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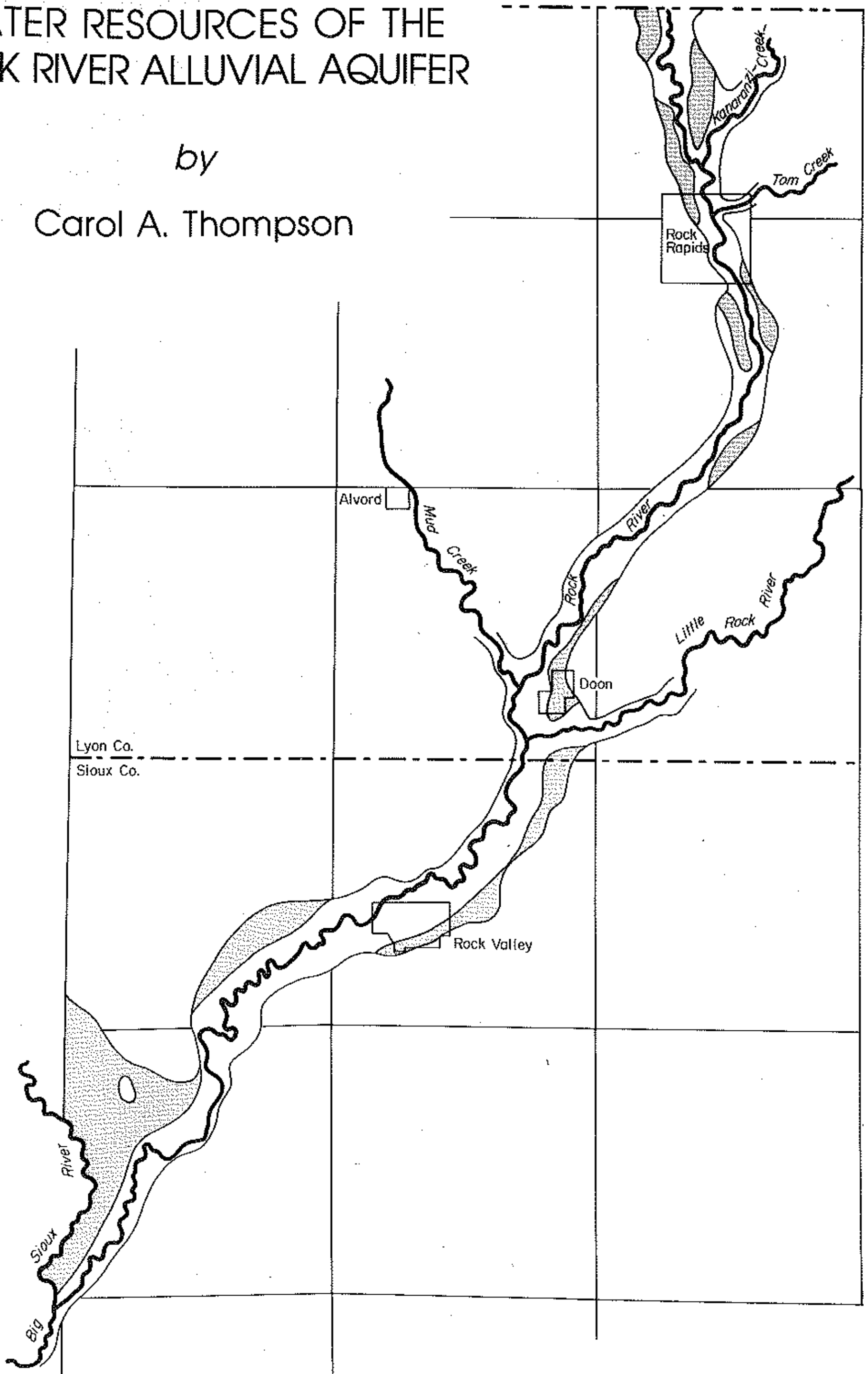
WATER RESOURCES OF THE ROCK RIVER ALLUVIAL AQUIFER

by

Carol A. Thompson



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The publication of this document has been financially aided through a contract with the United States Environmental Protection Agency.

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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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Conversion factors to change English (foot-pounds) units to International System (SI) units.

Multiply English units	by	To obtain SI units
feet (ft)	0.3048	meters (m)
miles (mi)	1.609	kilometers (km)
square feet (ft^2)	0.0929	square meters (m^2)
square miles (mi^2)	2.59	square kilometers (km^2)
acres (ac)	4046.9	square meters (m^2)
acres (ac)	0.4947	hectares (ha)
acre-feet (ac-ft)	1233.6	cubic meters (m^3)
gallons (g)	3.785	liters (l)
feet/second (ft/sec)	0.3048	meters/second (m/sec)
gallons per day/square foot (gpd/ft^2)	0.0408	meters/day (m/d)
square feet/day (ft^2/d)	0.0929	square meters/day (m/d)
gallons per day/foot (gpd/ft)	0.0124	square meters/day (m/d)
gallons/day (gpd)	0.0909	cubic meters/day (m^3/d)
gallons/minute (gpm)	5.42	cubic meters/day (m^3/d)
cubic feet/second (cfs)	0.0283	cubic meters/second (m^3/sec)
feet/mile (ft/mi)	0.1894	meters/kilometer (m/km)
pounds (lbs)	0.4536	kilograms (kg)
pounds - N per acre (lbs-N/ac)	1.091	kilograms - N per hectares (kg-N/ha)

EXECUTIVE SUMMARY

A study of the alluvial aquifer of the Rock River valley from the Minnesota border to its intersection with the Big Sioux valley was conducted to provide information on water availability and water quality.

The river valley was formed by meltwater from the latest Wisconsinan glaciation. The alluvial valley is wide and flat, and flanked by non-continuous terraces. The thickness of alluvial deposits ranges from seven to 87 feet, but averages only about 20 feet. The alluvial materials consist of coarse sands and gravels. Occasional finer sand underlies the coarser material.

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 stream, 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 moderately low flows are expected to recur frequently on the Rock River.

Transmissivities in the aquifer range from 95,000 to 400,000 gallons per day per foot. Water in storage in the Rock River alluvial system is estimated to be at least 3.2 billion gallons.

Water levels were measured monthly and ranged from 0.5 feet above ground level to 13 feet below ground level. Water levels varied an average of five feet during the course of the study. Water table gradients are low ranging from .001 (5 ft/mi) to .0018 (9.5 ft/mi). Both strong downward (.01 - .07) and upward (.006 - .38) gradients were observed at the nested well sets.

A total of 12 observation wells were installed at eight sites in the Rock River alluvial system. These were sampled monthly for nitrate and bacteria with a few wells being analyzed for pesticides. The groundwater can be classed as slightly alkaline freshwater with calcium and magnesium the dominant cations and bicarbonate the dominant anion. Nitrate concentrations are high and extensive areal contamination has occurred. Nitrate levels vary temporally and generally increase in response to increased infiltration. Higher nitrate levels are found in the Rock River system than in other alluvial systems studied in northwest Iowa. Land use, geology, and chemical processes all combine to effectively increase nitrate inputs to the Rock River alluvial system.

High bacteria levels were seen in almost all wells sampled. Much of this bacterial contamination may result from leakage along the casing or contamination introduced during sampling.

Limited pesticide sampling was done in the Rock River alluvial system. Atrazine was the only compound detected in groundwater. Four pesticides were detected in surfacewater. All concentrations detected are below acute toxicity levels.

The largest allocation of water at present is for irrigation, followed by municipal, rural-water system, livestock, and rural domestic uses. Adequate water is available during most seasons to meet current needs and to support projected future increases. Further degradation in water quality could limit use 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 this important resource. 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 these 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 Ocheyedan and Upper Little Sioux Rivers are located in northwest Iowa and primarily traverse two physiographic provinces (Figure 1) (Prior, 1976). The headwaters of both streams originate on the Des Moines Lobe, the area of the latest (Wisconsinan) glacial advance into Iowa. The upland topography of the Des Moines Lobe is flat to very irregular. The irregular landscape is referred to as "knob and kettle topography," and is the result of glacial stagnation and morainal development. Downstream, the rivers flow across the Northwest Iowa Plains. The topography of this region is the product of Pre-Illinoian glaciations, early Woodfordian ("Tazewell") glaciation, and subsequent erosion. The landscape is gently rolling with a well-defined drainage network. The highest elevations in the state occur in this region. The lower valley of the Little Sioux in Woodbury County flows briefly through the Southern Iowa Drift Plain and then enters the Western Loess Hills region. Here the river valley is bounded by prominent, angular bluffs and ridges of loess.

The study areas are the alluvial plains which border the rivers. These plains are broad, nearly flat valley floors adjacent to the rivers and are characterized by low relief and poor drainage. Terraces along the valley margins of the alluvial plains are remnants of earlier floodplains formed when the river was at a higher elevation. These terraces may occur anywhere from five to 100 feet above the present river level, and their deposits may or may not be hydraulically connected to the alluvial aquifer.

The area drained by the Ocheyedan River is 434 square miles. The drainage area of the Little Sioux above its confluence with the Ocheyedan River is 556

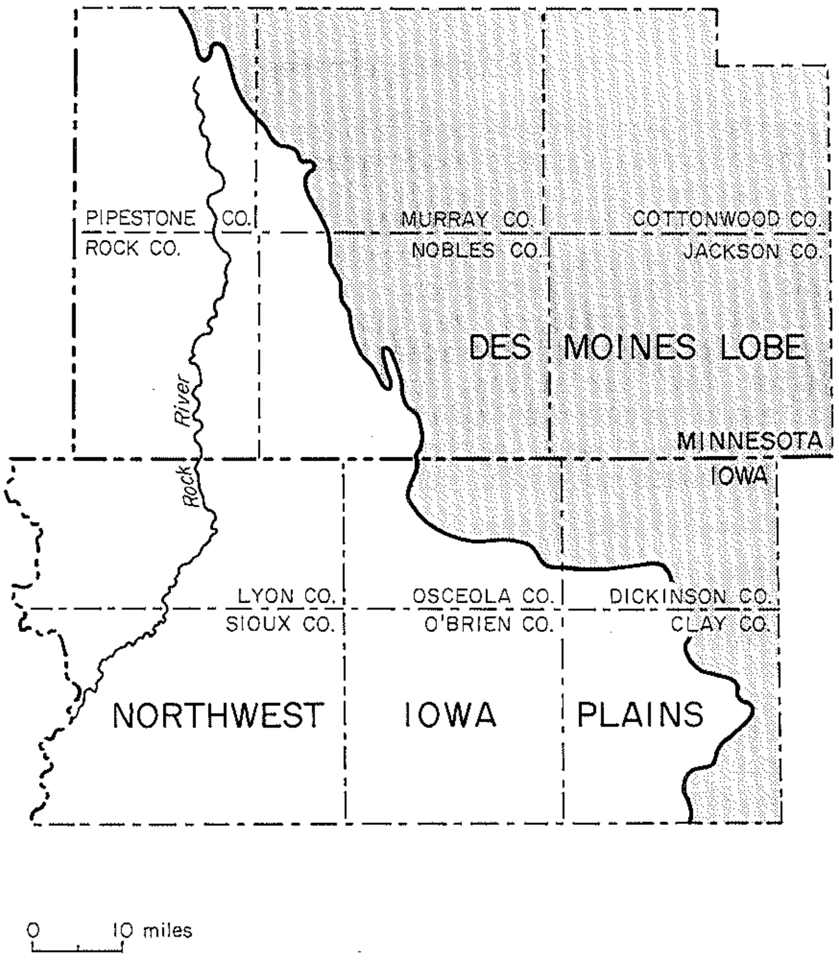

Figure 1. Location of the Rock River.

Northwest counties are drier; east and southeast counties are wetter. During most years, about 75 percent of all precipitation, normally 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 36 inches.

Geologic History and Setting

Previous work on the geology of the rivers in the study area was done by Wilder (1899). A hydrogeologic study of the Rock River in Minnesota was done by Adolphsen (1983). The Rock River starts in Pipestone County, Minnesota and flows through Rock County, Minnesota before entering Iowa. The river valley was formed by outwash streams flowing from the Bemis moraine, the edge of the latest Wisconsinan glacial advance. The river valley is flanked by one terrace in its upper reaches in Iowa and multiple terraces can be seen below the town of Rock Valley. The river is incised into Pre-Illinoian tills along its course, although near the intersection with the Big Sioux, Cretaceous shales and sandstones also underlie the alluvium.

GEOLOGICAL INVESTIGATIONS

Data Collection

A preliminary phase of this project included a compilation of the available 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 system 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 rural water district, municipal, and industrial test well borings in the alluvium. These data are contained in Appendix A and Figure A-1 shows their locations. Lithologic descriptions in Appendix A reflect interpretations by many different sources and are not necessarily consistent with Geological Survey Bureau (GSB) useage.

County soil survey maps prepared by the USDA Soil Conservation Service were used to determine subsoil lithologies and where possible, depths to the materials. Till-derived (glacial) soils were generally found along the uplands and valley slopes, and are the lateral boundary for alluvial materials. The soil maps proved especially useful in areas where the valley margins are subtle and not easily located.

In a few small 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 alluvial thicknesses can vary greatly, additional lateral control was needed. Seismic refraction surveys were conducted to supplement the available information. Drill holes were then used 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.

Results and Discussion

A total of 133 seismic spreads were run at eight different locations covering a linear distance of approximately 7.5 miles. Figure 2 shows the location of each traverse.

Borings were drilled at nine locations with a mud rotary unit. A total of 12 wells, including three 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 Figure 3 and well information can be found in Table 1. Driller's logs are located in Appendix C.

The Rock River valley heads on the Des Moines Lobe boundary in Pipestone County, Minnesota and flows through Rock County, Minnesota before entering Iowa. Studies by Adolphson (1983) show that the valley in Minnesota ranges in width from 0.5 to 1.5 miles. In the northern half, thin sands and gravels are interbedded with clay. To the south, the alluvial deposits thicken and are composed of fine to coarse sand interbedded with silt and gravel. Thicknesses range from 4 to 42 feet with average thickness changing from 19 feet in the north to 24 feet in the south.

The Rock River enters Iowa in Lyon County. Here the river valley is 0.5 to 1.25 miles wide with sand and gravel deposits ranging from 7 to 41 feet in thickness and averaging 18 feet in the north and 25 feet in the south. There are non-continuous terraces present on both sides of the river. The terraces are separated from the floodplain by a distinct scarp face, approximately 10 feet high. Thicker sands and gravels occur in the terraces and they are hydraulically connected to the rest of the alluvial system. Deposits in exposed gravel pits show a stratified sequence of fine, well-rounded gravel and coarse sand.

In Sioux County, multiple terraces are present. Valley width ranges from 0.75 to 1.5 miles. The thickness of alluvial deposits varies drastically ranging from 8 to 87 feet. The thicker deposits are on terraces and may intersect older channel material. These areas have a distinct stratification showing sand and gravel up to 50 feet thick over an additional 40 feet of sand. Just before the Rock valley merges with the Big Sioux valley, a sharp constriction in valley width occurs. South and west of this area the Rock River has dissected an extensive terrace containing coarse gravels and boulders. The deposits here are unlike those upstream in the Rock valley; they are thicker, ranging between 20 and 63 feet and averaging 33 feet. Much of the material was probably deposited by the Big Sioux River, which during Late Wisconsinan time drained the James Lobe in South Dakota. Figure 4 is an isopach map, which defines the thickness of sand and gravel in the valley. The thickness of alluvial materials along with water level measurements in Appendix D can be used to calculate the saturated thickness of the aquifer.

SURFACEWATER RESOURCES

Streamflow data are available for several gaging stations along the Rock River. 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.

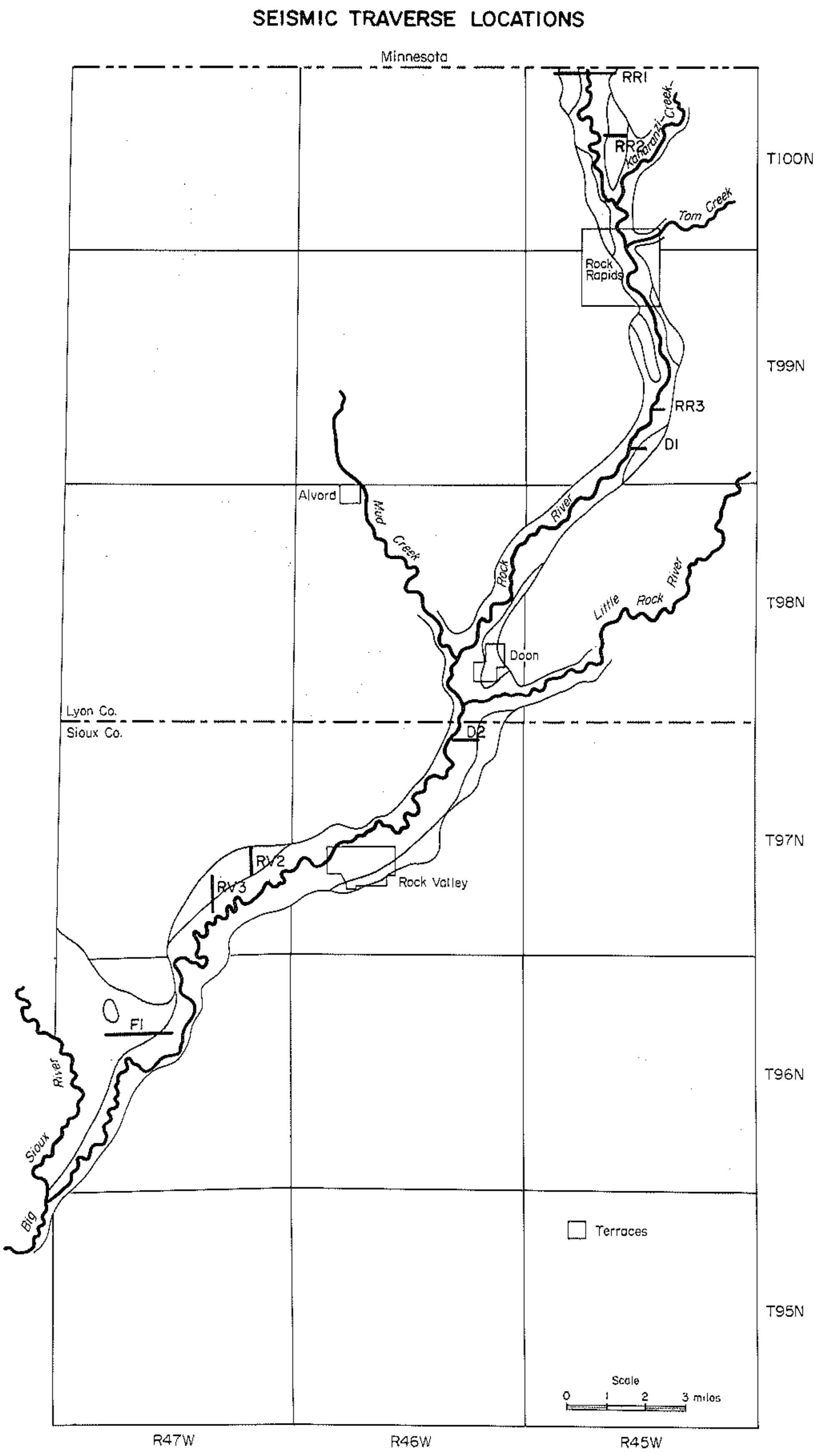

Figure 2. Seismic traverse locations.

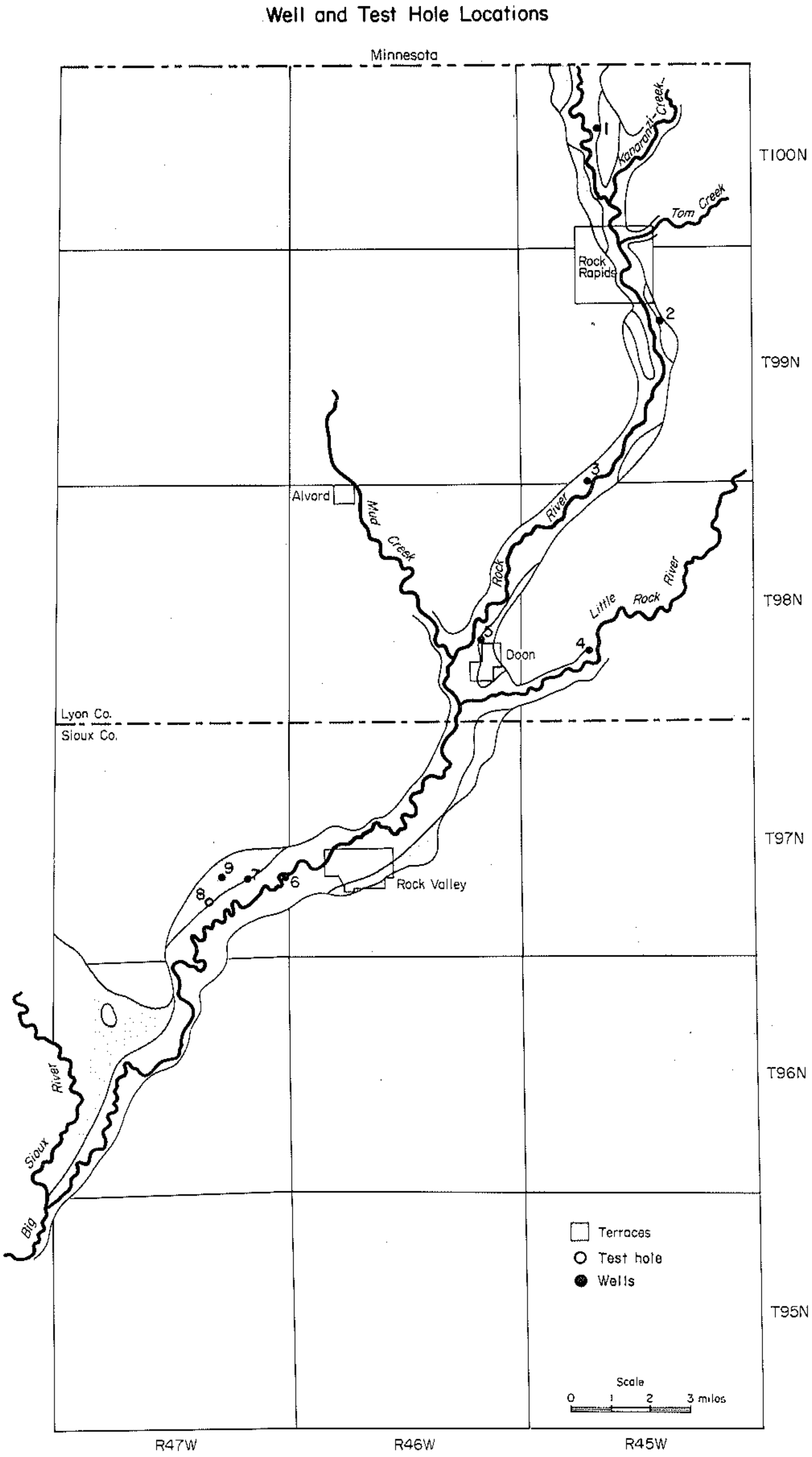

Figure 3. Well and test hole locations.

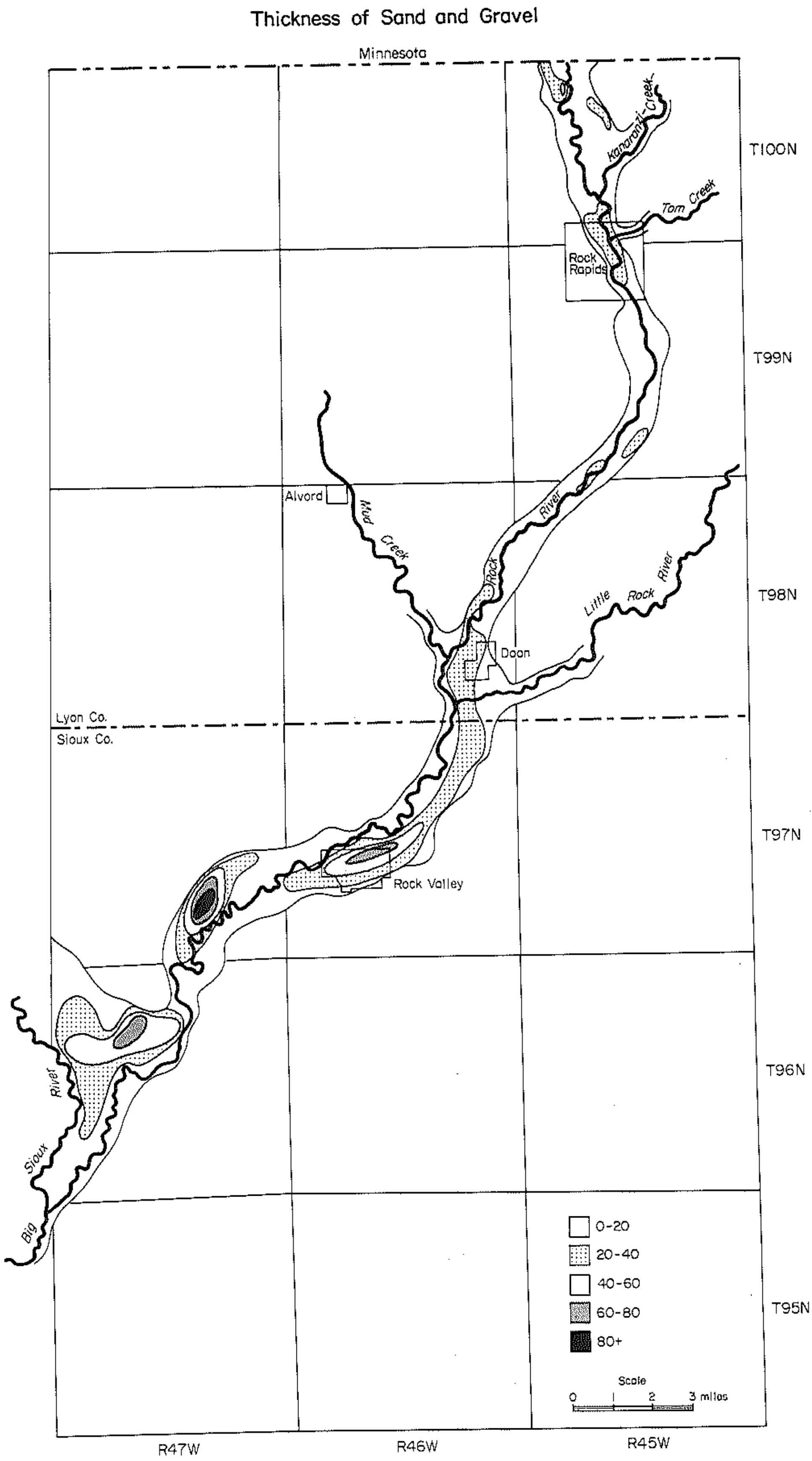

Figure 4. Thickness of alluvial deposits in the Rock River alluvial aquifer.

Table 1. Summary of Well and Test Hole Data.

	Well No.	Elevation (ft above mean sea level)	Screened Interval (ft)	Substrate Lithology	Thickness of Sand & Gravel (ft)	Depth to Sand and Gravel (ft)
27729 /71690	RR1	1339.0	10.15-12.5 19-23	Till	19	5
27730	RR2	1335.0	13-15	Till	13	3
27731	RR3	1297.0	11-13	Till	10	5
27732 /71697 /71699	RR4	1283.0	10-12 22-25 38-41	Till	41	2
27733 /71721	RR5	1274.6	16-17 26-29	Till	29	2
27734	RR6	1223.7	17-20	Till	21	2
27735	RR7	1224.1	17-19.5	Till	8	12
27736	RR8	1230.0	---	Clay/Shale	87	3
27737	RR9	1230.7	16-21	Till	21	1

The flow characteristics of streams are a function of weather, vegetative cover, topography, and geology. Stream discharge derives from precipitation, snowmelt, and 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 flow. 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

Table 2. Streamflow-gaging Stations on the Rock River.

Station No.	Station Name	Drainage Area (sq. mi.)	Station Type	Years of Record
06-4832.70	Rock River at Rock Rapids	788	Complete Record	8/60-10/74
06-4835.00	Rock River near Rock Valley	1592	Complete Record	6/48-Current

having well integrated, efficient drainage networks have a very rapid flow response 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 hydrograph are modulated or suppressed. The Rock River drainage basin is well-integrated with numerous tributary streams.

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 variable stream--one whose flow is largely controlled by surface runoff. Flat sloping curves indicate that streamflow is signficantly 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 Rock River gaging stations using computer programs available from the U.S. Geological Survey. June-September curves (Figure 5) are shown as this is the critical demand period for water and also eliminates the effects of ice. The curves are fairly steep indicating the importance of surface runoff in maintaining streamflow. The curve for Rock Rapids shows a larger amount of storage available then for an equivalent area at Rock Valley, however, this may be due to the length of record available and may not be a real effect.

Low-Flow Frequency

Iowa law limits the withdrawal of surfacewater during periods of low streamflow. 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.

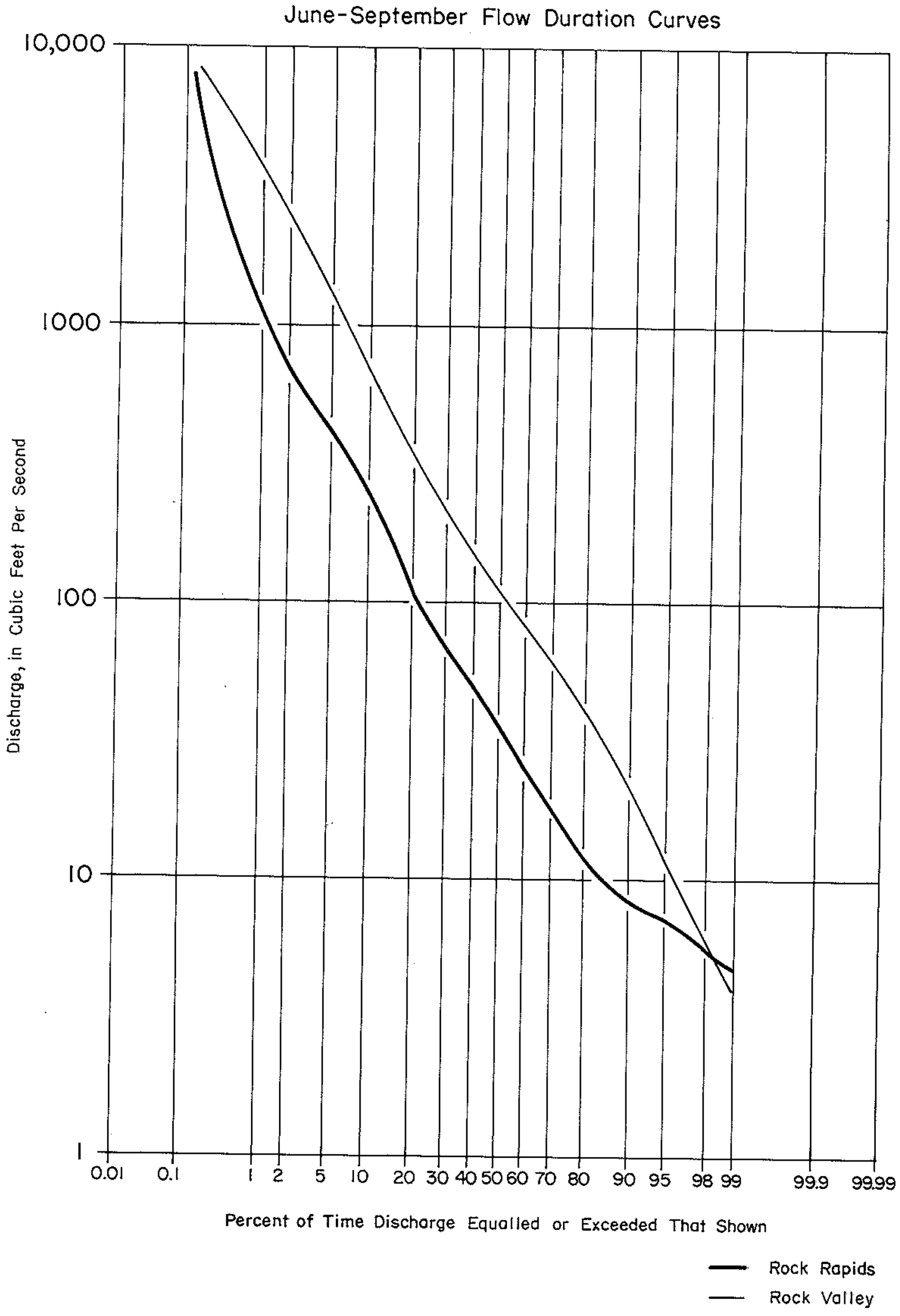

Figure 5. June-September flow-duration curves.

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 fifty 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 river. Protected flows at other points can be established as the need arises by comparison of streamflow data and basin characteristics.

Water developments that are based on withdrawals from streams or 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 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 and low-flow duration data for two 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 statistical probability of events occurring as recorded in historical streamflow records. For example, the table indicates that for the Rock River at Rock Rapids, the lowest flow anticipated to occur once in ten years for seven consecutive days (7Q10) is 1.6 cfs. Such conditions would be critical for a power plant requiring an uninterrupted supply of cooling water or municipal sewage plant discharging wastewater. In the latter case, the waste load allocation 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. This fact adds significantly to the cost of treatment plant construction and to its normal operating costs.

Groundwater and Surfacewater Relationships

Interactions between a stream and aquifer affect the distribution of water and the slope of the water table. Groundwater travels very slowly while surfacewater typically flows at rates 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 streambed, on the water-table gradient, and the permeability or hydraulic conductivity of the aquifer materials.

A streamflow hydrograph can be divided into two components: direct surface runoff and groundwater discharge. Direct surface runoff responds rapidly to precipitation events and is primarily responsible for the peaks of a

Table 3. Low-flow Values

Station	84% Duration Flow (cfs)	7Q10 (cfs) Annual	7Q10 (cfs) June/Sept
Rock River at Rock Rapids	11.0	1.6	3.8
Rock River near Rock Valley	19.0	1.7	6.1

hydrograph. Groundwater (baseflow) contributions supply most of streamflow during rainless periods. Since groundwater moves slowly, baseflow contributions display a lesser response to rainfall than surface runoff. Figure 6 is an idealized hydrograph showing the components of surface runoff and groundwater discharge. 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 again 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 7.

The hydrograph records for Rock River gaging stations were separated into surfaceflow and baseflow components using the method developed by the Institute of Hydrology (1980). Daily discharges are grouped into sets of five and a five day minimum flow is chosen. The selected minima are then sequentially evaluated by groups of three. If 0.9 of the mid-value in the group of three 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, for the period of record, results in volumes that are used to calculate an average baseflow contribution percentage. These percentages are presented in Table 5.

Baseflow recession curves define the relationship between baseflow discharge and time. The principal use of these curves is to forecast low flows especially when low flows occur during the growing season and water demand is highest. The curves provide estimates of normal streamflow recession rates in the absence of appreciable precipitation 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 8 shows curves developed for gaging sites in the study area.

TABLE 4. Magnitude and Frequency of Low Flows -- Rock River

Station 06-4832.70, Rock River, Rock Rapids

Recurrence Interval In Years	ANNUAL								JUNE-SEPTEMBER						
	Lowest average flow, in cu. ft./sec., for indicated period in consecutive days														
	3	7	14	30	60	90	120	183	3	7	14	30	60	90	120
2	4.7	5.2	5.9	7.6	10.5	15	19.7	27.5	7.5	8.5	9.8	12.0	22.0	40.8	71.1
5	2.2	2.4	2.8	2.7	5.3	7.7	10.3	15.1	4.2	4.9	5.8	7.3	13.7	21.2	33.5
10	1.4	1.6	1.8	2.5	3.6	5.2	7.2	10.6	3.2	3.8	4.6	5.9	11.0	15.7	23.1
20	1.0	1.1	1.3	1.7	2.6	3.7	5.3	7.7	2.7	3.1	3.8	5.1	9.3	12.5	17.1

Station 05-4835.00 Rock River, Rock Valley

Recurrence Interval In Years	ANNUAL								JUNE-SEPTEMBER						
	Lowest average flow, in cu. ft./sec., for indicated period in consecutive days														
	3	7	14	30	60	90	120	183	3	7	14	30	60	90	120
2	11.4	12.0	17.2	17.9	22.6	30.5	37.2	53.0	33.5	35.3	40.6	53.7	88.3	123	197
5	3.3	3.5	3.1	4.2	5.9	9.3	13.6	19.6	10.6	11.7	13.8	18.7	32.5	47.9	78.7
10	1.4	1.5	0.8	1.5	2.5	4.6	7.9	11.3	5.3	6.1	7.2	9.9	17.7	28.6	48.6
20	0.0	0.0	0.2	0.4	1.2	2.5	5.0	7.1	1.3	3.4	4.1	5.6	10.2	18.4	32.6

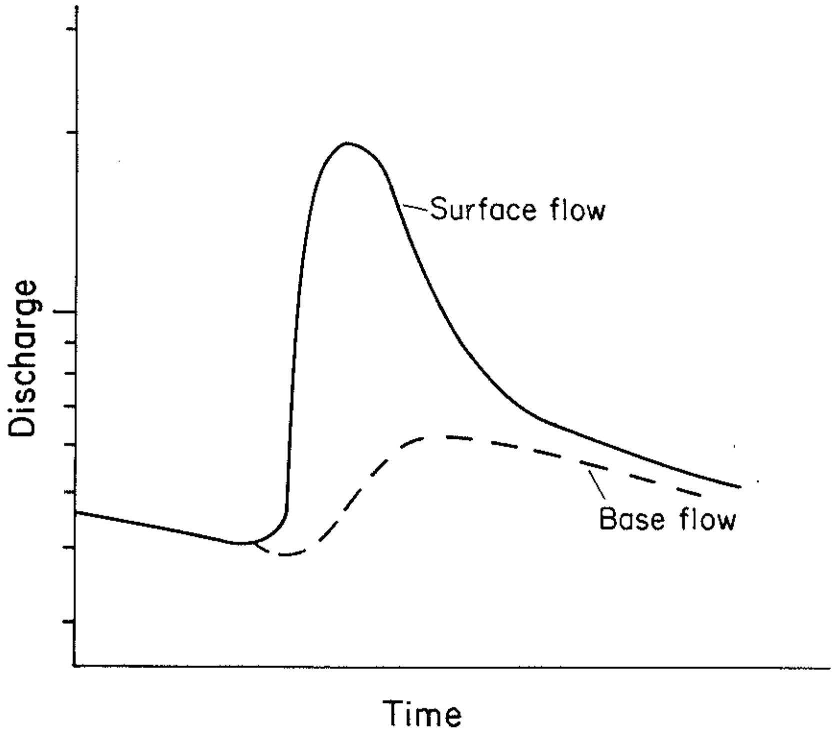

Figure 6. Idealized hydrograph illustrating the relative relationships of surface runoff and groundwater flow.

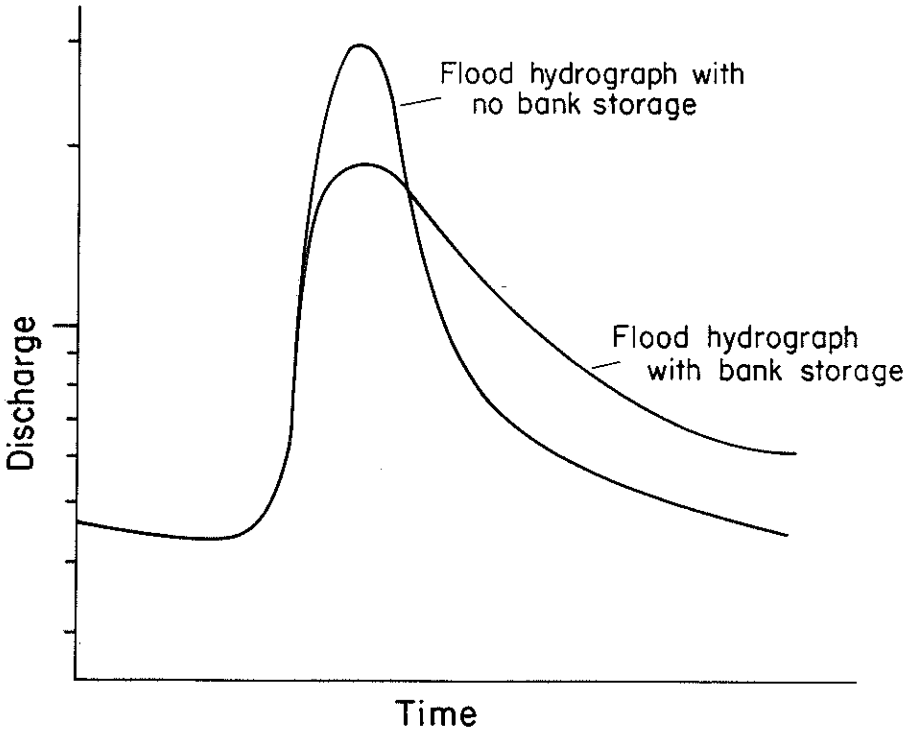

Figure 7. Idealized hydrograph showing the effects of bank storage.

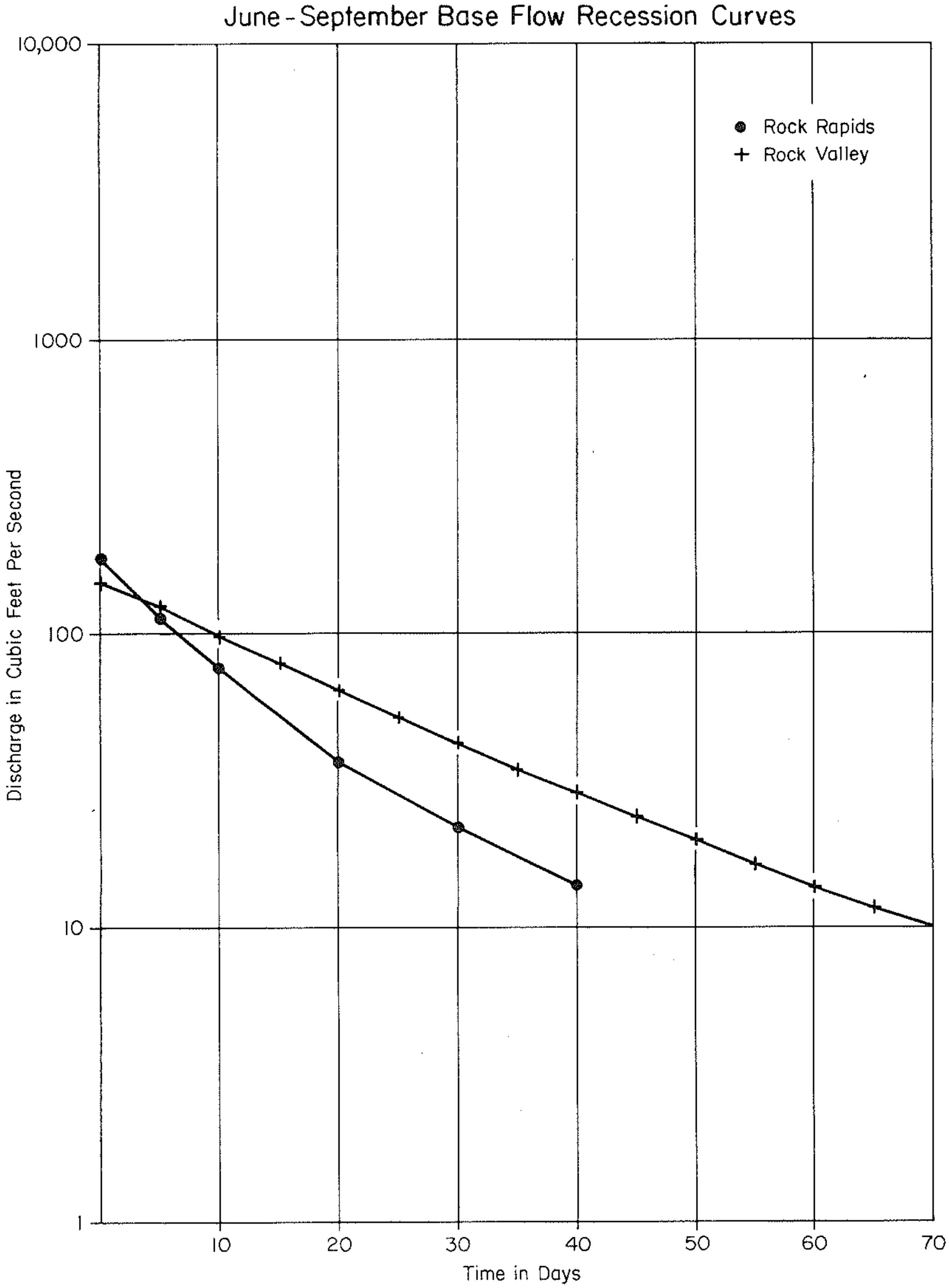

Figure 8. June-September baseflow recession curves.

Table 5. Baseflow Contribution Percentages.

Station	Long-Term Avg.	Range
Rock River at Rock Rapids	.32	.15 - .51
Rock River near Rock Valley	.43	.17 - .71

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 Rock River 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 by the water table, the level to which water will freely rise in a well or open hole. The surface of the associated stream defines the groundwater table where it intersects the land surface. The water table generally slopes from the higher land areas toward the stream. The source of the water in the alluvial system is precipitation which infiltrates through the soil. Groundwater levels change noticeably throughout the year in response to precipitation and evaporation and are highest in late spring and fall. Another source of water in the alluvial system is seepage from streams which cut through the aquifer. Pumping of wells results in lowering of the water table (static water level) and will induce infiltration from the river.

Figure 9 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 pumping 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 streambed, 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 yield per foot decline in the water table for a specific area. 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 given cross section of aquifer, with a specific gradient for a specified period of time. It is measured in units such as feet/second or gallons per day per 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 con-

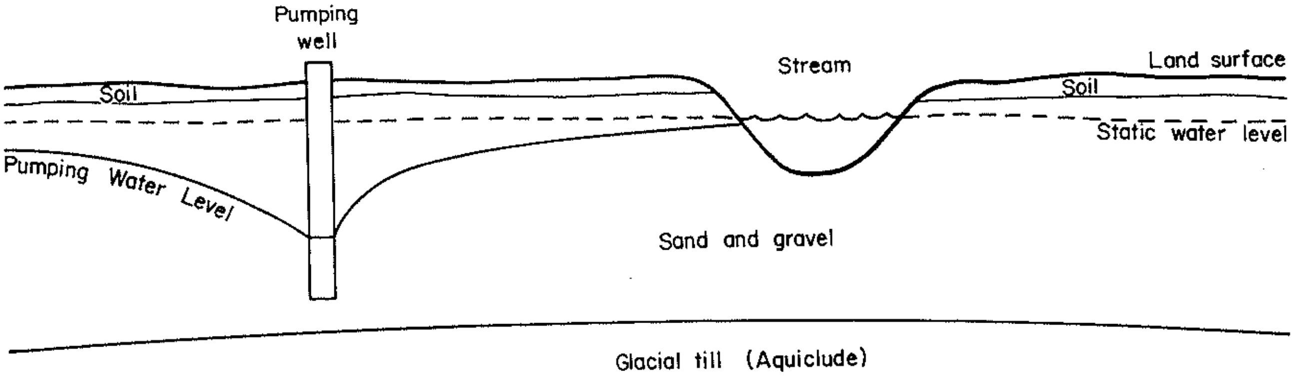

Figure 9. Schematic showing relationship between static water level and pumping water level.

ductivity 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 per foot or square feet per day.

Several pumping tests were done for rural water districts and municipalities along the Rock River. Values for transmissivity ranged from 95,000 to 400,000 gallons per day per foot. Storage or specific yield values range from 6×10^{-6} to 0.04. Corresponding values of hydraulic conductivity varied between 2,000 and 10,000 gpd/ft^2.

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 section. Often, the floodplain adjacent to the river will be covered with 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 storage in the Rock River alluvial system in Lyon and Sioux counties would be:

Area	x	Saturated Thickness	x	Specific Yield	x	Conversion Factor	=	Storage
1.3 billion ft^2	x	16 ft	x	0.02	x	7.48 gal/ft^3	=	3.2 billion gallons

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 saturated thickness will also affect the amount of water in storage . During drought the water table drops, decreasing the saturated thickness, thereby decreasing the amount of water in storage. In wet years more water is in storage.

The rate at which water moves through an alluvial aquifer and the path that it takes is dependent on both geologic factors and the gradient or slope of the water table. Geologic factors include the nature of the materials in the aquifer: bedding patterns, aquifer 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 quantify. The numbers presented here are a general guide to yield potentials. Actual development sites need to be evaluated by test-drilling and pumping to determine specific aquifer characteristics.

Water Levels

Water levels were measured from July, 1985 to October, 1986 at all well and river locations. All locations were surveyed to obtain accurate estimates of water table position. Water-level data are presented in Appendix D.

Groundwater levels ranged from approximately 0.5 feet above ground level to 13 feet below ground level during the course of this study and averaged about eight feet below ground level. Water levels in any one well showed an average variation of 4.6 feet with a maximum variation of only 5.6 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.

Surfacewater levels varied up to eight feet during the time of the study. Streams in the area are dependent on groundwater discharge to maintain flow. During prolonged drought,the streams will have suppressed flow levels and may even go dry.

Water table gradients measured in the study area range from 0.001 (5 ft/mi) to 0.0018 (9.5 ft/mi). Flow in the aquifer is towards the river and slightly down valley.

Vertical gradients were measured in the three sets of nested wells. One well set remained within measurement error of zero during the study. A second well set shows predominate downward gradients ranging from 0.01 to 0.07. The third nested set, which is a three well set, again is normally near zero. Occasionally upward gradients are present ranging from 0.006 to 0.38 ft/ft.

Even though the vertical gradients appear high in relation to horizontal gradients, water will not travel faster in the vertical direction. Hydraulic conductivity in a vertical direction is usually one-fifth to one-tenth that of horizontal conductivity (Bouwer, 1978). This effect, caused by particle orientation and layering, is called anisotropy, and is especially prevalent in alluvial deposits. Anisotropy in the horizontal plane also exists because of the nature of the deposits which are channelized and are most often aligned in a downstream pattern. Hydraulic conductivity will be greater in these channels and thus greater in the downstream direction. Thus, alluvial aquifers display three-dimensional anisotropy. This, in turn, may affect the distribution and movement of infiltrating contaminants.

Streamflow Depletion

As discussed previously, gradients in alluvial aquifers normally slope toward streams. Pumping can cause streamflow to be diverted to an aquifer. The reduction of streamflow caused by groundwater withdrawals is streamflow depletion. Streamflow depletion has two components, although not necessarily separable: a) flow induced directly from the stream, and b) water intercepted enroute to the stream. A method described by Jenkins (1968) was used to evaluate streamflow depletion for the Rock River. The method computes the percentages of total pumpage attributable to induced streamflow based on the distance of the pumping well to the stream, the rate and duration of pumping, and the aquifer's coefficients of storage and transmissivity. Figures 10 and 11 show graphs developed to provide a basis for predicting stream depletion effects along the Rock River.

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 curves for a specific yield of 0.02. 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 6 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 is based on are the same as those used for 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. 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), the Department of Natural Resources, Environmental Protection Division and from the files of rural water systems and municipalities. These data are contained in Appendix E.

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

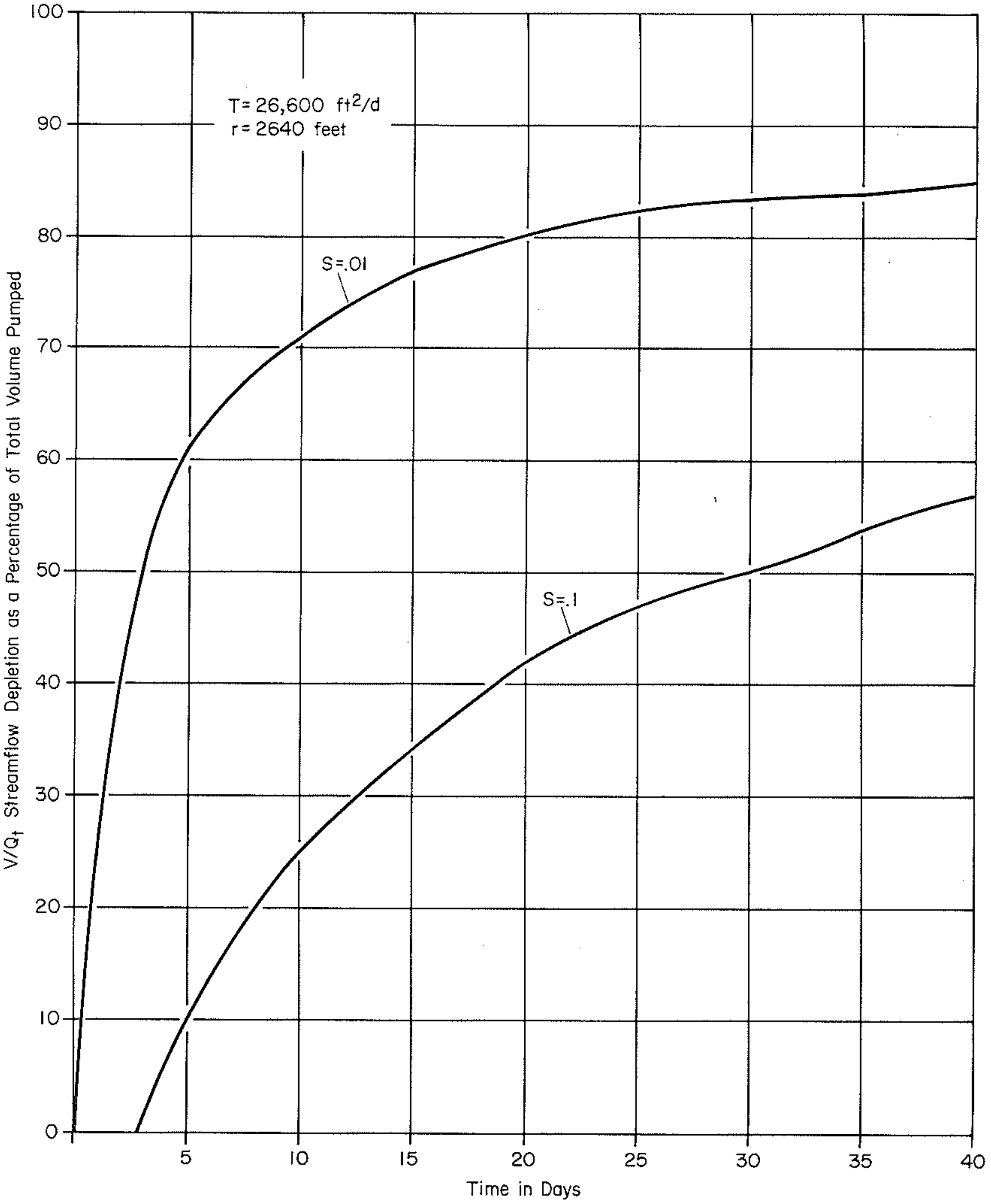

Figure 10. Streamflow depletion curves: time vs. depletion.

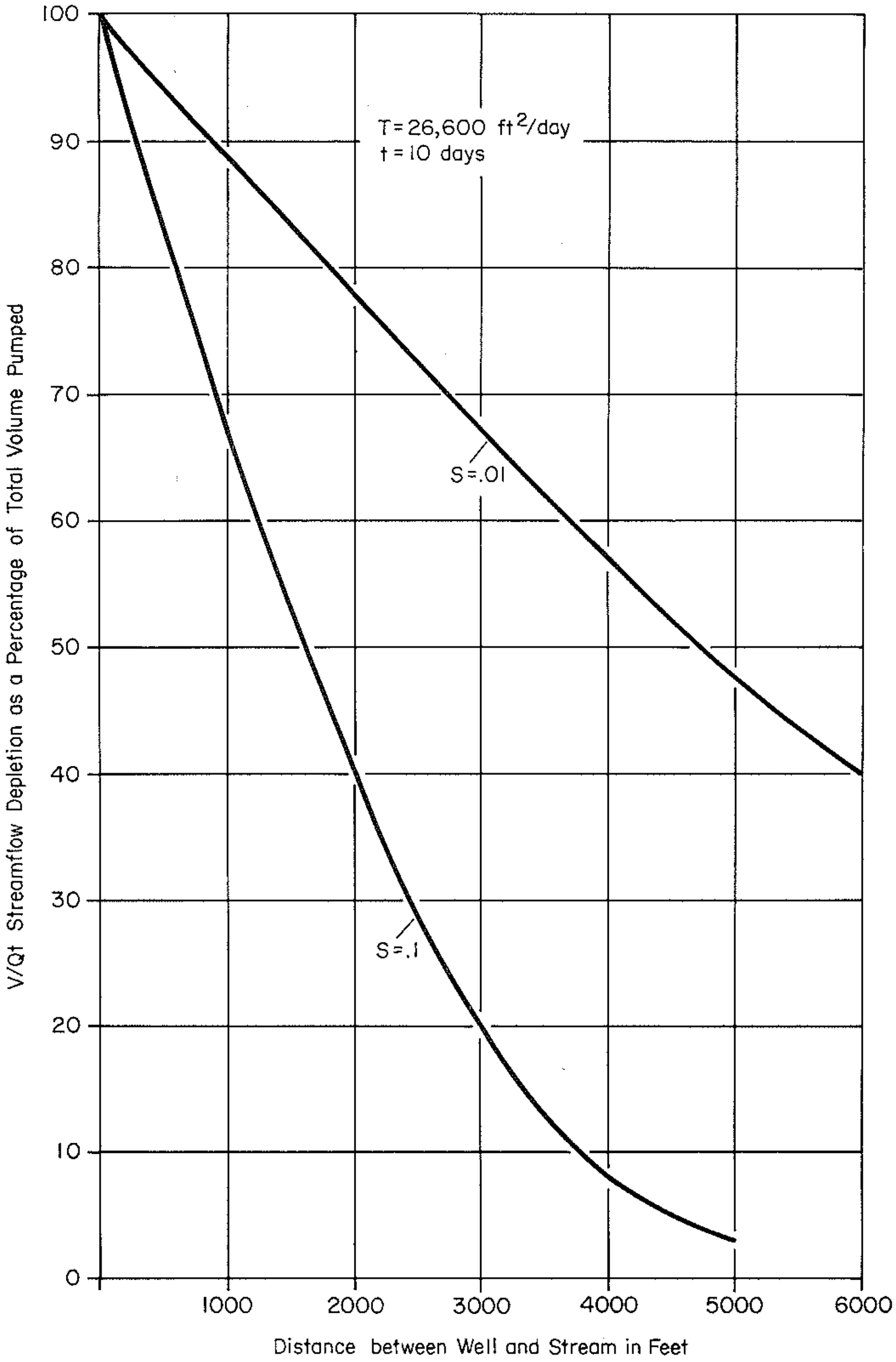

Figure 11. Streamflow depletion curves: distance vs. depletion.

Table 6. 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 four columns while time is varied. Time is constant over the second four columns and r is varied. For the chosen values of storage coefficient streamflow depletion is given in cfs and gpm induced by the pumping well. Calculations are given for two specific yields (Sy).

		Sy = 0.01		Sy = 0.1	
t (days)	r (feet)	cfs	gpm	cfs	gpm
1	2640	0.4	180	0	0
3	2640	0.8	350	0.1	45
5	2640	1.0	449	0.2	90
10	2640	1.1	497	0.4	180
20	2640	1.2	546	0.6	269
30	2640	1.3	581	0.8	350

		Sy = 0.01		Sy = 0.1	
t (days)	r (feet)	cfs	gpm	cfs	gpm
10	1000	1.4	628	1.0	449
10	2000	1.2	546	0.6	269
10	3000	1.0	449	0.3	135
10	4000	0.9	404	0.1	45
10	5000	0.8	350	0.05	22
10	6000	0.6	269	0	0

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.

Sulfate levels are moderate to high for typical alluvial water. Only a few of the analyses are, however, over the recommended limit of 250 mg/l. Nitrate (NO_3) levels are high, often approaching or exceeding the recommended limit of 45 mg/l (10 mg/l NO_3-N). Table 7 lists the National Drinking Water Standards and the description and significance of each parameter. Drinking water standards have been established by the Environmental Protection Agency as part of the Safe Drinking Water Act (PL 93-523). Primary standards are maximum contaminant levels (MCLs) which are the maximum permissable level of a contaminant in a public water supply. Recommended maximum contaminant levels (RMCL) are the maximum level of contaminant in drinking water at which no known or anticipated adverse effect on the health of a person would occur and which includes an adequate safety margin. RMCLs are non-enforcable health goals. Secondary standards apply to substances

TABLE 7. Drinking Water Standards and Significance of Chemical Constituents

	CONSTITUENTS	PRIMARY STANDARDS MCL	 RMCL	SECONDARY STANDARDS
		(All analyses in mg/l unless otherwise noted)		
1	Dissolved solids			500
2	Hardness (as $CaCO_3$)			
3	pH			6.5 - 8.5 pH units
4	Specific conductance			
5	Alkalinity			
6	Iron			.3
7	Manganese (Mn)			.05
8	Potassium (K) and Sodium (Na)			
9	Calcium (Ca) and Magnesium (Mg)			
10	Sulfate (SO_4)			250
11	Phosphorus (PO_4)			
12	Chloride (Cl)			250
13	Floride (Fl)	4.0	4.0	
	Nitrogen Series			
14	Nitrate-N	10		
15	Nitrite-N			
16	Organic-N			
17	Ammonia-N			
18	Dissolved Oxygen			
19	Turbidity	1 TU	5 TU	
20	Total coliform	1 organism/100 ml water		
21	Radioactivity	picocuries/l		
	Gross alpa	15		
	Radium 226 (Ra^{226})	3		
	Radium 226 & 228 (Ra^{226}, Ra^{228})	5		
	Strontium 90 (Sr^{90})	10		
	Gross beta (in absence of alpha emitters)	1000		
22	Metals	mg/l		
	Arsenic (As)	0.05		
	Barium (Ba)	1.0		
	Cadmium (Cd)	0.01		
	Chromium (Cr)	0.05		
	Copper (Cu)			1
	Lead (Pb)	0.05		
	Mercury (Hg)	0.002		
	Selenium (Se)	0.01		
	Silver (Ag)	0.05		
	Zinc (Zn)			5

TABLE 7. Continued.

Description/Significance

1 This refers to all material that is in solution. It affects the chemical and physical properties of water for many industrial uses. High concentrations will have a laxative effect and may cause an objectionable taste.

2 This affects the lathering ability of soap. Primarily caused by calcium and magnesium. Water is generally classified as: 0-100 mg/l as soft; 100-200 mg/l as moderate; anything above 200 mg/l as hard.

3 A chemical expression indicating hydrogen ion activity. A ph of 7.0 is neutral, pH greater than 7.0 is alkaline, pH less than 7.0 is acid.

4 Specific conductance is a measure of the ability of water to conduct an electric current.

5 Alkalinity is defined as the capacity of a solution to neutralize an acid.

6 Iron is objectionable as it may impart an unpleasant taste and may cause discoloration of laundered goods and porcelain fixtures.

7 Objectionable for the same reasons as iron.

8 When combined with chloride, imparts a salty or brackish taste. In the presence of suspended matter, causes foaming in boilers. Important ingredients in human cell metabolism. Low sodium diets are prescribed in the treatment of certain types of heart disease and high blood pressure.

9 Calcium and magnesium cause water hardness. They reduce the lathering ability of soap. They react with bicarbonate and sulfate to form scale in pipes.

10 Commonly has a laxative effect and imparts a bitter taste when concentrations exceed 500 mg/l, particularly when combined with magnesium or sodium. The effect is less when combined with calcium. Persons may become acclimatized to the water, but concentrations above 750 mg/l generally affect everyone. Sulfate combined with calcium causes scale in boilers and water heaters.

11 Phosphorus has been linked to increased eutrophication in lakes and streams. Humans utilize phosphorus in small amounts for bone growth and enzymatic processes.

12 Imparts a salty taste, especially when combined with sodium and potassium.

13 Concentrations of 0.8--1.3 mg/l are effective in reduction of tooth decay, especially in children. Concentrations in excess of 2.0 mg/l will cause mottling of dental enamel.

14 Concentrations of nitrate above the recommended limits may cause cyanosis or methemoglobinemia (blue baby syndrome) when used for feeding infants under one year of age. This disease reduces the ability of the blood to absorb oxygen and may be fatal unless properly treated.

15 Is highly toxic, but in natural situations quickly oxidizes to nitrate. Contains compounds such as protein, peptides, nucleic acid, urea, and synthetic organics.

16 Is not always available for reactions.

17 Is a breakdown of organic nitrogen compounds and urea. Ammonia standards applicable to streams are for the protection of aquatic organisms.

18 A measure of the amount of atmospheric oxygen dissolved in water. Groundwater normally has low levels. Surface waters are constantly aerated leading to high levels. Many aquatic organisms need high levels of dissolved oxygen.

19 Is a measure of the waters ability to transmit light.

20 Coliform bacteria are not a health problem themselves, but their prescence may indicate the prescence of other bacteria which can cause health problems. Small amounts of bacteria in drinking water are unsatifactory. Bacteria can be controlled by chlorination.

21 Groundwater may contain naturally occurring radioactivity. Human exposure to radiation is viewed as harmful, and unnecessary exposure should be avoided. Limits have been set insofar as is technically and economically feasible. Radioactive substances such as strontium and radium tend to bioaccumulate in bone and may lead to bone cancer or leukemia.

22 Can be very toxic in small quantities, exhibiting both acute and chronic effects. May inhibit oxygen transfer, affect the nervous system, damage chromosomes, or interfere with enzyme production or function. Metals are not rapidly excreted and tend to bioaccumulate. Metals are naturally occurring substances that normally occur in very small quantities.

which primarily affect aesthetic qualities related to public acceptance of drinking water. In addition to aesthetic degradation, health implications may also exist at considerably higher concentrations of these contaminants.

Nitrate contamination of 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 12). 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 which receive chemical applications (Figure 13). In a few counties more than 80 percent of the land is row-cropped. Most of the alluvial valleys are intensively farmed.

Figure 14 shows the percentage of water samples, from private wells less than 100 feet deep, that exceed the nitrate MCL. Of the private alluvial wells listed in Appendix E, 50 percent exceeded the recommended limit for nitrate. Many municipal supplies, particularly in northwest Iowa, have also exceeded the nitrate MCL (Figure 15).

Background surfacewater-quality data show a wide range of nitrate values from 0 to 22.5 mg/l NO_3 (0-5.0 mg/l NO_3-N). Organic nitrogen averages around 1.2 mg/l as N. Ammonia concentrations range from 0 to 7.8 mg/l as N. Fecal coliform concentrations also show a wide variation from <10 to 74,000 organisms per 100 milliliters (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 16).

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 17). In general, one well was set at the top of the aquifer near the water table, one near the middle, and one at the bottom of the aquifer if a thick enough section was available. Wells were constructed of 2-inch, PVC pipe with slotted intervals ranging from two to four feet.

Water quality sampling was done monthly on 12 wells and four surfacewater sites. Complete information and results for each monitoring well can be found in Appendix F. 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 75 percent ethyl alcohol solution.

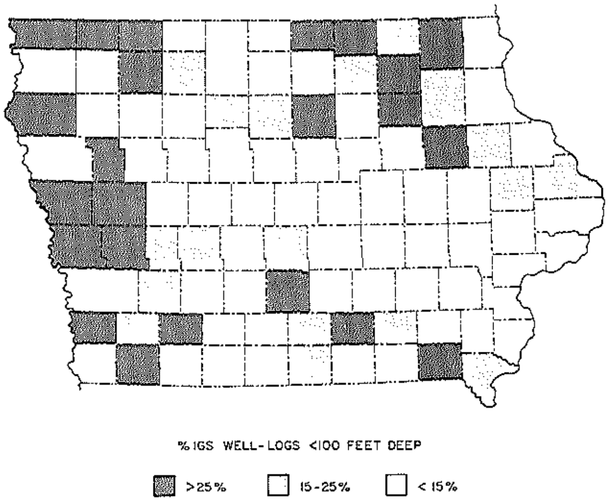

Fig. 12. Percentage of wells in Iowa less than 100 feet deep, by county. (Data from GSB files.)

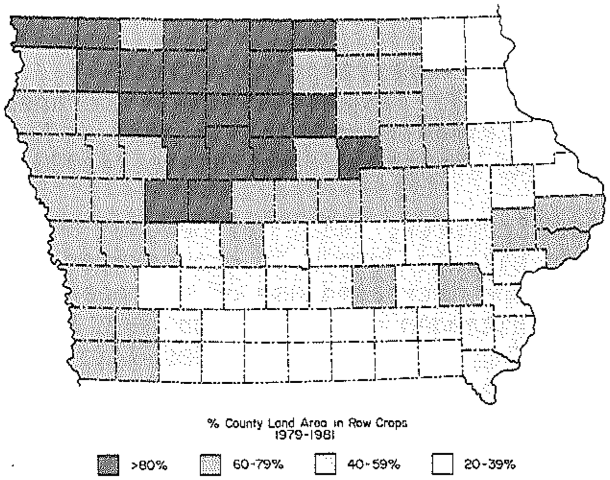

Fig. 13. Average percent of land area in corn and soybeans, by county, 1979-1981. (Data from Iowa Dept. of Ag., Crop and Livestock Rept. Serv.)

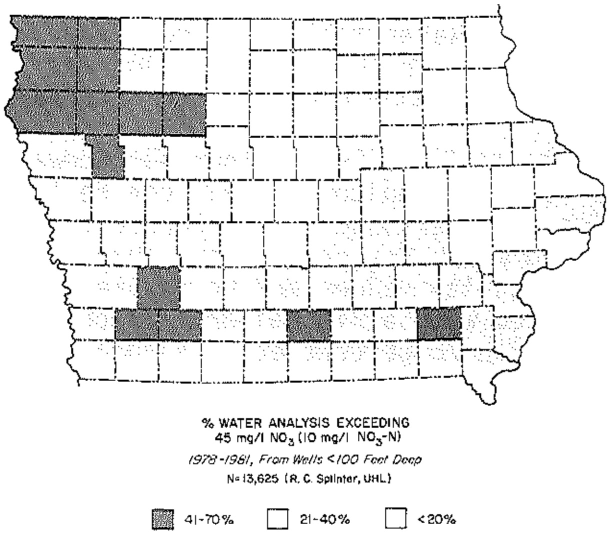

Fig. 14. Percent of water samples, by county, exceeding the nitrate MCL, from private wells less than 100 feet (30 m) deep analyzed by UHL between 1978-1981. N (number of samples) = 13,625; 28 percent of all samples exceeded the MCL. (Data from Roger Splinter, UHL, pers. commun.)

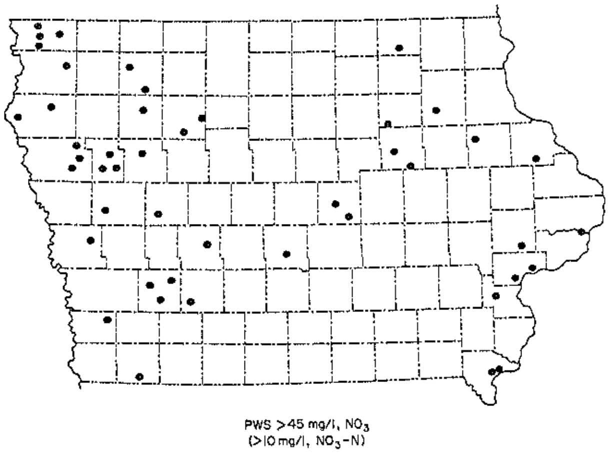

Fig. 15. Public water supplies which have exceeded the nitrate maximum contaminant level of 45 mg/l NO_3 (10 mg/l NO_3-N) since 1980. (From Hallberg, 1985.)

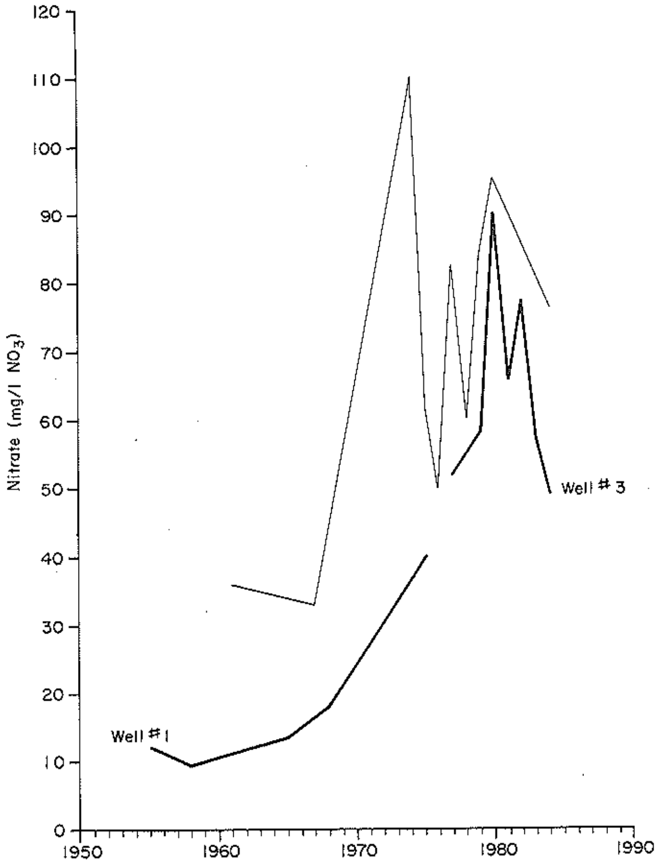

Fig. 16. Nitrate concentrations through time from public water supply wells in northwest Iowa. Light line - Rock River basin. Dark line - Ocheyedan-Little Sioux basin.

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. A Sargent-Welch pH meter, Model 2050, with automatic temperature compensation coupled with a glass combination electode was used to determine pH.

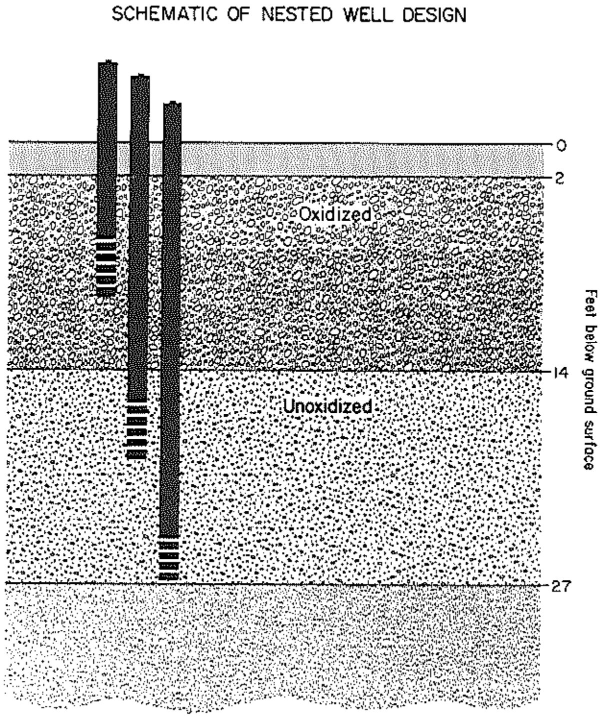

Fig. 17. Schematic diagram of nested, monitoring wells.

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

Bacteria

Total coliform bacteria were determined using the most probable number (MPN) method in accord with EPA standard methods (US 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

Pesticide concentrations in the water samples were run by standard gas-chromatographic column methods following EPA guidelines (US 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.

Nitrate Monitoring

Results of the nitrate monitoring show that extensive areal contamination has occurred. Though nitrate concentrations are not excessively high (Table 8), nitrate was detected at all wells and surfacewater sampling sites. Sixty-three percent (117/185) of the samples collected have shown detectable concentrations of nitrate. Eighteen percent (34/185) of all samples have exceeded the nitrate MCL. Surfacewater samples have shown 100 percent detection. As sampled, the Rock River never exceeded the nitrate MCL, although, samples from the Little Rock River exceeded the standard 46 percent of the time.

The distribution of nitrate is not constant and shows a high degree of both areal and temporal variability. Individual wells at a single site have shown a range of <5 to 170 mg/l NO_3 (<1 to 37.8 mg/l NO_3-N) over a 17 month period. Of the eleven wells sampled only one had nitrate present continually and it was never consistently over the nitrate MCL. Samples from streams in the area display similar patterns over time.

Figure 18 shows the temporal trends in three wells and the Rock River. 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 infiltration of precipitation and snowmelt.

The distribution of nitrate is also variable over the study area. Variations of 7 to 170 mg/l NO_3 (1.6-37.8 mg/l NO_3-N) have occurred at closely spaced wells for any 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.

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, 1986).

For the three sets of nested wells in the study area, one showed a decrease

Table 8. Nitrate Monitoring - Rock River Alluvial System

	LOCATION	SCREENED INTERVAL	JUN 19 1985	JUL 16 1985	AUG 20 1985	SEPT 10 1985	OCT 14-15 1985	NOV 11-12 1985	DEC 26 1985
1.	RR-1RA	SURFACE	-	-	-	18	25	27	-
2.	RR-1U	10.5-12.5	77	78	8	67	62/24/29	41	<5
3.	1L	19.0-23.0	<5	11	<5	<5	<5	<5	<5
4.	RR-1R	SURFACE	27	37	7	D/C	-	-	-
5.	RR-2	13.0-15.0	36	52	24	30	39	29	20/11
6.	RR-3	11.0-13.0	11	19	<5	14	15	15	<5
7.	RR-4U	10.0-12.0	<5	34	<5	8	<5	5	<5
8.	4M	22.0-24.5	6	18	<5	<5	<5	<5	<5
9.	4L	38.0-41.0	15	20	5	<5	<5	<5	14
10.	LR-1R	SURFACE	45	47	<5	38	43	39	-
11.	RR-5U	16.0-17.0	27	46	5	12	13	18	<5
12.	5L	26.0-29.0	53	61	26	27	22	23	<5
13.	RR-2RA	SURFACE	-	-	-	24	31	29	-
14.	RR-6	17.0-20.0	25	20	<5	7	6/<5/<5	6	<5
15.	RR-3R	SURFACE	35	37	6	29	38	-	-
16.	RR-7	17.0-19.5	155	167	111	170	170	11	84/97
17.	RR-9	16.0-21.0	9	-	-	-	-	-	<5

Table 8. Continued

	JAN 22 1986	FEB 18 1986	MAR 11 1986	APR 14 1986	MAY 5 1986	JUN 18 1986	JUL 22 1986	AUG 20 1986	SEPT 23 1986	OCT 21-22 1986
1.	-	-	-	28	27	27	29	12	7	29
2.	<5	38	23	<5/<5	10/<5	35	27	61	15/17	48
3.	<5	6	<5	<5	<5	<5	<5	6	<5	8
4.	-	-	-	-	-	-	-	-	-	-
5.	<5	60/62	39	50	53	34/32	53	48	58/63	43
6.	<5	15	<5/<5	<5	14	8	14/14	8/8	11	12/12
7.	<5	<5	5	<5	<5	<5	<5/<5	<5	<5	<5
8.	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
9.	22	19	<5	<5	5	<5	<5	7	11	
10.	-	-	-	47	49	42	29	14	36	38
11.	<5	18	<5	<5	5	6/6	6	8	<5	16
12.	21	47/47	8	9	15	32	29	52	61/57	54/53
13.	-	-	-	25	33	31	30	15	9	30
14.	<5	20	-	<5/<5	8/13	9	9	9	<5	30
15.	-	-	-	33	41	38	30	14	12/12	33
16.	79	118	<5	67	74	68	102	43/74	119	120/118
17.	-	-	-	-	-	-	-	-	-	-

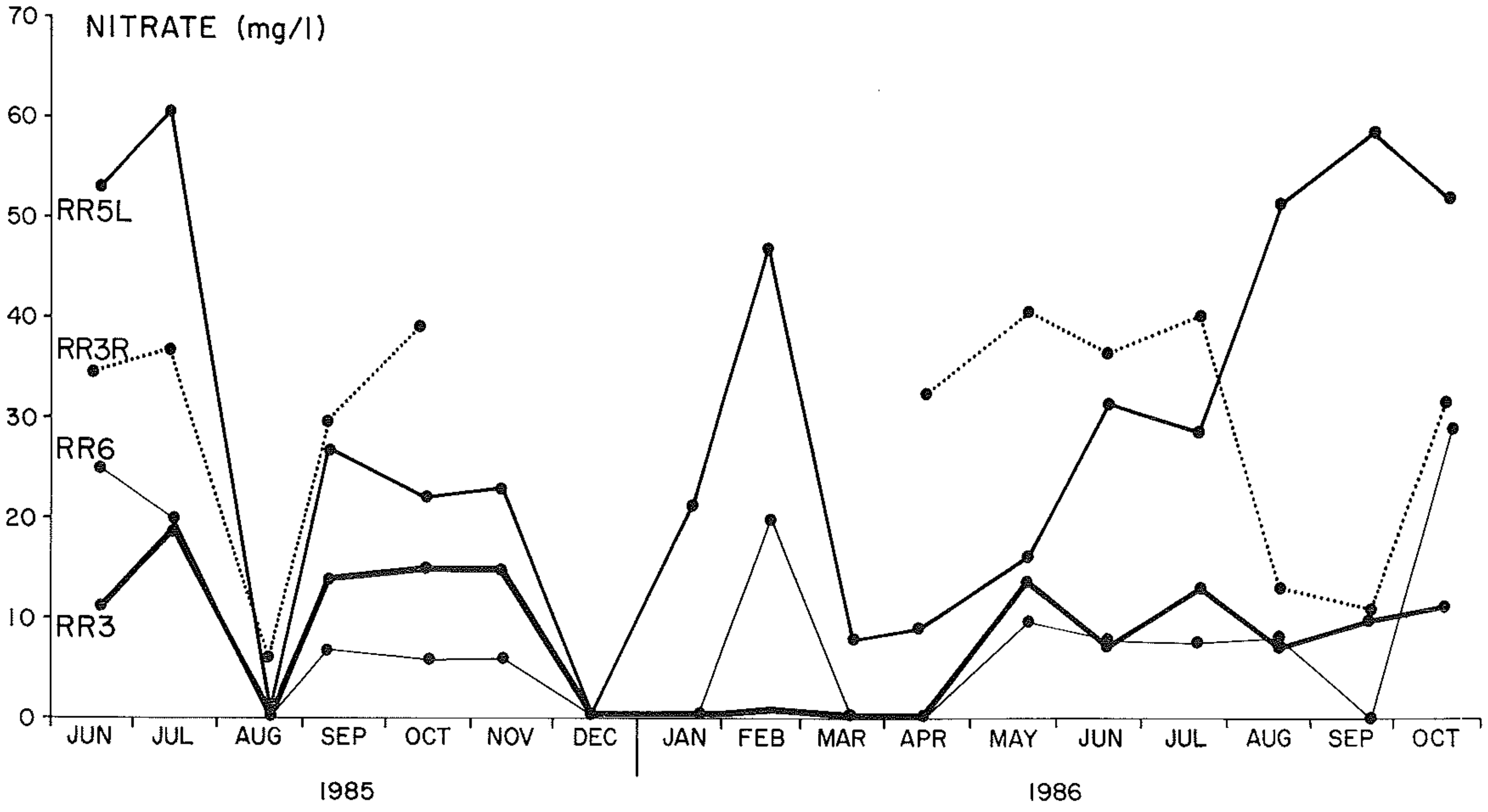

Figure 18. Variations in nitrate concentrations in the Rock River alluvial aquifer.

in nitrate with depth, one an increase in nitrate with depth, and the remaining site was variable. Thus, the chemical stratification observed in other systems is not apparent in the Rock River alluvial system. This lack of stratification may be, in part, attributable to the thickness of the alluvial materials. Alluvial deposits along the Rock River are thinner than other alluvial systems studied. The stratification observed in other systems may be a function of the time required for chemicals to migrate to the bottom of a thicker aquifer.

Differences in nitrate levels are also apparent between the Rock River and other alluvial systems studied in northwest Iowa. Figure 19 shows the average monthly nitrate concentration for the Rock River and two other alluvial systems in Iowa: the Des Moines and the Little Sioux Rivers. There is a fairly good correlation in the temporal trends among the systems. This is to be expected since infiltration is the major mechanism in all systems for the introduction of nitrate. Major recharge events will occur at approximately the same time over the area of the three alluvial systems. There are, however, noticeable differences in the magnitude of nitrate concentrations. The Rock River alluvial system shows the highest nitrate levels of any of the three systems.

There are several possible reasons, both physical and chemical, for the difference in nitrate concentration. The first relates to land use. Corn production is similar among the alluvial systems studied averaging about 50 percent of all acres planted. Livestock production, however, is greater in the Rock River basin. This results in an increase in manure N which increases the total N input to the basin. Topography and soil type are other factors contributing to the difference in nitrate concentration. Most of the drainage area of the Rock River is loess-mantled. Nitrate readily leaches through the loess to the water table and from there is then delivered via shallow groundwater flow to the alluvial valley. Numerous tributaries also collect runoff and shallow groundwater and deliver it to the river.

Changes can also occur in the form of the nitrogen. Fertilizer nitrogen is readily converted to nitrate in the soil. In some situations, this nitrate can be transformed to nitrogen gas by denitrifying bacteria. This process is called denitrification and occurs in anerobic environments where there is an available supply of organic carbon. The greatest potential for dentrification occurs in oxygen-deficient, water-saturated soil (Rolston, 1981). Thus, likely locations for denitrification to occur would be in organic-rich soils with high water tables. Such conditions are prevalent in many alluvial systems and in the till covered uplands in central Iowa. Indications of denitrification have been found in many of these locations (Thompson, 1986; Blackmer, pers. comm.). Comparisons between averaged monthly nitrate levels for each system shows that nitrate levels are considerably reduced in the Des Moines River alluvial system, a factor which has been attributed to denitrification. Water tables in the Des Moines River alluvial system averaged four feet below ground level, while at the same time water levels in the Rock River alluvial systems averaged eight feet below ground level. The water table is below the soil zone for most of the year in the Rock River alluvial system and denitrification apparently does not occur or at least is not significant. All of these factors affect the delivery of nitrate to groundwater and will effectively increase input loads to the aquifer.

Bacterial Monitoring

Historically, bacterial contamination of groundwater has not been thought to be a problem. The filtering action of soil and low concentrations of organic nutrients in groundwater have been cited 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 construction, or by

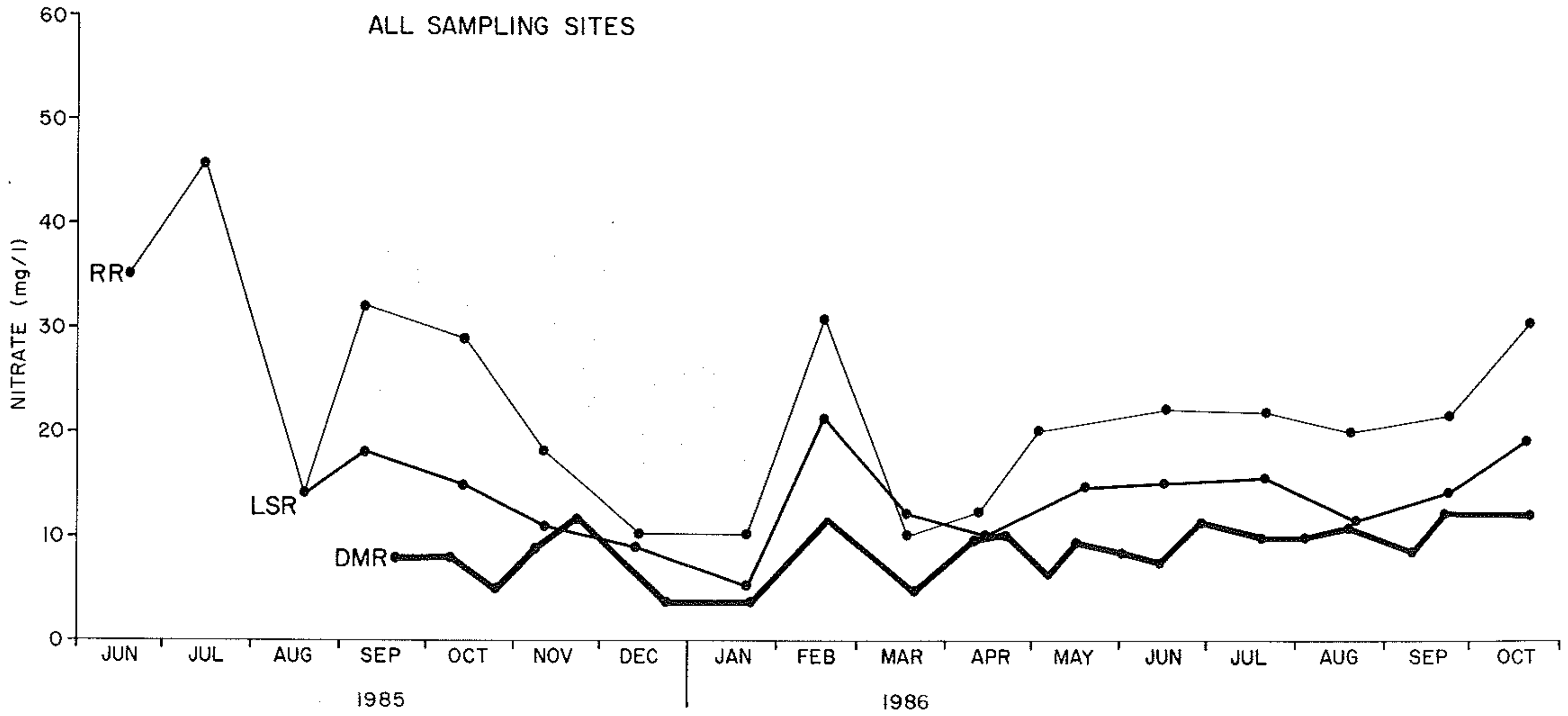

Figure 19. Average monthly nitrate concentrations for all sampling sites for three alluvial systems. LSR = Little Sioux River, DMR = Des Moines River, RR = Rock River.

seepage down the outside of a well casing, but do not migrate through an aquifer. Reneau and Pettry (1975) investigated the movement of coliform bacteria from septic tank effluent through three sandy soils. They found little evidence of migration of bacteria from the drainfield. Their conclusion was that bacteria would not be likely to move into groundwater. Recently, however, several studies have shown that bacteria can be present and active at considerable depths in the subsurface. Dockins and others (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 and others (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 bacteria in this study. Instead, water samples from wells in the monitoring network have been analyzed monthly for total coliform bacteria by the most probable number method (MPN). The results are given in Table 9. 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., 1975). Coliform bacteria are not a health problem themselves, but their occurrence may indicate the presence of other bacteria which can cause health problems. However, in alluvial and other shallow aquifers, non-harmful coliform bacteria occur quite frequently. Thus a positive indication for total coliforms may not be an indicator of pollution in these situations.

Previous studies in Iowa (Hallberg and Hoyer, 1982; Hallberg et al., 1983; Thompson, 1984) have documented bacterial contamination of groundwater. Fifty-seven percent (87/153) of the samples collected in this study showed coliform levels greater than 2.2. Chlorination of all monitoring wells was done immediately after installation. A strong possibility exists that much of the bacterial contamination seen is caused by leakage along the casing or contamination during sampling. Some migration of bacteria through the aquifer may occur.

Pesticide Monitoring

Studies by many agencies in Iowa over the last six years have shown that many of our commonly used pesticides are found in surfacewater and groundwater. 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 located along the Little Sioux River detected atrazine, cyanazine, metribuzin, terbufos, metolachlor, alachlor, and sulprofos (Kelley and Wnuk, 1986).

Only limited sampling for pesticides has been done for this study (Table 10). Six samples were collected in July, 1985, with an additional 14 collected between May and August, 1986. Atrazine was the only pesticide found in the groundwater and was detected at two sites. Four pesticides were detected in surfacewater: atrazine, alachlor, metochlor, and cyanazine. Multiple pesticides were found at all surfacewater sites and concentrations were higher

Table 9. Bacteria Monitoring - Rock River Alluvial System

	LOCATION	SCREENED INTERVAL	JUN 19 1985	JUL 16 1985	AUG 20 1985	SEPT 10 1985	OCT 14-15 1985	NOV 11-12 1985
1.	RR-1U	10.5-12.5	2.2	2.2	0	5.1	16+/16+/16+	16+
2.	1L	19.0-23.0	16+	0	0	5.1	5.1	9.2
3.	RR-2	13.0-15.0	16+	2.2	5.1	2.2	2.2	
4.	RR-3	11.0-13.0	16+	16+	0	0	0	0
5.	RR-4U	10.0-12.0	0	0	0	0	9.2	0
6.	4M	22.0-24.5	16	0	0	5.1	16+	16+
7.	4L	38.0-41.0	0	9.2	2.2	16+	5.1	0
8.	RR-5U	16.0-17.0	0	0	0	16+	5.1	16
9.	5L	26.0-29.0	16+	5.1	2.2	16+	16	9.2
10.	RR-6	17.0-20.0	16+	9.2	0	16+	9.2/16+/9.2	9.2
11.	RR-7	17.0-19.5	0	0	0	0	5.1	0

	JAN 22 1986	FEB 18 1986		APR 14 1986	MAY 05 1986	JUN 18 1986		JUL 22 1986	AUG 20 1986	SEPT 23 1986
1.	9.2	0	0F	9.2/16+	9.2/5.1	16+	0F	5.1	16+	16+/16+
2.	0	0	0F	0	0	16	0F	16+	9.2	16+
3.	0	0/0		0	0	16+/16		16+	16+	16+/16+
4.	0	2.2		0	0	16+		16+/16+	16+/16+	16+
5.	2.2	0	0F	2.2	16+	16+	0F	0/9.2	16	16+
6.	5.1	0	0F	0	0	5.1	0F	5.1	16+	16+
7.	5.1	5.1	0F	0	0	16		16+	16+	16+
8.	5.1	9.2		0	16+	16+/16+		16+	16+	16+
9.	2.2	0/0		0	16+	16+		16+	16+	16+/16+
10.	0	0		0/0	16/2.2	16+		16+	16	16+
11.	0	0		0	2.2	16+		16	16+/16+	16+

F refers to coliform numbers

Table 10. Pesticides - Rock River Alluvial System

		ATRAZINE ATREX	CYANAZINE BLADEX	METOLACHLOR DUAL	ALACHLOR LASSO	METRIBUZIN SENCOR	BUTYLATE SUTAN	TRIFLURALIN TREFLAN	FONOFOS DYFONATE	CARBOFURAN FURDAN
RR1U	7/16/85	<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
	8/20/86	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
RR1L	7/16/85	<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
RR2	7/16/85	<0.1	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
	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
RR5U	7/16/85	0.24	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
	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
RR5L	7/16/85	<0.1	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
	7/24/86	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
RR2RA	7/24/86	0.60	0.1	0.31	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
	8/20/86	0.15	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
RR3R	5/21/86	0.26	<0.1	0.48	0.1	<0.1	<0.1	<0.1	<0.1	<0.1
	6/18/86	0.38	0.18	0.22	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
RR6	8/20/86	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
RR7	7/16/85	<0.1	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
	7/24/86	0.13	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1

N.D. Not detected

than in groundwater. The concentrations of pesticides detected were 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.

WATER USE

The major categories of water use from the Rock River alluvial aquifer are rural-domestic and livestock, municipal, rural water distribution, irrigation, and industrial. No numbers are available on industrial useage. Table 11 lists water use by category for each county in the study area. Municipal water use figures were obtained from the Department of Natural Resources (DNR). When use numbers were not available, population figures were multiplied by an average use of 50 gal/day per 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 homesteads are actually located on the lowlands and some may use 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 are total amounts allocated under the DNR water 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.

Future Water Use

As can be seen in Table 11, irrigation is potentially 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 systems use may be projected to show some increases. Only minor increases in municipal use are forecast.

Estimates of future use for municipal and rural-domestic are tied to population projections. These range from +5 percent to -2 percent for the counties in the study area. However, in the period from 1970 to 1980 the rural population in Lyon and Sioux declined by 5 percent and 38 percent respectively. Therefore, only minor increases are to be expected in municipal and rural-domestic use.

RESOURCE ASSESSMENT

Significant development (municipal, rural water, and irrigation) has occurred in the Rock River alluvial aquifer. The aquifer is of variable thickness. In many places the aquifer is thin. Thicker deposits are found in terraces, but generally only a limited thickness is saturated. Despite this,

Table 11. Water Use from the Alluvial System by County and Category in Million Gallons per Year.

County	Municipal Avg.	Municipal Max.	Rural Water System Avg.	Rural-Domestic Avg.	Livestock Avg.	Irrigation Max.
Lyon	231.8	463.6	141.8	3.2	13.9	326.6
Sioux	118.3	283.7	54.8	7.0	12.9	1440.4
TOTA1	350.1	747.3	196.6	10.2	26.8	1767.0

the high transmissivities which characterize the aquifer allow a high level of utilization. Further development could be accomodated although the variability in thickness will preclude placement of high capacity wells in some areas. Test drilling will be necessary to locate favorable sites.

Degradation of water quality has occurred throughout the aquifer. In many places, future development will be limited by water quality. Long term trends in water quality are not necessarily predictable, but degradation has been increasing over the past twenty years. Further degradation could seriously limit certain uses of the system's resources. 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 continuous corn. Much of this 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 unaccounted for. In areas where shallow aquifers exist, much of this nitrate may be lost to the aquifers. The magnitude of these losses show that significant economic as well as environmental concerns exist. Resolving these problems in order to achieve a satisfactory balance between agricultural production and protection of our water supplies will require an effort from all segments of the agricultural community.

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APPENDIX A

PRELIMINARY GEOLOGIC INFORMATION

Well Logs
Bridge Borings

PRELIMINARY GEOLOGIC INFORMATION

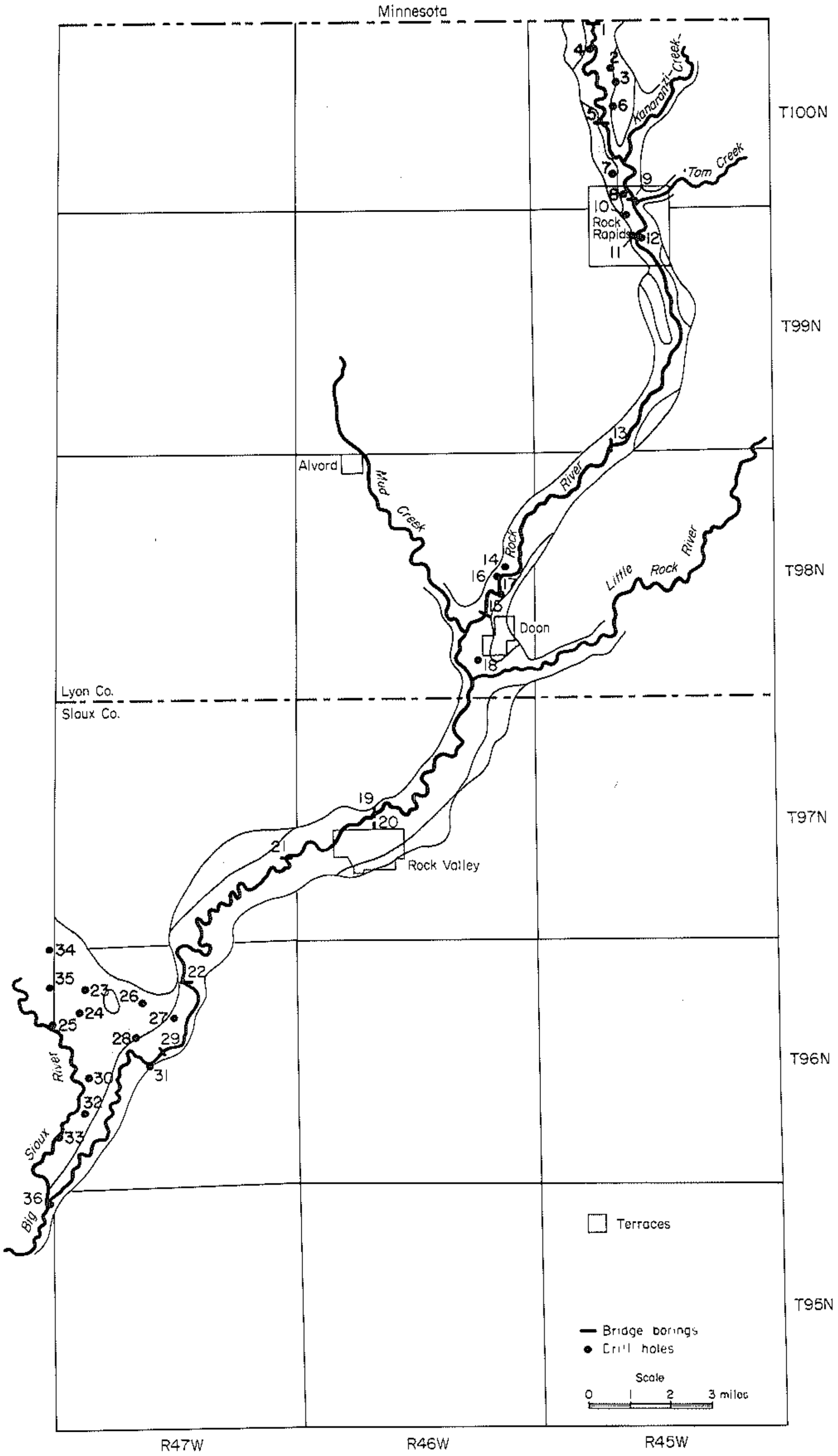

Figure A-1. Location of preliminary geologic information: Rock River.

Map Location	Other Designation	Location	Elevation ft.	From	To	Lithology
1	679(M)	NE SW SW NE Sec. 8	1377.53	0	14	Air
		T100 R45		14	16	Water
				16	19	Gravelly sd
				19	22	Boulders
				22	45	Till
1a	679(W)	NE SW SW NE Sec. 8	1374.53	0	6	Fill
		T100 R45		6	10	Sdy clay
				10	16	Gravelly sd
				16	17	Boulder
				17	55	Till
2	W5703	SW SW NW Sec. 16	1367	0	10	Soil
		T100 R45		10	30	S & G
				30		Till
3	TH9	SE SW SW Sec. 16	---	0	5	Soil
		T100 R45		5	20	Gravel, crs sd
				20	22.5	Boulders, gravel
				22.5		Till
4	W25511	NW NW NE Sec. 17	1360	0	40	S & G
		T100 R45		40	220	Till
				220	280	S & G
5	379(NW)	SW SE SE Sec. 20	1352.66	0	8	Sdy clay
		T100 R45		8	14	Gravelly sd
				14	16	Boulders
				16	55	Till
6	TH10	SW SW NW Sec. 21	---	0	4.5	Soil
		T100 R45		4.5	20	Gravel, crs sd
				20		Till
7	TH2	NE NW NW Sec. 33	---	0	3	Soil
		T100 R45		3	18	Gravel, crs sd
				18	23	Gravel, b
				23		Till

KEY: sd = sand, S & G = sand & gravel, b = boulders, f = fine, sdy = sandy, crs = coarse, v.f. = very fine, N/S = no sample

Map Location	Other Designation	Location	Elevation ft.	From	To	Lithology
7a	TH4	NW NE NW Sec. 33 T100 R45	---	0	2	Soil
				2	7	Clay
				7	11	Gravel, crs sd
				11	19	Boulders
7b	TH5	NW SE NE NW Sec. 33 T100 R45	1343	0	5	Soil
				5	25	Gravel, crs sd
				25	26	Boulders
				26		Till
7c		SW SE NE NW Sec. 33 T100 R45	1342	0	4	Clay
				4	19	Gravel
				19	20	Boulders
				20	23	Gravel
				23	30	Sd, Till
7d	TH3	SW NE NW Sec. 33 T100 R45	---	0	7	N/S
				7	10	Gravel, crs sd
				10	14.5	Gravel, b
				14.5		Till
7e	TH1	NE NE SW NW Sec. 33 T00 R45	---	0	3.5	Soil
				3.5	15	Gravel, crs sd
				15	23	Boulders, pebbles
				23		Till
7f	TH6	SW NE SW NW Sec. 33 T100 R45	---	0	3	Soil
				3	20	Gravel, crs sd
				20	32	Gravel, b
				32		Till
7g		SW NW SE NW Sec. 33 T100 R45	1342	0	4	Sdy soil
				4	5	Gravel, clay
				5	13	Gravel, crs sd
				13	33	Gravel, pebbles
				33	34	Boulders

Map Location	Other Designation	Location	Elevation ft.	From	To	Lithology
7h		NE SE NW Sec. 33 T100 R45	1342	0	3.5	Fill, soil
				3.5	23.5	S & G
7i	TH7	SW NE SW NW Sec. 33 T100 R45	---	0	3	Soil
				3	29	Gravel, crs sd
				29	37	Boulders, crs sd
				37	41	Clay, b
7j	TH8	SE SW NW Sec. 33 T100 R45	---	0	3.5	Soil
				3.5	27	Gravel, crs sd
				27	29.5	Boulders
7k	W7261	SW NW SE NW Sec. 33 T100 R45	1340	0	45	S & G
				45	175	Till
				175	190	S & G
				190	240	Shale
				240	365	Shale
				365	397	Quartzite
8	THIA	SW NW SW Sec. 33 T100 R45	---	0	3	Soil
				3	14	Gravel, crs sd
				14	14.5	Clay
				14.5	17	Gravel, b
				17	25	Crs sd, gravel
				25	28	Boulders, gravel
				28		Till
8a	W25301	SW NE SW Sec. 33 T100 R45	1340	0	7	N/S
				7	24.5	S & G
9	570(E)	NW NE Sec. 33 T100 R45	1331	0	3.8	Fill
				3.8	7.0	Sdy clay
				7.0	11.3	Sand
				11.3	14.6	Boulders
				14.6	47.5	Till

Map Location	Other Designation	Location	Elevation ft.	From	To	Lithology
10a	75-2	NW SE NE Sec. 4 T99 R45	---	0	3	Soil
				3	8	F-crs sd
				8	15	Gravel, crs sd
				15	23.5	Gravel, b
				23.5	33	Till
10b	75-3	NW SE NE Sec. 4 T99 R45	---	0	6	Soil
				6	14	Gravel, pebbles
				14	18	Gravel, b
				18	22	Gravel, pebbles
				22	24	Boulders
				24	33	Till
10c	75-9	NE SE NW Sec. 4 T99 R45	---	0	4	Sdy soil
				4	5	Gravel, clay
				5	15	Gravel, crs sd
				15	33	Gravel, pebbles
				33	34	Boulders, till
10d	75-8	SE SE NW Sec. 4 T99 R45	---	0	3.5	Sdy soil
				3.5	15	Gravel, crs sd
				15	17	Gravel, b
				17	18	Boulder
				18	33	Till
11	75-12	SE NE SW Sec. 4 T99 R45	---	0	2	Soil
				2	6	Brown clay
				6	16	Gravel, pebbles
				16	28	Till
12	75-7	NE SW SE Sec. 4 T99 R45	---	0	3.5	Sdy soil
				3.5	28	Gravel, crs sd
				28	32	Gravel, b
				32	43	Till

Map Location	Other Designation	Location	Elevation ft.	From	To	Lithology
13	275	Sec. 32/33 T99 R45	1309	0	12	Fill
				12	20	Sdy clay
				20	24	Sd, clay
				24	35	Crs sand
				35	43	S & G
				43	65.5	Till
14	H6	NW SW SW Sec. 13 T98 R46	---	0	3	Soil
				3	11	Clay
				11	20	S & G
				20	23	Clay
				23	31	S & G
				31	50	Clay
14a	H3	SW SW SW Sec. 13 T98 R46	---	0	3	Soil
				3	9	Clay
				9	34	Gravel
				34	50	Clay
14b	H5	NE SW SW Sec. 13 T98 R46	---	0	4	Soil
				4	36	S & G
				36	50	Clay
14c	H4	SE SW SW Sec. 13 T98 R46	---	0	3	Soil
				3	32	S & G
				32	50	Clay
15	165	Sec. 23/24 T98 R46	1280.9	0	13.7	Air
				13.7	15.1	Water
				15.1	20.1	Silt
				20.1	24.0	S & G, b
				24.0	26.0	Sdy clay
				26.0	42.0	Till
				42.0	46.0	Clayey sd
				46.0	48.0	Sdy till
				48.0	56.5	Clayey sd
				56.5	58.0	Sdy till
				58.0	60.0	Clayey sd
				60.0	62.5	Sdy till
16	H7	NN NW NW Sec. 24 T98 R46	---	0	2	Soil
				2	8	Clay
				8	34.5	S & G
				34.5	35	Clay

Map Location	Other Designation	Location	Elevation ft.	From	To	Lithology
17	H1	SW NW NW Sec. 24	---	0	3	Soil
		T98 R46		3	8	Clay
				8	12	Clay, Gravel
				12	37	S & G
				37	57	Clay
				57	60	Gravel
				60	80	Clay
18	W8278	NW NW NE Sec. 35	1270	0	25	S & G
		T98 R46		25	28	Till
19	248	Sec. 16/17	---	0	3	Fine sd
		T97 R46		3	15	Crs S & G
				15	17.5	Gray clay
				17.5	39.0	V f sd
				39.0	43	Sdy clay
20	148	Sec. 20/21	---	0	0	Sdy loam
		T97 R46		9	10	S & G
				10	11	Mud
				11	42	Sd, crs gravel
21	535	Sec. 24/25	1218.8	0	2	Black clay
		T97 R47		2	5	F-crs sd
				5	12.8	S & G
				12.8	36.0	Gray clay
22	160(W)	SW SW Sec. 3	---	0	4.2	Silty clay
		T96 R47		4.2	7.4	Crs sd
				7.4	38.0	Till
23	81-5	NE NW NE Sec. 7	---	0	4	Soil
		T96 R47		4	21	S & G
				21	22	Clay
				22	35	S & G
				35	42	Clay
				42	58	S & G
				58	62	Blue clay
24	#1	NW NW SE Sec. 7	---	0	5	Soil
		T96 R47		5	25	Gravel
				25	38	S & G
				38	39	Till

29271

	Map Location	Other Designation	Location	Elevation ft.	From	To	Lithology
29270	24a		NW SW SE Sec. 7	---	0	3	Soil
			T96 R47		3	15	Gravel
					15	20	Gravel, clay
					20	25	Gravel
					25	30	Gravel, boulders
					30	45	Gravel
					45	50	Gravel, sand
					50	55	Gravel, boulders
					55	57	Boulders
					57		Till
	24b	81-1	NW NE SE Sec. 7	---	0	3	Soil
			T96 R47		3	28	S & G
					28	62	Blue clay
	24c	81-2	NE NE SE Sec. 7	---	0	3	Soil
			T96 R47		3	25	S & G
					25	26	Clay
					26	38	S & G
					38	60	Blue clay
	24d	81-4	NE SE SE Sec. 7	---	0	2	Soil
			T96 R47		2	33	S & G
					33	38	Clay
					38	62	S & G
					62		Blue clay
51458	25	SD32	SW SW SW Sec. 7	---	0	2	Soil
			T96 R47		2	18	Clay till
					18	21	Sandy pebbly silt
					21	25	Clay
51457	26	SD42	W SW NW Sec. 9	---	0	2	Soil
			T96 R47		2	65	Sand
					65	70	Clay
514 56	27	SD41	SE SE SE Sec. 9	---	0	2	Soil
			T96 R47		2	8	Sdy clay
					8	55	Sand
					55	60	Clay

	Map Location	Other Designation	Location	Elevation ft.	From	To	Lithology
51455	28	SD39	SW SW NW Sec. 16 T96 R47	---	0	2	Soil
					2	39	Sand
					39	45	Clay
	29	150	SE SE Sec. 16 T96 R47	---	0	1.2	Water
					1.2	15.1	Cemented S & G
					15.1	29.5	Sand
51454	30	SD36	SW NW NW Sec. 20 T96 R47	---	0	2	Soil
					2	5	Clay
					5	26	Sand
					26	35	Clay
51453	31	SD40	NW NW NE Sec. 21 T96 R47	---	0	3	Soil
					3	23	Sand
					23	25	Clay
51452	32	SD37	NE NE NE Sec. 30 T96 R47	---	0	2	Soil
					2	5	Clay
					5	27	Sand
					27	30	Clay
51451	33	SD38	SW NW SW Sec. 30 T96 R47	---	0	3	Soil
					3	23	Clay, till
					23	26	Sand
					26	30	Clay
51450	34	SD34	NE NE NE Sec. 1 T96 R48	---	0	1	Soil
					1	15	S & G
					15		Hard rock
51449	35	SD33	SE SE SE Sec. 1 T96 R48	---	0	2	Soil
					2	15	S & G
					15		Hard rock
51464	36	SD43	NE SE NE Sec. 1 T95 R48	---	0	2	Soil
					2	7	Clay, till
					7	15	Sand
					15		Hard rock

APPENDIX B

SEISMIC REFRACTION

Theory and Previous Work

Seismic refraction methods have been commonly used by engineers and geologists for shallow subsurface investigations. Details of seismic refraction theory can be found in general geophysical exploration texts such as Dobrin (1976), and Musgrave (1967). Seismic refraction theory is based on the fact that sound waves travel at different velocities through different earth materials. An energy source (hammer blow, explosive) is used to generate sound waves which propogate through earth materials. These waves are bent (refracted) at the contacts between different velocity layers of earth materials, and then travel horizontally just below the contact. As the waves propagate along the contact they are continually refracted back to the surface. Figure B-1 schematically shows the raypaths followed by refracted sound waves in an ideal alluvial system.

For field measurements, a set of receivers (geophones) is placed at uniform distances from the seismic source. These receive the refracted energy created by the source, and create a continuous trace on the seismograph record. A distinct break occurs on the seismic trace at the time of arrival on the first wave (Fig. B-2). Geophones closest to the source may receive direct wave arrivals, those traveling directly along the land surface (path A-B-E-H on Fig. B-1). The first energy received by the geophones furthest from the source is from the second layer along path A-C-D-E. Even though the distance along path A-E at the surface is shorter, the waves traveling the segment C-D are accelerated and will arrive first. More distant geophones in the line will receive energy from the till layer along path A-J-K-L. The arrival time information, recorded by a seismograph, and the distance of the geophone from the source, can be used to plot the relationship of time versus distance (Fig. B-3). This is used to calculate average layer velocities. Other calculations are performed to determine the depth of the refracting surface.

Seismic refraction has long been used in groundwater studies. Bonini and Hickock (1958) and Warrick and Winslow (1960) used refraction methods to delineate bedrock topography below unconsolidated deposits. Woolard and Hanson (1954) worked in a variety of geological settings in Wisconsin, and had relatively good success in locating the water table in glacial till. McGinnis and Kempton (1961) correlated the low velocity surface layer with the weathered zone in glacial tills. They also found that accurate depth to and velocity of bedrock could not be determined if the bedrock was shallow (10-20 feet) and irregular. Johnson (1954) used refraction methods to distinguish between till layers in Illinois. His is one of the few studies which attempted to differentiate layers within shallow unconsolidated materials. Staub (1969) evaluated the method of the seismic refraction to solve geologic problems in Iowa. He used statistical methods to establish confidence levels on the results and to show where additional data was needed.

Equipment and Field Methods

Refraction data were collected using a Geometrics 12-channel signal-enhancement seismograph which operates from a 12-volt power source. Each channel has separate controls for adjusting the amplitude of the signal, to compensate for variations in input signal strength, and for adjusting the amplitude of the trace. Filters can be used to cancel extraneous noise, such as that caused by wind, power lines, and traffic. The recorded data are

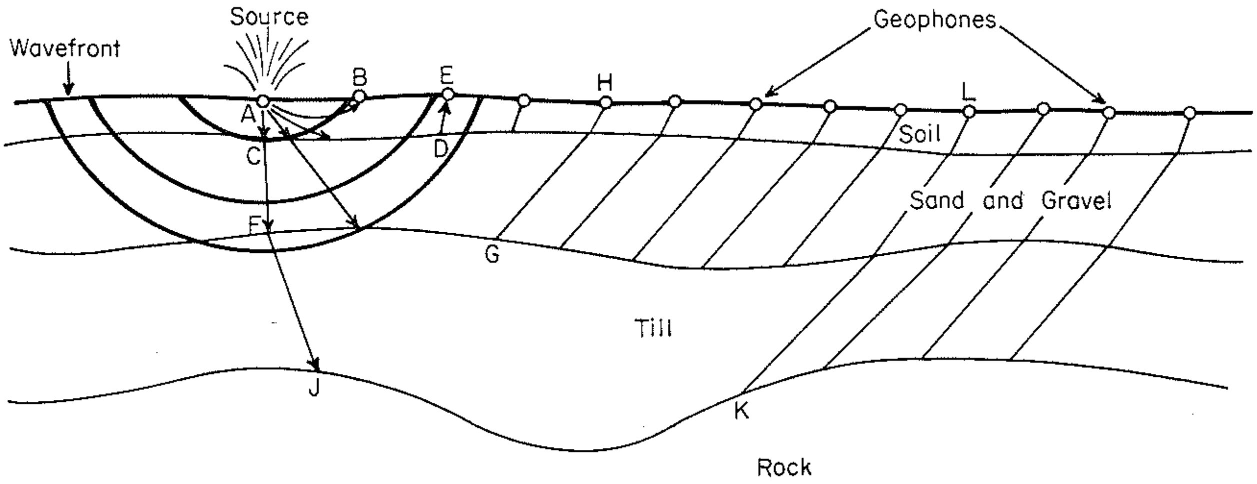

Figure B-1. Schematic of sound wave propagation through a typical alluvial sequence. Letters refer to discussion in text.

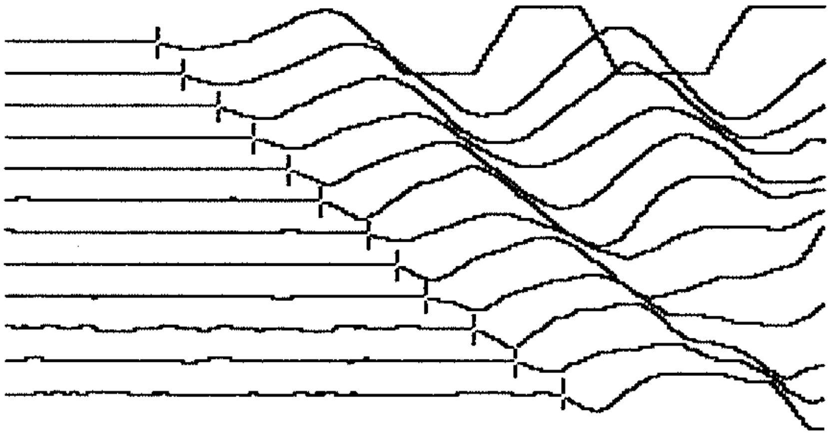

Figure B-2. Typical seismogram. Tic marks indicate time of arrival of wave on each channel.

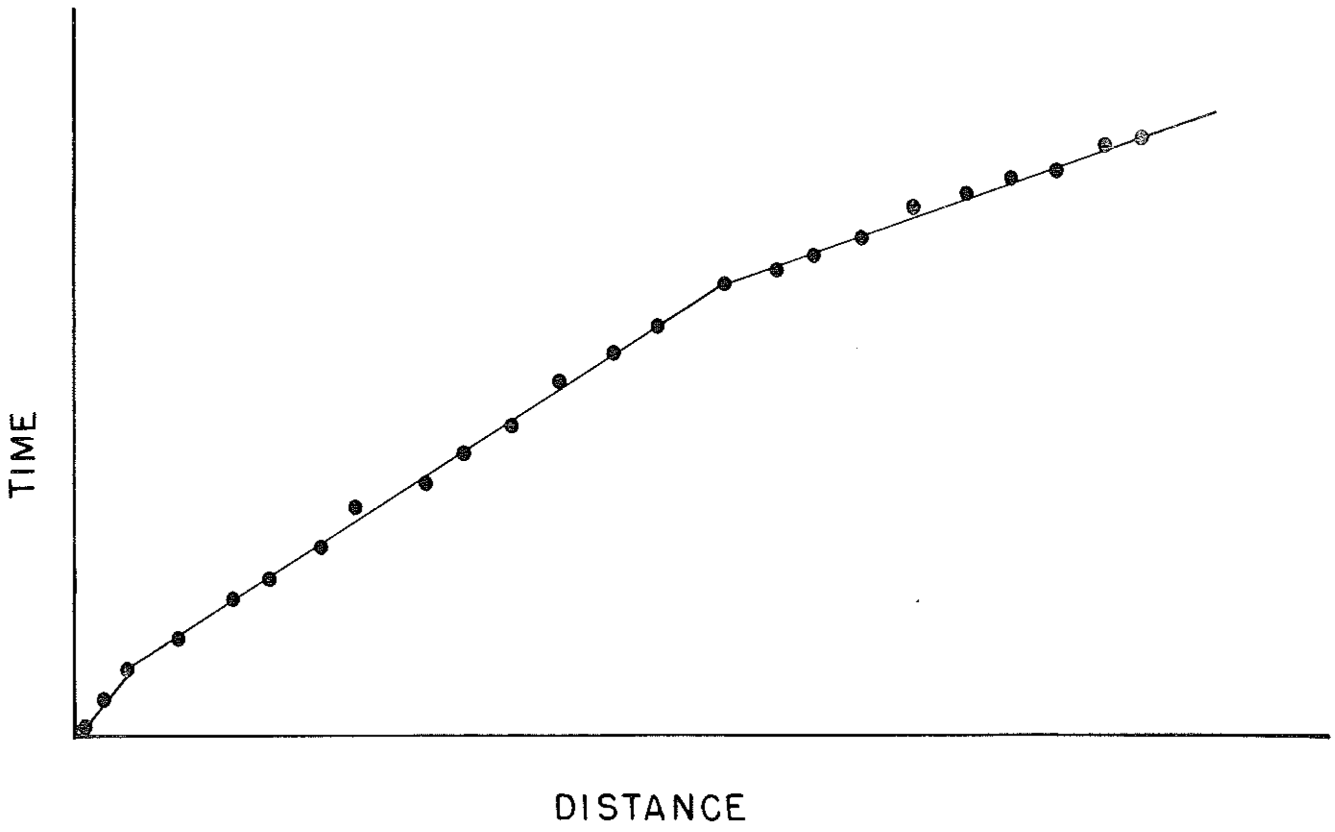

Figure B-3. Idealized time-distance graph. Each slope segment represents refractions from a particular interface. The velocity of the unit is equal to the inverse of the slope.

displayed on a video screen on the seismograph which allows the data quality to be checked before being recorded on magnetic tape. If data quality are poor, a shot may be repeated, either to replace the existing record or to enhance it. Hard copy data are an added option and can be obtained from the instrument's built-in printer. Satisfactory data are transferred to cassette tape for storage using a Nimbus digital recorder which also operates from a 12-volt power source.

Varying geophone spacings were used during the study depending on anticipated contact depths. Ten-foot spacings were primarily used to determine the contact between the alluvial materials and the underlying materials. Ten to twenty-five foot geophone spacings with shot offsets of up to 300 feet were used to obtain bedrock depths. The primary source of energy was a mechanical weight drop designed at the Iowa Geological Survey. Two weights were available: 125 pounds and 300 pounds; these were dropped from a height of six to eight feet onto a thick steel plate. The weight drop allowed better utilization of the signal enhancement feature of the seismograph.

The processing of field seismic data was accomplished on an Apple II microcomputer. The processing software used was developed by Exploranium/Geometrics of Canada, and has routines for auto-picking first breaks on seismic traces, interpretation of time-distance plots, depth, unit thickness, unit velocity computation, and a generalized reciprocal method for determining unit depths on irregular surfaces. The use of a portable computer allowed processing to be accomplished in the field and immediate verification of the accuracy of the seismic field data. Adjustments to the field arrangment (geophone spacings, shot offset) were made where targeted horizons were not observed in the data.

Results and Findings

Seismic Results

There were considerably more problems in interpretation of the refraction data than had been anticipated. Direct wave arrivals, indicating surficial material velocities, are observed only when geophone spacings of less than 10 feet were used. Figure B-4a is a time-distance plot (T-X) showing good fit to the data and recognizable slope breaks. It is infrequent, however, that all of the points can be fit to a straight line segment. Often, the best possible fit requires a curved surface (Fig. B-4b), which results from either an irregular refractor surface or laterally varying velocities. Another common occurrence is displacement of time-distance segments (Fig. B-4c). McGinnis and Heigold (1974) also observed this effect, and attributed it to the presence of a stepped refracting surface at the edge of a buried valley. A third problem involves slope change. Frequently, the time-distance plot exhibits an increase in slope which may be attributable to laterally varying velocities (Fig. B-4b,c).

Domzalski (1956) discussed at some length the problems inherent in shallow-refraction investigations. One of his discussions concerned changes in surface material velocities caused by firing a shot, while another dealt with the type of surface materials in which the geophones were placed. These effects can cause arrival times to be delayed by up to 2 milliseconds and change computed velocities by 100 feet/second. There are other problems which arise because, unlike in theory, the materials are not homogeneous or isotropic, especially in alluvial systems. There are horizontal and vertical

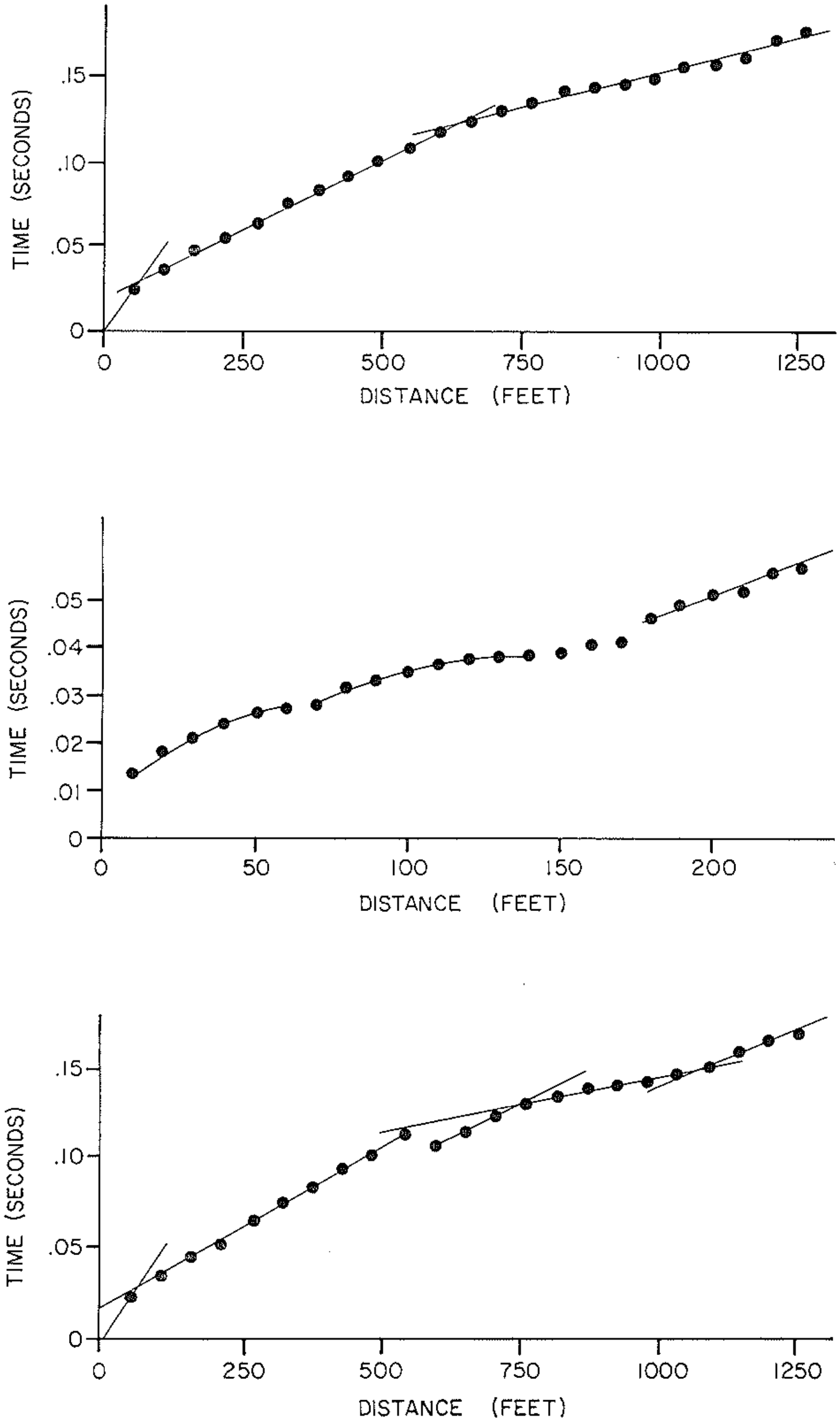

Figure B-4 a,b,c. Examples of time-distance plots.

variations in the velocity of the overburden as well as changes in thickness. Murphy (1977) used a combination of refraction and resistivity methods to study alluvial terrain in Louisiana, and found definite effects related to laterally varying velocities such as offsets and slope changes in time-distance plots. The bedrock refractor in most cases is irregular and weathered, either of which can greatly affect depth computations for shallow refractors.

A major problem, which is all too prevalent in Iowa, is the lack of sufficient velocity contrast between most unconsolidated materials. Sand and gravel (outwash material) have been observed to have velocities around 5000-6000 ft/sec. Glacial tills usually have velocities between 6000 and 8000 ft/sec. Observed bedrock velocities average between 7000-9000 ft/sec. -- Cretaceous sandstones and shales. Such close materials' velocities presents two problems. First, the slope break changes on a time-distance curve can be very subtle and difficult to identify. Second, the necessary velocity contrasts might not be reached at the interface, but rather within a formation. This is found to occur frequently within the glacial till.

Discussion

Rock Rapids 1 is located along the Iowa-Minnesota boundary (Fig. B-5). Approximately 5-30 feet of sand and gravel rest over till. Several interfaces are present in the till. An interface within the sand and gravel on the west side of the river may represent the water table. Drill hole data from 1978 does show the static water level at approximately the level of the interface. To the east the water level becomes coincident with the top of the sand and gravel. Rock Rapids 2 (Fig. B-6) has a 5-10 foot layer of soil and clay over the sand and gravel. This finer-textured material thickens to the east, where it may represent a fan deposited from the adjoining hillslope materials. Sand and gravel ranges in thickness from 5 to 25 feet. Two small channels may exist in the till to the east. Good agreement with existing data is seen. Rock Rapids 3 (Fig. B-7) has 7 to 20 feet of sand and gravel over till. One interface is present in the till.

Doon 1 (Fig. B-8) presents problems in interpretation. At least 5-15 feet of sand and gravel are present. A second layer has velocities which can represent either sand and gravel or till. An interface is also observed within the till. In Doon 2 (Fig. B-9), the soil and sand and gravel layer ranges from 10 to 20 feet thick. Several channels may exist in the till indicating thicker sand and gravels.

Rock Valley 3 (Fig. B-10) differentiates the soil layer and delineates the static water level (water table). A thick sand and gravel deposit (up to 40 feet) is seen, which in turn, lies on a sand. Only one point shows the sand/shale interface. Two interfaces are seen in the sand and gravel and may be either clay lenses or local concentrations of gravel. Rock Valley 2 (Fig. B-11) has a 5 foot layer of soil over 10 feet of clay over a 7 to 25 layer of sand and gravel. The entire package is underlain by a blue-gray sandy, silty clay which may be till.

Fairview 1 is the longest traverse done, about two miles, and is near the confluence of the Big Sioux and Rock Rivers (Fig. B-12). A thick layer of fine-grained, silty clay is present on top of the sand and gravel. The top of the sand and gravel surface is undulatory much like profiles across braided streams. The clay surface below is also slightly channelized.

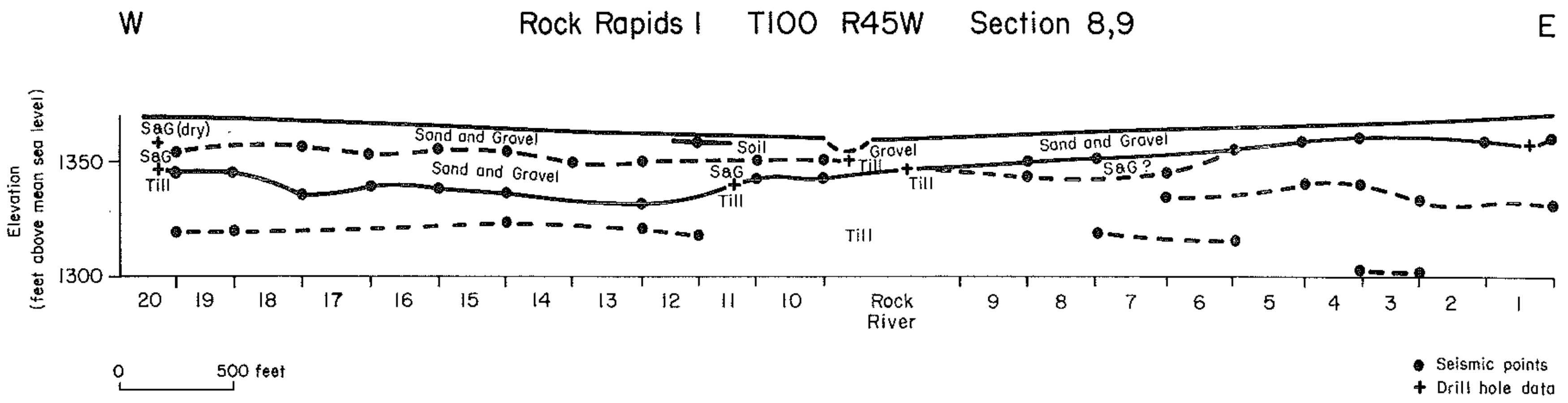

Figure B-5. Seismic profile section: Rock Rapids 1.

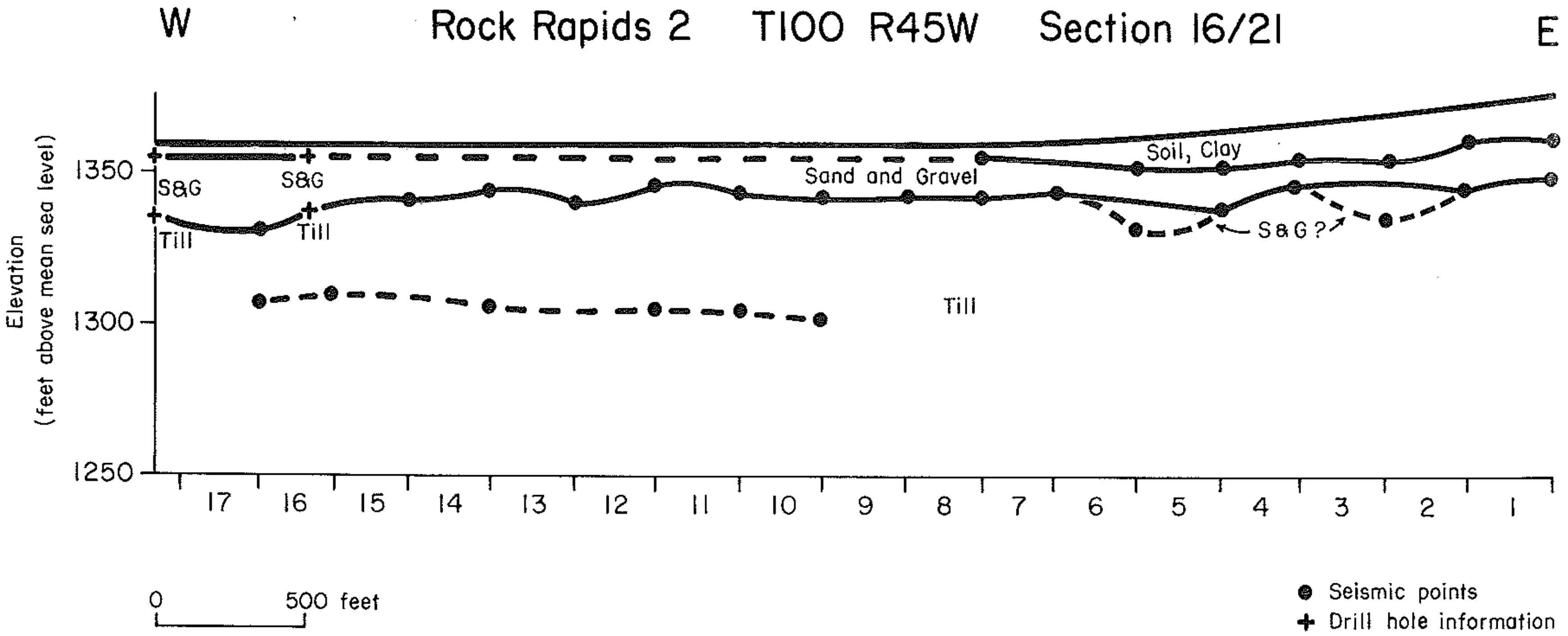

Figure B-6. Seismic profile section: Rock Rapids 2.

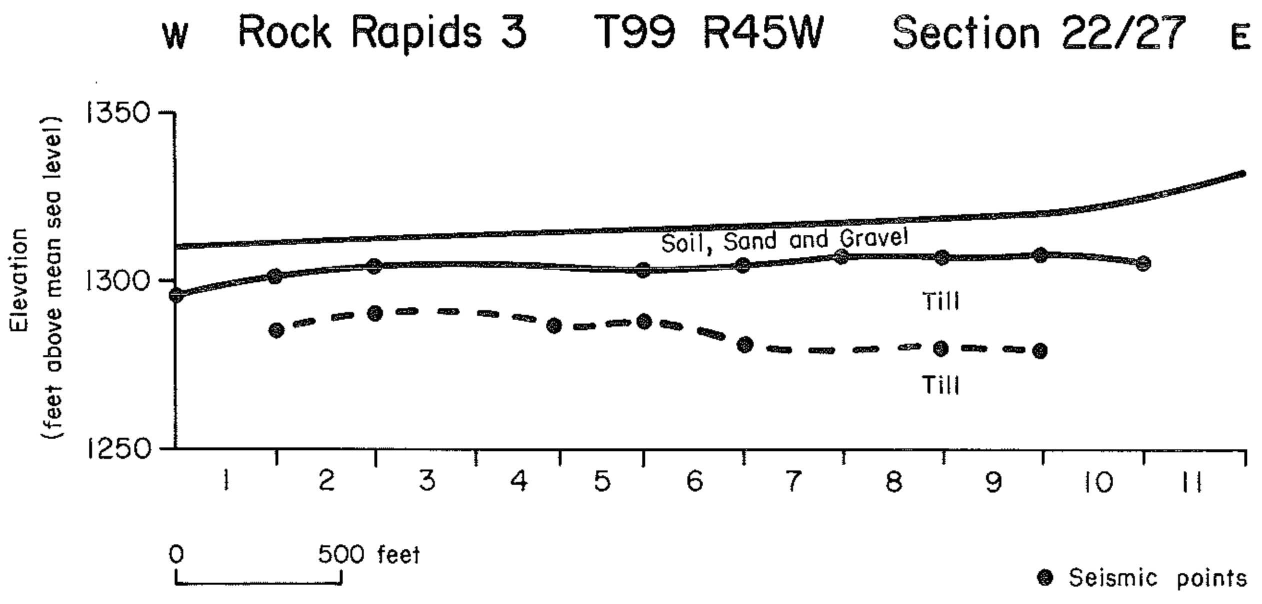

Figure B-7. Seismic profile section: Rock Rapids 3.

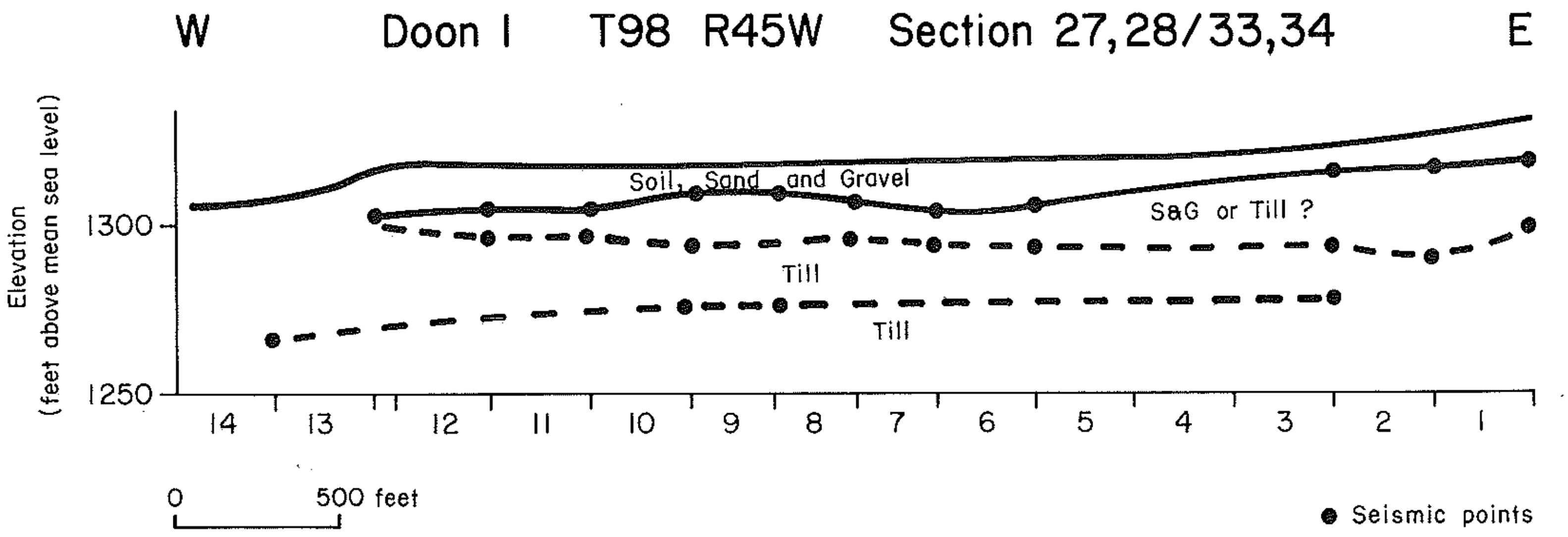

Figure B-8. Seismic profile section: Doon 1.

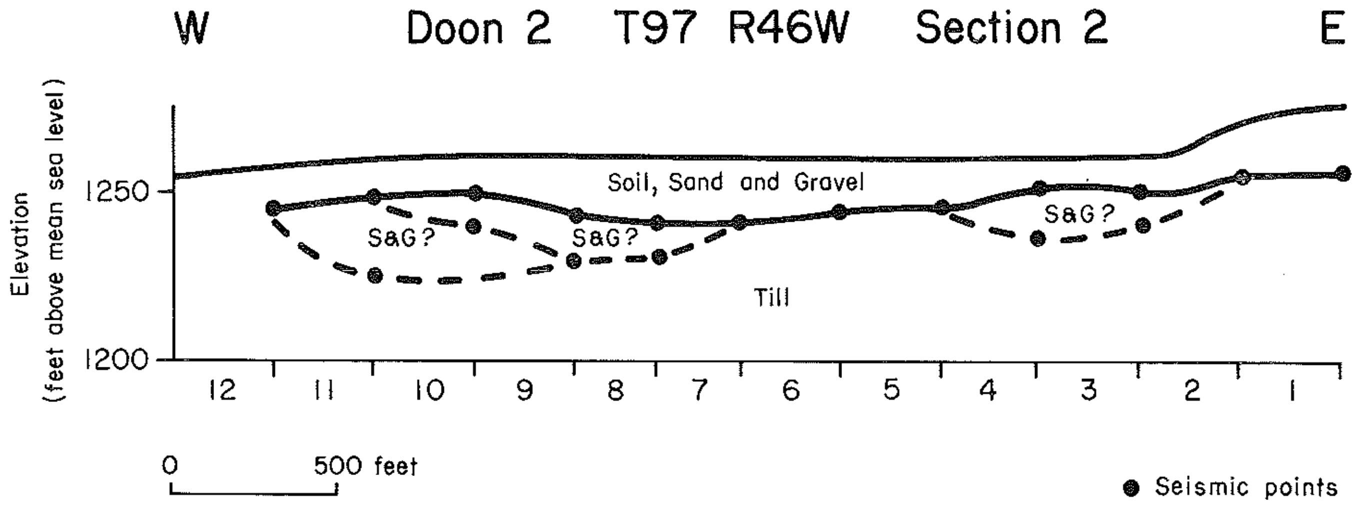

Figure B-9. Seismic profile section: Doon 2

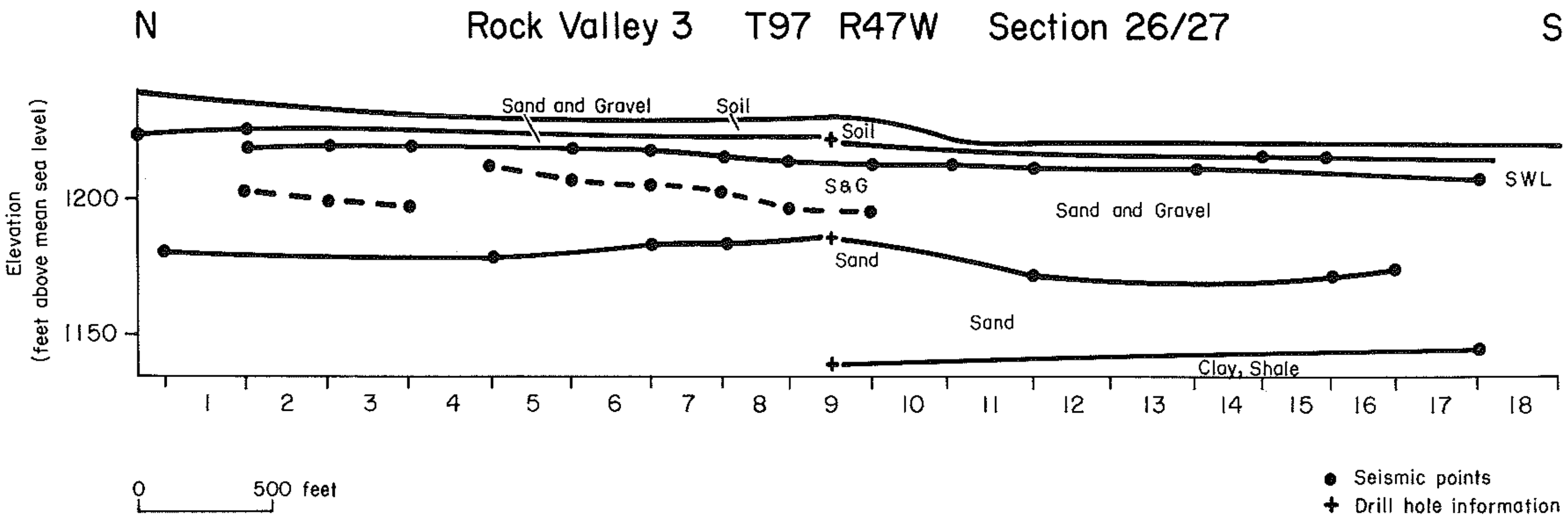

Figure B-10. Seismic profile section: Rock Valley 3.

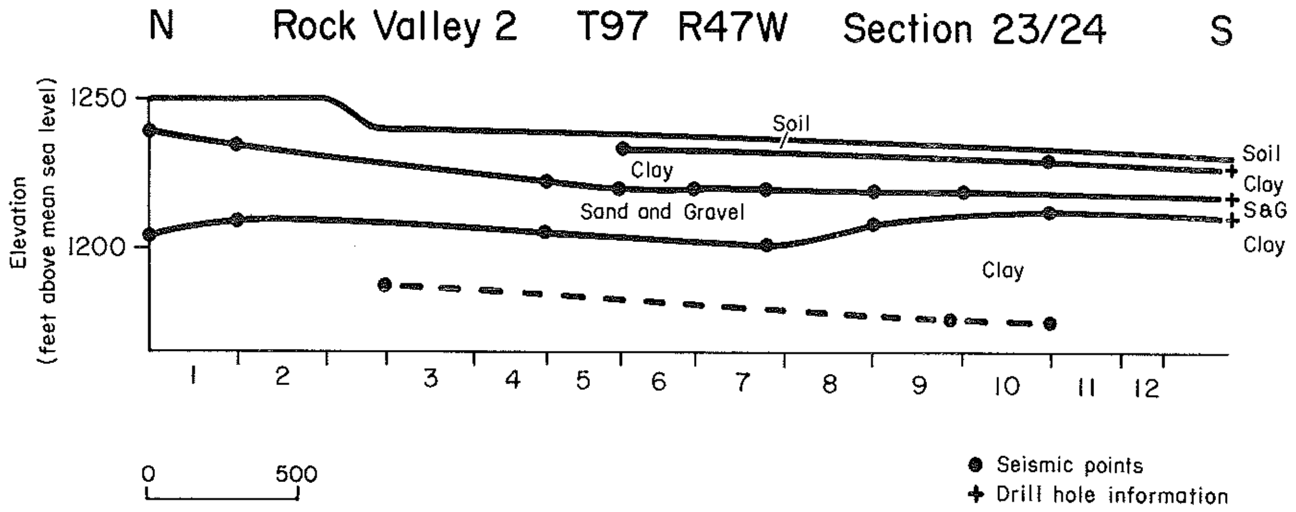

Figure B-11. Seismic profile section: Rock Valley 2.

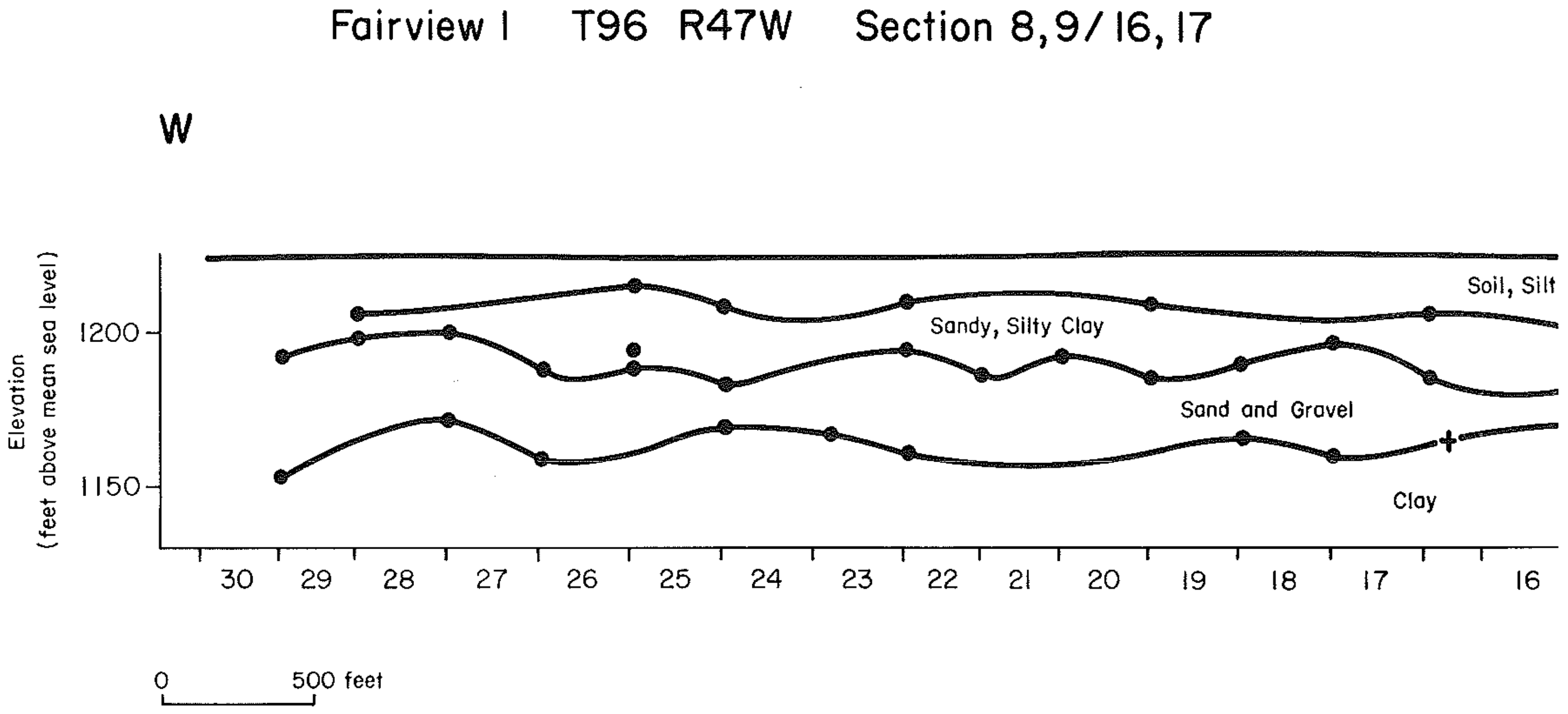

Figure B-12. Seismic profile section: Fairview 1.

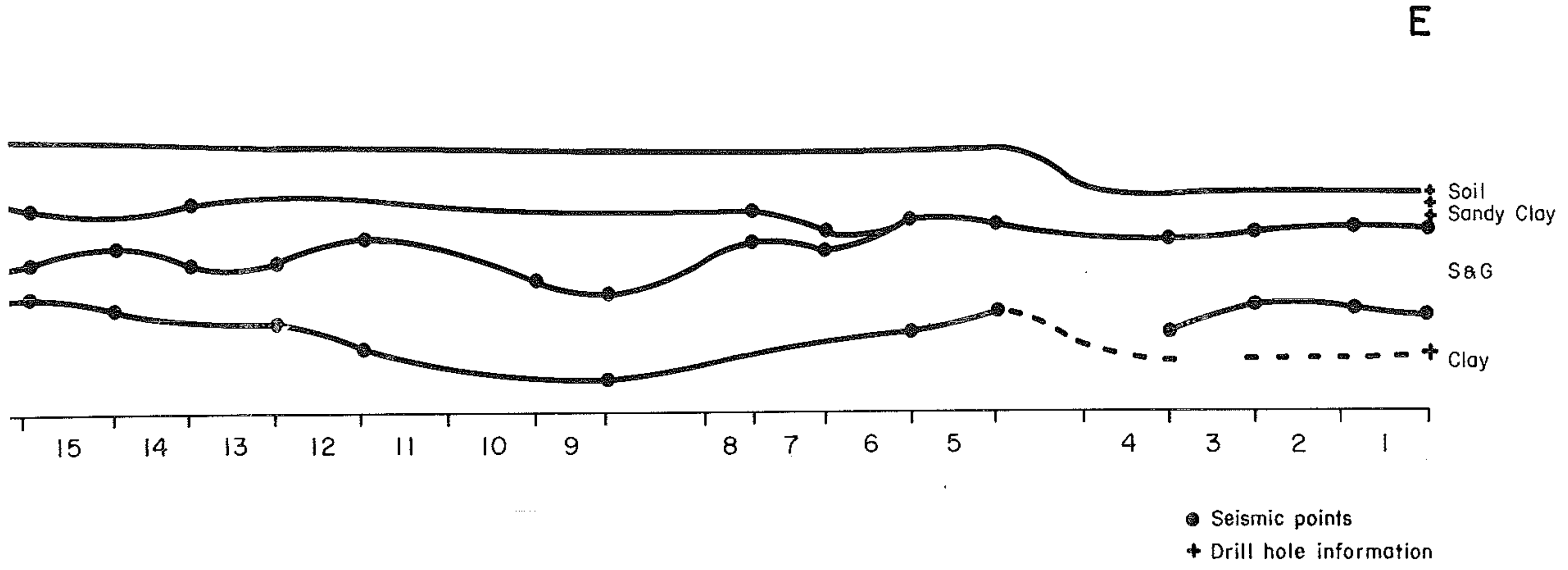

Figure B-12 (continued)

APPENDIX C

DRILLERS' LOGS

WELL NO.	LOCATION	ELEVATION (ft.)	FROM	TO	LITHOLOGY
RR-1	NW NW Sec. 21 T100 R45	1358	0	5	Fill, topsoil
			5	10	Fine brown sand, coarse gravel
			10	20	Fine yellow sand, coarse gravel, boulders at base
			20	24	Fine yellow sand, coarse gravel
			24	29	Yellow till, quartz boulder at 29 feet
RR-2	SE SW Sec. 10 T99 R45	1335	0	3	Topsoil, sandy brown clay
			3	8	Fine brown sand, coarse gravel
			8	12	Fine yellow sand, coarse gravel
			12	16	Fine yellow sand, coarse gravel, boulders at base
			16	19	Yellow till
			19	21	Yellow to blue gray till
RR-3	SE SE Sec. 32 T99 R45	1297	0	3	Topsoil, dark brown clay
			3	5	Sandy brown clay
			5	10	Fine brown sand, coarse gravel, boulders at 10 feet
			10	15	Fine yellow sand, coarse gravel, boulders
			15	21	Yellow-gray till
RR4	SW NE Sec. 29 T98 R45	1285	0	2	Topsoil, sandy clay
			2	5	Fine yellow sand, coarse gravel
			5	10	Fine brown sand, coarse gravel
			10	15	Fine yellow sand, coarse gravel, clay layer at top
			15	20	Brown sand and gravel
			20	30	Fine yellow sand, medium gravel
			30	43	Fine tan sand, medium to coarse gravel

WELL NO.	LOCATION	ELEVATION (ft.)	FROM	TO	LITHOLOGY
			43	45	Blue-gray sandy clay or till
			45	48	Green clay, some sand grains
RR-5	SW SW Sec. 24 T98 R46	1274	0	2	Sandy brown clay, topsoil
			2	8	Fine brown sand, coarse gravel
			8	31	Fine yellow sand, coarse gravel
			31	41	Blue-gray clay, some sand grains
RR-6	NE NE Sec. 25 T97 R47	1225	0	2	Sandy gravelly brown clay
			2	10	Fine brown sand, coarse gravel
			10	15	Fine yellow sand, very coarse gravel, boulders
			15	23	Fine yellow sand, coarse gravel
			23	32	Blue-gray sandy clay or till
RR-7	NW NW Sec. 25 T97 R47	1225	0	3	Topsoil, dark clay
			3	9	Gray to yellow silty clay
			9	10	Gray silty clay
			10	12	Yellow-gray silty sandy clay
			12	20	Fine yellow sand, coarse gravel
			20	33	Blue-gray sandy silty clay or till
			33	41	Green silty clay or shale, very fine cemented sand layers
RR-9	SW SW Sec. 23 T97 R47	1230	0	1	Topsoil
			1	4	Sandy gravelly yellow-brown clay
			4	8	Fine brown sand, coarse gravel
			8	22	Fine yellow sand, coarse gravel
			22	25	Blue-gray silty sandy clay or till

WELL NO.	LOCATION	ELEVATION (ft.)	FROM	TO	LITHOLOGY
RR-8	NW NW Sec. 26 T97 R47	1230	0	3	Road bed, topsoil
			3	10	Fine brown sand, coarse gravel
			10	54	Fine yellow sand, coarse gravel
			54	60	Fine to medium gray sand, thin sandy clay layers
			60	80	Fine to coarse green sand, sandy clay layers
			80	90	Fine to medium dark gray sand
			90	96	Gray clay or shale

APPENDIX D

WATER LEVEL DATA

WATER LEVELS - ROCK RIVER ALLUVIAL SYSTEM

	LOCATION	SCREENED INTERVAL	JUL 16 1985		AUG 20 1985		SEP 10 1985		OCT 14-15 1985	
			WATER LEVEL (FEET)	WATER LEVEL ELEV	WATER LEVEL (FEET)	WATER LEVEL ELEV	WATER LEVEL (FEET)	WATER LEVEL ELEV	WATER LEVEL (FEET)	WATER LEVEL ELEV
1	RR-1RA	SURFACE	-	-	-	-		1335.6		1336.6
2	RR-1U	10.5-12.5	7.8	1331.2	6.8	1332.2	7.9	1331.1	7.9	1331.1
3	1L	19.0-23.0	7.9	1331.1	7.8	1331.2	7.9	1331.1	7.9	1331.1
4	RR-2	13.0-15.0	-	-	11.1	1323.9	8.9	1326.1	9.8	1325.2
5	RR-3	11.0-13.0	9.0	1228.0	10.0	1287.0	9.5	1287.4	5.9	1291.1
6	RR-4U	10.0-12.0	10.6	1272.4	11.6	1271.4	10.1	1272.9	10.0	1273.0
7	4M	22.0-24.5	10.6	1272.4	11.5	1271.5	10.0	1272.9	9.5	1273.4
8	4L	38.0-41.0	10.6	1272.4	11.5	1271.5	9.6	1273.5	9.9	1273.1
9	LR-1R	SURFACE	-	-	-	-		1273.1		1273.2
10	RR-5U	16.0-17.0	12.2	1262.4	13.0	1261.6	12.8	1261.8	12.3	1262.3
11	5L	26.0-29.0	12.5	1262.1	13.0	1261.6	12.8	1261.8	12.3	1262.3
12	RR-2RA	SURFACE	-	-	-	-		1264.3		1263.4
13	RR-6	17.0-20.0	4.5	1219.2	5.1	1218.6	2.8	1220.9	3.0	1220.7
14	RR-3R	SURFACE	-	-	-	-		1218.9		1218.8
15	RR-7	17.0-19.5	4.9	1219.2	5.9	1218.2	5.5	1226.6	4.9	1219.2
16	RR-9	16.5-21.5	7.3	1223.4	-	-	7.4	1231.4	6.9	1223.8

WATER LEVELS - ROCK RIVER ALLUVIAL SYSTEM

	NOV 11-12 1985		DEC 16 1985		JAN 22 1986		FEB 18 1986		MAR 19 1986		APR 14 1986	
	WATER LEVEL (FEET)	WATER LEVEL ELEV	WATER LEVEL (FEET)	WATER LEVEL ELEV	WATER LEVEL (FEET)	WATER LEVEL ELEV	WATER LEVEL (FEET)	WATER LEVEL ELEV	WATER LEVEL (FEET)	WATER LEVEL ELEV	WATER LEVEL (FEET)	WATER LEVEL ELEV
1		1336.6	-	-	-	-	-	-	-	-	-	-
2	8.1	1330.9	8.1	1330.9	8.3	1330.7	8.4	1330.6	5.2	1333.8	6.9	1332.1
3	8.1	1330.9	8.2	1330.8	8.3	1330.7	8.4	1330.6	5.2	1333.8	6.9	1332.1
4	10.2	1324.8	10.8	1324.2	11.2	1323.8	11.5	1323.5	10.2	1324.8	9.6	1325.4
5	9.5	1287.5	9.4	1287.6	9.6	1287.4	9.7	1287.3	7.6	1289.4	6.0	1291.0
6	10.5	1272.5	10.3	1272.7	10.4	1272.6	10.6	1272.4	7.5	1275.5	8.4	1274.6
7	10.5	1272.5	10.2	1272.8	10.4	1272.6	10.6	1272.4	7.5	1275.5	8.4	1274.6
8	10.5	1272.5	10.2	1272.8	10.4	1272.6	10.4	1272.6	7.5	1275.5	8.4	1274.6
9		1271.9	-	-	-	-	-	-	-	-	-	-
10	12.6	1262.0	12.5	1261.9	12.9	1261.7	12.8	1261.8	11.5	1263.1	10.5	1264.1
11	12.7	1261.9	12.8	1261.8	13.0	1261.6	13.5	1261.1	11.6	1263.0	10.6	1264.0
12		1262.9	-	-	-	-	-	-	-	-	-	-
13	4.1	1219.6	3.9	1219.8	4.0	1219.7	4.4	1219.3	FLOODED		1.7	1222.0
14	-	-	-	-	-	-	-	-	-	-	-	-
15	5.3	1226.7	-	-	5.7	1218.4	5.9	1218.2	4.1	1220.0	3.0	1221.1
16	7.1	1231.6	6.6	1224.1	-	-	7.3	1223.4	6.2	1224.5	6.0	1224.7

WATER LEVELS - ROCK RIVER ALLUVIAL SYSTEM

	MAY 21 1986		JUNE 18 1986		JULY 22 1986		AUG 20 1986		SEPT 23 1986		OCT 22 1986	
	WATER LEVEL (FEET)	WATER LEVEL ELEV	WATER LEVEL (FEET)	WATER LEVEL ELEV	WATER LEVEL (FEET)	WATER LEVEL ELEV	WATER LEVEL (FEET)	WATER LEVEL ELEV	WATER LEVEL (FEET)	WATER LEVEL ELEV	WATER LEVEL (FEET)	WATER LEVEL ELEV
1		1336.9		1335.4		1335.4		1335.4		1342.4		1335.7
2	7.3	1331.7	7.7	1332.3	7.8	1331.2	8.1	1330.9	4.3	1334.7	7.7	1331.3
3	7.3	1331.7	7.7	1331.3	7.8	1331.2	8.1	1330.9	4.3	1334.7	7.7	1331.3
4	8.0	1327.0	10.5	1324.5	10.3	1333.7	10.9	1324.1	11.6	1324.4	10.7	1324.3
5	6.2	1290.8	7.6	1289.4	7.7	1288.9	8.7	1287.9	7.7	1289.3	7.6	1289.4
6	8.7	1274.3	9.8	1273.2	10.3	1272.7	10.9	1272.1	9.6	1273.4	10.2	1272.8
7	8.6	1274.4	9.8	1273.2	10.3	1272.7	10.9	1272.1	9.6	1273.4	10.2	1272.8
8	8.6	1274.4	9.7	1273.3	10.2	1272.8	10.9	1272.1	9.5	1273.5		
9		1273.4		1272.6		1272.2		1272.2		1271.9		1272.6
10	10.2	1264.5	10.9	1263.7	11.6	1263.0	12.3	1262.3	10.9	1263.7	11.1	1263.5
11	10.3	1264.3	11.0	1263.6	11.6	1263.0	12.4	1262.2	11.0	1263.6	11.2	1263.4
12		1263.8		1263.0		1262.9		1262.9		1270.9		1269.7
13	2.0	1221.7	3.2	1220.5	3.5	1220.2	4.7	1219.1	-0.5	1224.2	2.9	1220.8
14		1219.2	-	-		1217.9		1217.9		1224.4		1218.3
15	2.6	1221.5	3.9	1220.3	4.8	1219.3	5.6	1218.5	3.8	1220.3	4.2	1219.9
16	5.5	1225.2	6.2	1224.5	10.1	1223.4	-	-	6.6	1224.1	-	-

APPENDIX E

WATER QUALITY DATA

Table E-1. Municipal and other Public Alluvial Water Analyses (Source: UHL, DWAWM)
Tabulation of Water Analyses

(Dissolved constituents in parts per million unless otherwise stated)

Town and Well Number	Date	Depth (ft)	Diss. Solids	K	Na	Ca	Mg	Mn	NO_3	F	Cl	SO_4	HCO_3	Fe	Hardness	Conductance (micromohs)	ph[(a)]
Rock Rapids #1	1/14/57	34	515	4.4	14.3	105.0	34.5	<0.05	1.4	0.35	15	112.0	346	0.22	404	727	7.6
	9/27/60		487	3.6	12.5	102.0	22.4	<0.05	12.6	0.35	14	81.9	332	0.04	348	709	7.5
	12/19/66		473	3.8	15.0	94.4	32.1	<0.05	13.0	0.3	15	100.0	346	0.06	368	740	7.35
	9/21/70		459	3.6	13.0	92.8	24.5	<0.05	13.0	0.3	16	70.0	325	<0.02	352	700	7.15
	12/1/76		601	3.3	19.0	130.0	44.0	0.54	5.4	0.3	30	130.0	394	0.43	497	880	7.1
Rock Rapids #2	1/16/57	38	467	4.3	10.8	91.7	35.7	0.18	25.2	0.3	12	99.4	292	0.06	376	662	7.6
	9/27/60		472	2.0	9.3	99.2	28.2	<0.05	16.7	0.4	23	188.0	307	0.06	456	921	7.4
	12/19/66		532	3.8	14.0	109.0	33.5	0.08	45.0	0.3	18	95.0	333	0.04	410	820	7.35
	9/21/70		637	3.2	11.0	134.0	37.7	0.08	92.0	0.25	16	120.0	344	<0.02	490	930	7.1
	12/1/76		559	4.7	15.0	120.0	41.0	0.11	43.0	0.2	27	110.0	344	<0.01	461	850	7.4
Rock Rapids #3	12/1/52	26	611	11.4	13.7	110.0	39.1	<0.05	1.4	0.5	20	187.0	295	<0.05	436	832	7.5
	9/27/60		614	9.7	15.6	118.0	39.4	<0.05	18.0	0.4	23	180.0	307	0.06	456	921	7.4
	1/14/57		664	15.0	15.5	130.3	41.9	---	87.8	0.5	22	168.5	322	---	498	915	7.5
	12/19/66		597	8.8	19.0	116.0	36.5	<0.05	54.0	0.35	20	140.0	338	0.04	440	900	7.3
	9/21/70		627	10.0	18.0	124.0	34.0	<0.05	33.0	0.4	25	150.0	344	<0.02	450	930	7.15
Rock Rapids #4	1/14/57	25	416	3.4	8.1	90.0	35.2	<0.05	23.0	0.2	10	60.5	344	0.06	372	644	7.5
	9/27/60		311	1.9	6.9	68.9	19.4	<0.05	4.5	0.3	6	33.5	271	0.24	252	501	7.5
	12/6/67		397	2.9	9.1	84.0	29.2	0.35	4.4	0.3	18	59.0	326	0.21	330	650	7.3
	9/21/70		367	2.5	12.0	80.0	24.3	0.27	7.3	0.25	14	59.0	310	0.28	300	590	7.0
Rock Rapids #5	1/14/57	24	372	3.0	8.3	93.3	30.4	<0.05	26.6	0.25	8	63.4	326	0.16	358	644	7.65
	9/27/60		432	1.7	8.7	104.0	22.3	<0.05	17.1	0.3	10	70.8	329	0.10	352	665	7.4
	12/19/66		445	2.0	11.0	96.0	30.1	<0.05	18.0	0.25	16	61.0	375	0.10	375	740	7.3
	9/21/70		366	2.8	10.0	81.6	24.3	0.28	5.0	0.25	14	60.0	312	0.28	304	590	7.0
Rock Rapids #6	4/27/73	26	459	2.0	11.0	93.0	32.0	<0.01	28.0	0.2	14	74.0	310	0.02	352	670	7.45
	12/1/76		415	2.7	16.0	84.0	35.0	<0.01	7.4	0.25	31	56.0	317	<0.01	354	670	7.35
	9/16/82		477	3.5	18.0	84.0	35.0	<0.01	9.9	0.2	22	92.0	323	<0.01	354	740	7.3
Rock Rapids #7	12/1/76		714	7.5	34.0	140.0	48.0	0.01	23.0	0.3	54	150.0	424	<0.01	522	1110	7.25
	7/13/84		1180	9.4	130.0	130.0	48.0	0.01	95.0	0.3	220	381.0	---	0.03	657	1300	7.4
Rock Rapids #8	1/18/77	23	486	2.6	18.0	110.0	37.0	0.13	3.0	0.2	31	49.0	416	0.04	427	810	7.15
Rock Rapids #11	10/1/80	27	668	4.0	24.0	140.0	48.0	0.55	20.0	0.4	28	140.0	472	0.04	538	1000	7.2
Rock Rapids Test	3/15/75	35	772	8.4	88.0	120.0	42.0	<0.01	6.4	0.02	150	150.0	---	0.02	480	1200	7.35

Table E-1. Continued

Town and Well Number	Date	Depth (ft)	Diss. Solids	K	Na	Ca	Mg	Mn	NO_3	F	Cl	SO_4	HCO_3	Fe	Hard-ness	Conduct-ance (micro-mohs)	ph$^{(a)}$
Doon #1	9/12/34	32	849	---	---	134.0	36.6	---	32.0	1.0	36.0	116.3	300	0.1	485	---	7.3
	11/30/51		583	---	22.1	124.0	37.4	0	25.6	0.25	29.0	96.7	341	---	464	828	7.3
	4/21/59		566	4.2	16.0	110.0	37.7	<0.05	16.8	0.3	23.0	62.3	361	<0.02	430	725	7.4
	8/2/66		613	3.4	15.2	106.0	43.7	0.18	83.0	0.2	32.0	74.0	359	0.06	494	926	7.3
	7/3/74		1040	10.0	24.0	200.0	66.0	0.01	210.0	0.15	53.0	120.0	542	0.04	740	1400	7.1
Doon #2	4/21/59	50	476	4.4	9.4	99.1	35.0	<0.05	11.2	0.2	9.5	49.6	359	0.05	392	639	7.5
Doon #3	12/6/67		461	3.3	8.5	100.0	31.6	<0.06	2.1	0.2	13.0	97.0	318	<0.02	380	710	7.2
	11/3/80		---	---	---	---	---	---	107.0	---	---	---	---	---	---	---	---
	9/16/82		488	3.0	12.0	99.0	34.0	<0.01	28.0	0.2	25.0	94.0	334	<0.01	387	770	7.35
Lyon-Sioux RWS (Doon Subsystem)																	
D1	9/2/76	35	922	3.2	13.0	180.0	60.0	0.14	29.0	0.4	12.0	350.0	346	0.08	702	1200	7.2
D2	9/2/76	32	443	1.8	3.9	100.0	33.0	<0.01	18.0	0.3	10.0	75.0	331	<0.01	390	670	7.55
	5/13/81		---	---	---	---	---	---	55.0	---	---	---	---	---	---	---	
	4/19/82		690	---	15.0	140.0	---	---	---	0.4	---	---	---	---	---	---	7.7
Doon	6/12/29		---	---	---	---	---	---	23.0	---	---	---	---	---	---	---	---
	5/13/81		---	---	---	---	---	---	17.0	---	---	---	---	---	---	---	---
	12/14/81		---	---	---	---	---	---	45.0	---	---	---	---	---	---	---	---
	4/14/82		---	---	---	---	---	---	24.0	---	---	---	---	---	---	---	---
	5/24/83		---	---	---	---	---	---	20.0	---	---	---	---	---	---	---	---
	11/2/83		---	---	---	---	---	---	45.0	---	---	---	---	---	---	---	---
	12/7/83		---	---	---	---	---	---	32.0	---	---	---	---	---	---	---	---
	1/16/84		---	---	---	---	---	---	41.0	---	---	---	---	---	---	---	---
	4/23/84		---	---	---	---	---	---	31.0	---	---	---	---	---	---	---	---
	7/16/84		---	---	---	---	---	---	64.0	---	---	---	---	---	---	---	---
Rock Valley #1	9/13/34	29	806	---	23.0	142.5	37.6	---	12.0	---	19.0	231.9	307	---	511	---	7.3
	3/25/47		613		23.0	152.6	42.0	---	26.0	0.3	22.0	211.0	319	---	554	---	7.6
	11/26/57		726	3.5	23.2	143.0	40.6	<0.05	51.8	0.5	15.0	197.0	349	<0.02	524	991	7.45
	3/26/62		694	3.7	17.1	148.0	42.3	<0.05	41.9	0.25	18.0	232.0	344	<0.02	544	1030	7.4
	7/3/74		665	3.6	12.0	130.0	44.0	0.01	28.0	0.2	13.0	220.0	329	0.02	520	920	7.6
Rock Valley #2	11/26/57	64	719	3.5	22.6	142.0	40.1	<0.05	39.6	0.2	15.0	193.0	346	---	520	988	7.6
	3/26/62		619	3.9	12.9	138.0	38.9	<0.05	28.8	0.2	8.0	236.0	320	0.03	504	943	7.4
	7/23/68		740	3.8	12.0	142.0	42.5	<0.05	23.0	0.2	12.0	230.0	328	<0.02	530	920	7.1
	7/3/74		661	3.8	13.0	130.0	41.0	0.02	27.0	0.25	14.0	220.0	325	<0.01	540	910	7.55
Rock Valley #3	3/26/62	51	627	3.7	11.0	128.0	35.5	<0.05	33.3	0.25	11.0	199.0	304	0.04	466	896	7.4
	7/23/68		572	3.4	11.0	106.0	35.2	0.07	12.0	0.3	11.0	170.0	287	0.04	410	790	7.1
	7/3/74		643	3.9	12.0	130.0	44.0	0.02	24.0	0.25	11.0	210.0	344	<0.01	550	910	7.55
	11/3/76		606	3.8	10.0	130.0	44.0	<0.01	27.0	0.3	13.0	170.0	338	0.42	506	870	7.25
	3/20/80		545	4.0	11.0	120.0	33.0	0.07	27.0	0.25	19.0	140.0	313	0.05	433	830	7.3
	9/16/82		610	5.3	16.0	130.0	35.0	0.06	26.0	0.2	15.0	150.0	331	<0.01	461	860	7.7

Table E-1. Continued

Town and Well Number	Date	Depth (ft)	Diss. Solids	K	Na	Ca	Mg	Mn	NO_3	F	Cl	SO_4	HCO_3	Fe	Hard- ness	Conduct- ance (micro- mohs)	ph(a)
Rock Valley #4	7/3/74	70	694	3.5	12.0	140.0	43.0	0.02	27.0	0.2	15.0	250.0	317	0.04	520	960	7.5
	11/3/76		611	2.9	9.4	130.0	39.0	<0.01	39.0	0.3	14.0	170.0	314	<0.01	485	870	7.25
Rock Valley RWD	5/23/84		---	---	---	---	---	---	5.0	---	---	---	---	---	---	---	7.4
Rock Valley RWD #1	6/17/81	38	---	---	31.0	85.0	29.0	0.21	1.3	---	2.8	67.0	---	0.05	332	---	7.65
	10/4/82	38	469	2.7	11.0	94.0	32.0	0.3	19.0	0.3	4.5	120.0	310	0.22	367	730	7.4
Rock Valley RWD #2	6/17/81	40	---	---	29.0	109.0	35.0	0.30	0.9	---	7.8	67.0	---	0.04	---	---	7.39
	11/13/82	40		4.2	11.0	100.0	33.0	0.31	1.0	0.2	9.0	160.0	274	0.26	394	730	7.5

(a) pH units

Table E-2. Private Alluvial Water Analysis

(Analyses in mg/l unless other wise indicated)

No.	Location	Well Depth	Bacteria	Nitrate	Iron	Hardness	Sulfate	Date
1	T99 R45 Sec. 3	40	16+	65	---	---	---	6/84
2	T99 R45 Sec. 15	—	0	---	---	---	---	6/82
3	T99 R45 Sec. 27	42	0	26	---	---	---	11/84
4	T99 R45 Sec. 33	28	0	41	---	---	---	11/84
5	T98 R45 Sec. 6	18	0	57	---	---	---	6/82
		15	16+	80	---	---	---	5/82
6	T97 R46 Sec. 20	30	16+	177	---	---	---	6/83
7	T97 R46 Sec. 20	30	---	147	.1	450	---	1/81
8	T97 R46 Sec. 3	28	---	101	---	393	65	4/81
9	T97 R46 Sec. 30	9	---	159	.2	710	---	12/80
10	T97 R47 Sec. 26	30	---	46	---	257	235	4/81
11	T97 R47 Sec. 34	—	---	48	---	376	175	4/81
12	T97 R48 Sec. 25	—	---	26	---	291	95	4/81
13	T96 R47 Sec. 6	—	---	48	.1	428	120	4/81
14	T96 R47 Sec. 7	—	---	7	.1	239	100	4/81
15	T96 R47 Sec. 8	59	---	35	.1	291	55	4/81
16	T96 R47 Sec. 8	—	---	9	.15	342	200	4/81
17	T96 R47 Sec. 18	35	---	35	.05	359	180	4/81
18	T96 R47 Sec. 18	—	---	22	.1	274	100	4/81
19	T96 R48 Sec. 12	40	---	13	.35	342	90	4/81

Table E-3. Sampling Locations for River Quality Data

Station 1	Rock River	T100N R45W Sec. 20
Station 2	Rock River	Lyon Co. Dam
Station 3	Rock River	T99N R45W Sec. 10/15
Station 4	Rock River	T98N R46W Sec. 23/24
Station 5	Little Rock River	T98N R46W Sec. 35/36
Station 6	Rock River	T98N R46W Sec. 16/17
Station 7	Rock River	T97N R47W Sec. 24/25
Station 8	Rock River	T96N R47W Sec. 31
Station 9	Rock River	T95N R48W Sec. 6

Table E-4. Water Quality Analyses--Rock River (Source: UHL)

(All values in mg/l unless otherwise specified)

County	No.	Date	Temp (C°)	pH(a)	Nitrate N	Org. N	Amm. N	Tot. Alk.	Tot. P	Cl	Turb.(b)	Diss. Oxygen	Hardness	Conductance(c)	Fecal/100 ml Coliforms
Lyon	1	1/9/79	0	7.6	3.9	0.33	0.92	338	0.27	37	2.3	5.1	---	1100	10
Lyon	2	1/4/77	0	7.75	1.7	3.2	1.9	398	0.38	64	4.7	10.5	---	1100	<10
Lyon	3	9/13/76	18	8.05	0.6	3.1	0.3	167	0.34	160	17	11.9	316	1000	50
		1/3/77	0	7.75	1.9	3.2	7.8	424	2.4	150	16	4.3	---	1500	21,000
		1/9/79	0	7.6	5.0	0.99	3.4	371	1.2	83	2.9	7.24	---	1400	210,000
Lyon	4	9/13/76	18	8.0	<0.1	1.5	0.08	197	0.23	24	13	14.5	300	600	40
		1/3/77	0	7.6	0.5	0.72	0.48	300	0.22	39	5.3	6.8	---	860	<10
		1/9/79	0	7.6	3.5	0.36	0.79	338	0.27	37	2.3	5.1	---	1200	1100
Sioux	5	9/13/76	19	7.7	<0.1	1.8	0.02	184	0.31	15	16	9.8	316	620	750
		1/3/77	0	7.6	0.1	0.18	0.72	266	0.18	15	4.4	6.8	---	810	10
		1/9/79	0	7.6	0.2	0.39	0.66	352	0.11	23	3.5	9.0	---	1200	230
Sioux	6	9/13/76	18	7.8	<0.1	3.1	0.02	145	0.27	20	18	14.5	280	590	550
		1/3/77	0	7.55	2.7	0.93	0.29	320	0.15	31	3.5	11.7	---	970	50
		1/9/79	0	7.5	4.0	0.2	0.51	332	0.15	31	2.2	4.9	---	1200	140
Sioux	7	9/13/76	17	7.95	0.3	1.1	0.11	196	0.31	28	4.5	14.4	412	840	190
		1/3/77	0	7.6	1.7	0.4	3.5	322	0.88	56	4.2	6.0	---	1100	6,000
		1/9/79	0	7.5	3.5	0.51	1.7	336	0.43	40	2.6	3.3	---	1200	74,000
Sioux	8	9/13/76	18.5	8.05	<0.1	0.9	<0.01	173	0.2	15	4.2	11.8	320	650	400
		1/3/77	0	7.5	2.1	0.65	0.55	324	0.24	24	5.2	9.7	---	960	10
Sioux	9	1/9/79	0	7.5	3.7	0.36	0.36	340	0.23	32	2.5	5.4	---	1200	1,200

a) pH units
b) turbidity units
c) micromohs

APPENDIX F

MONITORING NETWORK DATA

MONITORING NETWORK DATA - ROCK RIVER ALLUVIAL SYSTEM

LOCATION RR-1RA MP ELEVATION 1352.8 FT.

DATE	WATER LEVEL M.P. (FT.)	WATER LEVEL ELEVATION	PH	TEMP (C)	COND. (UHMOS/CM)	NO3 (MG/L)
9/10/85	17.2	1335.6		16.1	775	18
10/15/85	16.2	1336.6	7.9	12.4	840	25
11/12/85	16.2	1336.6		3.0	530	27
4/14/86						28
5/21/86	16.8	1336.9	8.4	20.5	760	27
6/18/86	17.4	1335.4	8.4	19.0	800	27
7/22/86	17.4	1335.4	8.3	22.0	770	29
8/20/86	17.4	1335.4		22.0	650	12
9/23/86	10.4	1342.4	7.9	17.0	380	7
10/21/86	17.1	1335.7	8.4	16.0	720	29

LOCATION RR-1U

DATE INSTALLED 5/29/85 SCREENED INTERVAL 10-12 FT. MP ELEVATION 1341.6 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. (UHMOS/CM)	D.O. (MG/L)	NO3 (MG/L)	BACTERIA (MPN)
6/19/85									77	2.2
7/16/85		10.4	7.8	1331.2					78	2.2
8/20/85		9.4	6.8	1332.2					8	0
9/10/85	11.8	10.5	7.9	1331.1		16.1	640		67	5.1
10/15/85	11.8	10.5	7.9	1331.1	6.8	15.7	600	5.9	62/24/29	16+/16+/16+
11/12/85	11.8	10.7	8.1	1330.9		10.5	480	6/7.1	41	16+
12/16/85		10.7	8.1	1330.9					<5	
1/22/86		10.9	8.3	1330.7					<5	9.2
2/18/86		11.0	8.4	1330.6	7.5	5.0	640		38	0
3/19/86		7.8	5.2	1333.8					23	
4/14/86		9.5	6.9	1332.1					<5/<5	9.2/16+
5/21/86	11.8	9.9	7.3	1331.7	7.7	12.0	470	4.7	10/<5	9.2/5.1
6/18/86	11.7	10.3	7.7	1332.3	7.7	13.8	540	6.3	35	16+
7/22/86		10.4	7.8	1331.2	7.0	16.0	450	9.0	27	5.1
8/20/86		10.7	8.1	1330.9		16.0	450	4.0	61	16+
9/23/86		6.9	4.3	1334.7	7.5	14.0	570		15/17	16+
10/21/86		10.3	7.7	1331.3	7.5	14.0	490	4.8	48	

LOCATION RR-1L

DATE INSTALLED 5/29/85 SCREENED INTERVAL 19.5-23 FT. MP ELEVATION 1341.4 FT. CASING HT. 2.4 FT.

DATE	WELL DEPTH (FT.)	WATER LEVEL M.P. (FT.)	WATER LEVEL G.S. (FT.)	WATER LEVEL ELEVATION	PH	TEMP (C)	COND. (UHMOS/CM)	D.O. (MG/L)	NO3 (MG/L)	BACTERIA (MPN)
6/19/85									<5	16+
7/16/85		10.3	7.9	1331.1					11	0
8/20/85		10.2	7.8	1331.2					<5	0
9/10/85	22.9	10.3	7.9	1331.1		15.0	585		<5	5.1
10/15/85	22.9	10.3	7.9	1331.1	6.9	14.1	560	0.7	<5	5.1
11/12/85	23.0	10.5	8.1	1330.9		10.5	425	0.9	<5	5.1
12/16/85		10.6	8.2	1330.8					<5	9.2
1/22/86		10.7	8.3	1330.7					<5	0
2/18/86		10.8	8.4	1330.6	7.3	8.0	680		6	0
3/18/86		7.6	5.2	1333.8					<5	
4/14/86		9.3	6.9	1332.1					<5	0
5/21/86	22.9	9.7	7.3	1331.7	7.6	11.0	500	1.4	<5	0
6/18/86	22.8	10.1	7.7	1331.3	7.6	12.5	530	1.0	<5	16
7/22/86		10.2	7.8	1331.1	7.6	13.0	510	1.3	<5	16+
8/20/86		10.5	8.1	1330.9		15.0	450	0.5	6	9.2
9/23/86		6.7	4.3	1334.7	7.4	12.0	580		<5	16+
10/21/86		10.1	7.7	1331.3	7.6	13.0	520	1.0	8	

LOCATION RR-2

DATE INSTALLED 5/29/85 SCREENED INTERVAL 13-15 FT. MP ELEVATION 1337.8 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. (UHMOS/CM)	D.O. (MG/L)	NO3 (MG/L)	BACTERIA (MPN)
6/19/85									36	16+
7/16/85									52	2.2
8/20/85		13.9	11.1	1323.9					24	5.1
9/10/85	15.3	11.7	8.9	1326.1		14.2	750		30	2.2
10/15/85	15.2	12.6	9.8	1325.2	6.9	13.0	790	5.0	39	2.2
11/12/85	15.3	13.0	10.2	1324.8		11.0	650	5.5	29	
12/16/85		13.6	10.8	1324.2					20/11	
1/22/86		14.0	11.2	1323.8					<5	0
2/18/86		14.3	11.5	1323.5	7.5	8.0	1000		60/62	0/0
3/18/86		13.0	10.2	1324.8					39	
4/14/86		12.4	9.6	1325.4					50	0
5/21/86	15.3	10.8	8.0	1327.0	7.6	11.0	810	5.5	53	0
6/18/86	15.2	13.3	10.5	1324.5	7.4	12.0	860	5.4	35/32	16+/16
7/22/86		14.1	10.3	1333.7	7.2	14.5	810	6.2	53	16+
8/20/86		13.7	10.9	1324.1		13.0	620	6.6	48	16+
9/23/86		13.4	10.6	1324.3	7.3	12.0	860		58/63	16+/16+
10/21/86		13.5	10.7	1324.4	7.4	13.0	730	4.8	43	

LOCATION RR-3

DATE INSTALLED 5/30/85 SCREENED INTERVAL 11-13 FT. MP ELEVATION 1299.4 FT. CASING HT. 2.4 FT.

DATE	WELL DEPTH (FT.)	WATER LEVEL M.P. (FT.)	WATER LEVEL G.S. (FT.)	WATER LEVEL ELEVATION	PH	TEMP (C)	COND. (UHMOS/CM)	D.O. (MG/L)	NO3 (MG/L)	BACTERIA (MPN)
6/19/85									11	16+
7/16/85		11.4	9.0	1288.0					19	16+
8/20/85		12.4	10.0	1287.0					<5	0
9/10/85	13.1	12.0	9.5	1287.4	7.6	15.0	845		14	0
10/15/85	13.2	8.3	5.9	1291.1	6.4	12.0	740	3.7	15	0
11/12/85	13.2	11.9	9.5	1287.5		11.0	620	4.1	15	0
12/16/85		11.8	9.4	1287.6					<5	
1/22/86		12.0	9.6	1287.4					<5	0
2/18/86		12.1	9.7	1287.3	7.5	7.0	780		15	2.2
3/18/86		10.0	7.6	1289.4					<5/<5	
4/14/86		8.4	6.0	1291.0					<5	0
5/21/86	13.1	8.6	6.2	1290.8	7.5	10.2	720	2.7	14	0
6/18/86	13.1	10.0	7.6	1289.4	7.5	13.0	770	3.2	8	16+
7/22/86		10.5	7.7	1288.9	7.2	14.5		2.2	14/14	16+/16+
8/20/86		11.5	8.7	1287.9		14	600	3.0	8/8	16+/16+
9/23/86		10.1	7.7	1289.3	7.2	13.0	800		11	16+
10/21/86		10.0	7.6	1289.4	7.3	13.0	720	1.3	12/12	

LOCATION LR-1R MP ELEVATION 1286.0

DATE	WATER LEVEL M.P. (FT.)	WATER LEVEL ELEVATION	PH	TEMP (C)	COND. (UHMOS/CM)	NO3 (MG/L)
6/19/85						45
7/16/85						47
8/20/85						<5
9/10/85	12.9	1273.1	7.8	18.5	660	38
10/15/85	12.8	1273.2		9.8	875	43
11/12/85	14.1	1271.9		2.5	540	39
4/14/86			7.6	9.8	875	47
5/21/86	12.6	1273.4	8.5	21.0	790	49
6/18/86	13.4	1272.6	8.4	22.0	780	
7/22/86	13.8	1272.2	8.3	22.0		29
8/20/86	13.8	1272.2		22.0	720	14
9/23/86	14.1	1271.9	8.2	18.0	800	36
10/22/86	13.4	1272.6	8.3	13.0	860	38

LOCATION RR-4U

DATE INSTALLED 5/30/85 SCREENED INTERVAL 10-12 FT. MP ELEVATION 1286.2 FT. CASING HT. 3.2 FT.

DATE	WELL DEPTH (FT.)	WATER LEVEL M.P. (FT.)	WATER LEVEL G.S. (FT.)	WATER LEVEL ELEVATION	PH	TEMP (C)	COND. (UHMOS/CM)	D.O. (MG/L)	NO3 (MG/L)	BACTERIA (MPN)
6/19/85									<5	0
7/16/85		13.8	10.6	1272.4					34	0
8/20/85		14.8	11.6	1271.4					<5	0
9/10/85	12.0	13.3	10.1	1272.9	6.5	15.8	800		8	0
10/15/85	12.0	13.2	10.0	1273.0	6.9	12.7	840		<5	9.2
11/12/85	12.0	13.7	10.5	1272.5		10.0	560		5	0
12/16/85		13.5	10.3	1272.7					<5	
1/22/86		13.6	10.4	1272.6					<5	2.2
2/18/86		13.8	10.6	1272.4	7.5	7.0	950		<5	0
3/18/86		10.7	7.5	1275.5					5	
4/14/86		11.6	8.4	1274.6					<5	2.2
5/21/86	12.1	11.9	8.7	1274.3	7.5	11.0	850	9.1	<5	16+
6/18/86	12.1	13.0	9.8	1273.2	7.2	13.0	930	3.6	<5	16+
7/22/86		13.5	10.3	1272.7	7.2	15.0		3.8	<5/<5	0/9.2
8/20/86		14.1	10.1	1272.1		16.0	1000		<5	16
9/23/86		12.8	9.6	1273.4	7.3	14.0	1100		<5	
10/22/86		13.4	10.1	1272.8	7.3	13.0	920	4.2	<5	

LOCATION RR-4M

DATE INSTALLED 5/30/85 SCREENED INTERVAL 22-24.5 FT. MP ELEVATION 1286.2 FT. CASING HT. 3.2 FT.

DATE	WELL DEPTH (FT.)	WATER LEVEL M.P. (FT.)	WATER LEVEL G.S. (FT.)	WATER LEVEL ELEVATION	PH	TEMP (C)	COND. (UHMOS/CM)	D.O. (MG/L)	NO3 (MG/L)	BACTERIA (MPN)
6/19/85									6	16
7/16/85		13.8	10.6	1272.4					18	0
8/20/85		14.7	11.5	1271.5					<5	0
9/10/85	24.5	13.2	10.0	1272.9		14.5	830		<5	5.1
10/15/85	24.6	12.8	9.5	1273.4	7.1	10.9	910	0.7	<5	16+
11/12/85	24.5	13.7	10.5	1272.5		10.0	665	0.7	<5	16+
12/16/85		13.4	10.2	1272.8					<5	
1/22/86		13.6	10.4	1272.6					<5	5.1
2/18/86		13.8	10.6	1272.4	7.5	9.0	1000		<5	0
3/18/86		10.7	7.5	1275.5					<5	
4/14/86		11.6	8.4	1274.6					<5	0
5/21/86	24.5	11.8	8.6	1274.4	7.6	12.0	840	0.02	<5	0
6/18/86	24.5	13.0	9.8	1273.2	7.5	13.5	890	0.15	<5	5.1
7/22/86		13.5	10.3	1272.7	7.4	14.0		0.2	<5	5.1
8/20/86		14.1	10.9	1272.1		12.0	680	0.4	<5	16+
9/23/86		12.8	9.6	1273.4	7.6	11.0	1000		<5	16+
10/21/86		13.4	10.2	1272.8	7.5	12.0	1000	2.0	<5	

LOCATION RR-4L

DATE INSTALLED 5/30/85   SCREENED INTERVAL 38-41 FT. MP ELEVATION 1286.0 FT. CASING HT. 3.0 FT.

DATE	WELL DEPTH (FT.)	WATER LEVEL M.P. (FT.)	WATER LEVEL G.S. (FT.)	WATER LEVEL ELEVATION	PH	TEMP (C)	COND. (UHMOS/CM)	D.O. (MG/L)	NO3 (MG/L)	BACTERIA (MPN)
6/19/85									15	0
7/16/85		13.6	10.6	1272.4					20	9.2
8/20/85		14.5	11.5	1271.5					5	2.2
9/10/85	41.0	12.5	9.6	1273.5	8.4	14.7	880		<5	16+
10/15/85	40.7	12.9	9.9	1273.1	7.0	10.3	915	0.6	<5	5.1
11/12/85	40.9	13.5	10.5	1272.5		9.0	660	0.9	<5	0
12/16/85		13.2	10.2	1272.8					14	
1/22/86		13.4	10.4	1272.6					22	5.1
2/18/86		13.2	10.4	1272.6	7.1	9.0	1000		19	5.1
3/18/86		10.5	7.5	1275.5					<5	
4/14/86		11.4	8.4	1274.6					<5	0
5/21/86	40.9	11.6	8.6	1274.4	7.5	14.0	850	0.0	5	0
6/18/86	40.9	12.7	9.7	1273.3	7.3	15.0	920	0.2	<5	16
7/22/86		13.2	10.2	1272.8	7.2	14.0		0.3	<5	16+
8/20/86		13.9	10.9	1272.1		13.0	680	0.6	7	16+
9/23/86		12.5	9.5	1273.5	7.4	11.0	910		11	16+

LOCATION RR-5U

DATE INSTALLED 6/3/85   SCREENED INTERVAL 16-17 FT. MP ELEVATION 1277.7 FT. CASING HT. 3.1 FT.

DATE	WELL DEPTH (FT.)	WATER LEVEL M.P. (FT.)	WATER LEVEL G.S. (FT.)	WATER LEVEL ELEVATION	PH	TEMP (C)	COND. (UHMOS/CM)	D.O. (MG/L)	NO3 (MG/L)	BACTERIA (MPN)
6/19/85									27	0
7/16/85		15.3	12.2	1262.4					46	0
8/20/85		16.1	13.0	1261.6					5	0
9/10/85	16.9	15.9	12.8	1261.8	9.0	14.8	725		12	16+
10/15/85	16.7	15.4	12.3	1262.3	6.6	9.7	795	0.7	13	5.1
11/12/85	16.7	15.7	12.6	1262.0		10.0	580	.7/.15	18	16
12/16/85		15.8	12.5	1261.9					<5	
1/22/86		16.0	12.9	1261.7					<5	5.1
2/18/86		15.9	12.8	1261.8	7.4	8.5	910		18	9.2
3/18/86		14.6	11.5	1263.1					<5	
4/14/86		13.6	10.5	1264.1					<5	0
5/21/86	16.7	13.3	10.2	1264.5	7.4	11.0	695	4.6	5	16+
6/18/86	16.7	14.0	10.9	1263.7	7.3	12.0	760	0.3	6/6	16+/16+
7/22/86		14.7	11.6	1263.0	7.3	14.0	660	1.0	6	16+
8/20/86		15.4	12.3	1262.3		12.0	580	1.2	8	16+
9/23/86		14.0	10.9	1263.7	7.5	12.0	700		<5	16+
10/22/86		14.2	11.1	1263.5	7.3	11.0	780	0.8	16	

LOCATION RR-5L

DATE INSTALLED 6/3/85   SCREENED INTERVAL 26-29 FT. MP ELEVATION 1277.3 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. (UHMOS/CM)	D.O. (MG/L)	NO3 (MG/L)	BACTERIA (MPN)
6/19/85									53	16+
7/16/85		15.2	12.5	1262.1					61	5.1
8/20/85		15.7	13.0	1261.6					26	2.2
9/10/85	28.7	15.5	12.8	1261.8	8.4	14.7	740		27	16+
10/15/85	28.8	15.0	12.3	1262.3	6.5	8.7	765	0.7	22	16
11/12/85	28.8	15.4	12.7	1261.9		9.0	565	1.8	23	9.2
12/16/85		15.5	12.8	1261.8					<5	
1/22/86		15.7	13.0	1261.6					21	2.2
2/18/86		16.2	13.5	1261.1	7.3	9.0	800		47/47	0/0
3/18/86		14.3	11.6	1263.0					8	
4/14/86		13.3	10.6	1264.0					9	0
5/21/86	28.8	13.0	10.3	1264.3	7.7	11.0	700	8.2	15	16+
6/18/86	28.8	13.7	11.0	1263.6	7.5	13.0	650	8.2	32	16+
7/22/86		14.3	11.6	1263.0	7.3	14.0	640	8.1	29	16+
8/20/86		15.1	12.4	1262.2		11.0	520	9.6	32	16+
9/23/86		13.7	11.0	1263.6	7.4	10.0	640		61/57	16+
10/22/86		13.9	11.2	1263.4	7.4	10.0	740	7.6	54/53	

LOCATION RR-2RA MP ELEVATION 1280.3

DATE	WATER LEVEL M.P. (FT.)	WATER LEVEL ELEVATION	PH	TEMP (C)	COND. (UHMOS/CM)	NO3 (MG/L)
6/19/85						45
7/16/85						47
8/20/85						<5
9/10/85	16.0	1264.3	7.7	17.7	800	24
10/15/85	16.9	1263.4	7.8	6.9	760	31
11/12/85	17.4	1262.9		3.0	530	29
4/14/86						25
5/21/86	16.5	1263.8	8.5	22.0	795	33
6/18/86	17.3	1263.0	8.5	23.0	790	31
7/22/86	17.4	1262.9	8.3	24.0	860	30
8/20/86	17.4	1262.9		21.0	620	15
9/23/86	9.6	1270.9	8.0	18.0	390	9
10/21/86	17.8	1269.7	8.3	13.0	790	30

LOCATION RR-6

DATE INSTALLED 6/3/85 SCREENED INTERVAL 17-20 FT. MP ELEVATION 1226.5 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. (UHMOS/CM)	D.O. (MG/L)	NO3 (MG/L)	BACTERIA (MPN)
6/19/85									25	16+
7/16/85		7.3	4.5	1219.2					20	9.2
8/20/85		7.9	5.1	1218.6					<5	0
9/10/85	20.2	5.6	2.8	1220.9	7.4	15.9	690		7	16+
10/15/85	20.2	5.8	3.0	1220.7	6.8	11.0	650	1.1	6/<5/<5	9.2/16+/9.2
11/12/85	20.2	6.9	4.1	1219.6		10.5	640	1.8	6	9.2
12/16/85		6.7	3.9	1219.8					<5	
1/22/86		6.8	4.0	1219.7					<5	0
2/18/86		7.2	4.4	1219.3	7.4	9.0	1000		20	0
3/18/86		FLOODED								
4/14/86		4.5	1.7	1222.0					<5/<5	0/0
5/21/86	20.2	4.8	2.0	1221.7	7.5	12.0	790	5.4	8/13	16/2.2
6/18/86	20.1	6.0	3.2	1220.5	7.5	13.5	760	2.0	9	16+
7/22/86		6.3	3.5	1220.2	7.3	15.0	800	2.2	9	16+
8/20/86		7.5	4.7	1219.1		12.0	620	3.2	9	16
9/23/86		2.3	-0.5	1224.2	7.4	12.0	710		<5	16+
10/21/86		5.7	2.9	1220.8	7.3	11.0	1100	4.1	30	

LOCATION RR-3R MP ELEVATION 1211.8 FT.

DATE	WATER LEVEL M.P. (FT.)	WATER LEVEL ELEVATION	PH	TEMP (C)	COND. (UHMOS/CM)	NO3 (MG/L)
6/19/85						35
7/16/85						37
8/20/85						6
9/10/85	7.1	1218.9	7.6	16.9	820	29
10/14/85	7.0	1218.8	7.5	11.4	880	38
11/11/85				2.0	545	33
5/21/86	7.4	1219.2	8.5	23.0	840	41
6/18/86			8.4	22.0	850	38
7/22/86	6.1	1217.9	8.4	24.0	850	30
8/20/86	6.1	1217.9		21.0	580	14
9/23/86	12.6	1224.4	8.1	19.0	460	12/12
10/22/86	6.5	1218.3	8.3	14.0	820	33

LOCATION RR-7

DATE INSTALLED 6/4/85 SCREENED INTERVAL 17-19.5 FT. MP ELEVATION 1226.4 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. (UHMOS/CM)	D.O. (MG/L)	NO3 (MG/L)	BACTERIA (MPN)
6/19/85									155	0
7/16/85		7.2	4.9	1219.2					167	0
8/20/85		8.2	5.9	1218.2					111	0
9/10/85	19.2	7.8	5.5	1226.6	7.1	13.2	1000		170	0
10/15/85	19.4	7.2	4.9	1219.2	6.4	12.4	905	5.1	170	5.1
11/12/85	19.3	7.6	5.3	1226.7		10.0	680	5.7	11	0
12/16/85									84/97	
1/22/86		8.0	5.7	1218.4					79	0
2/18/86		8.2	5.9	1218.2	7.2	9.0	900		118	0
3/18/86		6.4	4.1	1220.0					<5	
4/14/86		5.3	3.0	1221.1					67	0
5/21/86	19.5	4.9	2.6	1221.5	7.5	11.0	810	1.2	74	2.2
6/18/86	19.2	6.2	3.9	1220.2	7.7	11.5	760	4.1	68	16+
7/22/86		7.1	4.8	1219.3	7.5	12.5	710	6.2	102	16
8/20/86		7.9	5.6	1218.5		11.0	580	5.2	43/74	16+/16+
9/23/86		6.1	3.8	1220.3	7.6	11.0	850		119	16+
10/21/86		6.5	4.2	1219.9	7.5	11.0	860	4.2	120/118	

LOCATION RR-9

DATE INSTALLED 6/5/85 SCREENED INTERVAL 16.5-21.5 FT. MP ELEVATION 1233.7 FT. CASING HT. 3.0 FT.

DATE	WELL DEPTH (FT.)	WATER LEVEL M.P. (FT.)	WATER LEVEL G.S. (FT.)	WATER LEVEL ELEVATION	PH	TEMP (C)	COND. (UHMOS/CM)	D.O. (MG/L)	NO3 (MG/L)
6/19/85									9
7/16/85		10.3	7.3	1223.4					
8/20/85									
9/10/85		10.4	7.4	1231.4					
10/15/85		9.9	6.9	1223.8					
11/12/85		10.1	7.1	1231.6					
12/16/85		9.6	6.6	1224.1					<5
1/22/86									
2/18/86		10.3	7.3	1223.4					
3/18/86		9.2	6.2	1224.5					
4/14/86		9.0	6.0	1224.7					
5/21/86		8.5	5.5	1225.2					
6/18/86		9.2	6.2	1224.5					
7/22/86		10.4	10.1	1223.4					
9/23/86		9.6	6.6	1224.1					

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.