16+ | 16+ | 16+F | 16+ | 16+/16+ |
| 8 | 0 | 0 | | 0 | 5.1/5.1 | 2.2 | | 5.1 | 16+ |
| 9 | 2.2/0 | 0 | | 0 | 16+ | 16+/16+ | | 16+ | 16+ |
| 10 | 9.2 | 0/0 | OF | 9.2 | 5.1 | | | 16+/16+ | 16+ |
| 11 | 0 | 0 | | 0 | 5.1 | 16+ | | 16+ | 5.1 |
| 12 | 0 | 5.1 | OF | 16+ | 16+/16+ | 16 | OF | 16 | 9.2 |
| 13 | 0 | | | 16+ | 16+ | 16 | | 16+ | 9.2 |
| 14 | 0 | 0 | | 2.2 | 2.2 | | | 16+/16+ | 16+ |
| 15 | | | | | | | | | |
| 16 | 16+/16+ | 5.1 | | 2.2 | 5.1 | 16+/16+ | | 16+ | 16+ |
| 17 | | | | | 2.2 | 16+ | | 16 | 16+ |
| 18 | | | | | 2.2 | 16 | | 16 | 16 |
| 19 | 5.1 | 9.2 | OF | 2.2/2.2 | 0 | 16+ | OF | 16 | 16 |
| 20 | 0 | 9.2/16+ | OF | 0 | 2.2 | 16 | | 16+/16+ | 16+ |
| 21 | 0 | 0 | | 0 | 0 | 9.2 | | 16 | 16 |
| 22 | 2.2 | 2.2 | | 9.2 | 2.2/0 | 2.2 | | 16 | 9.2 |
| 23 | 0 | 0 | | 2.2 | 2.2 | 16 | | 16+ | 16+ |
| 24 | 16+ | 5.1 | OF | 9.2 | 0 | 16/9.2 | OF | 16+ | 16+ |
| 25 | 0 | 0/0 | OF | 0 | 0 | 9.2 | | 5.1 | 16+ |
| 26 | 2.2 | 2.2 | | 0 | 0 | 16+ | | 16+/16+ | 16+/16+ |
| 27 | 0 | 0 | | 16 | 0 | 16 | | 16+ | 16+ |
| 28 | 2.2 | 0 | OF | 0 | 2.2 | 16 | OF | 16+ | 16+/16+ |
| 29 | 16+ | 2.2 | | 0/0 | 16+/16+ | 16+ | OF | 9.2 | 16+ |
| 30 | 16 | 16+ | | 16+ | 16+ | 16+ | OF | 9.2 | 16+ |
| 31 | 5.1 | 9.2/0 | OF | 5.1/5.1 | 5.1 | 16+ | OF | 16+ | 16+/16+ |

counts. Several of these wells were then shock-chlorinated to remove the bacteria. This technique proved ineffective for permanent removal, as bacteria were again detected within a short period of time.

A small subset of wells was analyzed for fecal coliforms in February 1986 and again in June 1986. A high level of fecal contamination was found at one well in June. All other wells showed zero MPN levels.

In view of the aquifer stratification discussed previously, it seems unlikely that bacteria should be found in the lower parts of the aquifer. However, bacterial distribution is constant throughout the aquifer. A strong possibility exists that much of the bacterial contamination seen is caused by leakage along the casing or contamination during sampling. The presence of fecal contamination at one well, however, suggests that some migration of bacteria through the aquifer can occur. Further work is being done to analyze the bacterial situation in alluvial aquifers.

## Pesticides

Studies by many agencies in Iowa over the last six years have shown that many of the commonly used pesticides are found in surface and groundwater. The presence of pesticides in surfacewater is not surprising in view of their strong adsorption to soil particles. The detection of pesticides in groundwater, in diverse geologic settings, shows that pesticides can move into groundwater via infiltration.

Pesticides were first detected in shallow alluvial groundwater in 1974 (Richard et al., 1974). A one-time study of selected public water supplies in Iowa was conducted from 1984 to 1985 (Kelley, 1985). Forty-nine percent (20/41) of alluvial well samples showed some pesticide contamination. Atrazine proved most common and was present throughout the year. Other pesticides were, with one exception, found only during June and July. Further studies on public water supplies from alluvial aquifers along the Little Sioux River (Kelley and Wnuk, 1986) detected atrazine, cyanazine, metribuzin, terbufos, metolachlor, alachlor, and sulprofos.

Only limited sampling for pesticides has been done for this study (Table 12). Five samples were collected in the fall of 1985 and atrazine was detected at one well at a concentration of 0.5 µg/l. Thirty-three pesticide samples were collected between May and August, 1986 from both surfacewater and groundwater monitoring points. Five different pesticides were detected: atrazine, alachlor, metolachlor, cyanazine, and carbofuran. Highest concentrations were found in surfacewater. Multiple pesticide products were detected only in surfacewater. Only two pesticides were found in the groundwater: atrazine at one site on the Little Sioux and metolachlor at one site on the Ocheyedan. Metolachlor was found in the middle well of a nested set, without being detected in the upper well. Also at this time, moderately high levels of nitrate were present and tritium values indicated a zone of preferential flow through the middle part of the aquifer.

The concentrations of pesticides detected are all below acute toxicity levels and below levels assumed to contribute to chronic health problems. Some recent testing has indicated that both atrazine and metolachlor may be carcinogenic, in which case the recommended maximum contaminant levels (RMCL) would be zero. Many of these compounds are still under review by EPA, and health advisories have yet to be issued. There are also questions to be answered relative to possible synergistic reactions between these pesticides and other compounds found in the water such as nitrates. These factors make it difficult to adequately evaluate risk.

Table 12. Pesticides - Ocheyedan and Little Sioux Alluvial System.

ALL ANALYSES IN PARTS PER BILLION (MICROGRAMS/LITER)

| | | ATRAZINE ATREX | CYANAZINE BLADEX | METOLACHLOR DUAL | ALACHLOR LASSO | METRIBUZIN SENCOR | BUTYLATE SUTAN | TRIFLURALIN TREFLON | FONOFOS DYFONATE | CARBOFURAN FURDAN |
|---|---|---|---|---|---|---|---|---|---|---|
| OR1U | 10/15/85 | <0.1 | N.D. | N.D. | N.D. | N.D. | N.D. | N.D. | N.D. | N.D. |
| | 5/21/86 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| | 7/24/86 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| | 8/20/86 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| ORIM | 5/21/86 | <0.1 | <0.1 | 0.24 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| | 6/18/86 | <0.1 | <0.1 | 0.25 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| | 7/24/86 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| | 8/20/86 | <0.1 | <0.1 | 0.19 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| ORIL | 5/21/86 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| OR7U | 6/17/86 | <0.2 | <0.2 | <0.5 | <0.5 | <0.2 | <0.2 | <0.2 | <0.2 | <0.2 |
| | 8/19/86 | | | | | | | | | |
| OR7L | 5/21/86 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| | 6/17/86 | <0.2 | <0.2 | <0.5 | <0.5 | <0.2 | <0.2 | <0.2 | <0.2 | <0.2 |
| | 8/19/86 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| OR6 | 7/23/86 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| OR11U | 8/19/86 | 2.1 | <0.1 | 0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | 0.13 |
| ORR2A | 7/23/86 | 0.19 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| | 8/20/86 | 0.73 | <0.1 | 0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | 0.19 |
| LSR1U | 7/23/86 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| LSR36U | 5/21/86 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| | 6/17/86 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| LSR36L | 5/21/86 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| | 6/17/86 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| LSR11 | 10/16/85 | <0.1 | N.D. | N.D. | N.D. | N.D. | N.D. | N.D. | N.D. | N.D. |
| LSRR3B | 8/22/86 | 0.22 | <0.1 | 0.14 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| LSR35U | 10/16/85 | <0.1 | N.D. | N.D. | N.D. | N.D. | N.D. | N.D. | N.D. | N.D. |
| | 7/25/86 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| | 8/21/86 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| LSR35M | 7/25/86 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| LSR21 | 10/17/85 | 0.50 | N.D. | N.D. | N.D. | N.D. | N.D. | N.D. | N.D. | N.D. |
| | 5/21/86 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| | 6/19/86 | 0.14 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| | 7/25/86 | 0.91 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| LSR22 | 8/22/86 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| LSR33 | 8/22/86 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| LSRR4 | 5/21/86 | 0.47 | 0.28 | 1.0 | 0.61 | <0.1 | <0.1 | <0.1 | <0.1 | 0.29 |
| | 6/19/86 | 0.28 | <0.1 | 0.15 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| LSRR3 | 7/25/86 | 0.29 | <0.1 | 0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| LSR31 | 10/17/85 | <0.1 | N.D. | N.D. | N.D. | N.D. | N.D. | N.D. | N.D. | N.D. |
| | 7/25/86 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |

N.D. - Not Detected

## WATER USE

The major categories of water use from the Ocheyedan-Little Sioux alluvial aquifer are rural-domestic and livestock, municipal, rural water distribution system, irrigation, and industrial. No numbers are available on industrial useage. Table 13 lists water use by category for each county in the study area. Municipal water use figures were obtained from the Environmental Protection Division of the Department of Natural Resources. When use numbers were not available, population figures were multiplied by an average use of 50 gal/day/capita. Rural population within the valley was estimated by multiplying the rural population of each township by the percentage of the township mapped as alluvial land. These estimates may be high as few houses are actually located on the lowlands and some may be on rural water. Livestock estimates were computed in a similar way using consumptive figures from Herrick (1978). Population and livestock numbers were obtained from the 1985 Iowa Statistical Profile. The numbers cited for irrigation use are total amounts allocated under the DNR permit system. The amount of water actually used for irrigation is extremely variable and is directly related to the amount of precipitation available during the growing season.

Table 13. Water use from the Ocheyedan-Little Sioux alluvial system by county ar category in million gallons per year.

| County | Municipal | | Rural Water System | | Rural-Domestic | Livestock | Irrigation |
|---|---|---|---|---|---|---|---|
| | Avg. | Max. | Avg. | Max. | Avg. | Avg. | Max |
| Osceola | 33.8 | 123.6 | 203.6 | 339.1 | 1.0 | 3.7 | 755.2 |
| Dickinson | -- | -- | -- | -- | 1.0 | 2.0 | 83.8 |
| Clay | 574.7 | 952.0 | 154.0 | -- | 4.2 | 6.8 | 512.1 |
| Buena Vista | 58.6 | 144 | -- | -- | .4 | 1.1 | -- |
| O'Brien | -- | -- | 78.6 | 147.8 | .2 | 1.2 | 48.9 |
| Cherokee | 10.2 | 39.8 | -- | -- | 1.3 | 10.0 | -- |
| Woodbury | 51.8 | 87.9 | -- | -- | 1.1 | 4.9 | -- |
| TOTAL | 729.1 | 1347.3 | 436.2 | 486.9 | 9.2 | 29.7 | 1400.0 |

## Future Water Use

As can be seen in Table 13, irrigation is the largest user of alluvial water. There are no projections available to forecast future useage. There are areas within the valley which are not presently utilized for irrigation. Another drought, such as that during 1975-1977, could stimulate renewed interest in irrigation. Rural-water system use may be projected to show slight increases as more hook-ups to existing systems are made. No new systems are forecast.

Estimates of future use for municipal and rural-domestic are tied to population projections. These range from +3% to -4% for the counties in the study area. However, in the period from 1970 to 1980 only Woodbury, Clay, and Dickinson showed an increase in rural population. Therefore only minor increases are expected in municipal and rural-domestic use.

# RESOURCE ASSESSMENT

The alluvial aquifer of the Little Sioux and Ocheyedan Rivers shows considerable variability. The Ocheyedan Valley in northern Osceola County lies on the Des Moines Lobe. The aquifer here is discontinuous and where present is thin, with poor water quality.

Below the town of Ocheyedan, the aquifer widens and thickens considerably. Significant development (irrigation, municipal, rural water system) has occurred along this reach. Concern has been expressed regarding the effect of pumping withdrawals on river levels. Flow in the Ocheyedan River, at most times, is dependent on the position of the water table. During drought periods, the Ocheyedan will go dry as the level of the water table falls. Despite this, the aquifer along this reach is characterized by high transmissivities and correspondingly small drawdowns. Most of the water pumped from wells is taken from groundwater storage and apparently does not impact river levels. This allows for heavy use of the aquifer, particularly from the thicker sections. Further development could be accommodated in this reach.

Some degradation of water quality has occurred, primarily in the upper parts of the aquifer. Nitrate levels are high and some pesticide contamination has occurred. The reduction of input loads of nitrogen resulting from denitrification also has been postulated for this stretch of the river. The denitrifying capability of the aquifer needs to be assessed in order to forecast future water quality. Further studies are also necessary to determine the effects of pumping on aquifer stratification. The monitoring wells were pumped only occasionally and at low rates. This would not develop drawdowns which could promote mixing in the aquifer. Higher rates of withdrawal and continuous pumping could lead to contamination of lower parts of the aquifer. Current pumping regimes do not appear to have disrupted the stratification. Conversely, the stratification currently observed may only be a function of time, and water quality may eventually deteriorate throughout the aquifer. Thus, future trends in water quality cannot be forecast.

The upper Little Sioux alluvial aquifer in Dickinson County is generally thin, although occasional thicker zones do occur. For the most part the aquifer is narrow and has little potential for development. One monitoring well was placed in this area, but it proved to be a dry hole.

In Clay County, the aquifers of the Little Sioux and Ocheyedan merge in the basin of the former Lake Spencer. At least 20 feet of glaciofluvial sand

and gravel is present over much of this area. There are, however, shallow spots where less than 10 feet of alluvial material is present. Much of the current water resources development has occurred near Spencer. The potential for further development is good over much of this former lake basin. Good quality water can be obtained from the lower parts of the alluvial aquifer, where thicknesses are adequate. However, in areas of thin aquifer material, as near the town of Everly, water quality is generally poor. As on the Ocheyedan, there is concern about the permanence of the observed water-quality stratification. Denitrification is thought to occur locally in this area as well.

East of the town of Spencer, there are thick deposits of sand and gravel located below a thin layer of till. While surface degradation of these supplies has not occurred, natural water quality is poor. High levels of dissolved solids and sulfates limit the uses of this water.

Between Spencer and Peterson, the valley narrows considerably. Any large-scale development would induce river water infiltration, either limiting aquifer use or necessitating extensive water treatment.

Below Peterson, at the intersection with Waterman Creek, thick alluvial deposits are present. Only a small area of these thicker deposits exist, however, and the area is already under intensive development. Further development is precluded.

From Waterman Creek to south of Cherokee, there are several areas of thick terrace deposits. Most of these are dry, however, and offer no potential for water supply development. In a few localities near the river, thicker deposits also occur and have shown the stratification of water quality seen in other areas. High pumping rates could cause infiltration of poor-quality surfacewater limiting the usefulness of these sites.

Below Cherokee to the Woodbury/Monona County line, the aquifer is moderately wide, although generally not very thick. Thicker deposits do occur beneath terraces but only a small portion of the section is saturated. Off the terraces, the deposits are thinner; saturated thicknesses average less than 20 feet. There is some development potential along this lower stretch of the river, but it is limited by the generally poor water quality. High levels of nitrate contamination have been seen. Municipal supplies in the area show multiple residues and high concentrations of pesticides. This contrasts with results from the monitoring network which show little pesticide contamination. Possibly the higher municipal pumping rates have induced surfacewater infiltration. Little reduction in the nitrate loads by denitrification processes is seen. The water table is generally lower, out of the soil zone, and thus conditions are not conducive to dentrification.

Alluvial aquifers are extremely variable in thickness and water quality. Test drilling and water-quality sampling is still necessary to locate favorable sites, especially for high-capacity wells.

The potential for resource development is good along many reaches of the Ocheyedan-Little Sioux alluvial aquifer. In many localities this development is limited by water quality. Long-term trends in water quality are not necessarily predictable, but degradation has been increasing over the past 20 years. Further degradation could seriously limit certain uses of this resource. Efficient management of fertilizer and pesticide applications could significantly improve the current situation. Experiment-farm studies in Iowa and Minnesota have shown that only 35 percent or less of the fertilizer nitrogen applied is removed in the harvested grain (Hallberg, 1986). This is particularly true for fields continuously planted to corn. Much of the nitrogen is lost in tile-effluent or stored in the soil at depths of 2 to 5 meters (5 to 15 feet). Up to 30 percent is not recovered and is unaccounted for. In areas where shallow aquifers exist, much of this nitrate is translated into the aquifer. The magnitude of these chemical losses show that significant economic as well as environmental concerns exist. Clearly some of these losses could be minimized by the implementation of better management strategies. Resolving these problems in order to achieve a satisfactory balance between agricultural production and water-supply protection, will require an effort from all segments of the agricultural community.

REFERENCES CITED

## REFERENCES CITED


Carman, J.E. 1915. The Pleistocene geology of northwestern Iowa: Iowa Geol. Surv. Ann. Rept. 26:233-445.

Dockins, W.S., G.J. Olson, G.A. McFeters, and S.C. Trubak. 1980. Dissimilatory bacterial sulfate reduction in Montana groundwaters: Geomicrobiology Journal. 2(1):83-98.

Hallberg, G.R. 1985. Agricultural chemicals and groundwater quality in Iowa: status report 1985: in Proc. Ia. 38th Ann. Fert. and Ag-Chem. Dealers Conf. Ia. St. Univ., Coop. Ext. Ser. CE2158. 11 p.

Hallberg, G.R. 1986. Agrichemicals and water quality: prepared for Colloquim on Agrichemical Management and Water Quality, for Board on Agriculture, National Academy of Sciences/National Research Council, 21 March 1986. Wash., D.C.

Hallberg, G.R. and B.E. Hoyer. 1982. Sinkholes, hydrogeology and groundwater quality in northeast Iowa: Iowa Geol. Surv. Open-File Report 82-3, 120 p.

Hallberg, G.R., B.E. Hoyer, E.A. Bettis III., and R.D. Libra. 1983. Hydrogeology, water quality and land management in the Big Spring basin, Clayton County, Iowa: Ia. Geol. Surv. Open-File Report 83-3, 120 p.

Hallberg, G.R., R.D. Libra, E.A. Bettis III, and B.E. Hoyer. 1984. Hydrogeologic and water quality investigations in the Big Spring basin, Clayton County, Iowa: 1983 Water-Year. Ia. Geol. Surv. Open-File Report 84-4, 231 p.

Hendry, M.J., R.W. Gillham, and J.A. Cherry. 1983. An integrated approach to hydrogeologic investigations - A case history: Jour. Hydrol. 63:211-232.

Herrick, J.B. 1978. Water quality for livestock: Animal Health Fact Sheet No. 8, Ia. St. Univ., Coop. Ext. Ser. 8 p.

Hoyer, B.E. 1980. Geomorphic history of the Little Sioux River valley: Geol. Soc. Iowa Field Guide #34, 94 p.

Jenkins, C.T. 1968. Techniques for computing rate and volume of stream depletion by wells: Ground Water. 6(2):37-46.

Institute of Hydrology. 1980. Low flow studies: No. 3 - Catchment characteristic estimation manual. Gifford, Wallingford, Oxfordshire, England.

Kelley, R.D. 1985. Synthetic organic compound sampling survey of public water supplies: Iowa DWAWM Report, April 1985. 32 p.

Kelley, R.D. and M. Wnuk. 1986. Little Sioux river synthetic organic compound municipal well sampling survey: Iowa DWAWM report, March 1986. 24 p.

Macbride, T.H. 1901. Geology of Clay and O'Brien Counties: Iowa Geol. Surv. Ann. Rept. 11:461-508.

Maier, W.J., R.G. Gast, C.T. Anderson, and W.W. Nelson. 1976. Carbon contents of surface and underground waters in south-central Minnesota: J. Environ. Qual. 5(2):124-128.

McDonald, D.B. and R.C. Splinter. 1982. Long-term trends in nitrate concentration in water supplies: Research and Tech. Jour. AWWA., 74(8):437-440.

Pederson, D.E. and R.A. Lohnes. 1963. Preliminary investigation of the Little Sioux River valley: Proc. Iowa Acad. Sci. 70:326-333.

Prior, J.C. 1976. A regional guide to Iowa landforms: Ia. Geol. Surv. Educ. Series 3, 72 p.

Reneau, R.B. Jr. and D.E. Pettry. 1975. Movement of coliform bacteria from septic tank effluent through selected coastal plain soils of Virginia: Jour. Environ. Qual. 4:117-123.

Richard, J., A. Junk, F. Nehring, and H.J. Svec. 1974. Analysis of various Iowa waters for selected pesticides: Atrazine, DDE, and Dieldrin: Pestic. Monitoring Jour. 9:117-123.

Rolston, D.E. 1981. Nitrous oxide and nitrogen gas production in fertilized land: in Denitrification, Nitrification, and Atmospheric Nitrous Oxide, C.C. Delwiche, ed. Wiley Publishing, New York.

Rand, MC., A.E. Greenberg, and M.J. Taras., ed. 1976. Standard Methods for the Examination of Water and Wastewater, 14th ed. Am. Public Health Assoc., Am. Water Works Assoc., Water Pollution Control Fed. USA.

Stetzenbach, L.D., L.M. Kelley, and N.A. Sinclair. 1986. Isolation, identification, and growth of well-water bacteria: Groundwater. 24(1):6-10.

Thompson, C.A. 1984. Hydrogeology and water quality of the upper Des Moines River alluvial aquifer: Iowa Geol. Surv. Open-File Report 84-5, 169 p.

Thompson, C.A. 1986. Water resources of the Little Sioux and Ocheyedan alluvial aquifers: Data report: Iowa Geol. Surv. Open-File Report 86-4.

Trudell, M.R., R.W. Gillham, and J.A. Cherry. 1986. An in-situ study of the occurrence and rate of denitrification in a shallow unconfined sand aquifer: Jour. Hydrol. 83:251-268.

U.S.E.P.A. 1978. Microbiological methods for monitoring the environment, water, and wastes: EPA-600-8-78-017.

U.S.E.P.A. 1982. The determination of triazine pesticides in industrial and municipal wastewater: Method 619. EPA.

U.S.E.P.A. 1983. Methods for chemical analysis of water and wastes: EPA-600/4-79-020.

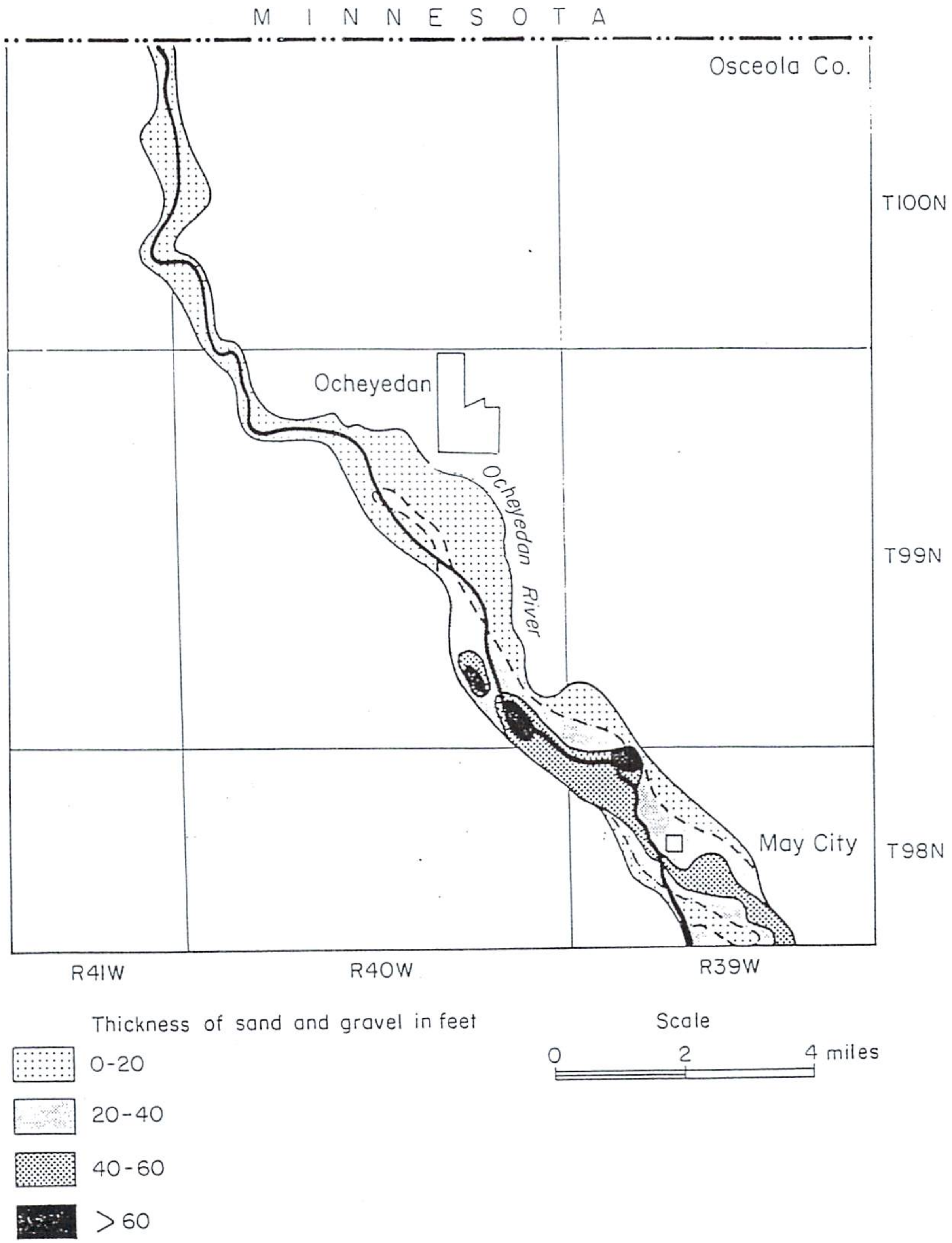
Wehtje, G.R., R.F. Spalding, O.C. Burnside, S.R. Lowry, and J.R.C. Levitt. 1983. Biological significance and fate of Atrazine under aquifer conditions: Weed Science. 31:610-618.

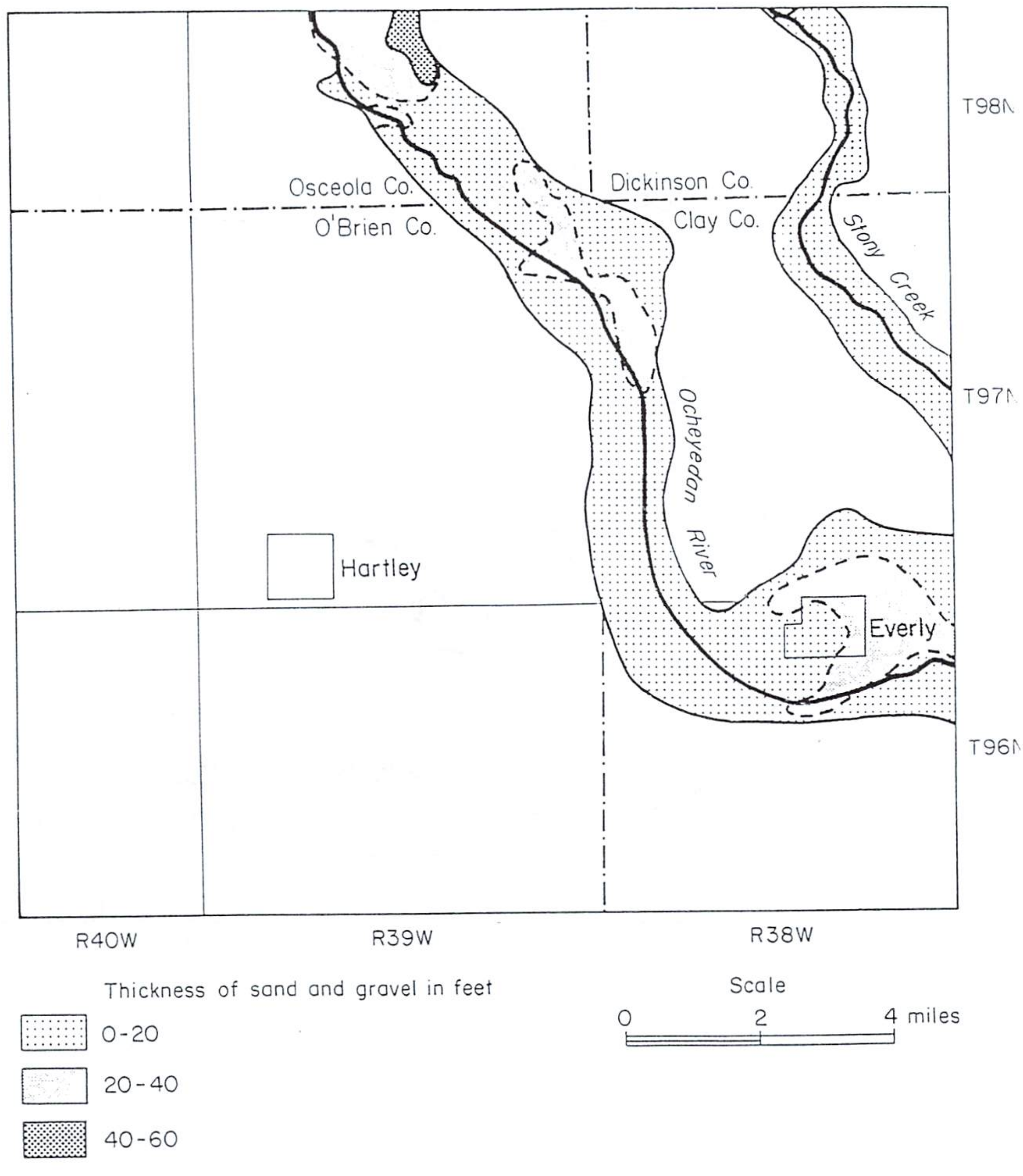
Whitelaw, K. and J.F. Rees. 1980. Nitrate-reducing and ammonium-oxidizing bacteria in the vadose zone of the Chalk Aquifer of England: Geomicrobiology Journal. 2(2):179-187.

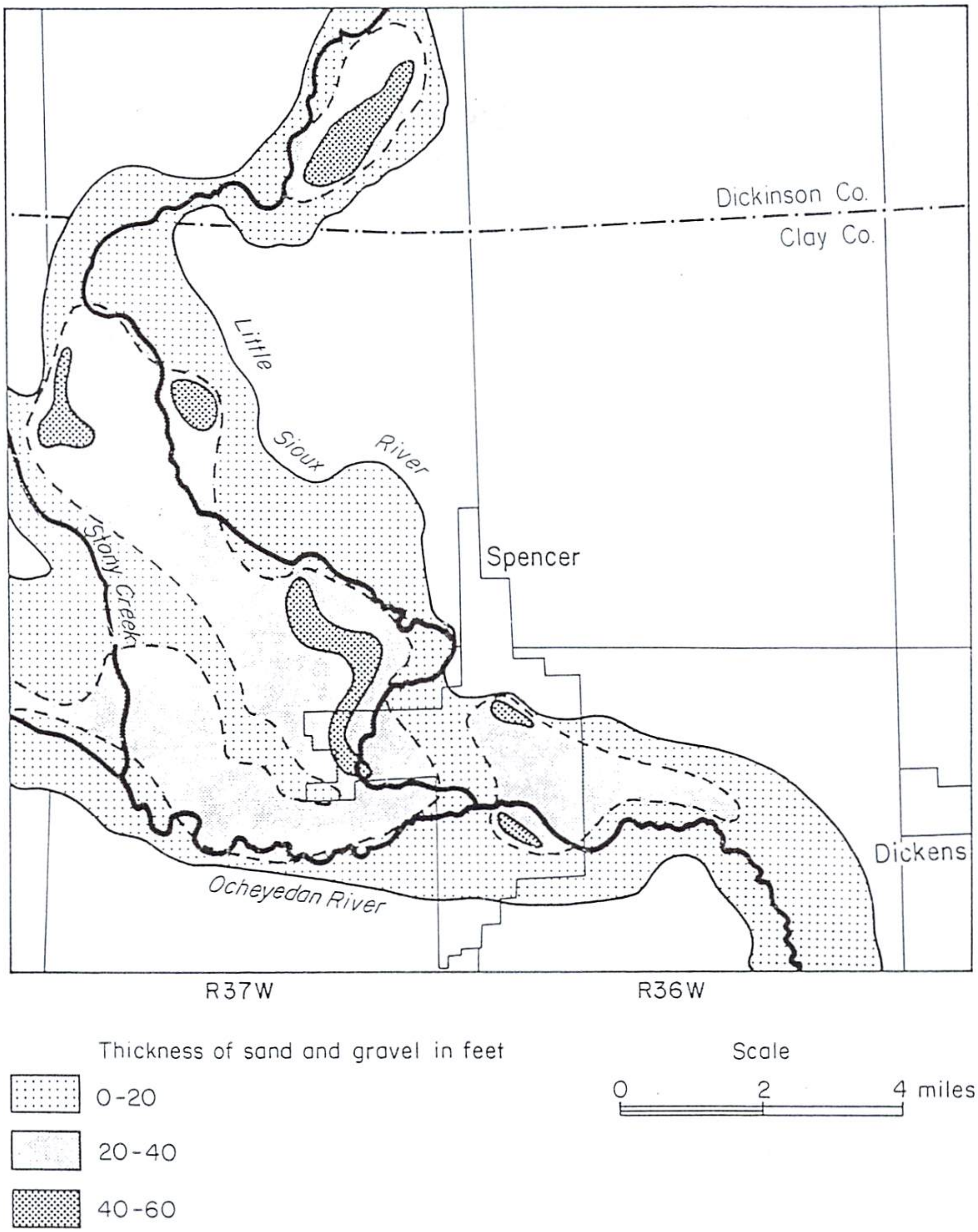
Wilson, J.T., J.F. McNabb, D.L. Balkwill, and W.C. Ghiorse. 1983. Enumeration and characterization of bacteria indigenous to a shallow water-table aquifer: Groundwater. 21(2):134-142.

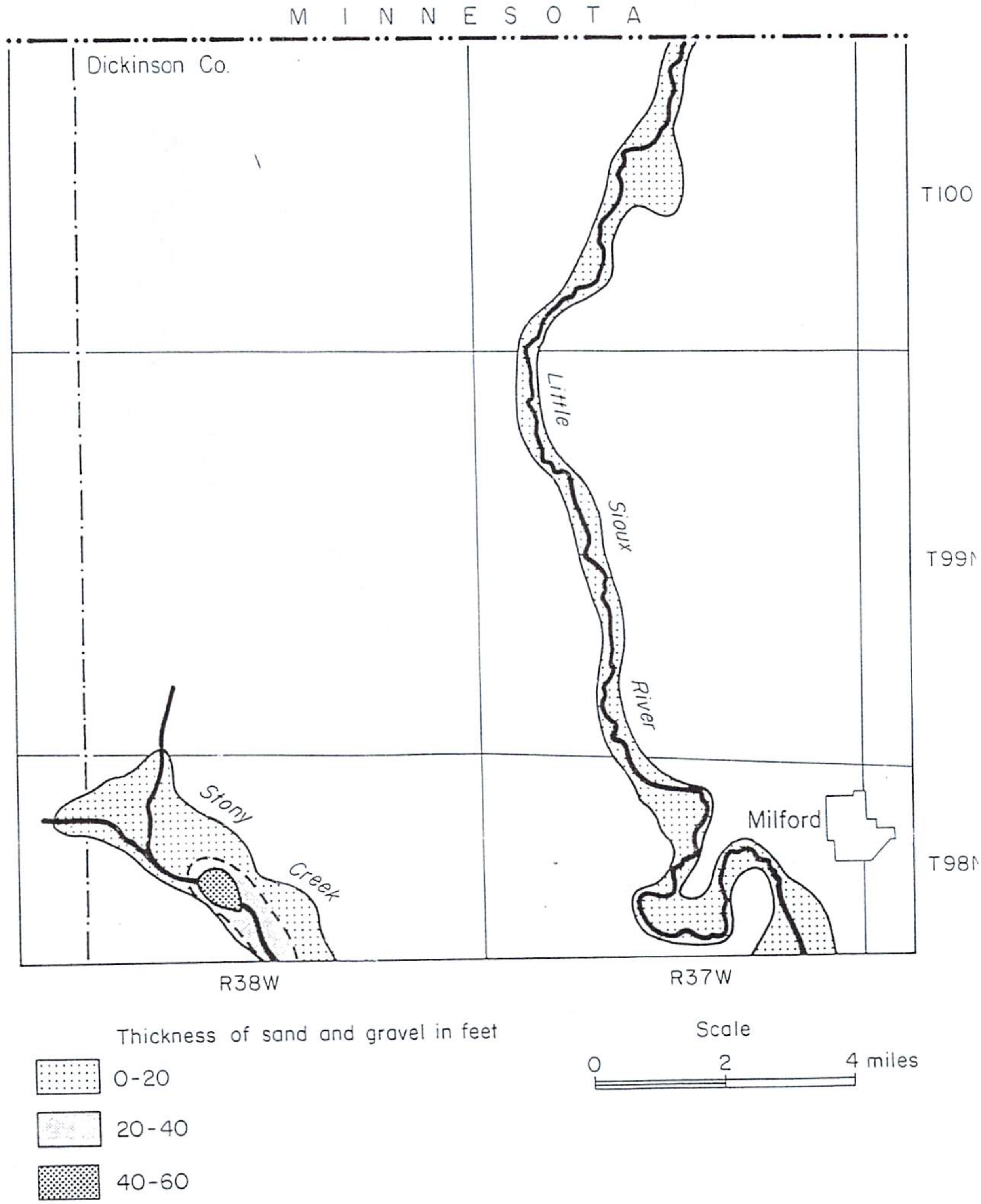
# APPENDIX I

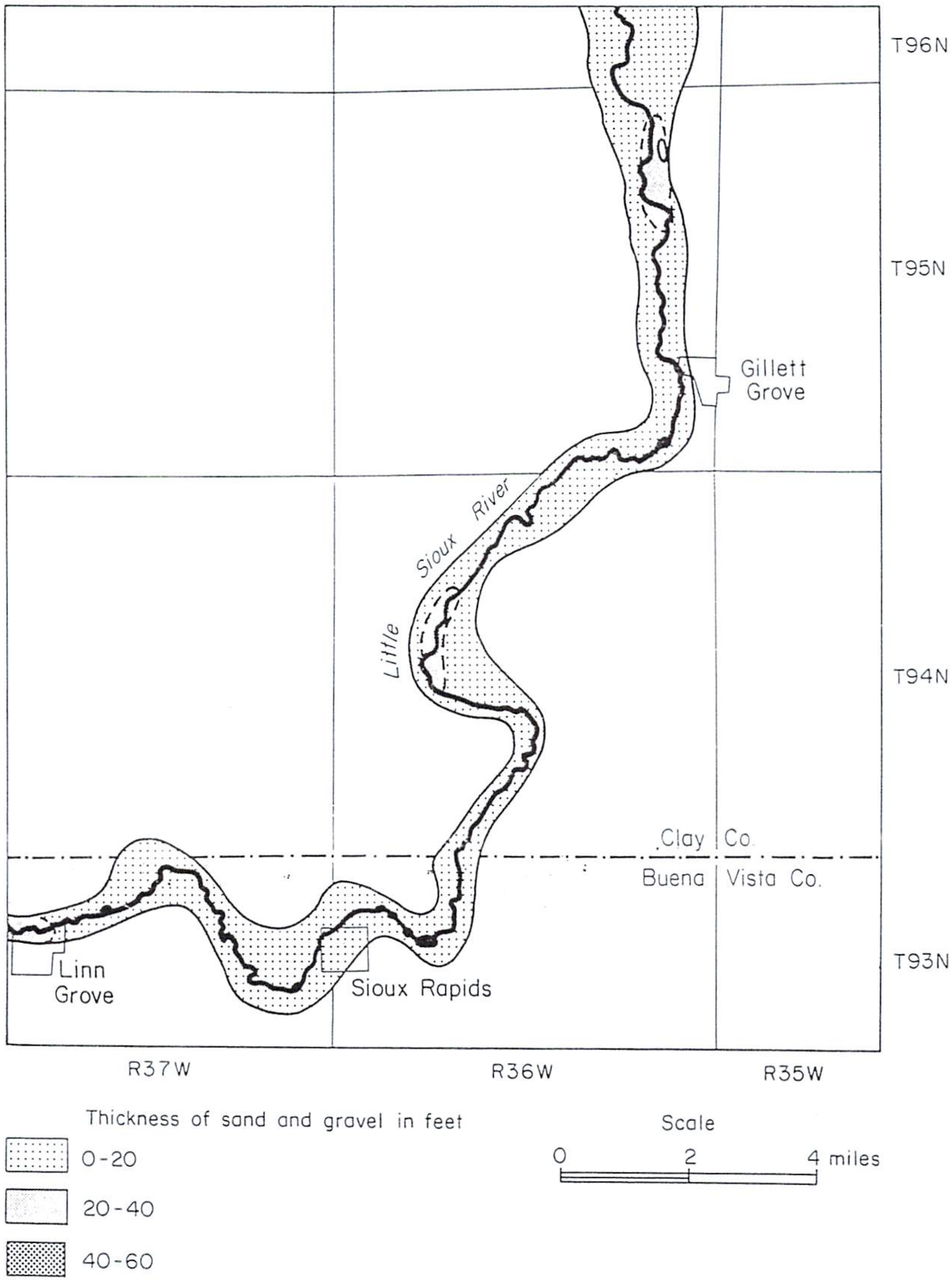
# ISOPACH MAPS

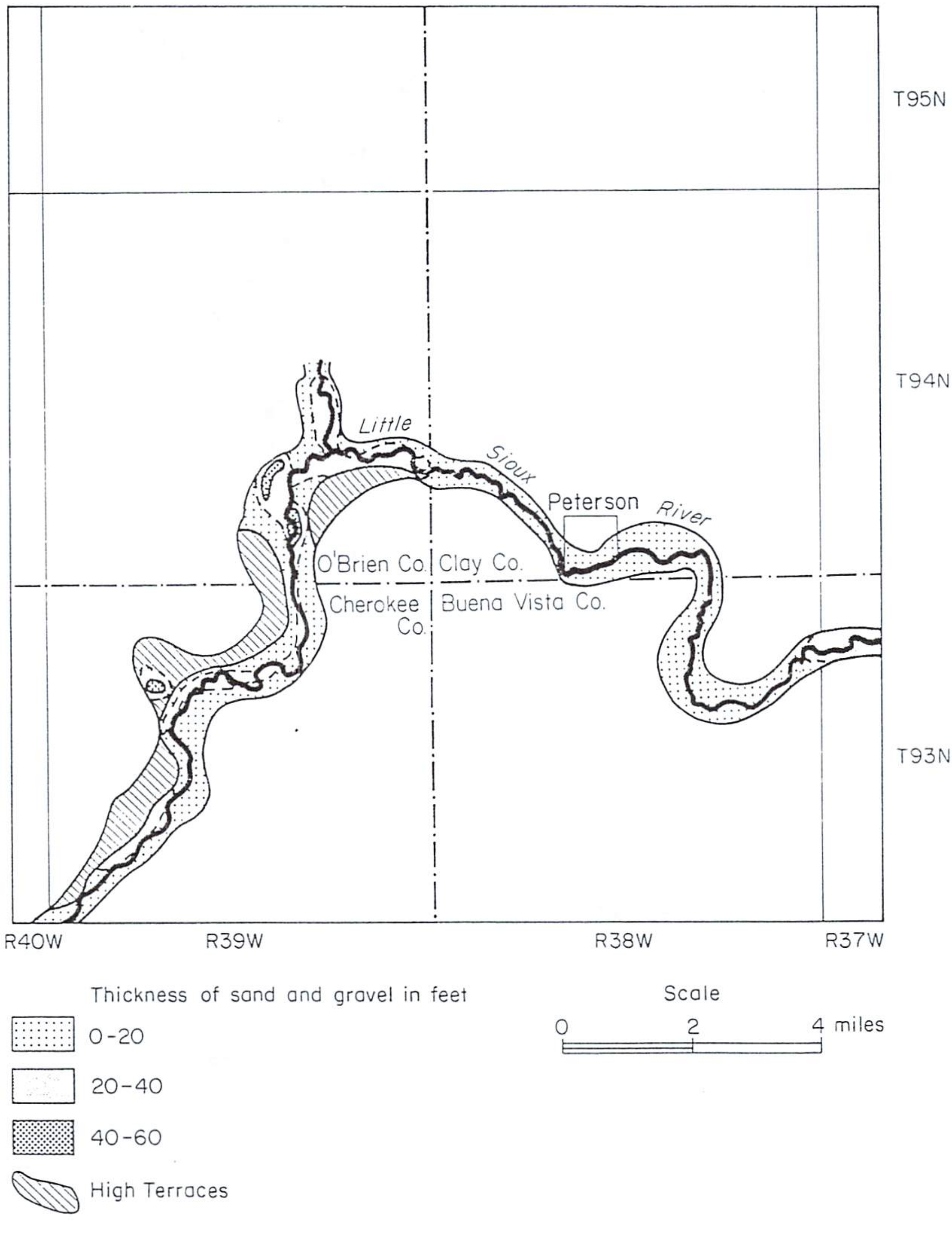

MINNESOTA
Osceola Co.
T100N
Ocheyedan
Ocheyedan River
T99N
May City
T98N
R41W
R40W
R39W
Thickness of sand and gravel in feet
0-20
20-40
40-60
>60
Scale
0
2
4 miles

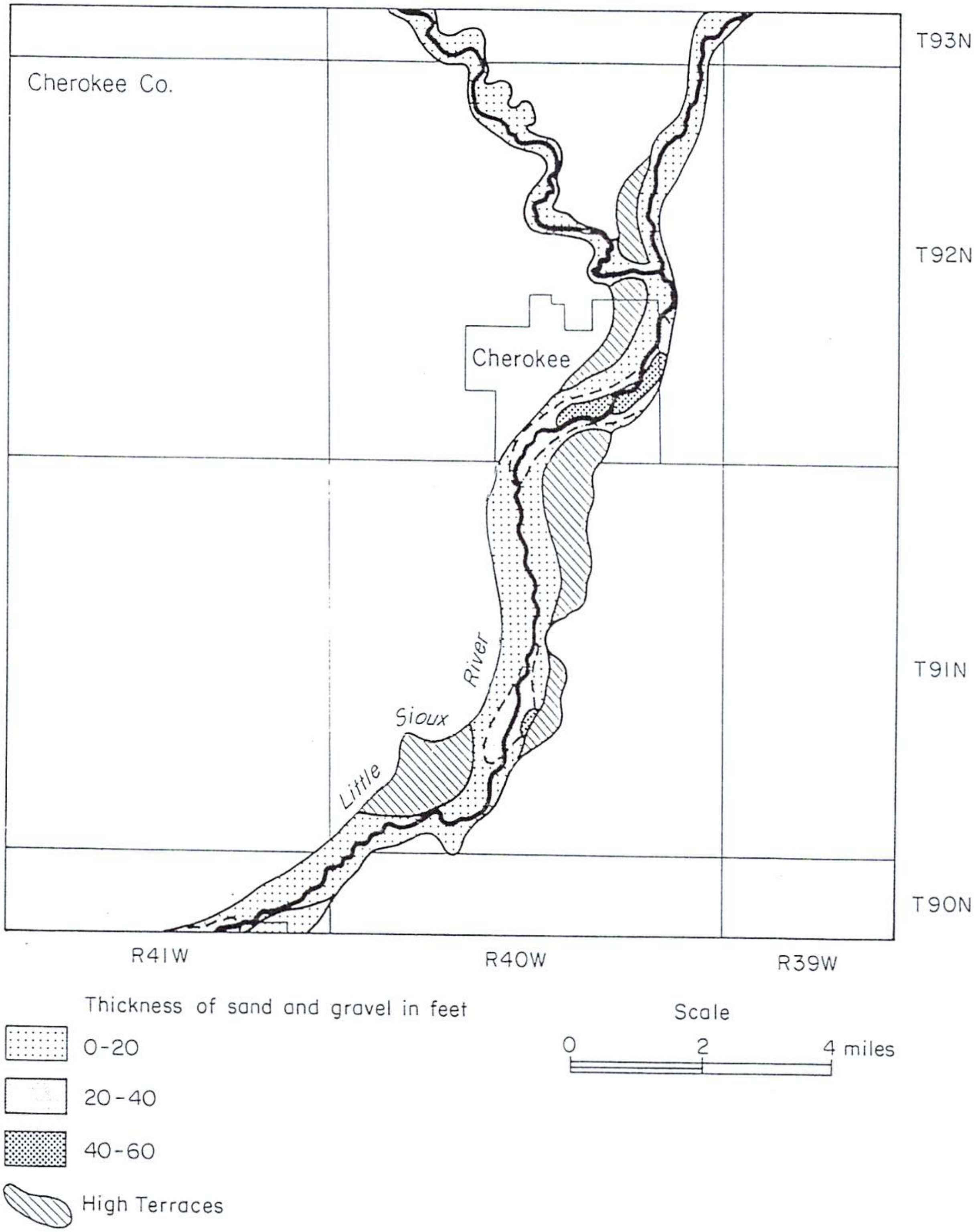

Osceola Co.
Dickinson Co.
O'Brien Co.
Clay Co.
Stony Creek
Ocheyedan River
Hartley
Everly
T98N
T97N
T96N
R40W
R39W
R38W
Thickness of sand and gravel in feet
0-20
20-40
40-60
Scale
0
2
4 miles

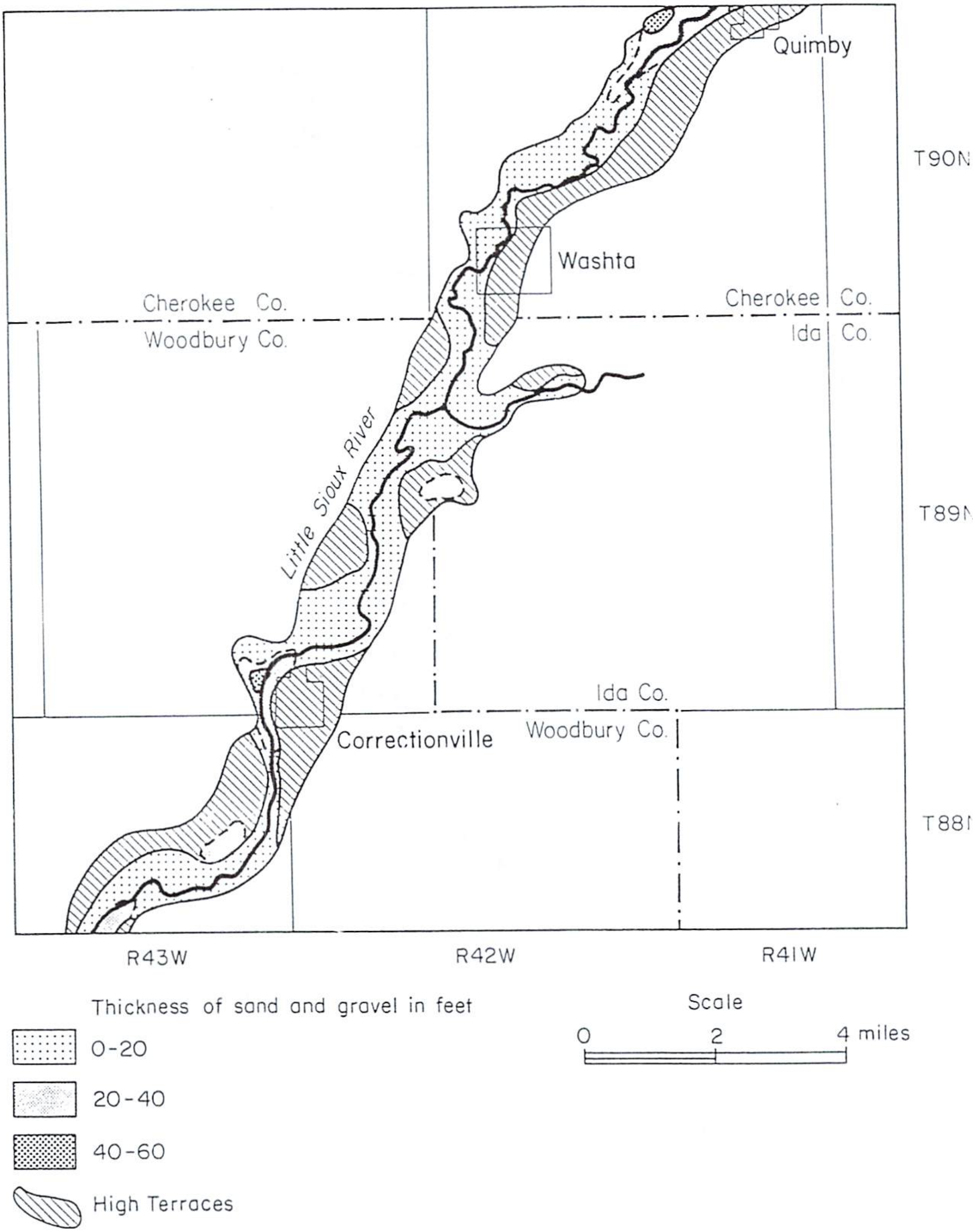

T98N
Dickinson Co.
Clay Co.
Little Sioux River
T97N
Stony Creek
Spencer
T96N
Dickens
Ocheyedan River
R37W
R36W
Thickness of sand and gravel in feet
0-20
20-40
40-60
Scale
0
2
4 miles

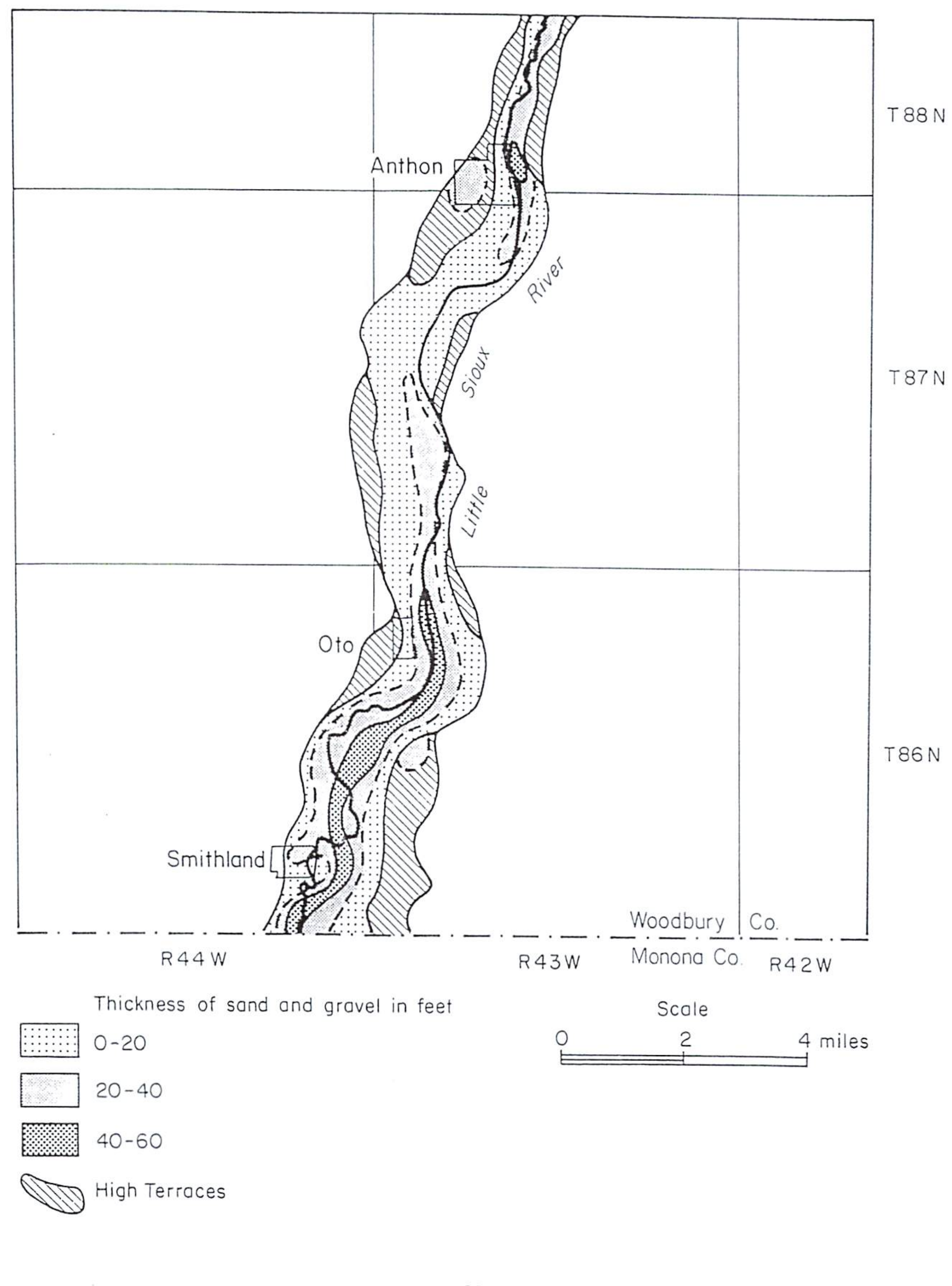

MINNESOTA
Dickinson Co.
T100
T99N
T98N
Little Sioux River
Stony Creek
Milford
R38W
R37W
Thickness of sand and gravel in feet
0-20
20-40
40-60
Scale
0
2
4 miles


T96N
T95N
T94N
T93N
Gillett
Grove
Little Sioux River
Clay Co.
Buena Vista Co.
Linn
Grove
Sioux Rapids
R37W
R36W
R35W
Thickness of sand and gravel in feet
0-20
20-40
40-60
Scale
0
2
4 miles


T95N
T94N
T93N
Little
Sioux
River
Peterson
O'Brien Co.
Clay Co.
Cherokee Co.
Buena Vista Co.
R40W
R39W
R38W
R37W
Thickness of sand and gravel in feet
0-20
20-40
40-60
High Terraces
Scale
0
2
4 miles


Cherokee Co.
Cherokee
Little Sioux River
T93N
T92N
T91N
T90N
R41W
R40W
R39W
Thickness of sand and gravel in feet
0-20
20-40
40-60
High Terraces
Scale
0
2
4 miles


Quimby
T90N
Washta
Cherokee Co.
Woodbury Co.
Cherokee Co.
Ida Co.
Little Sioux River
T89N
Ida Co.
Woodbury Co.
Correctionville
T88N
R43W
R42W
R41W
Thickness of sand and gravel in feet
0-20
20-40
40-60
High Terraces
Scale
0
2
4 miles


T 88 N
Anthon
River
T 87 N
Sioux
Little
Oto
T 86 N
Smithland
Woodbury Co.
R 44 W
R 43 W
Monona Co.
R 42 W
Thickness of sand and gravel in feet
0-20
20-40
40-60
High Terraces
Scale
0 2 4 miles

APPENDIX II

MONITORING NETWORK DATA

## MONITORING NETWORK DATA - OCHEYEDAN AND LITTLE SIOUX ALLUVIAL SYSTEMS

LOCATION OR-1U

DATE INSTALLED 6/10/85 SCREENED INTERVAL 7-9 FT. MP ELEVATION 1453.8 FT. CASING HT. 2.2 FT.

| DATE | WELL DEPTH (Ft.) | WATER LEVEL M.P. (Ft.) | WATER LEVEL G.S. (Ft.) | WATER LEVEL ELEVATION | pH | TEMP ( C) | COND. (UMHOS/CM) | D.O. (Mg/L) | NO3 (Mg/L) | BACTERIA (MPN) |
|---|---|---|---|---|---|---|---|---|---|---|
| 6/19/85 | | | | | | | | | 53 | 2.2 |
| 7/18/85 | | 8.0 | 5.8 | 1445.8 | | | | | | |
| 8/20/85 | | 9.4 | 7.2 | 1444.4 | | | | | 40 | 16+ |
| 9/10/85 | | 8.8 | 6.6 | 1445.0 | | 17.8 | 650 | | 40 | 16+ |
| 10/15/85 | 9.7 | 8.0 | 5.8 | 1445.8 | | 14.0 | 670 | 3.6 | 41 | 16+ |
| 11/12/85 | 9.7 | 8.3 | 6.1 | 1445.5 | | 9.0 | 490 | | 45 | 16 |
| 12/26/85 | | 8.5 | 6.3 | 1445.3 | | | | | 11 | |
| 1/22/86 | | 8.8 | 6.6 | 1445.0 | | | | | <5 | 9.2 |
| 2/18/86 | | 9.0 | 6.8 | 1444.8 | 7.2 | 5.0 | | | 43 | 5.1 |
| 3/19/86 | | 4.8 | 2.6 | 1449.0 | | | | | 31 | |
| 4/14/86 | | 4.7 | 2.5 | 1449.2 | | | | | <5 | 16 |
| 5/21/86 | 9.7 | 4.4 | 2.2 | 1449.4 | 7.8 | 12.9 | 780 | 2.5 | 67 | 9.2 |
| 6/18/86 | 9.7 | 7.3 | 5.1 | 1446.5 | 7.6 | 13.0 | 640 | 5.2 | 55 | 16 |
| 7/23/86 | | 7.2 | 5.0 | 1446.6 | 7.4 | 15.0 | 660 | 3.6 | 50/50 | 16+/16+ |
| 8/20/86 | | 8.2 | 6.0 | 1445.6 | | 13.0 | 500 | 3.4 | 33 | 16+ |

LOCATION OR-1M

DATE INSTALLED 6/10/86 SCREENED INTERVAL 26-30 FT. MP ELEVATION 1453.6 FT. CASING HT. 1.9 FT.

| DATE | WELL DEPTH (Ft.) | WATER LEVEL M.P. (Ft.) | WATER LEVEL G.S. (Ft.) | WATER LEVEL ELEVATION | pH | TEMP ( C) | COND. (UMHOS/CM) | D.O. (Mg/L) | NO3 (Mg/L) | BACTERIA (MPN) |
|---|---|---|---|---|---|---|---|---|---|---|
| 6/19/85 | | | | | | | | | 47 | 5.1 |
| 7/18/85 | | 7.8 | 5.9 | 1445.8 | | | | | | |
| 8/20/85 | | 9.1 | 7.2 | 1444.5 | | | | | 30 | 0 |
| 9/10/85 | 30.3 | 8.6 | 6.7 | 1445.0 | | 15.6 | 705 | | 6 | 16 |
| 10/15/85 | 30.3 | 7.8 | 5.9 | 1445.8 | | 12.0 | 575 | 0.6 | <5/<5/<5 | 2.2/0/2.2 |
| 11/12/85 | 30.3 | 8.1 | 6.2 | 1445.5 | | 8.0 | 550 | 0.8 | <5 | 2.2 |
| 12/26/85 | | 8.3 | 6.4 | 1445.3 | | | | | <5 | |
| 1/22/86 | | 8.5 | 6.6 | 1445.1 | | | | | 6 | 0 |
| 2/18/86 | | 8.8 | 6.9 | 1444.8 | 7.1 | 8.3 | | | 49 | 0 |
| 3/19/86 | | 5.5 | 3.6 | 1448.1 | | | | | 19 | |
| 4/14/86 | | 5.0 | 3.1 | 1448.6 | | | | | 58 | 16+ |
| 5/21/86 | 30.3 | 4.6 | 2.7 | 1449.0 | 7.4 | 13.1 | 640 | 0.1 | 36 | 5.1 |
| 6/18/86 | 30.3 | 6.2 | 4.3 | 1447.4 | 7.5 | 14.0 | 620 | 1.6 | 24/22 | 16+/16 |
| 7/23/86 | | 7.0 | 5.1 | 1446.6 | 7.3 | 14.0 | 680 | 0.4 | 16 | 16+ |
| 8/20/86 | | 8.0 | 6.1 | 1445.7 | | 13.0 | 520 | 0.7 | 14 | 16+ |

LOCATION OR-1L

DATE INSTALLED 6/10/85  SCREENED INTERVAL  54-58  FT.  MP ELEVATION  1453.4  FT.  CASING HT. 1.7 FT  FT.

| DATE | WELL DEPTH (Ft.) | WATER LEVEL M.P.(Ft.) | WATER LEVEL G.S.(Ft.) | WATER LEVEL ELEVATION | pH | TEMP ( C) | COND. (UMHOS/CM) | D.O. (Mg/L) | NO3 (Mg/L) | BACTERIA (MPN) |
|---|---|---|---|---|---|---|---|---|---|---|
| 6/19/85 | | | | | | | | | <5 | 0 |
| 7/18/85 | | 7.6 | 5.9 | 1445.8 | | | | | | |
| 8/20/85 | | 9.0 | 7.3 | 1444.4 | | | | | <5 | 0 |
| 9/10/85 | 57.5 | 8.4 | 6.7 | 1445.0 | | 15.0 | 810 | | <5 | 5.1 |
| 10/15/85 | 57.6 | 7.6 | 5.9 | 1445.8 | | 11.5 | 745 | 0.6 | <5 | 0 |
| 11/12/85 | 57.6 | 7.9 | 6.2 | 1445.5 | | 8.5 | 530 | 0.9 | <5 | 9.2 |
| 12/26/85 | | 8.1 | 6.4 | 1445.3 | | | | | <5 | |
| 1/22/86 | | 8.3 | 6.6 | 1445.1 | | | | | <5 | 0 |
| 2/18/86 | | 8.6 | 6.9 | 1444.8 | 7.1 | 7.2 | | | <5 | 0 |
| 3/19/86 | | 5.6 | 3.9 | 1447.8 | | | | | <5 | |
| 4/14/86 | | 5.0 | 3.3 | 1448.4 | | | | | <5 | 16 |
| 5/21/86 | 57.5 | 4.5 | 2.8 | 1448.9 | 6.9 | 11.2 | 620 | 0.1 | <5 | 0 |
| 6/18/86 | 57.5 | 6.1 | 4.4 | 1447.3 | 7.5 | 12.0 | 720 | 0.1 | <5 | 16+ |
| 7/23/86 | | 6.9 | 5.2 | 1446.5 | 7.3 | 13.0 | 720 | 0.4 | <5 | 16+ |
| 8/20/86 | | 7.8 | 6.1 | 1445.6 | | 12.5 | 440 | 1.0 | <5 | 16+ |

LOCATION OR-R2  MP ELEVATION 1461.0 FT.

| DATE | WATER LEVEL M.P. (FT.) | WATER LEVEL ELEVATION | PH | TEMP ( C) | COND. (UMHOS/CM) | NO3 (MG/L) |
|---|---|---|---|---|---|---|
| 6/19/85 | | | | | | 20 |
| 8/20/85 | | | | | | <5 |
| 9/10/85 | 18.9 | 1442.1 | | 19.5 | 710 | 33 |
| 10/15/85 | 18.9 | 1442.1 | | 13.0 | 690 | 33 |
| 11/12/85 | 18.4 | 1442.6 | | 3.0 | 450 | 21 |
| 2/18/86 | | | 7.7 | 1.7 | 800 | 22 |
| 5/21/86 | 18.3 | 1442.7 | 8.4 | 16.0 | 580 | 22/22 |
| 6/18/86 | 19.5 | 1441.5 | 8.3 | 15.0 | 700 | 42/33 |
| 7/23/86 | 19.9 | 1441.1 | 8.1 | 17.0 | 680 | 25 |
| 8/20/86 | 19.5 | 1441.5 | | 19.0 | 460 | 6 |

LOCATION OR-7U

DATE INSTALLED 6/12/85 SCREENED INTERVAL 6-7 FT. MP ELEVATION 1402.4 FT. CASING HT. 3.6 FT.

| DATE | WELL DEPTH (Ft.) | WATER LEVEL M.P. (Ft.) | WATER LEVEL G.S. (Ft.) | WATER LEVEL ELEVATION | pH | TEMP ( C) | COND. (UMHOS/CM) | D.O. (Mg/L) | NO3 (Mg/L) | BACTERIA (MPN) |
|---|---|---|---|---|---|---|---|---|---|---|
| 6/19/85 | | | | | | | | | <5 | 16+ |
| 7/15/85 | | 9.2 | 5.6 | 1393.2 | | | | | | |
| 8/20/85 | | 9.5 | 5.9 | 1392.9 | | | | | <5 | 16+ |
| 9/10/85 | 7.1 | 8.8 | 5.2 | 1393.6 | | 13.9 | 940 | | <5 | 9.2 |
| 10/15/85 | 7.5 | 8.3 | 4.7 | 1394.1 | | 12.0 | 820 | | <5 | 2.2 |
| 11/12/85 | 7.6 | 8.7 | 5.1 | 1393.0 | | 8.0 | 720 | | <5 | 0/<2.2 |
| 12/26/85 | | 8.9 | 5.3 | 1392.8 | | | | | | |
| 1/22/86 | | 9.1 | 5.5 | 1392.6 | | | | | <5 | 0 |
| 2/18/86 | | 9.4 | 5.8 | 1393.0 | 7.5 | 3.9 | | | <5/<5 | 0/2.2 |
| 3/19/86 | | 6.0 | 2.4 | 1396.4 | | | | | <5 | |
| 4/14/86 | | 7.5 | 3.9 | 1394.9 | | | | | <5 | 5.1 |
| 5/21/86 | 7.6 | 8.1 | 4.5 | 1394.3 | 7.4 | 10.0 | 760 | 11.2 | <5 | 0.0 |
| 6/18/86 | 7.6 | 8.4 | 4.8 | 1394.0 | 7.6 | 13.0 | 860 | | <5 | 16 |
| 7/23/86 | | 8.2 | 4.6 | 1394.2 | 7.6 | 14.0 | 800 | | <5 | 2.2 |
| 8/20/86 | | 8.9 | 5.3 | 1393.5 | | 13.5 | 680 | 1.2 | <5 | 16+ |

LOCATION OR-7L

DATE INSTALLED 6/12/85 SCREENED INTERVAL 12.5-16 FT. MP ELEVATION 1402.1 FT. CASING HT. 3.3 FT.

| DATE | WELL DEPTH (Ft.) | WATER LEVEL M.P. (Ft.) | WATER LEVEL G.S. (Ft.) | WATER LEVEL ELEVATION | pH | TEMP ( C) | COND. (UMHOS/CM) | D.O. (Mg/L) | NO3 (Mg/L) | BACTERIA (MPN) |
|---|---|---|---|---|---|---|---|---|---|---|
| 6/19/85 | | | | | | | | | <5 | 16+ |
| 7/15/85 | | 8.8 | 5.5 | 1393.3 | | | | | | |
| 8/20/85 | | 9.2 | 5.9 | 1392.9 | | | | | <5 | 5.1 |
| 9/10/85 | 16.3 | 8.3 | 5.0 | 1393.8 | | 13.3 | 820 | | <5 | 9.2 |
| 10/15/85 | 16.1 | 7.8 | 4.5 | 1394.3 | | 12.0 | 770 | 0.4 | <5 | 5.1 |
| 11/12/85 | 16.1 | 8.2 | 4.9 | 1393.9 | | 8.5 | 540 | 0.9 | <5 | 2.2 |
| 12/26/85 | | 8.6 | 5.3 | 1393.5 | | | | | <5 | |
| 1/22/86 | | 8.6 | 5.3 | 1393.5 | | | | | <5 | 0 |
| 2/18/86 | | 9.0 | 5.7 | 1393.1 | 7.4 | 6.7 | | | <5 | 0 |
| 3/19/86 | | 5.5 | 2.2 | 1396.6 | | | | | <5 | |
| 4/14/86 | | 6.9 | 3.6 | 1395.3 | | | | | <5 | 0 |
| 5/21/86 | 16.0 | 7.6 | 4.3 | 1394.5 | 7.4 | 10.0 | 655 | 0.0 | <5 | 0 |
| 6/18/86 | 16.0 | 7.8 | 4.5 | 1394.3 | 7.5 | 11.0 | 670 | 0.2 | <5 | 5.1 |
| 7/23/86 | | 7.6 | 4.3 | 1394.5 | 7.4 | 12.0 | 780 | 6.2 | <5 | 0 |
| 8/20/86 | | 8.5 | 5.2 | 1393.6 | | 11.0 | 690 | 0.2 | <5 | 16+ |

LOCATION OR-6

DATE INSTALLED 6/12/85 SCREENED INTERVAL 16-19 FT. MP ELEVATION 1372.8 FT. CASING HT. 2.2 FT.

| DATE | WELL DEPTH (Ft.) | WATER LEVEL M.P.(Ft.) | WATER LEVEL G.S.(Ft.) | WATER LEVEL ELEVATION | pH | TEMP ( C) | COND. (UMHOS/CM) | D.O. (Mg/L) | NO3 (Mg/L) | BACTERIA (MPN) |
|---|---|---|---|---|---|---|---|---|---|---|
| 6/19/85 | | | | | | | | | 59 | 0 |
| 7/15/85 | | 6.3 | 4.1 | 1366.5 | | | | | | |
| 8/20/85 | | 8.0 | 5.8 | 1364.8 | | | | | 75 | 0 |
| 9/10/85 | 19.2 | 6.8 | 4.6 | 1366.0 | | 12.2 | 470 | | 52 | 16+ |
| 10/15/85 | 19.2 | 5.9 | 3.7 | 1366.9 | | 10.8 | 830 | 0.7 | 33 | 16+ |
| 11/12/85 | 19.2 | 6.4 | 4.2 | 1366.4 | | 9.0 | 600 | 2.7 | 7 | 16+ |
| 12/26/85 | | 6.5 | 4.3 | 1366.3 | | | | | 38/40 | |
| 1/22/86 | | 6.7 | 4.5 | 1366.1 | | | | | 33/48 | 0/0 |
| 2/20/86 | | 7.3 | 5.1 | 1365.5 | | 6.0 | | 4.7 | 67 | 0 |
| 3/19/86 | | 5.6 | 3.4 | 1367.2 | | | | | 58 | |
| 4/14/86 | | 5.5 | 3.3 | 1367.3 | | | | | 8 | 0 |
| 5/21/86 | 19.3 | 5.0 | 2.8 | 1367.8 | 7.8 | 9.0 | 618 | 0.1 | 18 | 2.2 |
| 6/18/86 | 19.2 | 6.2 | 4.0 | 1366.6 | 7.5 | 10.0 | 710 | 1.5 | 26/22 | 16+/16+ |
| 7/23/86 | | 6.1 | 3.9 | 1366.7 | 7.7 | 11.0 | 660 | 8.2 | 57 | 16 |
| 8/20/86 | | 6.6 | 4.4 | 1366.2 | | 12.5 | 670 | 7.6 | 41 | 16+ |

LOCATION OR-11U

DATE INSTALLED 7/31/85 SCREENED INTERVAL 10-13 FT. MP ELVATION 1364.8 FT. CASING HT. 2.5 FT.

| DATE | WELL DEPTH (Ft.) | WATER LEVEL M.P.(Ft.) | WATER LEVEL G.S.(Ft.) | WATER LEVEL ELEVATION | pH | TEMP ( C) | COND. (UMHOS/CM) | D.O. (Mg/L) | NO3 (Mg/L) | BACTERIA (MPN) |
|---|---|---|---|---|---|---|---|---|---|---|
| 8/06/85 | | 8.3 | 5.8 | 1356.5 | | | | | | |
| 8/20/85 | | 8.7 | 6.2 | 1356.1 | | | | | 71 | 2.2 |
| 9/10/85 | 13.5 | 8.7 | 6.2 | 1356.1 | | 16.2 | 440 | | <5 | 16+ |
| 10/15/85 | 13.5 | 8.9 | 6.4 | 1355.9 | | 13.6 | 540 | 7.3 | 9 | 16+ |
| 11/12/85 | 13.5 | 9.2 | 6.7 | 1355.6 | | 11.5 | 460 | 8.2 | 26/24 | 16+/16+ |
| 12/26/85 | | 9.5 | 7.0 | 1355.3 | | | | | <5 | |
| 1/22/86 | | 9.8 | 7.3 | 1355.0 | | | | | <5 | 0 |
| 2/20/86 | | 10.1 | 7.6 | 1354.7 | 7.6 | 7.0 | | 3.8 | 43 | 9.2 |
| 3/19/86 | | 12.5 | 10.0 | 1352.3 | | | | | 25 | |
| 4/14/86 | | 8.8 | 6.3 | 1356.0 | | | | | 9/7 | 5.1/2.2 |
| 5/21/86 | 13.5 | 6.8 | 4.3 | 1358.0 | 7.9 | 10.0 | 230 | 10.0 | <5 | 16+ |
| 6/18/86 | | 8.9 | 6.4 | 1355.9 | 7.8 | 12.0 | 460 | 9.1 | <5 | 16+ |
| 7/23/86 | | 7.2 | 4.7 | 1357.6 | 7.5 | 15.0 | 450 | 10.0 | 20 | 16+ |
| 8/20/86 | | 8.2 | 5.7 | 1356.6 | | 17.0 | 340 | 8.2 | 20/24 | 16+/16+ |

LOCATION OR-11L

DATE INSTALLED 7/31/85 SCREENED INTERVAL 26-30 FT. MP ELEVATION 1364.6 FT. CASING HT. 2.3 FT.

| DATE | WELL DEPTH (Ft.) | WATER LEVEL M.P.(Ft.) | WATER LEVEL G.S.(Ft.) | WATER LEVEL ELEVATION | pH | TEMP ( C) | COND. (UMHOS/CM) | D.O. (Mg/L) | NO3 (Mg/L) | BACTERIA (MPN) |
|---|---|---|---|---|---|---|---|---|---|---|
| 8/06/85 | | 10.1 | 7.8 | 1354.5 | | | | | | |
| 8/20/85 | | 10.4 | 8.1 | 1354.2 | | | | | <5 | 16+ |
| 9/10/85 | 29.8 | 10.0 | 7.7 | 1354.6 | | 14.7 | 640 | | <5 | 16+ |
| 10/15/85 | 29.9 | 10.0 | 7.7 | 1354.6 | | 11.0 | 520 | 0.6 | <5 | 16+ |
| 11/12/85 | 29.9 | 10.4 | 8.1 | 1354.2 | | 10.0 | 460 | 0.6 | 5 | 5.1 |
| 12/26/85 | | 10.9 | 8.6 | 1353.7 | | | | | <5 | |
| 1/22/86 | | 11.0 | 8.7 | 1353.6 | | | | | <5 | 0 |
| 2/20/86 | | 12.0 | 9.7 | 1352.6 | 7.4 | 6.0 | | | <5 | 0 |
| 3/19/86 | | 10.6 | 8.3 | 1354.0 | | | | | <5 | |
| 4/14/86 | | 9.6 | 7.3 | 1355.0 | | | | | <5 | 0 |
| 5/21/86 | 29.9 | 8.4 | 6.1 | 1356.2 | 7.5 | 11.0 | 400 | 0.1 | <5/<5 | 5.1/5.1 |
| 6/18/86 | | 7.4 | 5.1 | 1357.2 | 7.8 | 11.5 | 450 | 0.4 | <5 | 2.2 |
| 7/23/86 | | 8.8 | 6.5 | 1355.8 | 7.6 | 13.0 | 500 | 0.2 | <5 | 5.1 |
| 8/20/86 | | 9.2 | 6.9 | 1355.4 | | 14.0 | 380 | 0.4 | <5 | 16+ |

LOCATION LSR-6

DATE INSTALLED 6/25/85 SCREENED INTERVAL 11-18 FT. MP ELEVATION 1419.1 FT. CASING HT. 1.7 FT.

| DATE | WELL DEPTH (Ft.) | WATER LEVEL M.P.(Ft.) | WATER LEVEL G.S.(Ft.) | WATER LEVEL ELEVATION | pH | TEMP ( C) | COND. (UMHOS/CM) | D.O. (Mg/L) | NO3 (Mg/L) | BACTERIA (MPN) |
|---|---|---|---|---|---|---|---|---|---|---|
| 7/15/85 | | 11.1 | 9.4 | 1408.0 | | | | | 25 | 0 |
| 8/19/85 | | 12.1 | 10.4 | 1407.0 | | | | | 7 | 0 |
| 9/10/85 | 17.9 | 12.3 | 10.7 | 1406.8 | | 13.9 | 545 | | 13 | 9.2 |
| 10/15/85 | 17.9 | 12.3 | 10.7 | 1406.8 | | 13.0 | 735 | 0.7 | 8 | 2.2 |
| 11/13/85 | 18.0 | 12.4 | 10.8 | 1406.7 | | 8.5 | 520 | 0.8 | 12/12 | 2.2/2.2 |
| 12/26/85 | | 12.3 | 10.6 | 1406.8 | | | | | <5/<5 | |
| 1/22/86 | | 12.5 | 10.8 | 1406.6 | | | | | <5/<5 | 2.2/0 |
| 2/18/86 | | 12.7 | 11.0 | 1406.4 | 7.1 | 4.4 | | | <5 | 0 |
| 3/19/86 | | 11.9 | 10.2 | 1407.2 | | | | | <5 | |
| 4/14/86 | | 11.4 | 9.7 | 1407.7 | | | | | <5 | 0 |
| 5/21/86 | 17.9 | 10.6 | 8.9 | 1408.6 | 7.0 | 8.0 | 630 | 0.0 | 15 | 16+ |
| 6/18/86 | 17.9 | 11.0 | 9.3 | 1408.1 | 7.6 | 10.5 | 660 | 0.4 | 7/7 | 16+/16 |
| 7/23/86 | | 11.1 | 9.4 | 1408.0 | 7.4 | 13.0 | 590 | 0.4 | 5 | 16+ |
| 8/20/86 | | 11.7 | 10.0 | 1407.4 | | 13.0 | 620 | 0.5 | 11 | 16+ |

LOCATION OR-R2A MP ELEVATION 1311.7 FT.

| DATE | WATER LEVEL M.P. (FT.) | WATER LEVEL ELEVATION | PH | TEMP ( C) | COND. (UMHOS/CM) | NO3 (MG/L) |
|---|---|---|---|---|---|---|
| 9/10/85 | | | | 17.8 | 770 | 38 |
| 10/16/85 | 3.6 | 1315.3 | | 7.7 | 550 | 39 |
| 11/13/85 | | | | 4.0 | 495 | 31 |
| 2/20/86 | | | 7.5 | .2 | 580 | 19 |
| 5/21/86 | 4.9 | 1316.6 | 8.3 | 20.5 | 730 | 42 |
| 6/18/86 | 3.4 | 1315.1 | 8.4 | 19.0 | 830 | |
| 7/23/86 | 3.0 | 1314.7 | 8.3 | | 760 | 30 |
| 8/20/86 | 2.8 | 1314.5 | | 25.0 | 540 | 13 |

LOCATION STONEY CREEK MP ELEVATION 1421.7 FT.

| DATE | WATER LEVEL M.P. (FT.) | WATER LEVEL ELEVATION | PH | TEMP ( C) | COND. (UMHOS/CM) | NO3 (MG/L) |
|---|---|---|---|---|---|---|
| 9/10/85 | 16.6 | 1405.1 | | | | |
| 10/15/85 | 16.0 | 1405.7 | 7.6 | 14.3 | 630 | |
| 6/18/86 | | | 8.25 | 20.0 | 710 | |

LOCATION LSR-R1B MP ELEVATION 1332.5 FT.

| DATE | WATER LEVEL M.P. (FT.) | WATER LEVEL ELEVATION | PH | TEMP ( C) | COND. (UMHOS/CM) | NO3 (MG/L) |
|---|---|---|---|---|---|---|
| 6/19/85 | | | | | | |
| 8/20/85 | | | | | | |
| 9/11/85 | | | | 17.2 | | |
| 10/16/85 | 12.4 | 1320.1 | | 8.6 | 600 | |
| 11/13/85 | 11.5 | 1321.0 | | 1.0 | 490 | |
| 5/21/86 | 8.6 | 1323.9 | 8.2 | 20.0 | 615 | |
| 6/18/86 | 11.9 | 1320.6 | 8.3 | 21.5 | 700 | |
| 7/23/86 | 11.9 | 1320.6 | 7.8 | 26.0 | 630 | |
| 8/20/86 | 13.0 | 1319.5 | | 26.0 | 420 | |

LOCATION LSR-1U

DATE INSTALLED 6/17/85 SCREENED INTERVAL 16-17 FT. MP ELEVATION 1352.5 FT. CASING HT. 2.3 FT.

| DATE | WELL DEPTH (Ft.) | WATER LEVEL M.P.(Ft.) | WATER LEVEL G.S.(Ft.) | WATER LEVEL ELEVATION | pH | TEMP ( C) | COND. (UMHOS/CM) | D.O. (Mg/L) | NO3 (Mg/L) | BACTERIA (MPN) |
|---|---|---|---|---|---|---|---|---|---|---|
| 6/19/85 | | | | | | | | | 41 | 16 |
| 7/15/85 | | 11.3 | 9.0 | 1341.2 | | | | | | |
| 8/19/85 | | 15.1 | 12.8 | 1337.4 | | | | | 64 | 5.1 |
| 9/11/85 | 16.7 | 12.1 | 9.4 | 1340.4 | | 12.8 | 690 | | 68 | 2.2 |
| 10/16/85 | 17.2 | 11.7 | 9.4 | 1340.8 | | 10.2 | 530 | 7.6 | 6 | 16 |
| 11/13/85 | 17.2 | 12.2 | 9.9 | 1340.3 | | 10.0 | 580 | 9.5 | 11 | 16+ |
| 12/26/85 | | 12.6 | 10.3 | 1339.9 | | | | | 27/34 | |
| 1/22/86 | | 13.0 | 10.7 | 1339.5 | | | | | 6 | 9.2 |
| 2/20/86 | | 13.6 | 11.3 | 1338.9 | | 8.0 | | 3.7 | 67/64 | 0/0 |
| 3/19/86 | | 12.5 | 10.2 | 1340.0 | | | | | 46 | |
| 4/14/86 | | 11.3 | 9.0 | 1341.2 | | | | | 24 | 9.2 |
| 5/21/86 | 17.2 | 9.7 | 7.4 | 1342.8 | 7.5 | 9.8 | 610 | 10.1 | 24 | 5.1 |
| 6/18/86 | 17.1 | 10.8 | 8.5 | 1341.7 | 7.7 | 10.0 | 630 | 11.4 | | |
| 7/23/86 | | 11.1 | 8.8 | 1341.4 | 7.1 | 12.0 | 510 | 9.8 | <5/12 | 16+/16+ |
| 8/20/86 | | 11.6 | 9.3 | 1340.9 | | 13.0 | 490 | 8.0 | 6 | 16+ |

LOCATION LSR-1L

DATE INSTALLED 6/17/85 SCREENED INTERVAL 85-90 FT. MP ELEVATION 1352.3 FT. CASING HT. 2.1 FT.

| DATE | WELL DEPTH (Ft.) | WATER LEVEL M.P.(Ft.) | WATER LEVEL G.S.(Ft.) | WATER LEVEL ELEVATION | pH | TEMP ( C) | COND. (UMHOS/CM) | D.O. (Mg/L) | NO3 (Mg/L) | BACTERIA (MPN) |
|---|---|---|---|---|---|---|---|---|---|---|
| 6/19/85 | | | | | | | | | <5 | 9.2 |
| 7/15/85 | | 14.7 | 12.6 | 1337.6 | | | | | | |
| 8/19/85 | | 15.1 | 13.0 | 1337.2 | | | | | <5 | 5.1 |
| 9/11/85 | 89.2 | 14.7 | 16.2 | 1337.6 | | 12.2 | 590 | | <5 | 0 |
| 10/16/85 | 89.1 | 14.8 | 12.7 | 1337.5 | | 8.5 | 485 | 0.5 | <5 | 16+ |
| 11/13/85 | 89.2 | 14.9 | 12.8 | 1337.4 | | 8.0 | 500 | 0.5 | <5 | 9.2 |
| 12/26/85 | | 15.2 | 13.1 | 1337.1 | | | | | <5 | |
| 1/22/86 | | 15.4 | 13.3 | 1336.9 | | | | | <5 | 0 |
| 2/20/86 | | 15.8 | 13.7 | 1336.5 | | 6.0 | | | <5 | 0 |
| 3/19/86 | | 14.8 | 12.7 | 1337.5 | | | | | <5 | |
| 4/14/86 | | 14.4 | 12.3 | 1337.9 | | | | | <5 | 0 |
| 5/21/86 | 90.1 | 12.9 | 10.8 | 1339.4 | 7.6 | 11.0 | 430 | 0.0 | <5 | 5.1 |
| 6/18/86 | | 13.5 | 11.4 | 1338.8 | 7.4 | 11.0 | 660 | 0.2 | <5 | 16+ |
| 7/23/86 | | 13.8 | 11.7 | 1338.5 | 7.0 | 12.0 | 540 | 0.4 | <5 | 16+ |
| 8/20/86 | | 14.1 | 12.0 | 1338.2 | | 13.0 | 380 | 0.4 | <5 | 5.1 |

LOCATION LSR-36U

DATE INSTALLED 7/29/85 SCREENED INTERVAL 6-8 FT. MP ELEVATION CASING HT. 2.9 FT.

| DATE | WELL DEPTH (Ft.) | WATER LEVEL M.P. (Ft.) | WATER LEVEL G.S. (Ft.) | WATER LEVEL ELEVATION | pH | TEMP ( C) | COND. (UMHOS/CM) | D.O. (Mg/L) | NO3 (Mg/L) | BACTERIA (MPN) |
|---|---|---|---|---|---|---|---|---|---|---|
| 8/6/85 | | 8.4 | 5.5 | | | | | | | |
| 8/19/85 | | 8.8 | 5.9 | | | | | | 18 | 5.1 |
| 10/16/85 | 8.4 | 6.7 | 3.8 | | | 13.0 | 540 | 2.5 | 9 | 0 |
| 11/13/85 | 8.3 | 7.8 | 4.9 | | | 10.0 | 420 | 2.7 | <5 | 0 |
| 1/20/86 | | | | | | | | | <5 | 0 |
| 2/20/86 | | 9.1 | 6.2 | | | 4.0 | | 3.7 | <5 | 5.1 |
| 3/19/86 | | 8.7 | 5.8 | | | | | | 12 | |
| 4/14/86 | | | | | | | | | 35 | 16+ |
| 5/21/86 | 8.3 | 5.7 | 2.8 | | 7.4 | 10.0 | 680 | 4.1 | 6/6 | 16+/16+ |
| 6/18/86 | | 6.5 | 3.6 | | 7.4 | 14.0 | 590 | 3.4 | 10 | 16 |
| 7/23/86 | | 6.5 | 3.6 | | 7.3 | 16.0 | 450 | 2.8 | 6 | 16+ |
| 8/20/86 | | 7.8 | 4.9 | | | 17.0 | 435 | 1.5 | <5 | 9.2 |

LOCATION LSR-36L

DATE INSTALLED 7/29/85 SCREENED INTERVAL 21-24.5 FT. MP ELEVATION CASING HT. 2.8 FT.

| DATE | WELL DEPTH (Ft.) | WATER LEVEL M.P. (Ft.) | WATER LEVEL G.S. (Ft.) | WATER LEVEL ELEVATION | pH | TEMP ( C) | COND. (UMHOS/CM) | D.O. (Mg/L) | NO3 (Mg/L) | BACTERIA (MPN) |
|---|---|---|---|---|---|---|---|---|---|---|
| 8/06/85 | | 8.5 | 5.7 | | | | | | | |
| 8/19/85 | | 8.6 | 5.8 | | | | | | <5 | 0 |
| 10/16/85 | 24.6 | 6.6 | 3.8 | | | 11.0 | 705 | 0.5 | <5 | 0 |
| 11/13/85 | 24.5 | 7.8 | 5.0 | | | 10.0 | 425 | 0.6 | <5/<5 | 9.2/5.1 |
| 1/20/86 | | | | | | | | | <5 | 0 |
| 2/20/86 | | 9.5 | 6.7 | | | 9.0 | | 0.1 | | |
| 3/19/86 | | 8.5 | 5.7 | | | | | | <5 | |
| 4/14/86 | | | | | | | | | 33 | 16+ |
| 5/21/86 | 24.5 | 5.5 | 2.7 | | 7.5 | 10.5 | 550 | 0.0 | <5 | 16+ |
| 6/18/86 | | 6.4 | 3.6 | | 7.7 | 11.5 | 490 | 0.5 | <5 | 16 |
| 7/23/86 | | 6.7 | 3.9 | | 7.5 | 12.0 | 480 | 0.3 | <5 | 16+ |
| 8/20/86 | | 7.6 | 4.9 | | | 15.0 | 370 | 0.4 | <5 | 9.2 |

LOCATION LSR-11

DATE INSTALLED 7/01/85 SCREENED INTERVAL 14.5-16.5 FT. MP ELEVATION 1301.8 FT. CASING HT. 2.8 FT.

| DATE | WELL DEPTH (Ft.) | WATER LEVEL M.P.(Ft.) | WATER LEVEL G.S.(Ft.) | WATER LEVEL ELEVATION | pH | TEMP ( C) | COND. (UMHOS/CM) | D.O. (Mg/L) | NO3 (Mg/L) | BACTERIA (MPN) |
|---|---|---|---|---|---|---|---|---|---|---|
| 7/15/85 | | 6.4 | 3.6 | 1295.4 | | | | | 20 | 16+ |
| 8/19/85 | | 6.7 | 3.9 | 1295.1 | | | | | <5 | 16+ |
| 9/11/85 | 16.5 | 4.8 | 2.1 | 1297.0 | | 18.3 | 930 | | <5 | 5.1 |
| 10/16/85 | 16.4 | 4.7 | 1.9 | 1297.1 | | 10.0 | 1150 | 0.6 | <5/<5/<5 | 16+/9.2/16+ |
| 11/13/85 | 16.5 | 4.6 | 1.8 | 1297.2 | | 8.5 | 1090 | 0.7 | <5 | 0 |
| 12/26/85 | | 5.1 | 2.3 | 1296.7 | | | | | <5/<5 | |
| 1/22/86 | | 5.2 | 2.4 | 1296.6 | | | | | <5 | 0 |
| 2/19/86 | | 6.7 | 3.9 | 1295.1 | 7.6 | 5.0 | 1500 | 0.1 | <5 | 0 |
| 3/19/86 | | 3.8 | 1.0 | 1298.0 | | | | | <5 | |
| 4/14/86 | | 4.5 | 1.7 | 1297.3 | | | | | <5 | 2.2 |
| 5/21/86 | | 2.6 | -0.3 | 1299.3 | 7.1 | 10.0 | 1200 | 0.0 | <5 | 2.2 |
| 6/18/86 | 16.4 | 5.5 | 2.7 | 1296.3 | 7.1 | 10.0 | 1400 | 0.2 | | |
| 7/23/86 | | 5.1 | 2.3 | 1296.7 | 6.7 | 13.5 | 1130 | 0.3 | <5/<5 | 16+/16+ |
| 8/20/86 | | 5.3 | 2.5 | 1296.5 | | 14.0 | 1100 | 0.4 | <5 | 16+ |

LOCATION LSR-12

DATE INSTALLED 7/2/85 SCREENED INTERVAL 17-19 FT. MP ELEVATION 1294.3 FT. CASING HT. 1.8 FT.

| DATE | WELL DEPTH (Ft.) | WATER LEVEL M.P.(Ft.) | WATER LEVEL G.S.(Ft.) | WATER LEVEL ELEVATION | pH | TEMP ( C) | COND. (UMHOS/CM) | D.O. (Mg/L) | NO3 (Mg/L) | BACTERIA (MPN) |
|---|---|---|---|---|---|---|---|---|---|---|
| 7/15/85 | | 10.0 | 7.6 | 1284.3 | | | | | <5 | |
| 8/19/85 | | 11.4 | 9.0 | 1282.9 | | | | | <5 | 16+ |

LOCATION LSR-14

DATE INSTALLED 7/2/85 SCREENED INTERVAL 22-28 FT. MP ELEVATION 1281.1 FT. CASING HT. 1.8 FT.

| DATE | WELL DEPTH (Ft.) | WATER LEVEL M.P.(Ft.) | WATER LEVEL G.S.(Ft.) | WATER LEVEL ELEVATION | pH | TEMP ( C) | COND. (UMHOS/CM) | D.O. (Mg/L) | NO3 (Mg/L) | BACTERIA (MPN) |
|---|---|---|---|---|---|---|---|---|---|---|
| 7/15/85 | | 9.8 | 8.0 | 1271.3 | | | | | 32 | 16+ |
| 8/19/85 | | 11.0 | 9.2 | 1270.1 | | | | | 10 | 5.1 |
| 9/11/85 | 27.9 | 8.6 | 6.7 | 1272.5 | | 12.8 | 670 | | 15 | 16+ |
| 10/16/85 | 27.9 | 7.8 | 6.0 | 1273.3 | | 11.0 | 560 | 0.9 | 16 | 2.2 |
| 11/13/85 | 27.9 | 9.2 | 7.4 | 1271.9 | | 9.0 | 530 | 1.0 | <5 | 9.2 |
| 12/26/85 | | 8.8 | 7.0 | 1272.3 | | | | | 15 | |
| 1/22/85 | | 9.2 | 7.4 | 1271.9 | | | | | <5/<5 | 16+/16+ |
| 2/20/86 | | 9.8 | 8.0 | 1271.3 | | 9.0 | | 1.6 | 16 | 5.1 |
| 3/19/86 | | FLOODED | | | | | | | | |
| 4/14/86 | | 3.9 | 2.1 | 1277.2 | | | | | 6 | 2.2 |
| 5/21/86 | 28.0 | 2.2 | 0.4 | 1278.9 | 7.5 | 11.0 | 690 | 0.0 | 10 | 5.1 |
| 6/18/86 | 27.9 | 7.3 | 5.5 | 1273.8 | 7.4 | 11.0 | 690 | 1.2 | 9/6 | 16+/16+ |
| 7/23/86 | | 8.3 | 6.5 | 1272.8 | 7.0 | 12.0 | 650 | 0.4 | 10 | 16+ |
| 8/20/86 | | 9.1 | 7.3 | 1272.0 | | 11.0 | 440 | 1.6 | 6 | 16+ |

LOCATION LSR-R3B MP ELEVATION 1173.7 FT.

| DATE | WATER LEVEL M.P. (FT.) | WATER LEVEL ELEVATION | PH | TEMP ( C) | COND. UMHOS/CM | NO3 MG/L |
|---|---|---|---|---|---|---|
| 9/11/85 | | | | 20.6 | | 26 |
| 10/16/85 | 21.9 | 1151.8 | | 12.5 | 640 | 38 |
| 11/13/85 | 22.6 | 1151.1 | | 2.5 | 460 | 27 |
| 5/21/86 | 16.4 | 1157.3 | 7.2 | 18.0 | 620 | |
| 6/18/86 | 21.5 | 1152.2 | 8.2 | 20.0 | 690 | 33 |
| 7/23/86 | 22.7 | 1151.0 | 8.3 | 24.0 | 730 | 23 |
| 8/20/86 | 23.4 | 1150.3 | | 22.0 | 480 | 10/10 |

LOCATION LSR-38U

DATE INSTALLED 7/31/85 SCREENED INTERVAL 23.5-29.5 FT. MP ELEVATION 1193.9 FT. CASING HT. 1.9 FT.

| DATE | WELL DEPTH (Ft.) | WATER LEVEL M.P.(Ft.) | WATER LEVEL G.S.(Ft.) | WATER LEVEL ELEVATION | pH | TEMP ( C) | COND. (UMHOS/CM) | D.O. (Mg/L) | NO3 (Mg/L) | BACTERIA (MPN) |
|---|---|---|---|---|---|---|---|---|---|---|
| 8/19/85 | | 13.0 | 11.1 | 1180.9 | | | | | <5 | 16+ |
| 9/11/85 | 28.6 | 10.7 | 8.8 | 1183.2 | | 12.8 | 810 | | <5 | 16+ |
| 10/16/85 | 28.5 | 10.1 | 8.2 | 1183.8 | | 12.5 | 560 | 0.7 | <5 | 5.1 |
| 11/13/85 | 28.5 | | | | | 9.0 | 530 | | <5 | 0/<2.2 |
| 5/21/86 | 28.5 | 4.5 | 2.6 | 1189.4 | 7.4 | 10.5 | 770 | 0.0 | <5 | 2.2 |
| 6/18/86 | 28.5 | 10.2 | 8.3 | 1183.7 | 7.2 | 11.5 | 660 | 0.2 | <5 | 16+ |
| 7/23/86 | | 10.4 | 8.5 | 1183.6 | 7.3 | 14.0 | 630 | 0.1 | <5 | 16 |
| 8/20/86 | | 11.4 | 9.5 | 1182.5 | | 11.0 | 500 | 0.4 | <5 | 16+ |

LOCATION LSR-38L

DATE INSTALLED 7/31/85 SCREENED INTERVAL 44-50 FT. MP ELEVATION 1193.7 FT. CASING HT. 1.6 FT.

| DATE | WELL DEPTH (Ft.) | WATER LEVEL M.P.(Ft.) | WATER LEVEL G.S.(Ft.) | WATER LEVEL ELEVATION | pH | TEMP ( C) | COND. (UMHOS/CM) | D.O. (Mg/L) | NO3 (Mg/L) | BACTERIA (MPN) |
|---|---|---|---|---|---|---|---|---|---|---|
| 8/19/85 | | 12.8 | 11.2 | 1180.9 | | | | | <5 | 16+ |
| 9/11/85 | 50.3 | 10.3 | 8.7 | 1183.4 | | 12.8 | 1100 | | <5 | 16+ |
| 10/16/85 | 50.2 | 9.9 | 8.3 | 1183.8 | | 12.5 | 885 | 0.5 | <5 | 16+ |
| 11/13/85 | 50.3 | 11.0 | 9.4 | 1182.7 | | 9.0 | 785 | 0.5 | <5 | 16+ |
| 5/21/86 | 50.3 | 4.3 | 2.7 | 1189.4 | 7.3 | 11.0 | 1110 | 0.0 | <5 | 2.2 |
| 6/18/86 | 50.2 | 8.9 | 7.3 | 1184.8 | 7.0 | 12.5 | 1050 | 0.2 | <5 | 16 |
| 7/23/86 | | 10.1 | 8.5 | 1183.6 | 7.3 | 14.0 | 890 | 0.3 | <5 | 16 |
| 8/20/86 | | 11.1 | 9.5 | 1182.6 | | 12.0 | 660 | 0.8 | <5 | 16 |

LOCATION LSR-35U

DATE INSTALLED 7/25/85 SCREENED INTERVAL 20.5-22.5 FT. MP ELEVATION 1179.7 FT. CASING HT. 2.2 FT.

| DATE | WELL DEPTH (Ft.) | WATER LEVEL M.P. (Ft.) | WATER LEVEL G.S. (Ft.) | WATER LEVEL ELEVATION | pH | TEMP ( C) | COND. (UMHOS/CM) | D.O. (Mg/L) | NO3 (Mg/L) | BACTERIA (MPN) |
|---|---|---|---|---|---|---|---|---|---|---|
| 8/06/85 | | 17.7 | 15.5 | 1162.0 | | | | | | |
| 8/19/85 | | 18.2 | 15.7 | 1161.5 | | | | | <5 | 16+ |
| 9/11/85 | 23.1 | 17.8 | 15.5 | 1161.9 | | 12.8 | 960 | | 26 | 16+ |
| 10/16/85 | 23.0 | 16.7 | 14.2 | 1163.0 | | 12.0 | 1200 | 0.9 | 10 | 2.2 |
| 11/13/85 | 23.0 | 17.0 | 14.5 | 1162.7 | | 9.0 | 940 | 1.0 | 23/21 | 9.2/16+ |
| 12/26/85 | | 16.0 | 13.5 | 1163.7 | | | | | <5 | |
| 1/22/86 | | 16.4 | 13.9 | 1163.3 | | | | | <5 | 5.1 |
| 2/20/86 | | 16.8 | 14.3 | 1162.9 | | 8.0 | | 0.5 | 40 | 9.2 |
| 3/19/86 | | 9.6 | 7.1 | 1170.1 | | | | | 17 | |
| 4/14/86 | | 9.8 | 7.3 | 1169.9 | | | | | 8/<5 | 2.2/2.2 |
| 5/21/86 | 23.0 | 9.4 | 6.9 | 1170.3 | 7.2 | 11.5 | 970 | 0.0 | 16 | 0 |
| 6/18/86 | 23.0 | 12.4 | 10.0 | 1167.2 | 7.1 | 13.0 | 750 | 0.4 | 22 | 16+ |
| 7/23/86 | | 14.9 | 12.7 | 1164.8 | 7.1 | 12.0 | 680 | 0.3 | 13 | 16+ |
| 8/20/86 | | 16.4 | 14.2 | 1163.3 | | 12.0 | 540 | | 26 | 16 |

LOCATION LSR-35M

DATE INSTALLED 7/25/85 SCREENED INTERVAL 35.5-37.5 FT. MP ELEVATION 1179.4 FT. CASING HT. 2.3 FT.

| DATE | WELL DEPTH (Ft.) | WATER LEVEL M.P. (Ft.) | WATER LEVEL G.S. (Ft.) | WATER LEVEL ELEVATION | pH | TEMP ( C) | COND. (UMHOS/CM) | D.O. (Mg/L) | NO3 (Mg/L) | BACTERIA (MPN) |
|---|---|---|---|---|---|---|---|---|---|---|
| 8/06/85 | | 17.4 | 15.1 | 1162.0 | | | | | | |
| 8/19/85 | | 18.0 | 17.7 | 1161.4 | | | | | 33 | 2.2 |
| 9/11/85 | 37.5 | 17.6 | 15.4 | 1161.8 | | 12.8 | 1100 | | 36 | 16+ |
| 10/16/85 | 37.3 | 16.4 | 14.1 | 1163.0 | | 11.5 | 1200 | 0.8 | 28 | 16+ |
| 11/13/85 | 37.4 | 16.8 | 14.5 | 1162.6 | | 8.0 | 1200 | 0.6 | 8 | 16+ |
| 12/26/85 | | 15.7 | 13.4 | 1163.7 | | | | | 25 | |
| 1/22/86 | | 16.2 | 13.9 | 1163.2 | | | | | 24 | 0 |
| 2/20/86 | | 16.6 | 13.3 | 1162.8 | | 7.0 | | | 32/30 | 9.2/16+ |
| 3/19/86 | | 9.3 | 7.0 | 1170.1 | | | | | 25 | |
| 4/14/86 | | 9.6 | 7.3 | 1169.8 | | | | | 31 | 0 |
| 5/21/86 | 37.3 | 9.2 | 6.9 | 1170.2 | 7.2 | 12.0 | 820 | 0.0 | 17 | 2.2 |
| 6/18/86 | 37.4 | 12.3 | 10.0 | 1167.2 | 7.0 | 13.5 | 1100 | 0.2 | 17 | 16 |
| 7/23/86 | | 14.7 | 12.4 | 1164.7 | 7.1 | 13.0 | 870 | 0.2 | 18/24 | 16+/16+ |
| 8/20/86 | | 16.3 | 14.0 | 1163.1 | | 12.0 | 620 | 0.8 | 19 | 16+ |

LOCATION LSR-35L

DATE INSTALLED 7/25/85 SCREENED INTERVAL 50-52 FT. MP ELEVATION 1179.2 FT. CASING HT. 2.0 FT.

| DATE | WELL DEPTH (Ft.) | WATER LEVEL M.P.(Ft.) | WATER LEVEL G.S.(Ft.) | WATER LEVEL ELEVATION | pH | TEMP ( C) | COND. (UMHOS/CM) | D.O. (Mg/L) | NO3 (Mg/L) | BACTERIA (MPN) |
|---|---|---|---|---|---|---|---|---|---|---|
| 8/06/85 | | 17.1 | 15.1 | 1162.1 | | | | | | |
| 8/19/85 | | 17.7 | 15.7 | 1161.5 | | | | | <5 | 16 |
| 9/11/85 | 52.0 | 17.4 | 15.5 | 1161.8 | | 12.8 | 1400 | | <5 | 16+ |
| 10/16/85 | 51.9 | 16.2 | 14.2 | 1163.0 | | 13.0 | 1400 | 0.5 | <5 | 16+ |
| 11/13/85 | 51.9 | 16.2 | 14.2 | 1163.0 | | 8.5 | 1800 | 0.5 | <5 | 9.2 |
| 12/26/85 | | 15.5 | 13.5 | 1163.7 | | | | | <5 | |
| 1/22/86 | | 16.0 | 14.0 | 1163.2 | | | | | <5 | 0 |
| 2/20/86 | | 16.4 | 14.4 | 1162.8 | | 8.0 | | | <5 | 0 |
| 3/19/86 | | 9.1 | 7.1 | 1170.1 | | | | | <5 | |
| 4/14/86 | | 9.4 | 7.4 | 1169.8 | | | | | <5 | 0 |
| 5/21/86 | 52.0 | 9.0 | 7.0 | 1170.2 | 7.3 | 12.5 | 1600 | 0.0 | <5 | 0 |
| 6/18/86 | 51.9 | 12.0 | 10.0 | 1167.2 | 6.9 | 13.5 | 1200 | 0.2 | <5 | 9.2 |
| 7/23/86 | | 14.5 | 12.5 | 1164.7 | 7.0 | 12.5 | 1100 | 0.2 | <5 | 16 |
| 8/20/86 | | 16.0 | 14.0 | 1163.2 | | 12.0 | 380 | 0.8 | <5 | 16 |

LOCATION LSR-34U

DATE INSTALLED 7/24/85 SCREENED INTERVAL 17.5-19 FT. MP ELEVATION 1208.9 FT. CASING HT. 2.7 FT.

| DATE | WELL DEPTH (Ft.) | WATER LEVEL M.P.(Ft.) | WATER LEVEL G.S.(Ft.) | WATER LEVEL ELEVATION | pH | TEMP ( C) | COND. (UMHOS/CM) | D.O. (Mg/L) | NO3 (Mg/L) | BACTERIA (MPN) |
|---|---|---|---|---|---|---|---|---|---|---|
| 8/06/85 | | 18.9 | 16.2 | 1190.0 | | | | | | |
| 8/19/85 | | 19.0 | 16.3 | 1189.9 | | | | | 9 | 16+ |
| 9/11/85 | 19.0 | 17.7 | 15.0 | 1191.2 | | 16.1 | 720 | | <5 | 16+ |
| 10/16/85 | 19.0 | 19.4 | 16.7 | 1189.5 | | 13.0 | 770 | | 13 | 16+ |
| 11/13/85 | 19.0 | 19.6 | 16.9 | 1189.3 | | 10.0 | 745 | | 9 | 16+ |
| 12/26/85 | | 19.8 | 17.1 | 1189.1 | | | | | <5 | |
| 1/22/86 | | 19.9 | 17.2 | 1189.0 | | | | | <5 | 2.2 |
| 2/20/86 | | 20.0 | 17.3 | 1188.9 | | 5.0 | 440 | 1.9 | 8 | 2.2 |
| 3/19/86 | | 19.4 | 16.7 | 1189.5 | | | | | <5 | |
| 4/14/86 | | 19.5 | 16.8 | 1189.4 | | | | | <5 | 9.2 |
| 5/21/86 | 19.1 | 19.0 | 16.3 | 1189.9 | 7.8 | 15.0 | 710 | | 32/32 | 2.2/0 |
| 6/18/86 | 19.1 | 18.7 | 16.1 | 1190.2 | 7.4 | 13.0 | 640 | 2.3 | 10 | 2.2 |
| 7/23/86 | | 19.1 | 16.4 | 1189.9 | 7.4 | 13.0 | 620 | 0.4 | <5 | 16 |
| 8/20/86 | | 18.4 | 15.7 | 1190.5 | | 14.0 | 480 | | 37 | 9.2 |

LOCATION LSR-21

DATE INSTALLED 7/10/85 SCREENED INTERVAL 12-13 FT. MP ELEVATION 1164.9 FT. CASING HT. 1.9 FT.

| DATE | WELL DEPTH (Ft.) | WATER LEVEL M.P. (Ft.) | WATER LEVEL G.S. (Ft.) | WATER LEVEL ELEVATION | pH | TEMP ( C) | COND. (UMHOS/CM) | D.O. (Mg/L) | NO3 (Mg/L) | BACTERIA (MPN) |
|---|---|---|---|---|---|---|---|---|---|---|
| 7/15/85 | | 8.3 | 6.4 | 1156.6 | | | | | 172 | 0 |
| 8/19/85 | | 8.9 | 7.0 | 1156.0 | | | | | 8 | 0 |
| 9/12/85 | 12.9 | 9.1 | 6.6 | 1155.8 | | 15.6 | 560 | | 92 | 5.1 |
| 10/16/85 | 13.5 | 9.4 | 7.5 | 1155.5 | | 14.7 | 510 | 6.0 | 54 | 0 |
| 11/14/85 | 13.5 | 9.4 | 7.5 | 1155.5 | | 12.0 | 600 | 7.4 | 54 | 5.1 |
| 12/26/85 | | | | | | | | | | |
| 1/22/86 | | | | | | | | | <5 | 2.2 |
| 2/20/86 | | 9.6 | 7.7 | 1157.2 | | 6.0 | | 6.4 | 78 | 2.2 |
| 3/19/86 | | 8.7 | 6.8 | 1156.2 | | | | | <5 | |
| 4/14/86 | | 6.7 | 4.8 | 1158.2 | | | | | <5 | 0 |
| 5/21/86 | 13.4 | 6.4 | 4.5 | 1158.6 | 7.7 | 11.5 | 380 | 9.0 | 40 | 0 |
| 6/18/86 | 13.4 | 7.4 | 5.5 | 1157.5 | 7.2 | 15.0 | 430 | 9.6 | 59 | 16+ |
| 7/23/86 | | 5.4 | 3.5 | 1159.5 | 7.1 | 18.0 | 480 | 3.9 | 40/48 | 16+/16+ |
| 8/20/86 | | 9.2 | 7.3 | 1155.7 | | 17.0 | 405 | 7.2 | 25/36 | 16+/16+ |

LOCATION LSR-22

DATE INSTALLED 7/10/85 SCREENED INTERVAL 23-26 FT. MP ELEVATION 1146.7 FT. CASING HT. 2.3 FT.

| DATE | WELL DEPTH (Ft.) | WATER LEVEL M.P. (Ft.) | WATER LEVEL G.S. (Ft.) | WATER LEVEL ELEVATION | pH | TEMP ( C) | COND. (UMHOS/CM) | D.O. (Mg/L) | NO3 (Mg/L) | BACTERIA (MPN) |
|---|---|---|---|---|---|---|---|---|---|---|
| 7/15/85 | | 13.5 | 11.2 | 1133.2 | | | | | 57 | 5.1 |
| 8/19/85 | | 14.5 | 12.3 | 1132.2 | | | | | 33 | 0 |
| 9/12/85 | 25.7 | 9.0 | 6.6 | 1137.7 | | 12.8 | 730 | | 24 | 16+ |
| 10/16/85 | 25.8 | 15.5 | 13.2 | 1131.2 | | 12.9 | 600 | 9.0 | 14 | 16+ |
| 11/14/85 | 25.8 | 15.7 | 13.4 | 1131.0 | | 9.0 | 785 | 10.1 | 19 | 16 |
| 12/26/85 | | 16.0 | 13.7 | 1130.7 | | | | | 48 | |
| 1/22/86 | | 16.0 | 13.7 | 1130.7 | | | | | 34 | 0 |
| 2/20/86 | | | | | | 6.0 | | 4.8 | 49 | 0 |
| 3/19/86 | | 15.1 | 12.9 | 1131.6 | | | | | 25 | |
| 4/14/86 | | 14.9 | 12.6 | 1131.8 | | | | | 27 | 16 |
| 5/21/86 | 25.7 | 11.9 | 9.6 | 1134.8 | 7.6 | 12.0 | 660 | 9.0 | 45 | 0 |
| 6/18/86 | 25.7 | 12.2 | 9.9 | 1134.5 | 7.3 | 12.5 | 660 | 10.2 | 19 | 16 |
| 7/23/86 | | 13.2 | 10.9 | 1133.5 | 7.3 | 14.0 | 670 | 10.0 | 24 | 16+ |
| 8/20/86 | | 14.2 | 11.9 | 1132.5 | | 12.0 | 480 | 9.8 | 26 | 16+ |

LOCATION LSR-33

DATE INSTALLED 7/24/85 SCREENED INTERVAL 24-25.5 FT. MP ELEVATION 1136.9 FT. CASING HT. 2.6 FT.

| DATE | WELL DEPTH (Ft.) | WATER LEVEL M.P. (Ft.) | WATER LEVEL G.S. (Ft.) | WATER LEVEL ELEVATION | pH | TEMP ( C) | COND. (UMHOS/CM) | D.O. (Mg/L) | NO3 (Mg/L) | BACTERIA (MPN) |
|---|---|---|---|---|---|---|---|---|---|---|
| 8/06/85 | | 11.2 | 8.6 | 1125.7 | | | | | | |
| 8/19/85 | | 11.6 | 9.0 | 1125.3 | | | | | 17 | 0 |
| 9/12/85 | 25.7 | 11.5 | 8.9 | 1125.4 | | 12.8 | 630 | | 16 | 16+ |
| 10/16/85 | 25.7 | 11.6 | 9.0 | 1125.3 | | 12.7 | 655 | 7.1 | 9 | 16 |
| 11/14/85 | 25.7 | 11.9 | 9.3 | 1125.0 | | 10.0 | 660 | 7.7 | 9 | 9.2 |
| 12/26/85 | | 12.3 | 9.7 | 1124.6 | | | | | 13 | |
| 1/22/86 | | 12.1 | 9.5 | 1124.8 | | | | | 11 | 2.2 |
| 2/20/86 | | 12.1 | 9.5 | 1124.8 | | 8.0 | | 4.1 | 22 | 0 |
| 3/19/86 | | 10.1 | 7.5 | 1126.8 | | | | | 19 | |
| 4/14/86 | | 10.0 | 7.4 | 1126.9 | | | | | 17 | 0 |
| 5/21/86 | 25.7 | 9.3 | 6.7 | 1127.6 | 7.7 | 12.0 | 610 | 4.4 | 9.0 | 2.2 |
| 6/18/86 | 25.7 | 9.3 | 6.7 | 1127.7 | 7.5 | 13.2 | 580 | | 8 | 16 |
| 7/23/86 | | 10.7 | 8.1 | 1126.2 | 7.4 | 14.0 | 540 | 7.2 | 6 | 16+ |
| 8/20/86 | | 11.3 | 8.7 | 1125.6 | | 12.0 | 380 | 6.6 | 12/8 | 16+/16+ |

LOCATION LSR-R4 MP ELEVATION 1096.5 FT.

| DATE | WATER LEVEL M.P. (FT.) | WATER LEVEL ELEVATION | PH | TEMP ( C) | COND. (UMHOS/CM) | NO3 (MG/L) |
|---|---|---|---|---|---|---|
| 9/12/85 | 7.5 | 1104.0 | | 17.8 | 710 | 28 |
| 10/16/85 | 8.1 | 1104.6 | 7.9 | 13.5 | 780 | 38 |
| 11/13/85 | | | | 4.0 | 740 | 31 |
| 12/26/85 | | | | | | - |
| 2/20/86 | | | | 1.5 | 500 | 30 |
| 5/21/86 | 13.6 | 1110.1 | 8.5 | 21.5 | 620 | 34 |
| 6/18/86 | | | 8.3 | 24.0 | 740 | 38 |
| 7/23/86 | 7.4 | 1103.9 | 8.3 | 24.0 | 760 | 25 |
| 8/20/86 | 6.8 | 1103.3 | | 22.0 | 470 | 11 |

LOCATION LSR-23

DATE INSTALLED 7/11/85 SCREENED INTERVAL 28-31 FT. MP ELEVATION 1131.6 FT. CASING HT. 2.0 FT.

| DATE | WELL DEPTH (Ft.) | WATER LEVEL M.P. (Ft.) | WATER LEVEL G.S. (Ft.) | WATER LEVEL ELEVATION | pH | TEMP ( C) | COND. (UMHOS/CM) | D.O. (Mg/L) | NO3 (Mg/L) | BACTERIA (MPN) |
|---|---|---|---|---|---|---|---|---|---|---|
| 7/15/85 | | 18.5 | 16.5 | 1113.1 | | | | | 18 | 0 |
| 8/19/85 | | 19.5 | 17.5 | 1112.1 | | | | | <5 | 0 |
| 9/12/85 | 31.3 | 19.3 | 17.4 | 1112.3 | | 13.3 | 610 | | <5 | 16+ |
| 10/16/85 | 31.2 | 19.4 | 17.4 | 1112.2 | | 13.5 | 590 | 1.6 | <5/<5 | 16+/16+ |
| 11/14/85 | 31.2 | 19.5 | 17.5 | 1112.1 | | 10.0 | 680 | 1.7 | 5 | 16 |
| 12/26/85 | | 19.6 | 17.6 | 1112.0 | | | | | <5 | |
| 1/22/86 | | 19.6 | 17.6 | 1112.0 | | | | | <5 | 16+ |
| 2/20/86 | | 19.4 | 17.4 | 1112.2 | | 8.0 | | 1.6 | <5 | 2.2 |
| 3/19/86 | | 17.3 | 15.3 | 1114.3 | | | | | <5 | |
| 4/14/86 | | 17.4 | 15.4 | 1114.2 | | | | | <5/<5 | 0/0 |
| 5/21/86 | 31.2 | 16.7 | 14.1 | 1115.7 | 7.7 | 13.0 | 610 | 0.1 | <5/<5 | 16+/16+ |
| 6/18/86 | 31.2 | 17.9 | 15.9 | 1113.7 | 7.5 | 14.0 | 390 | 1.9 | <5 | 16+ |
| 7/23/86 | | 17.9 | 15.9 | 1113.7 | 7.4 | 13.5 | 540 | 1.6 | <5 | 9.2 |
| 8/20/86 | | 18.8 | 16.8 | 1112.8 | | 11.5 | 490 | | <5 | 16+ |

LOCATION LSR-25

DATE INSTALLED 7/18/85 SCREENED INTERVAL 19-24 FT. MP ELEVATION 1090.3 FT. CASING HT. 2.3 FT.

| DATE | WELL DEPTH (Ft.) | WATER LEVEL M.P. (Ft.) | WATER LEVEL G.S. (Ft.) | WATER LEVEL ELEVATION | pH | TEMP ( C) | COND. (UMHOS/CM) | D.O. (Mg/L) | NO3 (Mg/L) | BACTERIA (MPN) |
|---|---|---|---|---|---|---|---|---|---|---|
| 8/06/85 | | 10.2 | 7.9 | 1080.1 | | | | | | |
| 8/19/85 | | 10.7 | 8.4 | 1079.6 | | | | | <5 | 16+ |
| 9/12/85 | 24.4 | 11.1 | 8.5 | 1079.2 | | 13.9 | 710 | | 11 | 16+ |
| 10/16/85 | 24.7 | 11.2 | 8.9 | 1079.1 | | 13.9 | 750 | 0.7 | 6 | 16+ |
| 11/14/85 | 24.8 | 11.4 | 9.1 | 1078.9 | | 11.0 | 755 | 0.5 | <5 | 16+/<2.2 |
| 12/26/85 | | 11.2 | 8.9 | 1079.1 | | | | | <5/<5 | |
| 1/22/86 | | 11.3 | 9.0 | 1079.0 | | | | | <5 | 16 |
| 2/20/86 | | 11.8 | 9.5 | 1078.5 | | 9.0 | | 0.1 | <5 | 16+ |
| 3/19/86 | | 9.7 | 7.4 | 1080.6 | | | | | <5/<5 | |
| 4/14/86 | | 9.3 | 7.0 | 1081.0 | | | | | <5 | 16+ |
| 5/21/86 | 24.6 | 8.0 | 5.7 | 1082.3 | | 11.0 | 495 | 0.0 | 6 | 16+ |
| 6/18/86 | 24.5 | 8.1 | 5.8 | 1082.1 | 7.4 | 13.0 | 680 | 0.5 | 8 | 16+ |
| 7/23/86 | | 9.4 | 7.1 | 1080.9 | 7.3 | 14.0 | 600 | 0.2 | 23 | 9.2 |
| 8/20/86 | | 10.5 | 8.2 | 1079.8 | | 12.0 | 540 | 2.3 | 8 | 16+ |

LOCATION LSR-31

DATE INSTALLED 7/23/85 SCREENED INTERVAL 34-37.5 FT. MP ELEVATION 1073.2 FT. CASING HT. 1.6 FT.

| DATE | WELL DEPTH (Ft.) | WATER LEVEL M.P.(Ft.) | WATER LEVEL G.S.(Ft.) | WATER LEVEL ELEVATION | pH | TEMP ( C) | COND. (UMHOS/CM) | D.O. (Mg/L) | NO3 (Mg/L) | BACTERIA (MPN) |
|---|---|---|---|---|---|---|---|---|---|---|
| 8/06/85 | | 13.7 | 12.1 | 1059.5 | | | | | | |
| 8/19/85 | | 13.9 | 12.3 | 1059.3 | | | | | 58 | 0 |
| 9/12/85 | 37.9 | 12.9 | 11.3 | 1060.3 | | 12.8 | 620 | | 57 | 16 |
| 10/16/85 | 37.9 | 12.6 | 11.0 | 1060.6 | | 11.3 | 670 | 1.6 | 44 | 16 |
| 11/14/85 | 37.9 | 13.4 | 11.8 | 1059.8 | | 10.0 | 640 | 1.8 | <5/<5 | 5.1/9.2 |
| 12/26/85 | | | | | | | | | 24 | |
| 1/22/86 | | 13.5 | 11.9 | 1059.7 | | | | | 8 | 5.1 |
| 2/20/86 | | 13.9 | 12.3 | 1059.3 | | 9.0 | | 0.9 | 49/48 | 9.2/0 |
| 3/19/86 | | 7.6 | 6.0 | 1065.6 | | | | | 42 | |
| 4/14/86 | | 9.1 | 7.5 | 1064.1 | | | | | 34/27 | 5.1/5.1 |
| 5/21/86 | 37.9 | 7.4 | 5.8 | 1065.8 | 7.7 | 12.5 | 620 | 1.6 | 16 | 5.1 |
| 6/18/86 | 37.9 | 10.4 | 8.8 | 1062.8 | 7.5 | 14.0 | 570 | 2.6 | 29 | |
| 7/23/86 | | 11.5 | 9.9 | 1061.7 | 7.4 | 15.0 | 540 | 1.6 | 52 | 16+ |
| 8/20/86 | | 12.5 | 10.9 | 1060.7 | | 12.0 | 440 | 2.2 | 26/34 | 16+ |

ABBREVIATIONS

MP Measuring Point
GS Ground Surface
HT Height
FT Feet
COND Conductivity
DO Dissolved Oxygen
NO3 Nitrate

Duplicate samples for nitrate and bacteria were collected each month on random samples as part of the quality control program.