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HYDROGEOLOGY AND WATER QUALITY OF THE UPPER DES MOINES RIVER ALLUVIAL AQUIFER

Carol A. Thompson
Research Geologist, Water Resources Division

A report on contract number G 007246-01-0
of the United States Environmental Protection Agency
from the
Iowa Geological Survey
Donald L. Koch, State Geologist and Director
123 North Capitol Street
Iowa City, Iowa 52242

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EXECUTIVE SUMMARY

A study of the Des Moines River alluvial aquifer from Boone County north to the Minnesota border was conducted to provide information on water availability and water quality. The study was partially funded through a contract with the U.S. Environmental Protection Agency. The data collection techniques included a seismic refraction survey of the alluvial valley to determine alluvial thicknesses, well-installation and measurement of water levels, and collection of water samples for chemical analysis.

The alluvial materials which comprise the system were deposited by outwash streams during the melting of the late Wisconsinan glaciers. The outwash materials along the west fork are very coarse, anisotropic, and stratified. They range from matrix-supported pebbly layers to clast-supported cobble layers with occasional sand lenses. Textures in the east fork are finer with more sand being present. The terraces along the lower river show a three-fold stratigraphy of fine and coarse layers described.

Seismic refraction surveys were done during the summer of 1982. Twenty-five miles of seismic lines were run at 38 different locations. The sands and gravels comprising the alluvial aquifer were found to range from less than ten to greater then fifty feet. The thickest parts of the aquifer occurred along the west fork north of Bradgate and along the east fork, south of Irvington. The alluvial valley below the junction of the two forks is characterized by numerous terrace and bench deposits. These are variable in thickness, but are often no more than a thin veneer. The alluvial sands and gravels are, for the most part, underlain by Des Moines Lobe till, but also can be underlain by Mississippian limestone and Pennsylvanian shales, sandstones, and limestones.

Recharge to the alluvial system is from precipitation. Interactions between the stream and the aquifer will also affect the water table. Normally the water table slopes from the aquifer to the stream, however at high stream stage conditions, the stream can contribute water to the aquifer. Water in storage in the alluvium along the west fork north of Bradgate was computed to range from 3 to 74 billion gallons.

Streamflow in the Des Moines varies from year to year and season to season. The drainage basin of the Des Moines is not well-integrated. The hydrographs are characterized by diffuse peaks. Flow-duration data indicate that in the upper ends of the basin streamflow is highly variable and groundwater inflow is negligible and is not capable of maintaining streamflow. Variability decreases downstream as groundwater recharge becomes more significant.

Water levels in wells ranged from two feet above ground level to 24 feet below ground level and averaged about six feet below ground. Water levels in any one well varied by a maximum of 8.5 feet. Horizontal gradients in the alluvial system range from .0007 parallel to the river to .001 perpendicular to the river. The water table generally slopes to the river, but many other configurations were also seen. Vertical gradients were downward at one location and not well-defined at others.

A pumping test was conducted four miles north of Emmetsburg. The well was pumped at 1,000 gallons per minute for 16 hours. Maximum drawdown at the observation well located 60 feet away was 2.5 feet. Transmissivities were calculated to be between 30,000-550,000 gpd/ft with storage coefficients from .005 to 0.2.

Well yields will be highest along the west fork from Bradgate north to Graettinger. Yields suitable for irrigation can be obtained in this area. Yields adequate for rural-domestic and livestock use will be generally obtainable anywhere in the alluvial sections. Exceptions are on high terraces which are not hydraulically connected to the river and areas of extremely thin alluvium. Higher yields may be obtainable from areas where the alluvium is thin or storage is negligible, however there will be a greater impact on the stream.

Groundwater in the study area is a calcium magnesium bicarbonate type. Total dissolved solids are generally less than 1000 mg/l. Information from either past data or from the water-quality inventory showed that 20-30% of the wells have nitrate concentrations greater than the recommended limit of 45 mg/l. Monthly sampling of the monitoring network showed that nitrate does not appear to be infitrating the groundwater system to any depth. In general, wells open between the water table and 10 feet below the water table show nitrate. There are exceptions where no nitrate is occurring even at the water table. These appear to be regulated, in part, by soil type which may hinder infiltration and promote denitrification. Coliform bacteria also appears prevalent in the groundwater, occurring in over 50% of the samples.

The largest amount of water presently allocated is for irrigation, followed by municipal, rural-domestic and livestock. Adequate water will be available during most seasons to meet current needs and to support some im-creases. During drought conditions, irrigation water may have more of an impact on stream levels due to more frequent useage and lower storage capability in the aquifer.

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ALLUVIAL AQUIFER STUDY: DES MOINES RIVER

INTRODUCTION

Consistent with the Iowa Geological Survey's goal of expanding the information base for water resources in the State of Iowa, an alluvial aquifer study was begun during 1981. Although many Iowa municipalities, rural water distribution systems, irrigators, and rural residents draw water from alluvial systems, little is known of their development potential or limitations. In several regions of the state, alluvial systems are the only source of good quality water, and competition for alluvial water is increasing. 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.

Physiographic Setting

The Des Moines River above Saylorville Reservoir was chosen as the study area for the initial study. In this region the river traverses the Des Moines Lobe, an area fashioned by the latest glacial advance in Iowa (Figure 1). The topography of the Des Moines Lobe is flat to irregular. The irregular landscape is referred to as knob and kettle topography, and is the result of the deposition of materials and the retreat of glacial ice. The study area itself is an alluvial plain which borders the river. The alluvial plain is the low-lying land area adjacent to the river, characterized by its low relief and poor drainage. Terraces which are present along the valley margins of the present alluvial plain are remnants of former floodplains. These terraces may or may not be hydraulically connected to the aquifer beneath the floodplain, but were included for a brief evaluation in this study. The drainage area of the Des Moines River at the Boone-Polk County line is 5677 square miles.

Climatic Setting

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

Mean annual temperatures in the project area range from about 48 degrees F in the southern counties to 46 degrees in the northern counties, Figure 2. The growing season, the period between spring thaw and fall freeze, extends from about the 5th of May to the 5th of October. Within given years, temperature extremes can vary from winter lows of less than -20 degrees F to summer highs above 100 degrees F.

Normally, precipitation in the project area ranges between 28 and 32 inches annually. As shown in Figure 3, the precipitation gradient decreases

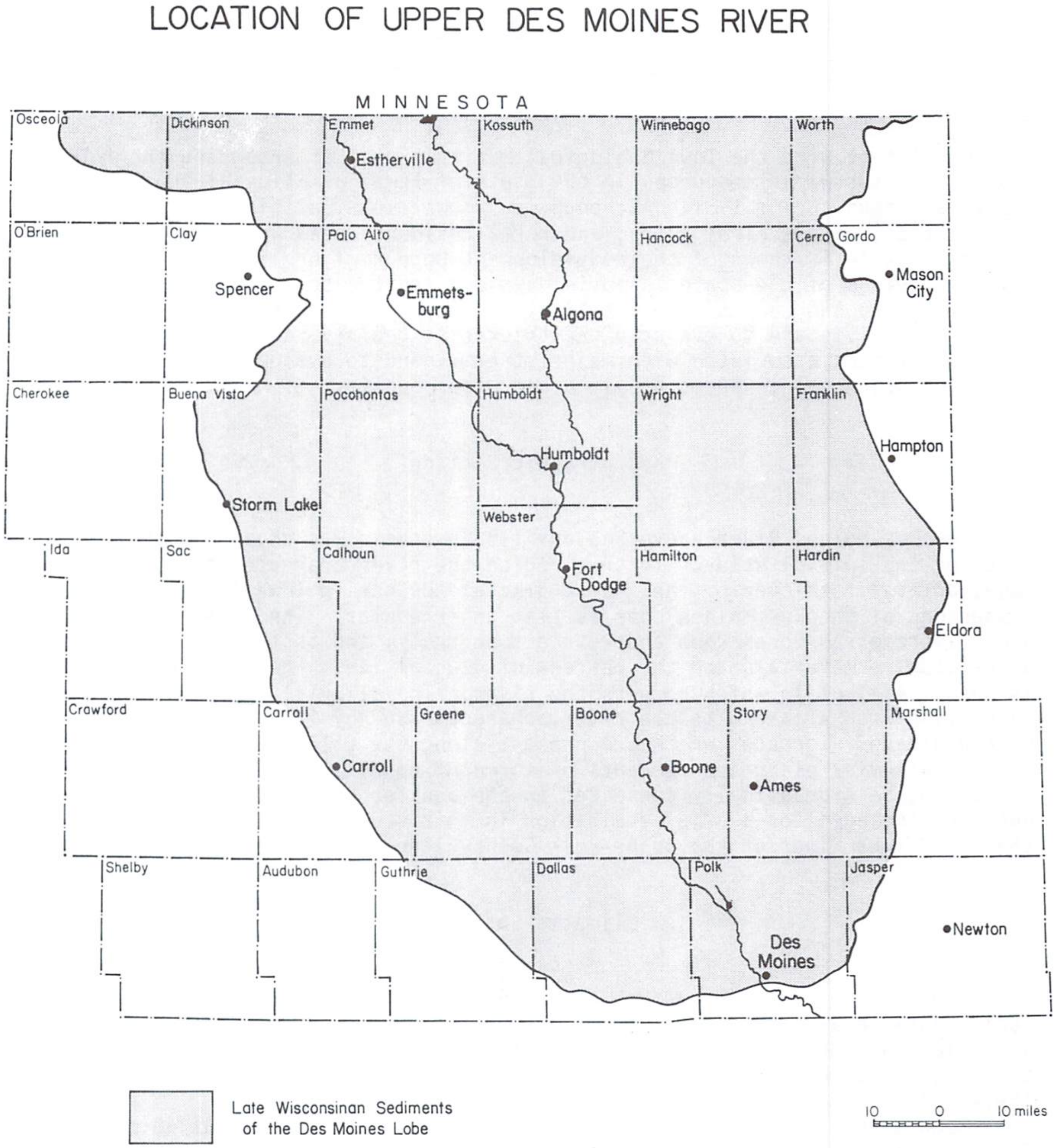


Figure 1. The Des Moines Lobe showing the location of the Upper Des Moines River.

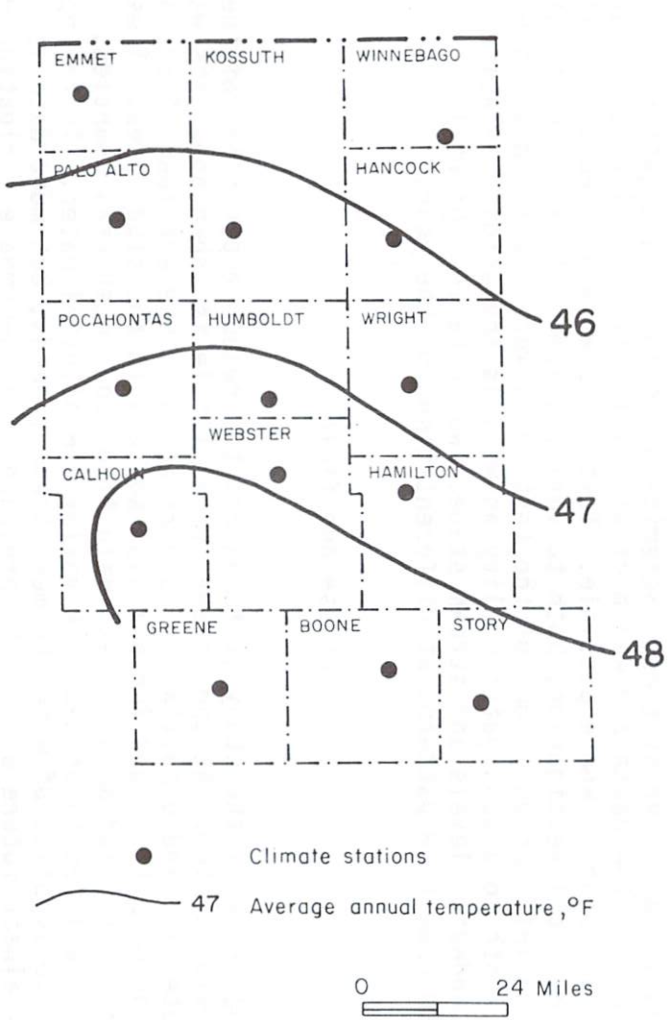


Figure 2. Mean annual temperatures in the study area (from Iowa Water Plan '78).

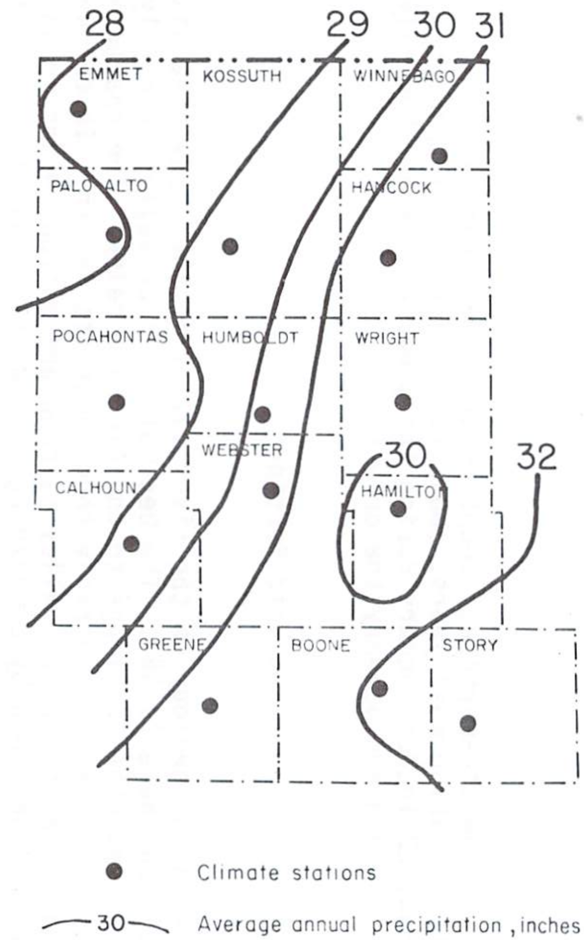


Figure 3. Mean annual precipitation in the study area. (from Iowa Water Plan '78).

from southeast to northwest--northwest counties are drier, east and southeast counties are wetter. During most years, about 75 percent of all precipitation, normally about 22 inches, occurs during the growing season. Normally, June is the wettest month and January the driest.

Geologic Setting

Previous work on the geology of the river valley in the study area was done by Lees (1916) and Hale (1955). The Des Moines River valley primarily originated as an ice-marginal drainage to the Algona Moraine. The character of the river's valley varies considerably throughout its length. In the upper reaches near Estherville, the river valley is deep and narrow, widening and becoming shallower to the south by Emmetsburg. In Webster and Boone counties, the river has cut a narrow, deep gorge which may be, in part, a re-excavation of older valleys. The river's associated alluvial deposits are underlain by a variety of geologic materials including glacial till, sandstone, limestone, dolomite, and shale.

STUDY OBJECTIVES

Hydrogeology

The geology and geometry of the alluvial valley has been evaluated to determine its water-storage capability as well as interconnections with other aquifers and surfacewater systems. Seismic-refraction investigations were done to determine the depth and width of alluvial fill as well as substrate composition and bedrock where possible. Test holes were drilled as a follow-up to the seismic investigation, both to verify seismic findings and to give more detailed information. Some of the test holes were developed as observation wells, both to assess water quality as well as investigate relationships between groundwater levels and stream stage. Water-table maps will be completed to show flow patterns at different times of the year.

Water Use and Yield

One objective of the study is to assess the resource potential of the Des Moines alluvial system. At the present time, little is known about its water-yielding potential and q antitative numbers on water use are few. There are 55 irrigation permits issued for alluvial sources in the study area. These permits are distributed among Emmet, Palo Alto, and Pocahontas counties. Five of the municipalities in or near the valley use alluvial water. There appears to be adequate supplies of water to meet present needs, but more data is needed to evaluate future uses. The presence of high-pumpage irrigation wells may allow pumping tests to be conducted to calculate transmissivities and storage coefficients for the aquifer.

Water Quality

A prime objective of this study is to assess the quality of the alluvial water and to relate any contamination problems to source where possible. Other areas of investigation included seasonal changes in nitrate concentration and distribution, precipitation and infiltration relationships and possible quality stratification in the aquifer.

Outside of some water-quality analyses from municipal sources and a few private analyses, little is known about the quality of water in the alluvial system. Hallberg and Hoyer (1982) and Hallberg et al. (1983) documented significant groundwater contamination of shallow carbonate aquifers in northeast Iowa. Studies by McDonald and Splinter (1982) and Saffinga and Keeney (1977) suggest that nitrate concentrations in water have been increasing over the past two decades. Other studies (Exner and Spaulding, 1979; Hegert et al., 1982, and Wehrmann, 1983) have demonstrated that infiltration of surface pollutants, in particular nitrogen, is a severe problem in shallow sand and gravel aquifers and can be related to the use of chemical nitrogen fertilizers and septic tank effluent. Pesticides have been found in alluvial systems in Wisconsin by Rothschild et al. (1982) and in Iowa by Richards et al. (1975).

PRELIMINARY GEOLOGICAL INVESTIGATIONS

A preliminary phase of this project included an evaluation 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 Iowa Geological Survey were researched for information about the alluvial system. Most wells of record were in upland areas away from the river. These were used to determine bedrock lithologies and, in some cases, to approximate the depth to bedrock. These data were supplemented with information obtained from Department of Transportation bridge borings and sand and gravel pit tests. Appendix I contains the tabulated information, and Figures 4 and 5 show location.

Soil maps obtained from county soil surveys were used to determine subsoil lithologies and possible depths to the sub-soil material (Fig. 6). Till-derived soils were generally found in positions corresponding to the valley slopes, and served as confirmation of the lateral boundary of alluvial materials. The soil maps proved very useful in the lower reaches of the river where numerous terraces exist. Some of these terraces are not connected with the alluvial aquifer, but are benched terraces, cut into till or bedrock and positioned above the modern floodplain. The relatively thin sand and gravel deposits on these benched terraces generally do not have permanent water tables. The presence of benched terraces could be determined from the soil maps because the terrace scarps were mapped as soils formed in till or bedrock, rather than sand and gravel.

In combination, these data, even in areas where most dense, are not sufficient to reconstruct the geometry of the alluvial aquifer. Most of the information on sand and gravel pits is in the form of minimum estimates of thickness of sand and gravel. The bridge borings provide reliable data, but only for the area immediately adjacent to the river. Few well logs in the alluvial valley are available. To obtain a more representative picture of the

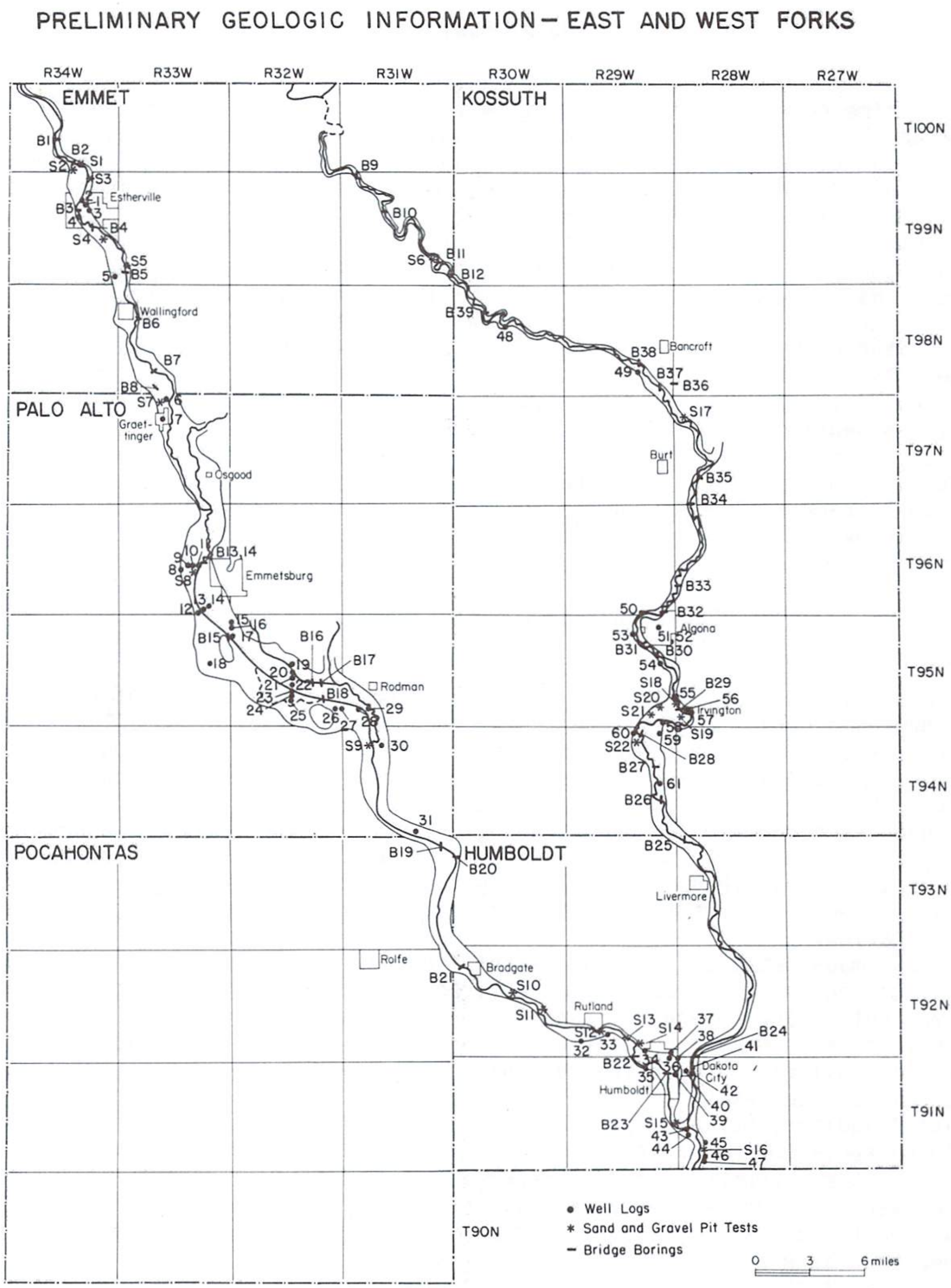


Figure 4. Location of well log, bridge boring, and sand and gravel pit data: East and West Fork.

PRELIMINARY GEOLOGIC INFORMATION— LOWER RIVER

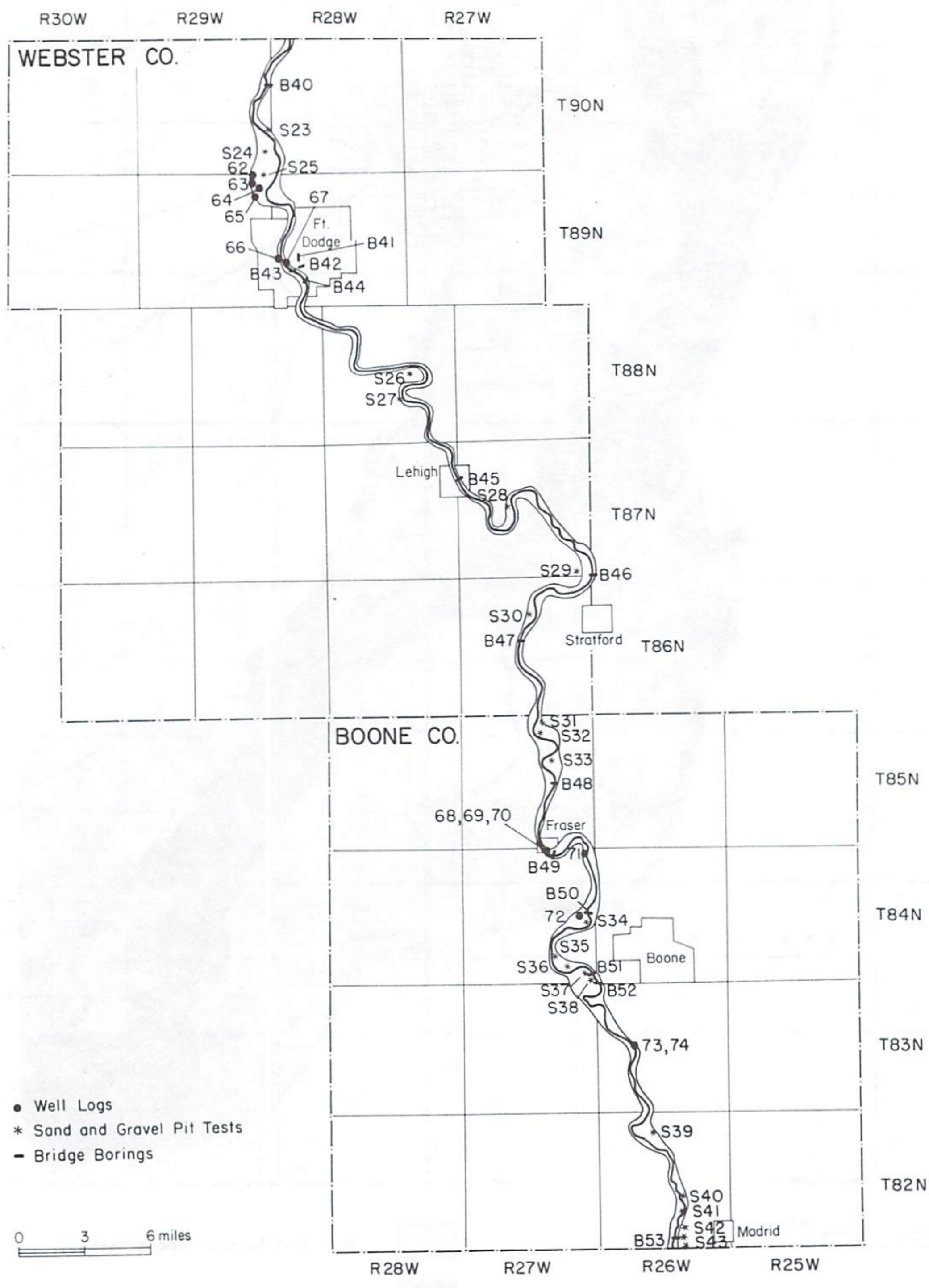
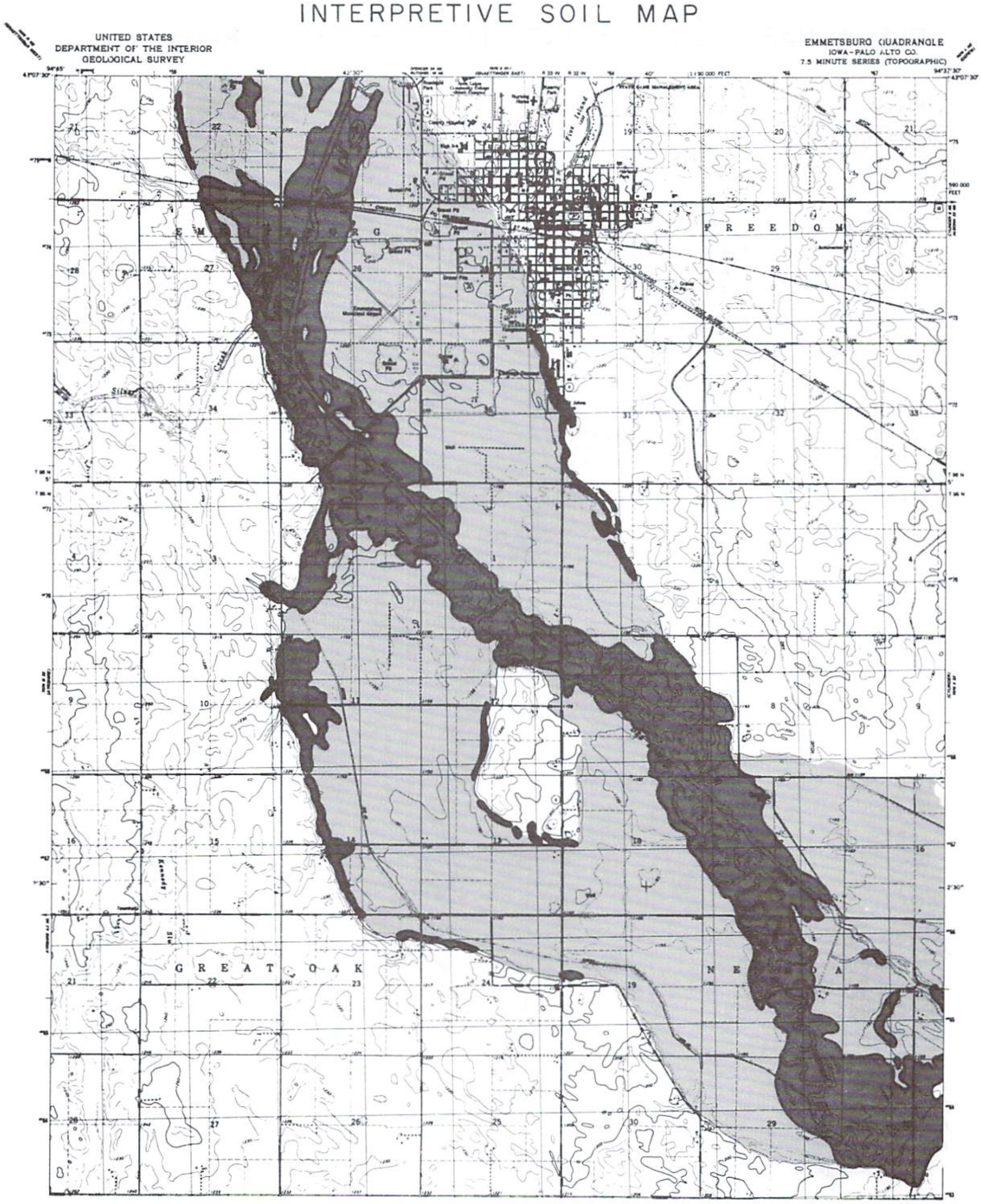


Figure 5. Locations of well log, bridge borings, and sand and gravel pit data: Lower River.

INTERPRETIVE SOIL MAP



0 1 mile

Underlain by sand and gravel

Underlain by silty alluvium

Underlain by wind blown fine sands

Figure 6. Example of substrate map prepared from soils data.

entire aquifer, it was necessary to collect new data. The conventional method for obtaining information in shallow systems is to drill a series of holes across the valley at various locations along the river. This approach, while providing highly accurate information on thicknesses and lithologies, is also very expensive. As an alternative, the method of seismic refraction was used. It was felt that the technique could be used as a rapid reconiassance method capable of giving reasonable depths and gross lithologies as well as the desired lateral control. A few selected drill holes would then be used to obtain further information in areas targeted by the seismic work.

SEISMIC REFRACTION

Theory and Previous Work

Seismic refraction methods have commonly been 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 layers of earth materials, then travel horizontally just below the contact, and are continually refracted back to the surface. Figure 7 schematically shows the raypaths followed by refracted sound waves in an ideal alluvial system.

For field measurements, a set of receivers, called geophones, are placed at increasing distances from the seismic sources. 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 of the first wave (Fig. 8). Geophones closest to the source may receive direct wave arrivals, those traveling directly along the land surface (path A-B-E-H on Figure 7). The first energy received by geophones further 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. 9). This is used to calculate average layer velocities. Other calculations are performed to determine the depth to the refracting surface.

Seismic refraction has long been used in groundwater studies. Bonini and Hickock (1958) and Warrick and Winslow (1960) all used refraction methods to delineate bedrock topography below unconsolidated deposits. Woolard and Hanson (1954) worked in a variety of environments 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 geologic 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. This is one of the few studies which

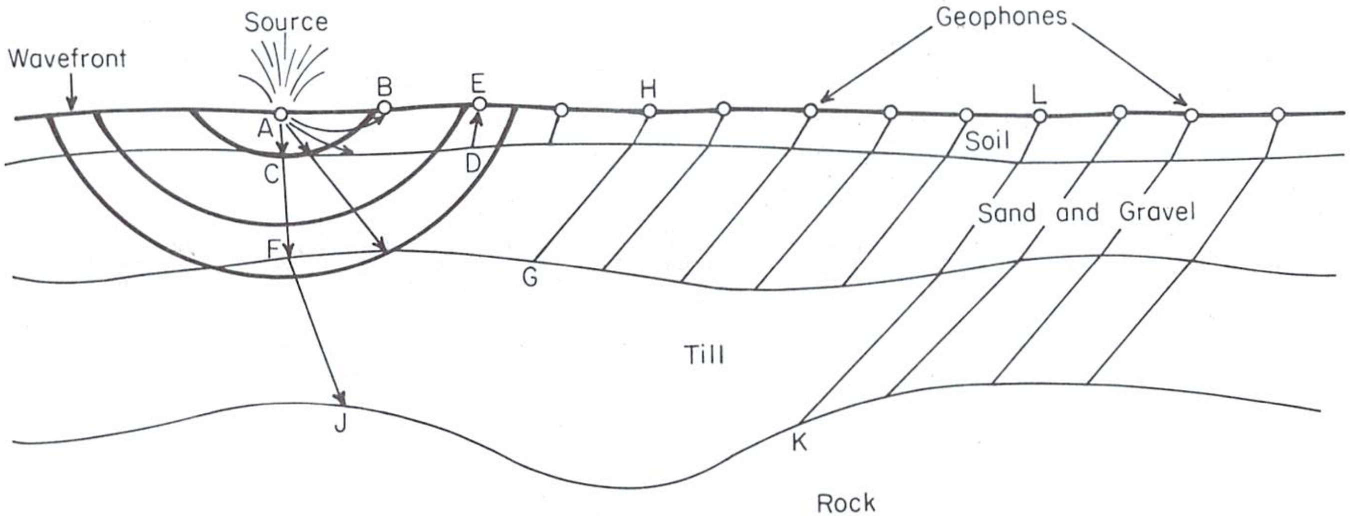


Figure 7. Schematic of sound wave propagation through a typical alluvial sequence. Letters refer to discussion in text.

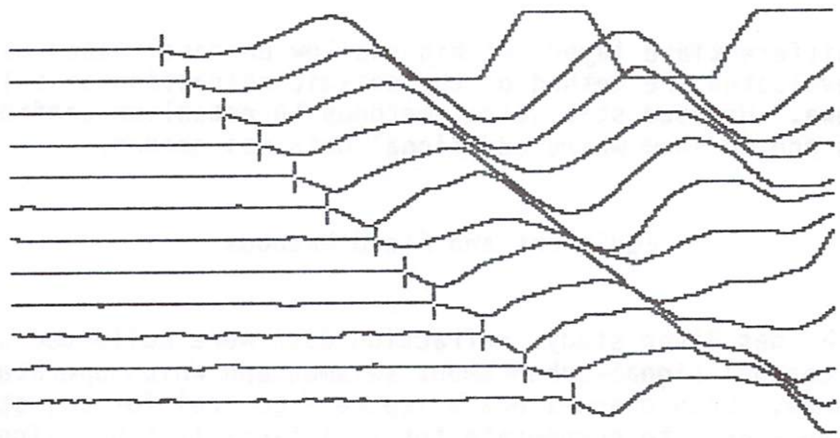


Figure 8. Typical seismogram. Tic marks indicate time of arrival of wave on each channel.

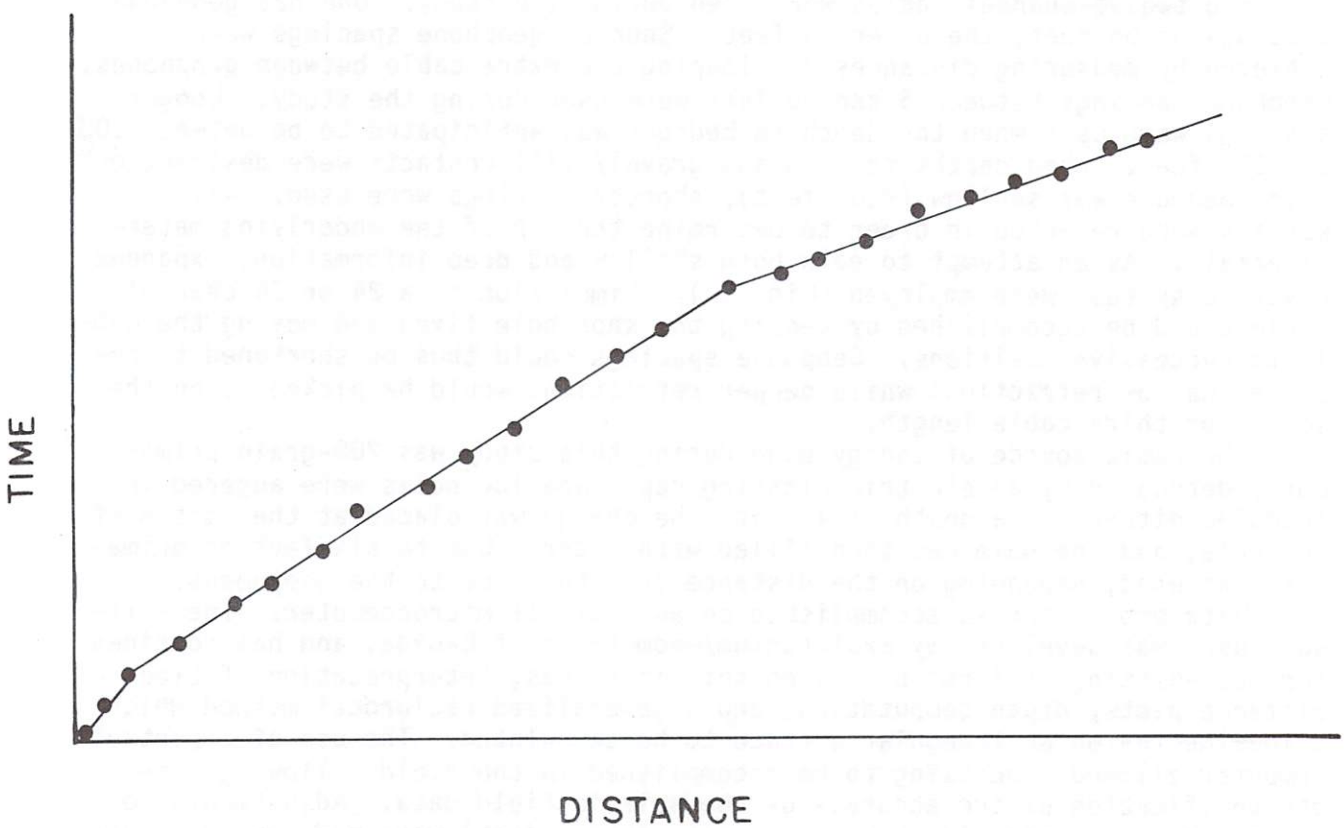


Figure 9. Idealized time-distance graph. Each slope segment represents refractions from a particular interface. The velocity of the unit is equal to the inverse of the slope.

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

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

Two twelve-channel cables were used during the study. One had geophone spacings of 55 feet, the other 25 feet. Shorter geophone spacings were achieved by measuring distances and looping the extra cable between geophones. Geophone spacings between 5 and 55 feet were used during the study. Longer spacings were used when the depth to bedrock was anticipated to be between 100 and 300 feet. When depths to sand and gravel/ till contacts were desired, or where bedrock was shallow (<100 feet), shorter spacings were used. All spreads were reversed in order to determine the dip of the underlying mater-materials. As an attempt to gain both shallow and deep information, expanded reversed spreads were employed (Fig. 10). Simulation of a 24 or 36 channel cable could be accomplished by keeping the shot hole fixed and moving the cable to successive positions. Geophone spacings could thus be shortened to receive shallow refractions while deeper refractions would be picked up on the second or third cable length.

The basic source of energy used during this study was 200-grain primacord, detonated by an electric blasting cap. Shallow holes were augered in roadside ditches to a depth of 4 feet, the charge was placed at the bottom of the hole, and the hole was then filled with water. One to six feet of primacord was used, depending on the distance from the shot to the geophones.

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

Geometry For 37 Station Expanded Reversed Spread

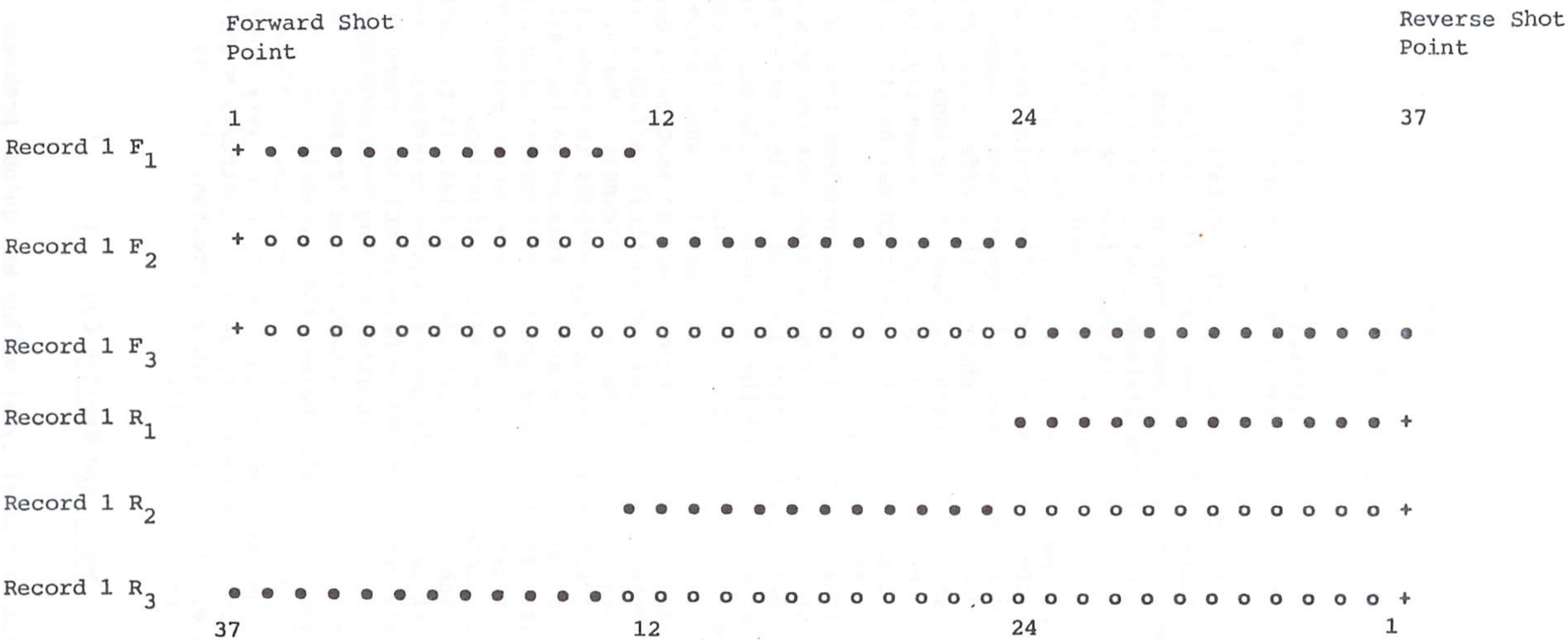


Figure 10. The procedure for shooting utilizes 6 shots; 3 forward, 3 reverse. Twelve channels are shot at a time. The filled circles are the receiving phones for each shot. The open circles are phone positions for previous shots. The + represents the shot hole location. The station spacing can vary for each spread depending upon depths to the refracting surface.

Results and Findings

Seismic Results

One hundred and thirty-one total spreads (456 shots) were run at 38 different locations (approximately 25 linear miles). Figures 11 and 12 show the location of each traverse.

There were considerably more problems in interpretation of the refraction data than had been anticipated. Direct wave arrivals, indicating surficial material velocities, were observed only when geophone spacings of less than 10 feet were used. Figure 13a is a time-distance plot (T-X) showing good fit to the data and recognizable slope breaks. It was infrequent, however, that all of the points could be fit to a straight line segment. Often the best possible fit would have required a curved surface (Fig. 13b), which result from either an irregular refractor surface or a laterally-varying velocities. Another common occurrence was displacement of time-distance segments (Fig. 13c). 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 changing of slope. Frequently, the time-distance plot will exhibit an increase in slope which may be attributable to laterally-varying velocities (Fig. 13b,c).

Domzalski (1956) discussed at some length the problems inherent in shallow-refraction investigations. One of his discussions concerns changes in surface material velocities caused by firing a shot, while another deals with the type of surface materials in which the geophones are placed. These effects can change arrival times 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 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 the time-distance plots. The bedrock refractor in most cases is irregular and weathered, either of which can greatly affect depth computations for shallow situations.

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) were observed to have velocities around 5000-6000 ft/sec. Glacial tills usually had velocities ranging from 6000-8000 ft/sec. Bedrock velocities observed averaged 7000-9000 ft/sec for shales, 8000-9000 ft/sec for Cretaceous sandstones and shales, and 11,000-13,000 ft/sec for the Mississippian and Devonian limestones. This presents two problems. First, the slope break changes on the 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 was found to occur frequently within the glacial till.

Boone and Webster Counties

Data from each area of the alluvial valley had unique problems, and interpretations achieved varying levels of accuracy. In Boone and Webster

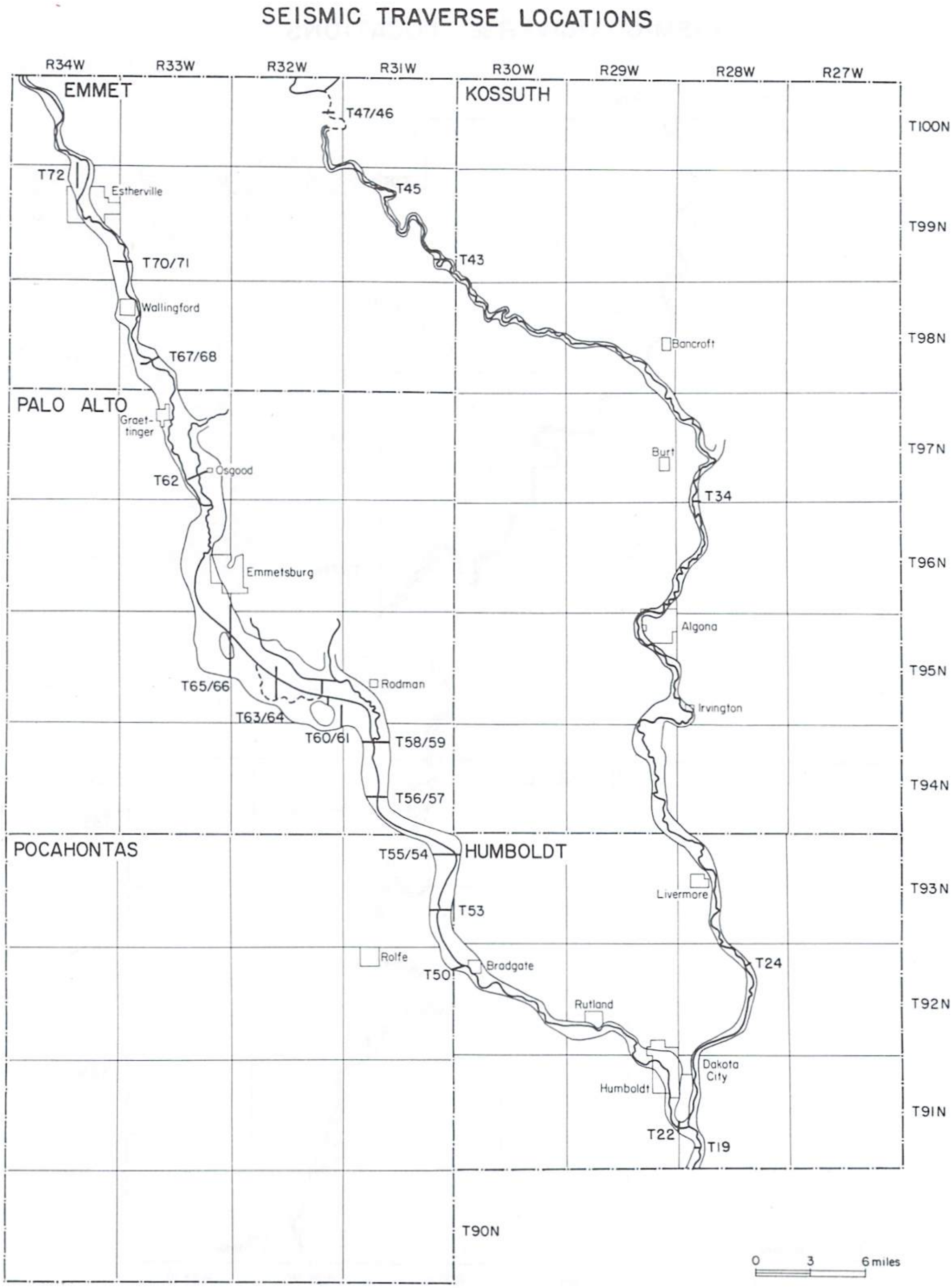


Figure 11. Location of seismic traverses: East and West Fork.

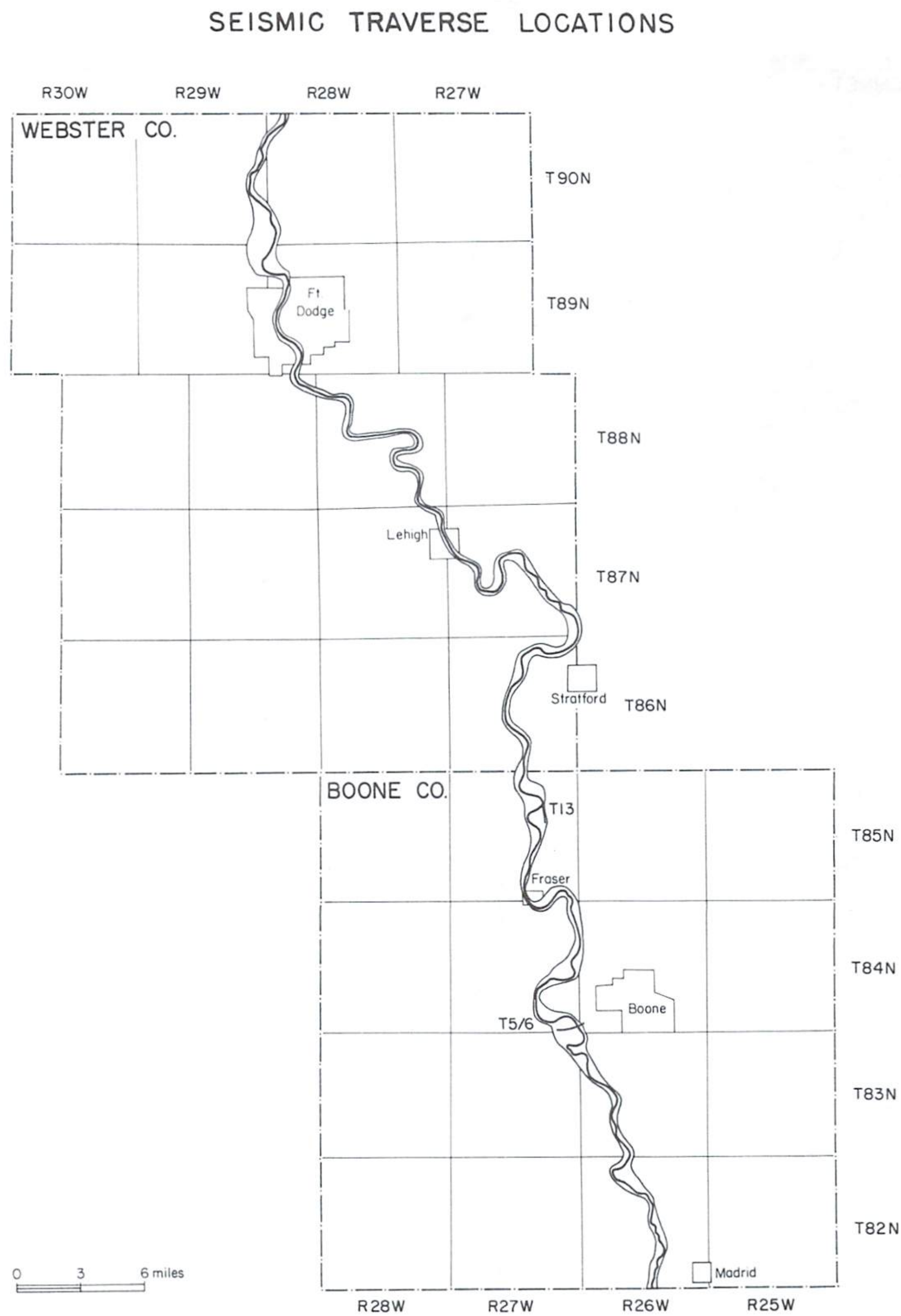
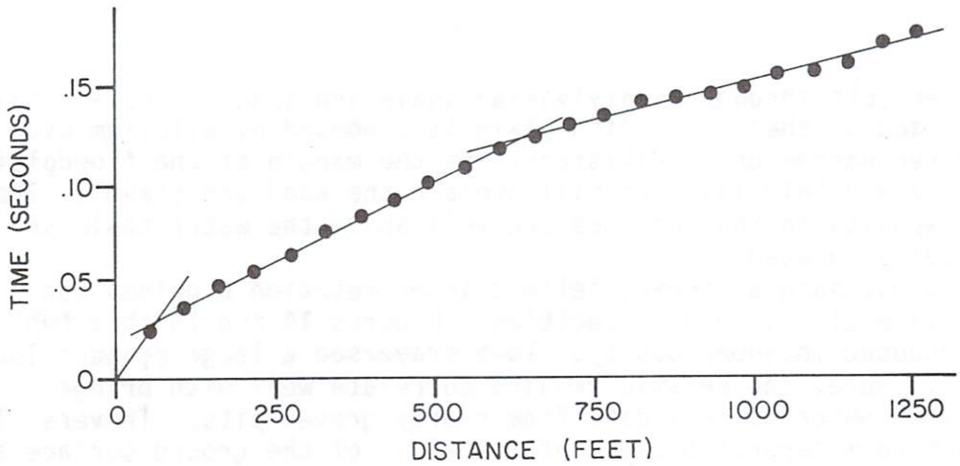
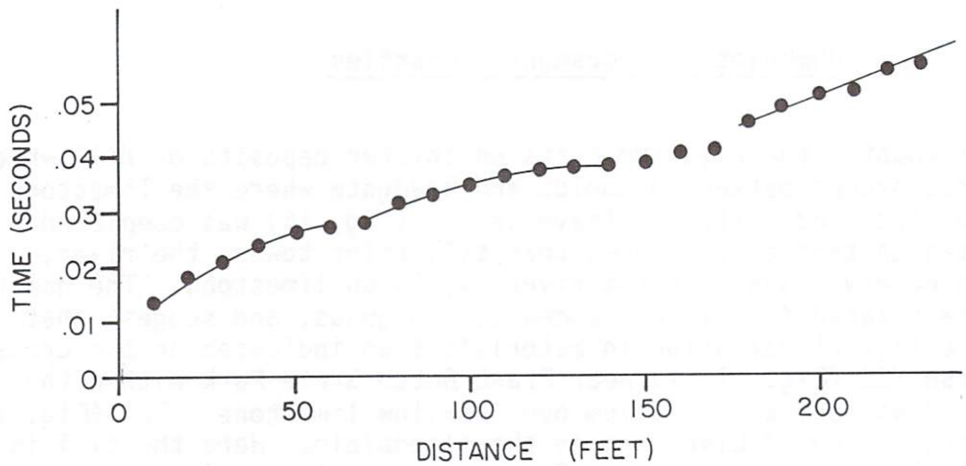


Figure 12. Location of seismic traverses: Lower River.





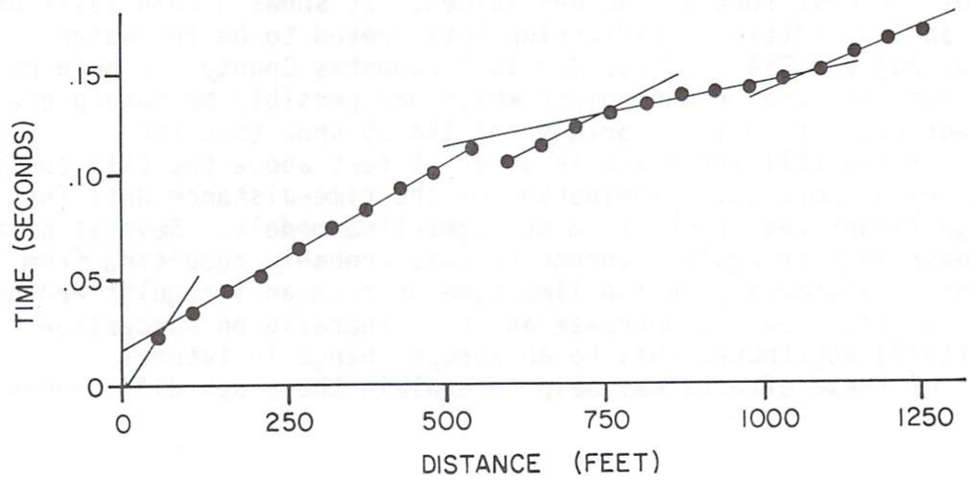


Figure 13 a,b,c. Examples of time-distance plots.

Counties, the river cuts through Pennsylvanian shale and sandstones, and has numerous terraces and benches. The floodplain is composed of alluvium over bedrock and is often narrow or non-existent. At the margin of the floodplain, terraces usually have a thin layer of till beneath the sand and gravel. The sand and gravel deposits in the terraces are well above the water table and are often not water saturated.

In terraced areas such as these, seismic interpretation problems can arise because of laterally varying velocities. Figures 14 and 15 show two cross sections produced in Boone County. T5-6 traversed a large meander loop on the floodplain. Here, the seismic results correlate well with bridge-boring data and with observational data from nearby gravel pits. Traverse T13 was more difficult to interpret because of the slope of the ground surface and noise on the traces. No seismic traverses were run in Webster County. For the most part, the river in Webster County is deeply entrenched and the floodplain is narrow.

Humboldt and Pocahontas Counties

In Humboldt County, the alluvium rests on thicker deposits of till which overlie limestone, except between Humboldt and Bradgate where the limestone is within 10 feet of the land surface. Traverse T19 (Fig. 16) was completed across a 50 foot-high terrace and shows that till thins toward the river. This agrees with observations that the river bed is on limestone. The depth and velocities calculated for T19 are somewhat ambiguous, and suggest that there may be more lateral variation in materials than indicated on the cross section. Traverse T22 (Fig. 17) is near Frank Gotch State Park within the floodplain, and shows soil and alluvium over shallow limestone. T24 (Fig. 18) is a short traverse south of Livermore on the floodplain. Here the till is considerably thickened over limestone. On the land surface this is expressed by a rise in elevation of over 100 feet, but in subsurface the Mississippian bedrock remains at a relatively constant elevation. T49-50 (Fig. 19) is on the floodplain of the west fork of the Des Moines. It shows a thin layer of sand and gravel and an additional refraction interpreted to be the water table. T53 (Fig. 20) and T54-55 (Fig. 21) in Pocahontas County are both on the floodplain, but have one or two points which may possibly be interpreted as Cretaceous bedrock. The bridge borings for T54-55 show that the seismically-interpreted till interface is about 11 feet above the till contact determined from bridge borings. Examination of the time-distance data for T54-55 shows significant deviations from straight-line models. Several of the T-X plots have extremely irregular bedrock curves, probably resulting from either variations in weathering on the limestone or from an irregular bedrock surface. Slope is often seen to decrease and then increase on successive segments. Murphy (1977) attributed this to an abrupt change in lateral velocities. All of these effects may help to explain the depth differences observed.

Palo Alto County

Along the West Fork of the Des Moines in Palo Alto County, the river valley widens to over 2 miles southeast of Emmetsburg. The valley floor is

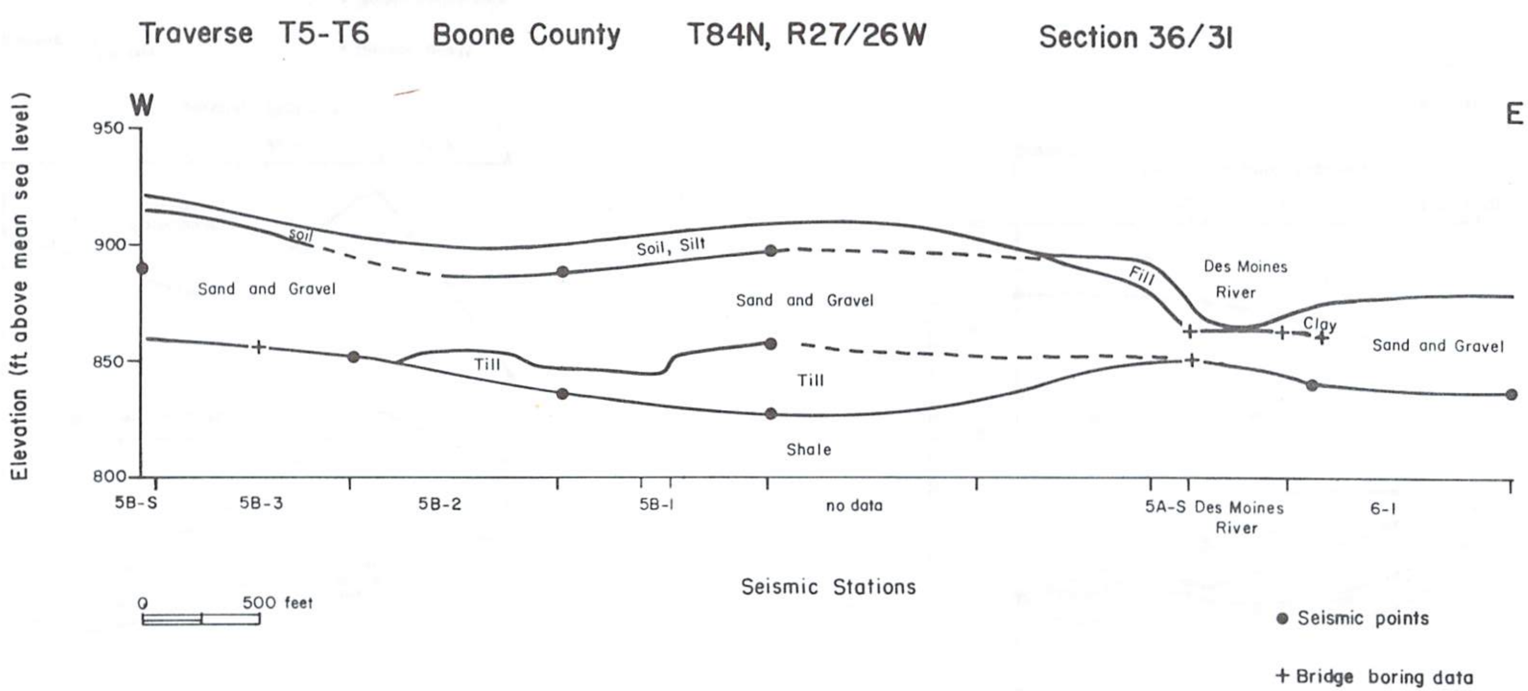


Figure 14. Seismic profile section: T5-6.

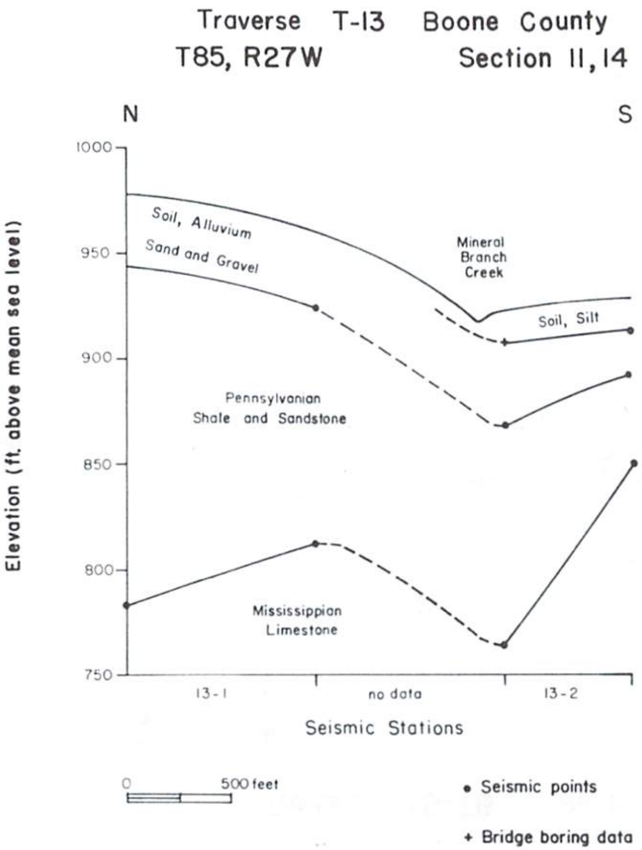


Figure 15. Seismic profile section: T13.

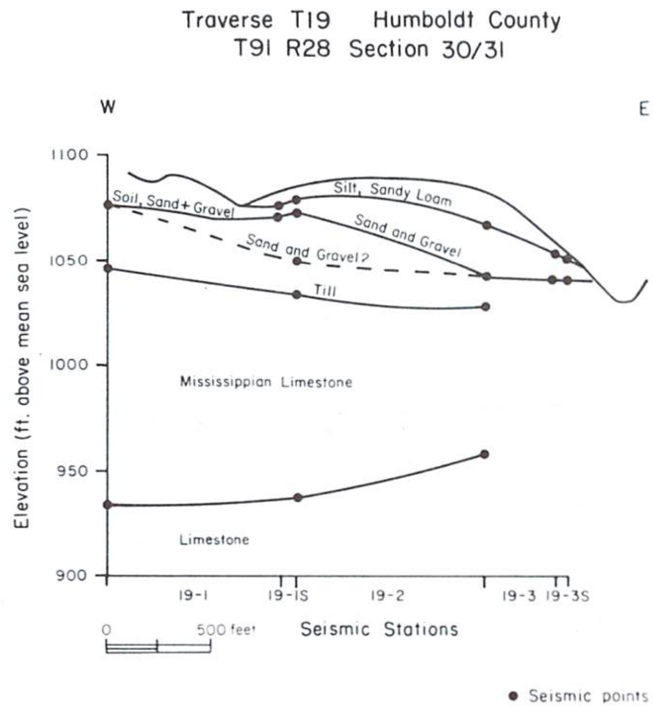


Figure 16. Seismic profile section: T19.

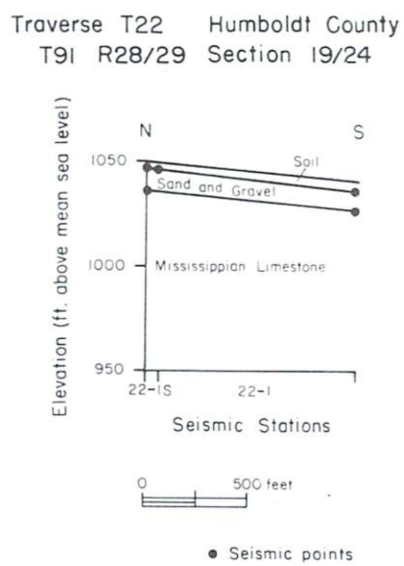


Figure 17.
Seismic profile section: T22.

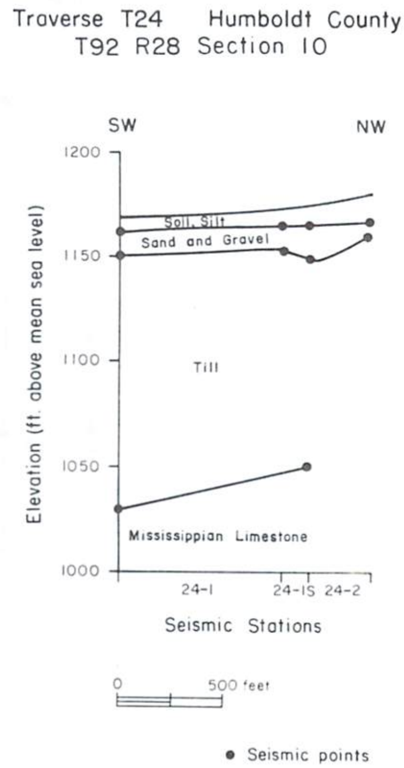


Figure 18.
Seismic profile section: T24.

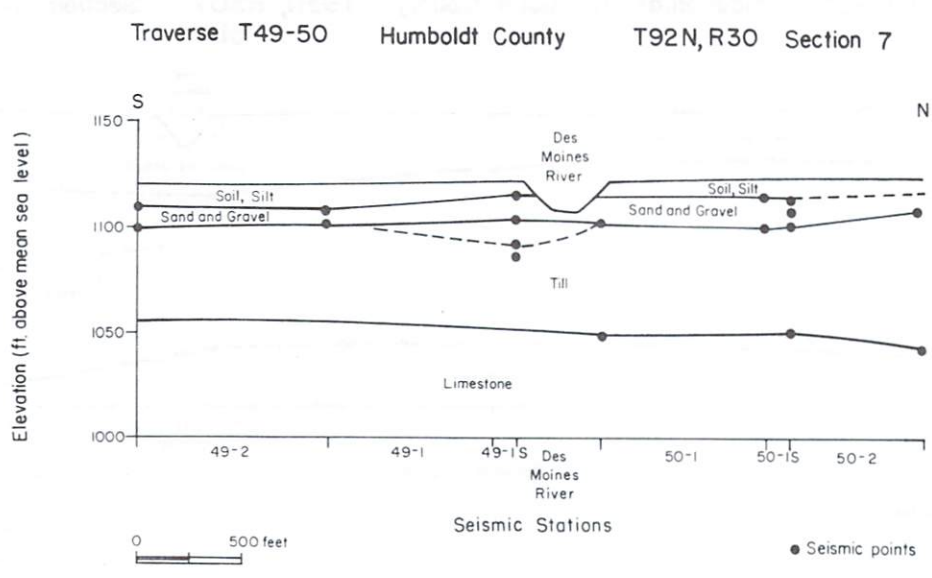


Figure 19. Seismic profile section: T49-50

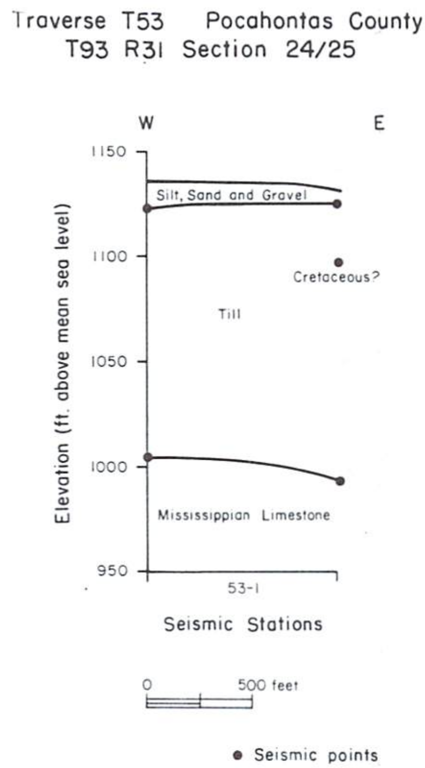


Figure 20. Seismic profile section: T53.

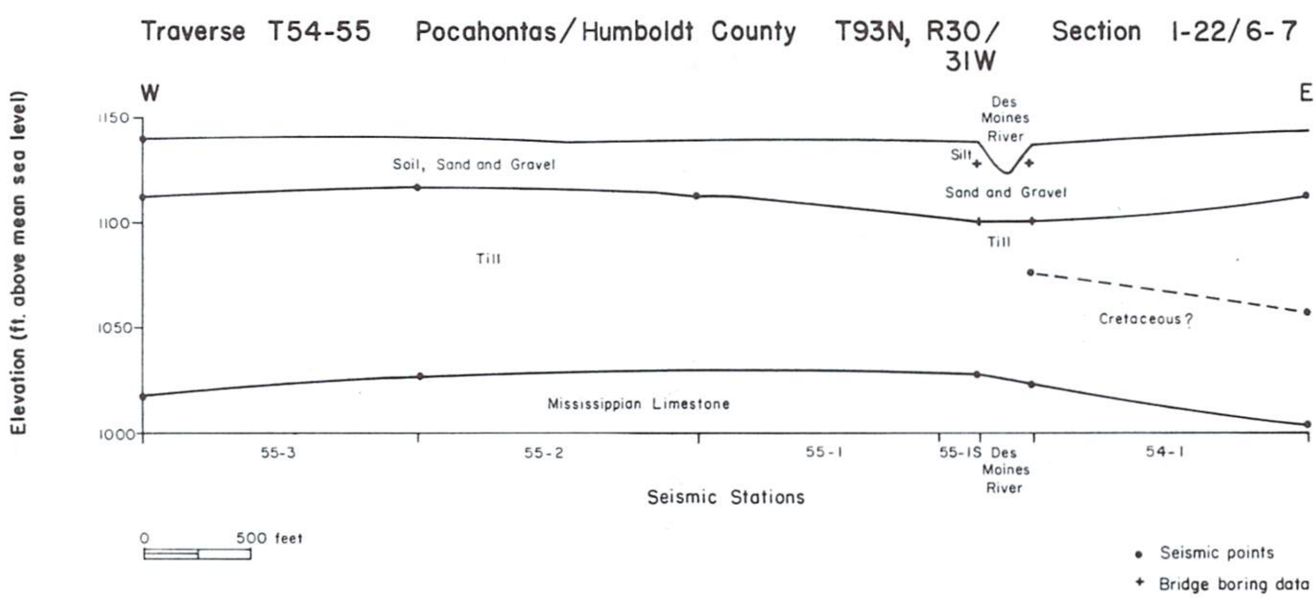


Figure 21. Seismic profile section: T54-55.

very flat and the walls rise to only about 20-30 feet above it. This is a large outwash plain formed during melting of the glaciers. The river flows in a straightened channel in the southern half of the county where considerable land on the floodplain is irrigated. Traverse 58-59 (Fig. 22) shows several interesting features. The sand and gravel reaches a thickness of greater than 50 feet in an outwash channel cut into the till. The seismically derived top of the till agrees well with the test-hole data. The Dakota Formation (Cretaceous) is about 33 feet below its seismically interpreted position according to drilling data. The presence of a low-velocity layer of basal sand could account for this discrepancy. With the presence of such a low-velocity layer computed depths would be greater because of the retarding effect of the sand. The surface of the Devonian limestone would also be more shallow than is shown. The top of the sand and gravel layer was detected, and probably corresponds with the water table.

Traverse 60-61 (Fig. 23-25) is more ambiguous. All of the seismically derived surfaces appear to be lower than actual surfaces. This may be related to errors of interpretation or to some inherent property of the surface materials, possibly variations in velocity. Traverse 63-64, (Figure 26) while having an accurate sand and gravel/till interface, shows three other surfaces which were assumed to correspond to levels within the Dakota Formation. Traverse 65-66 (Fig. 28) was the longest traverse completed (in this reach), and shows an interesting surface feature; a high in the floodplain which may have been an island in the paleoriver. The interpreted depth to the till surface appears to be fairly accurate. However, the simple picture shown by the seismic data, till over limestone, is highly misleading when compared with the drilling data. The drilling data shows that there are several till layers as well as interlayered sand and gravel. The presence of these low-velocity layers should make the layer labeled as "shale-limestone" more shallow, so that it may correspond to the shaly layer seen in the deep drill hole. Cretaceous rocks were not detected in this traverse, which agrees with other data that show a large bedrock channel in this area. T 62 (Fig. 27) shows till over Dakota, over Devonian limestone. The Devonian is topographically 100 feet lower than farther south in the County. There are alternate surfaces to which the top of the till might correspond, but there is no way of confirming this without drill data.

Emmet County

The river valley of the West Fork in Emmet County is narrow and well-defined by walls rising 60 feet or more. Just north of Estherville, the river comes off the Algona moraine and flows along its edge until it leaves the county. The west valley wall throughout this length is steeper than the east wall. There are several large gravel terraces north of Estherville and also near Wallingford.

The three seismic cross-sections from the west fork are nearly identical (Figs. 29-31). Agreement with the till interface is good. The stratigraphic sequence appears to be sand and gravel over till (100-200 feet thick), over Cretaceous shale and sandstone. Sand and gravel thicknesses are 10-20 feet.

The East Fork of the Des Moines River flows out of Tuttle Lake. The river flows through a sag in the morainal material which forms a valley that

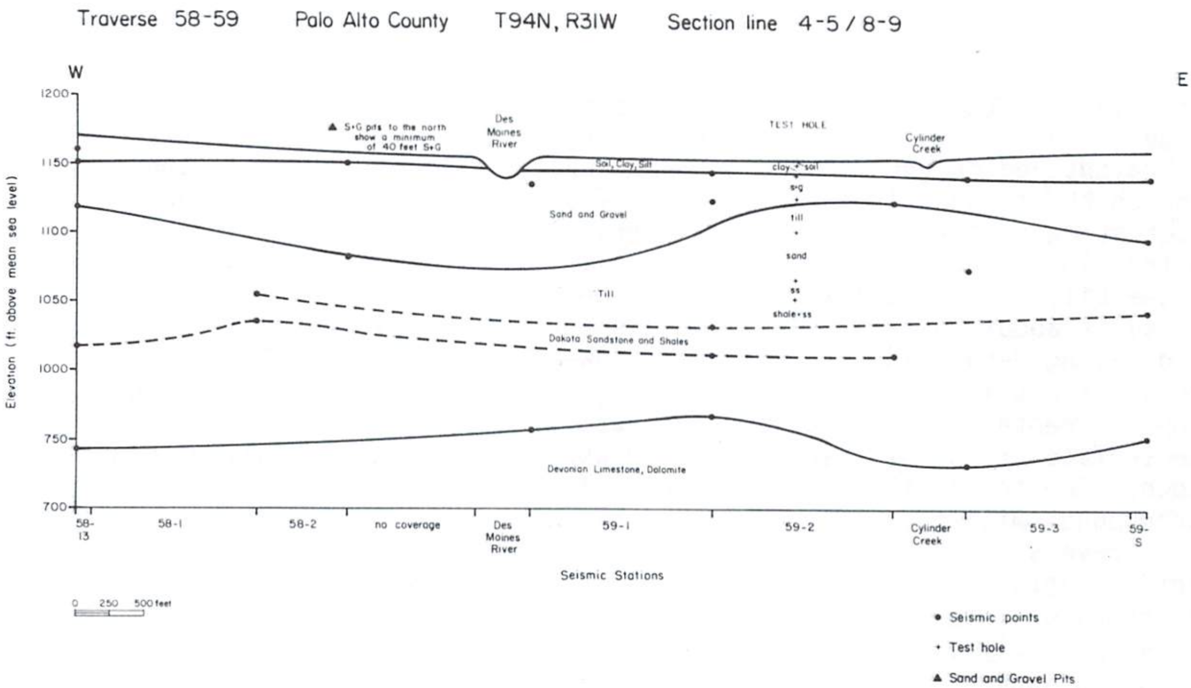


Figure 22. Seismic profile section: T58-59.

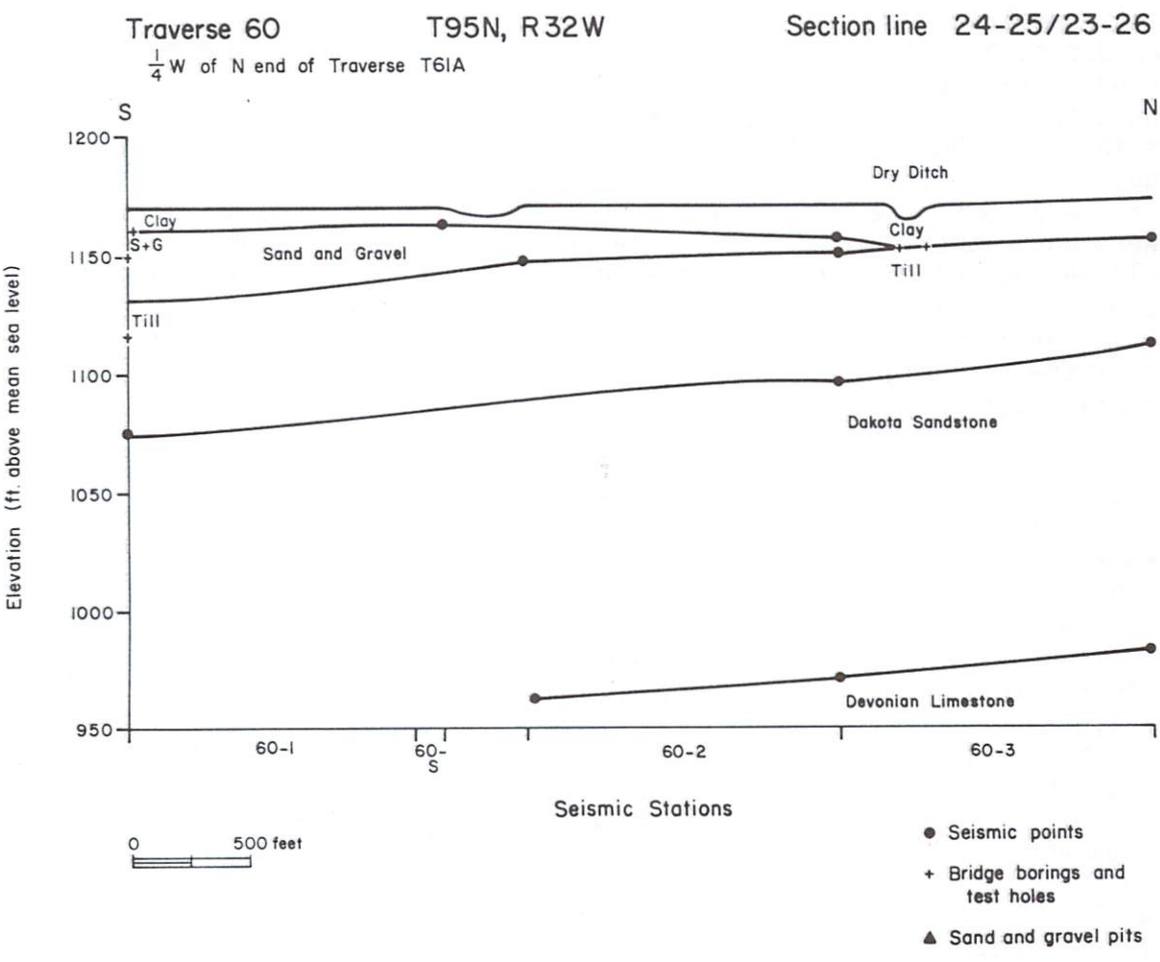


Figure 23. Seismic profile section: T60.

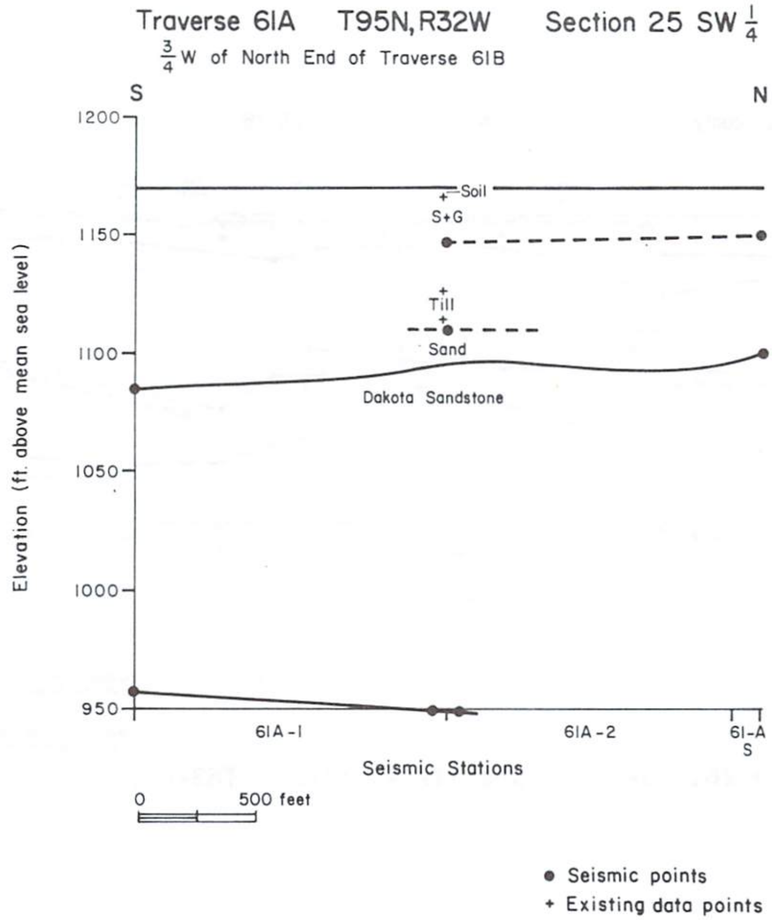


Figure 24. Seismic profile section: T61A.

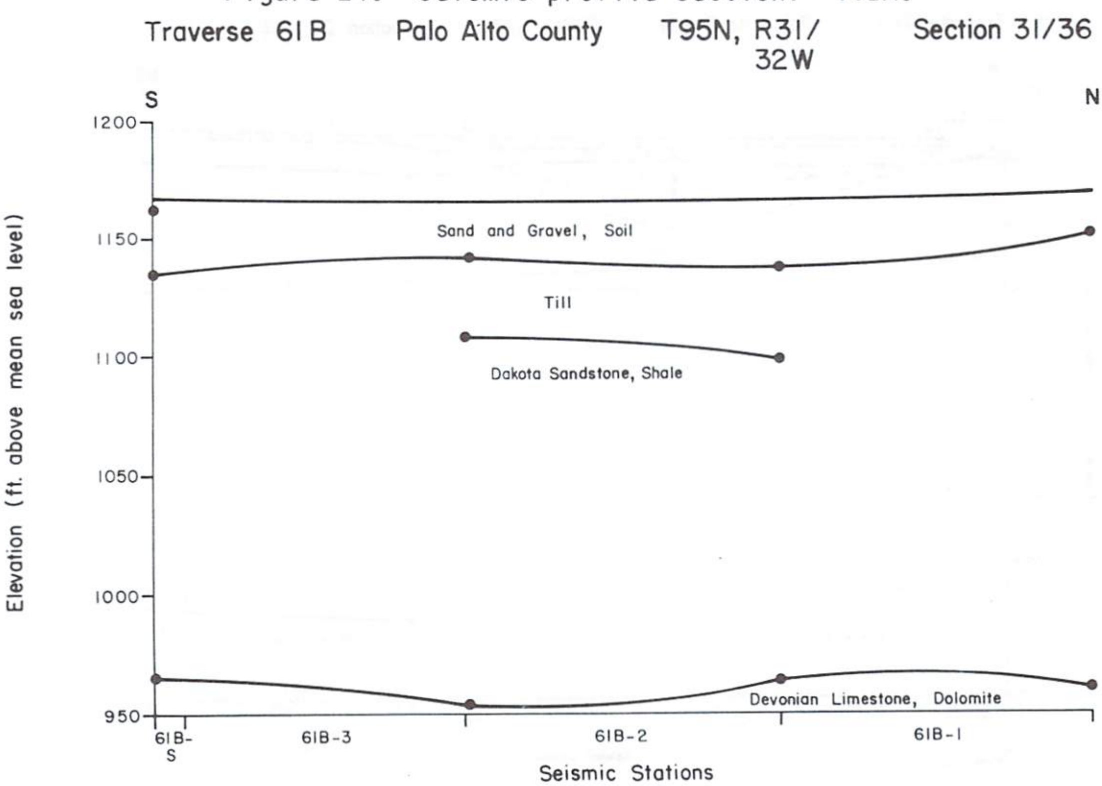


Figure 25. Seismic profile section: T61B.

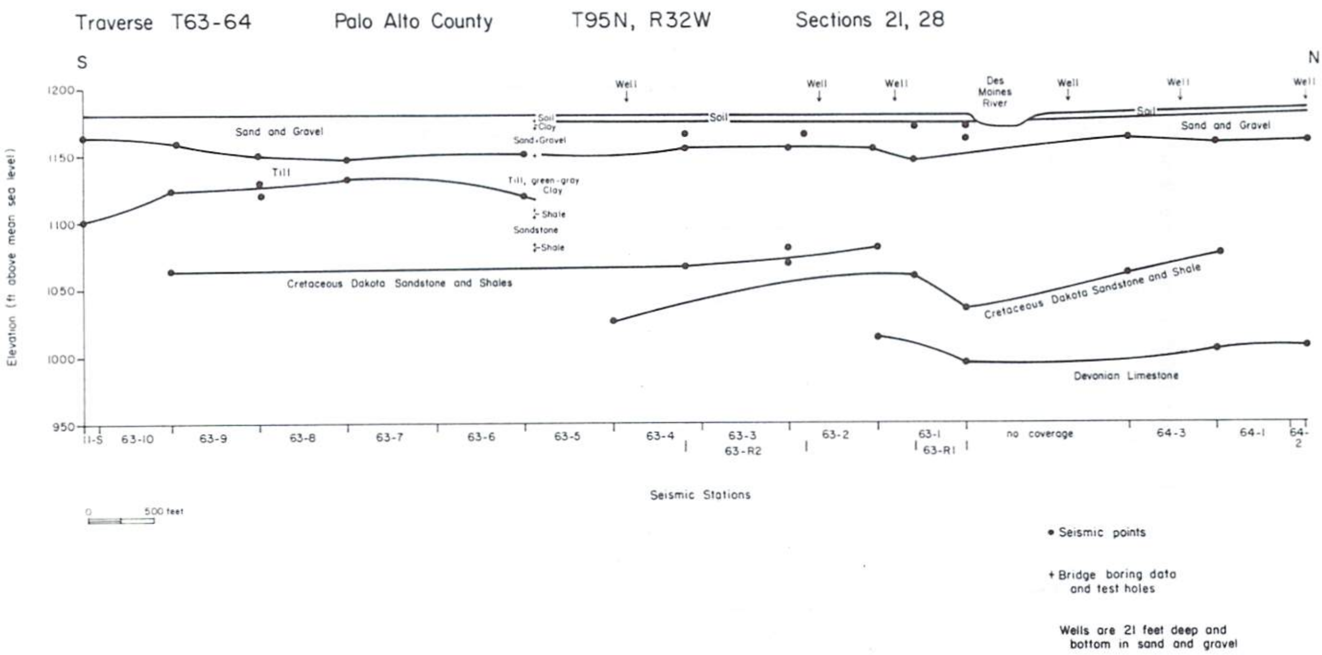


Figure 26. Seismic profile section: T63-64.

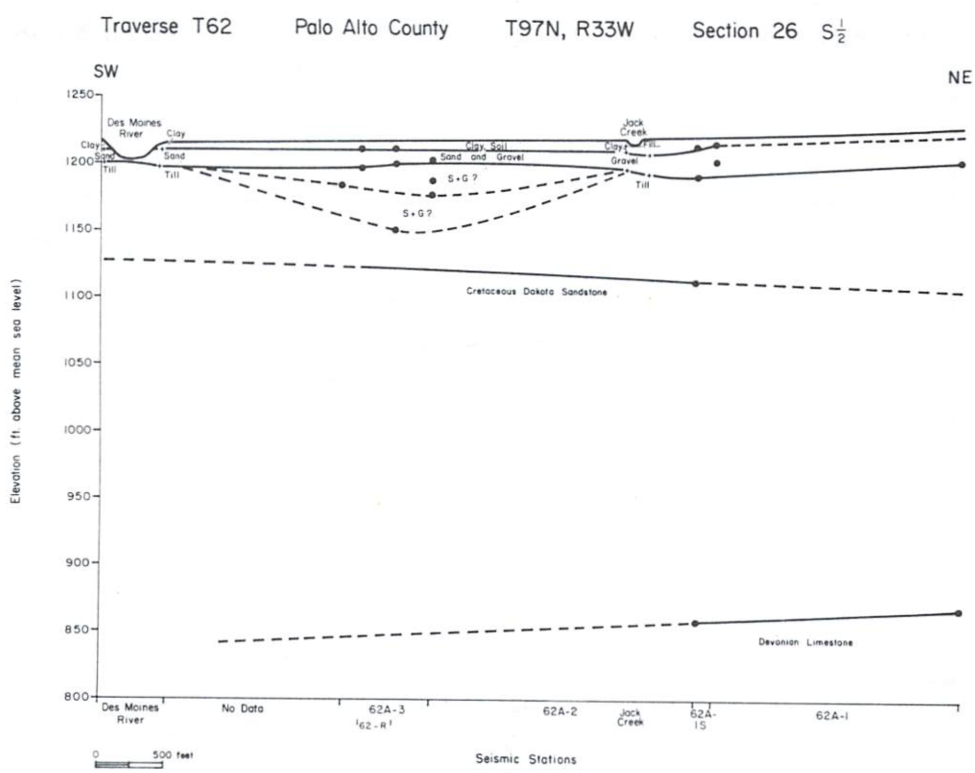


Figure 27. Seismic profile section: T62.

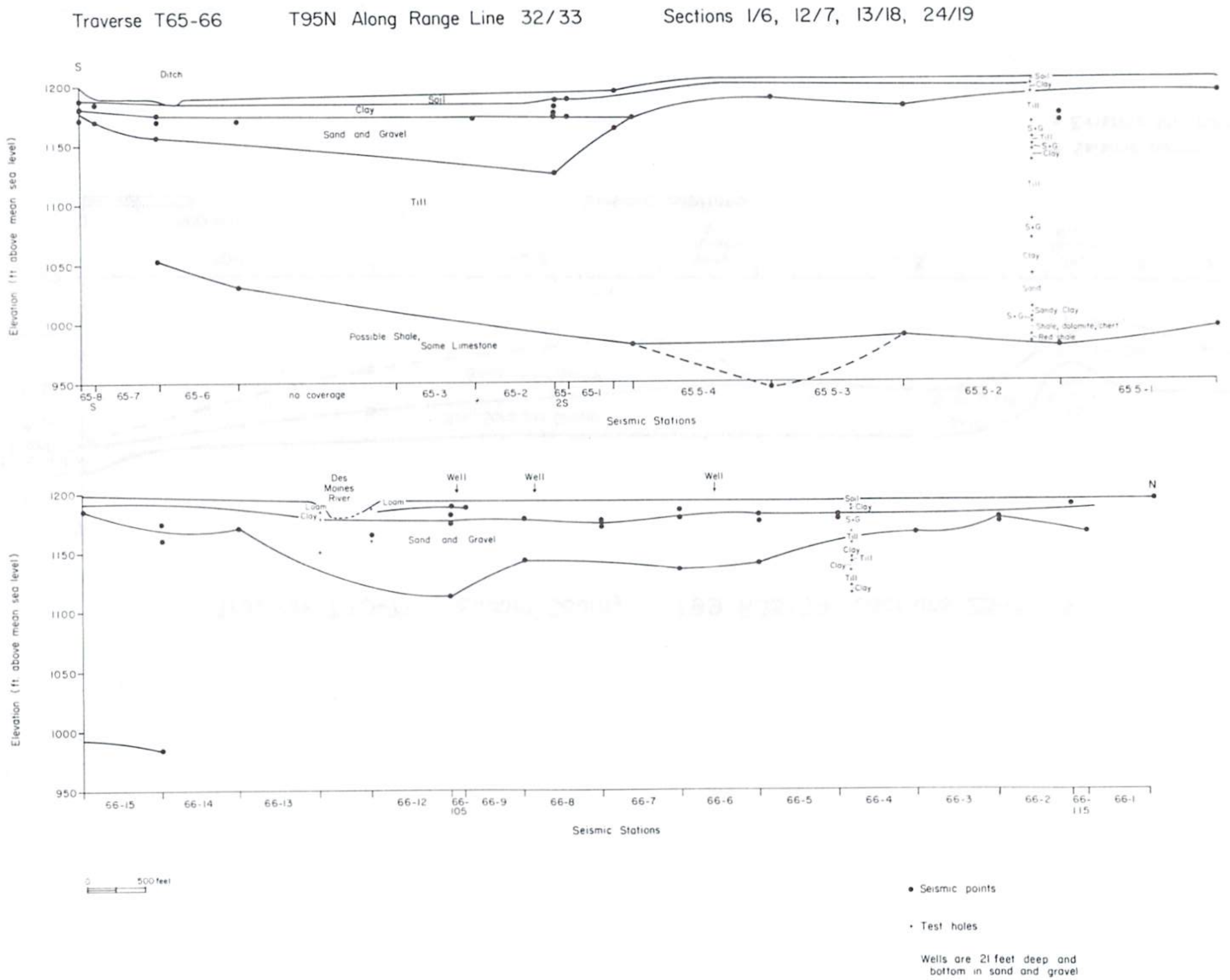


Figure 28. Seismic profile section: T65-66.

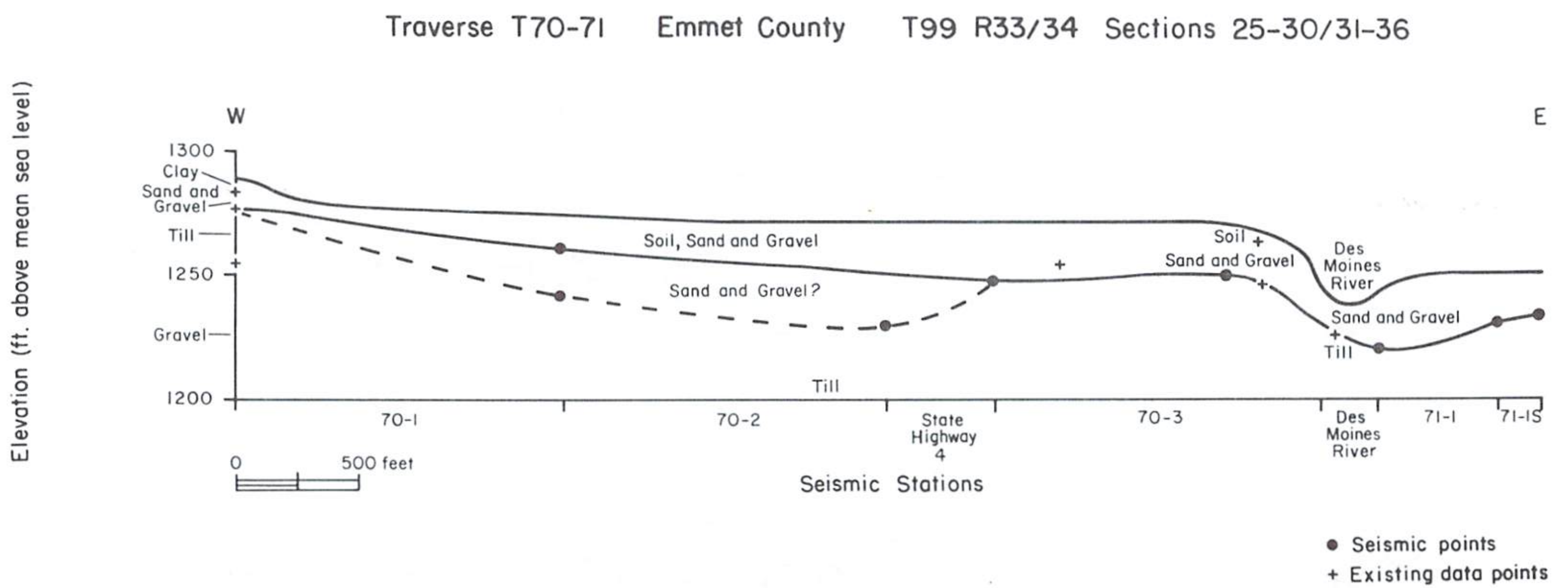


Figure 29. Seismic profile section: T70-71.

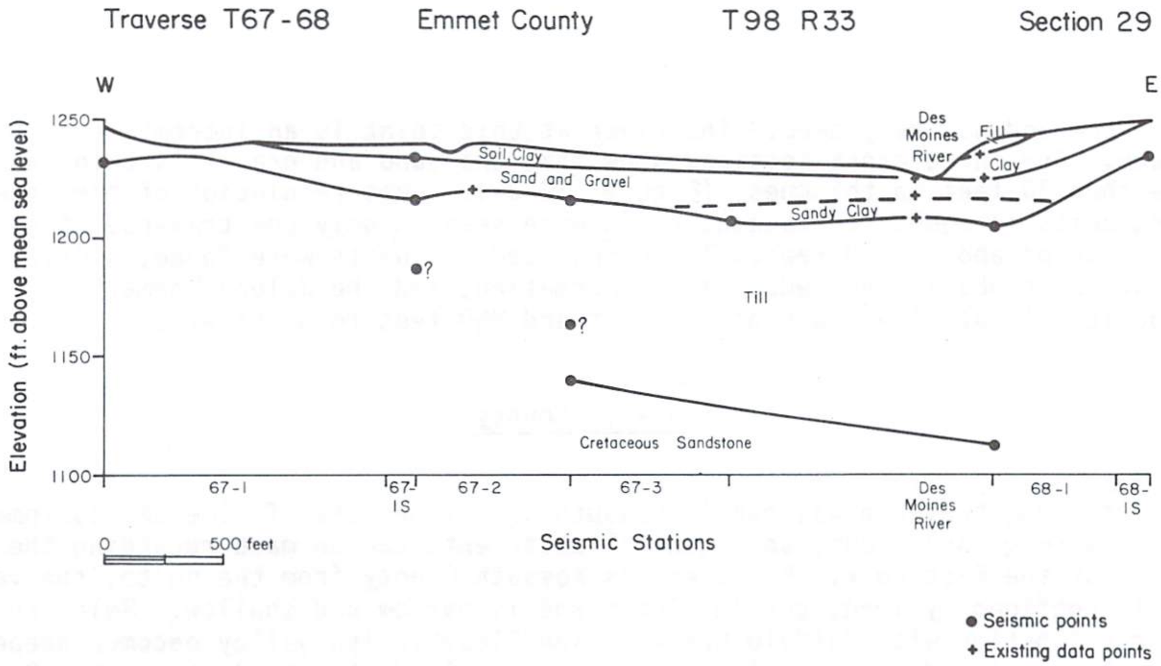


Figure 30. Seismic profile section: T67-68.

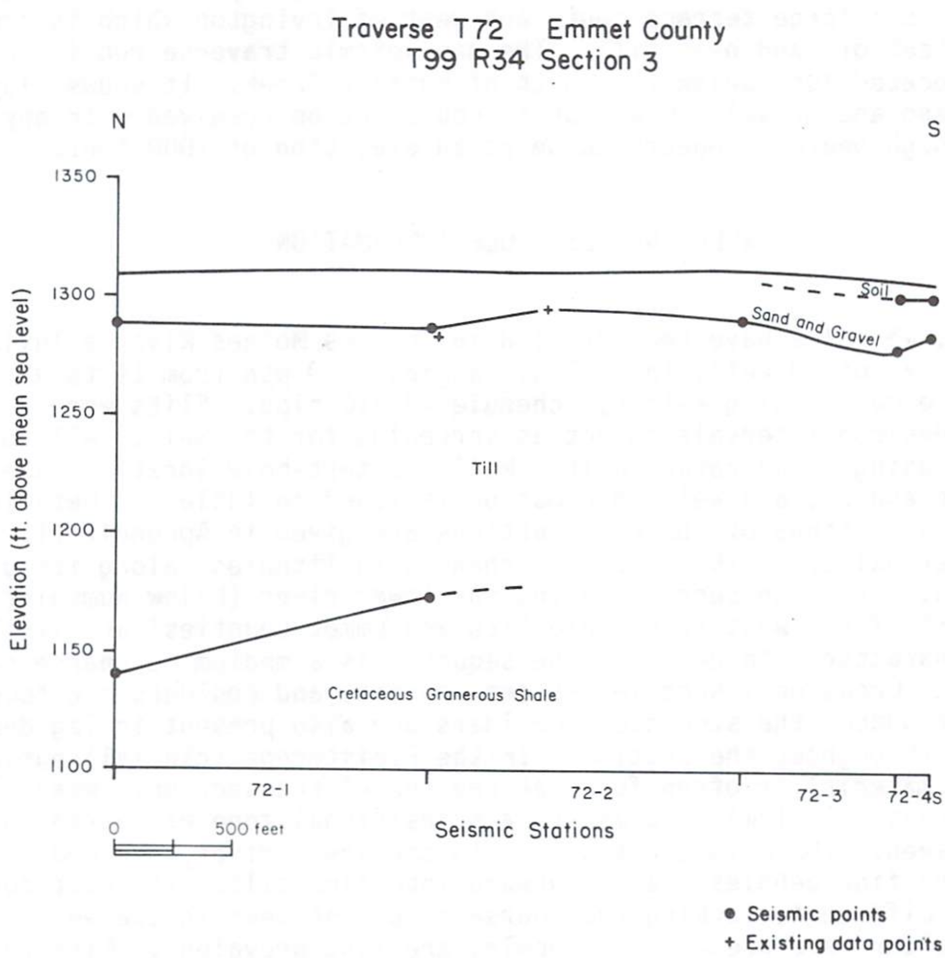


Figure 31. Seismic profile section: T72.

is narrow and not very deep. The river at this point is an intermittent stream. The three cross-sections show that the sand and gravel is thin, no more than 20 feet in thickness (Figures 32-34). Less resolution of the underlying units is seen. Cretaceous rocks were seen in only one traverse at an elevation of about 1000 feet. Two deeper bedrock units were found, a Devonian limestone, probably the Cedar Valley Formation, and the Galena Formation (Ordovician), at elevations of 950 feet and 850 feet respectively.

Kossuth County

Only one traverse was run in Kossuth County because of time and equipment problems (Fig. 35). But, some general statements can be made regarding the valley of the East Fork. As it enters Kossuth County from the north, the valley is confined by long, gentle slopes and is narrow and shallow. Below the river's junction with Buffalo Creek (Union Slough), its valley becomes deeper and better defined. Both valley walls rise to 40 feet near Burt and to 80 feet near Algona. Lees (1914) has hypothesized that the river, below its junction with Buffalo Creek, is occupying the drainageway of a former glacial lake. There is a large terrace south and west of Irvington which is composed of up to 30 feet of sand over till. The one seismic traverse run in the county was located just below the mouth of Buffalo Creek. It shows clay over 20 feet of sand and gravel. Lower units could not be resolved with any certainty, although bedrock appears to be at an elevation of 1000 feet.

WELL AND TEST-HOLE INFORMATION

To date, 45 holes have been drilled in the Des Moines River alluvial system, and a total of 30 wells installed, ranging in depth from 14 to 93 feet. All wells were cased using 2-inch, schedule 40 PVC pipe. Slits were cut into the pipe at desired intervals to act as screening for the well. All holes were drilled using a mud rotary unit. Well and test-hole locations are shown in Figures 36 and 37, and well information is found in Table 1. Detailed lithologic descriptions of the well cuttings are given in Appendix II.

The river valley exhibits several changes in lithology along its different stretches. The high terraces along the lower river (below Humboldt) and the upper part of the west fork (Palo Alto and Emmet counties) are similar in lithologic character. In general, the sequence is a medium to coarse sand with cobbles. Occasional sand lenses are present, and boulders are found scattered throughout the sequence. Boulders are also present in lag deposits at intervals throughout the section. In the Pleistocene (glacial) outwash, the coarsest material is often found at the top of the section. Where the Holocene (recent alluvium) is present, a transitional zone of coarse to fine sand can be seen. The Holocene sequence in the lower river is a medium to coarse sand to fine pebbles grading upward into fine silt. The east fork is considerably different, lacking the coarse component seen in the west fork. Almost no boulders are present and cobbles are less prevalent. Fine to coarse sand with fine gravel is most commonly seen. These lithologies can be related to geomorphic regimes of the river during deposition and will have a significant affect on the water flow patterns and water quality characteristics

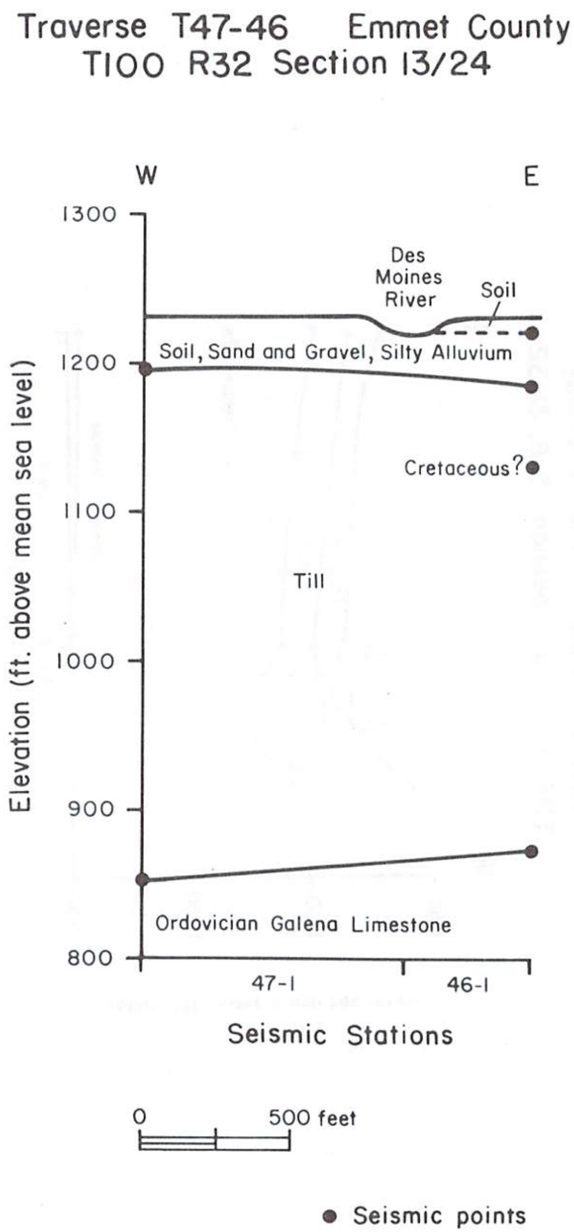


Figure 32. Seismic profile section: T47-46.

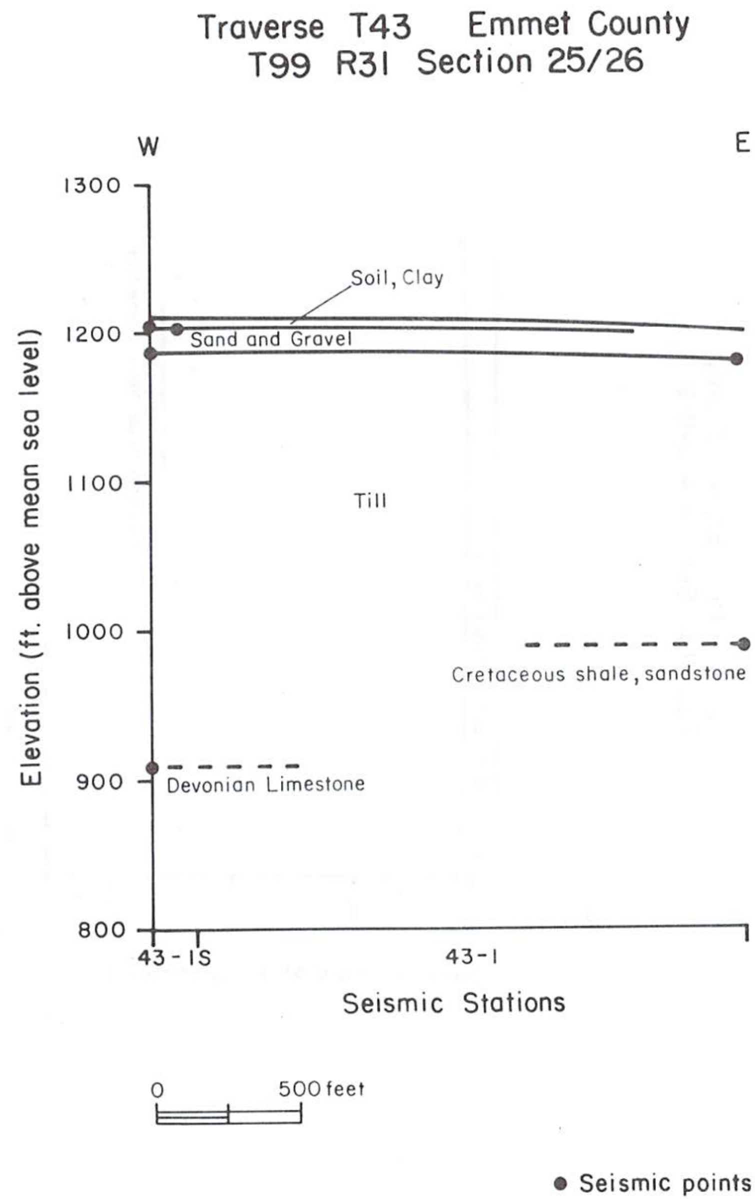


Figure 33. Seismic profile section: T43.

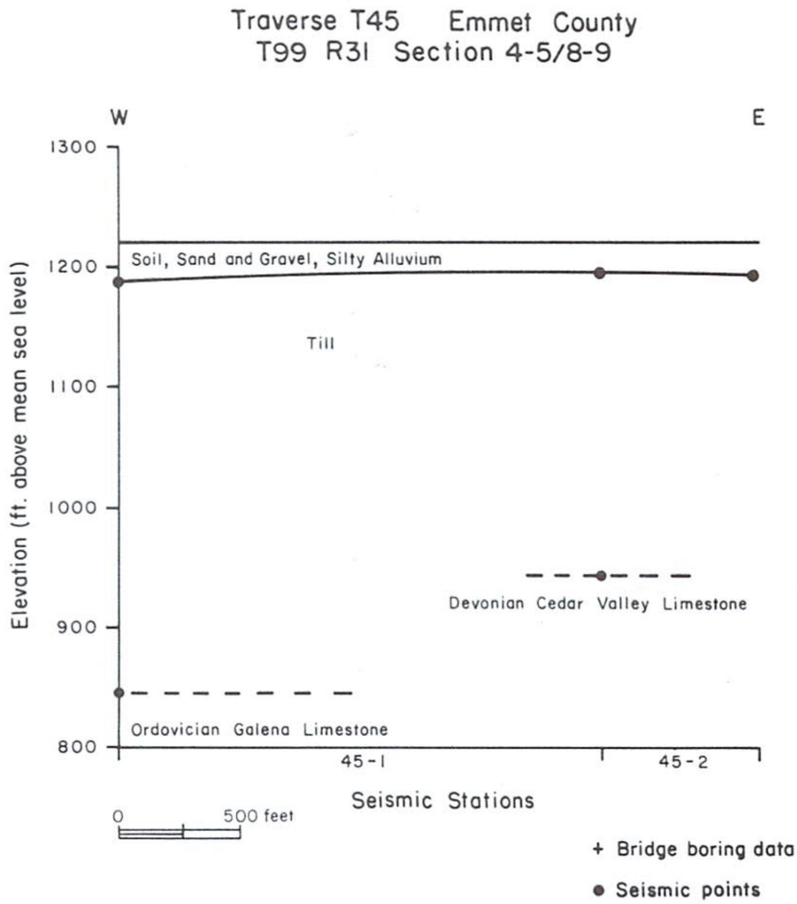


Figure 34. Seismic profile section: T45.

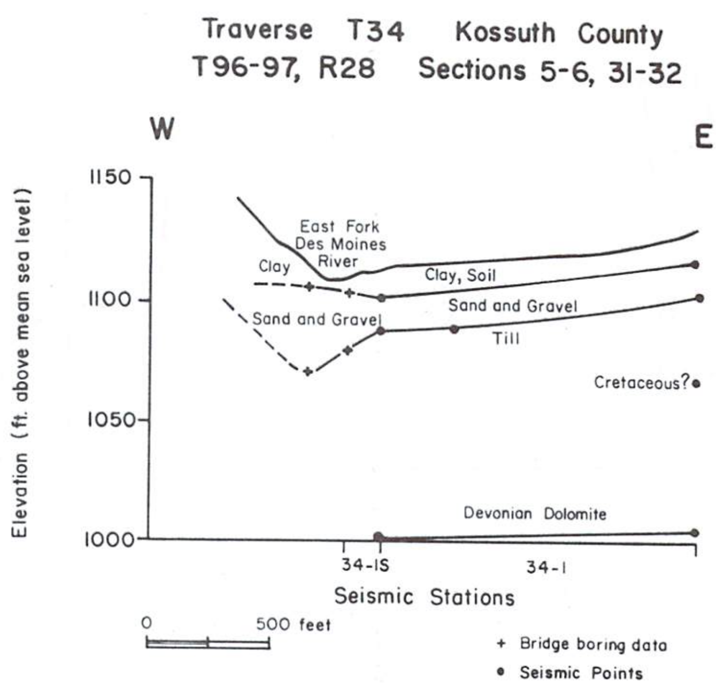


Figure 35. Seismic profile section: T34.

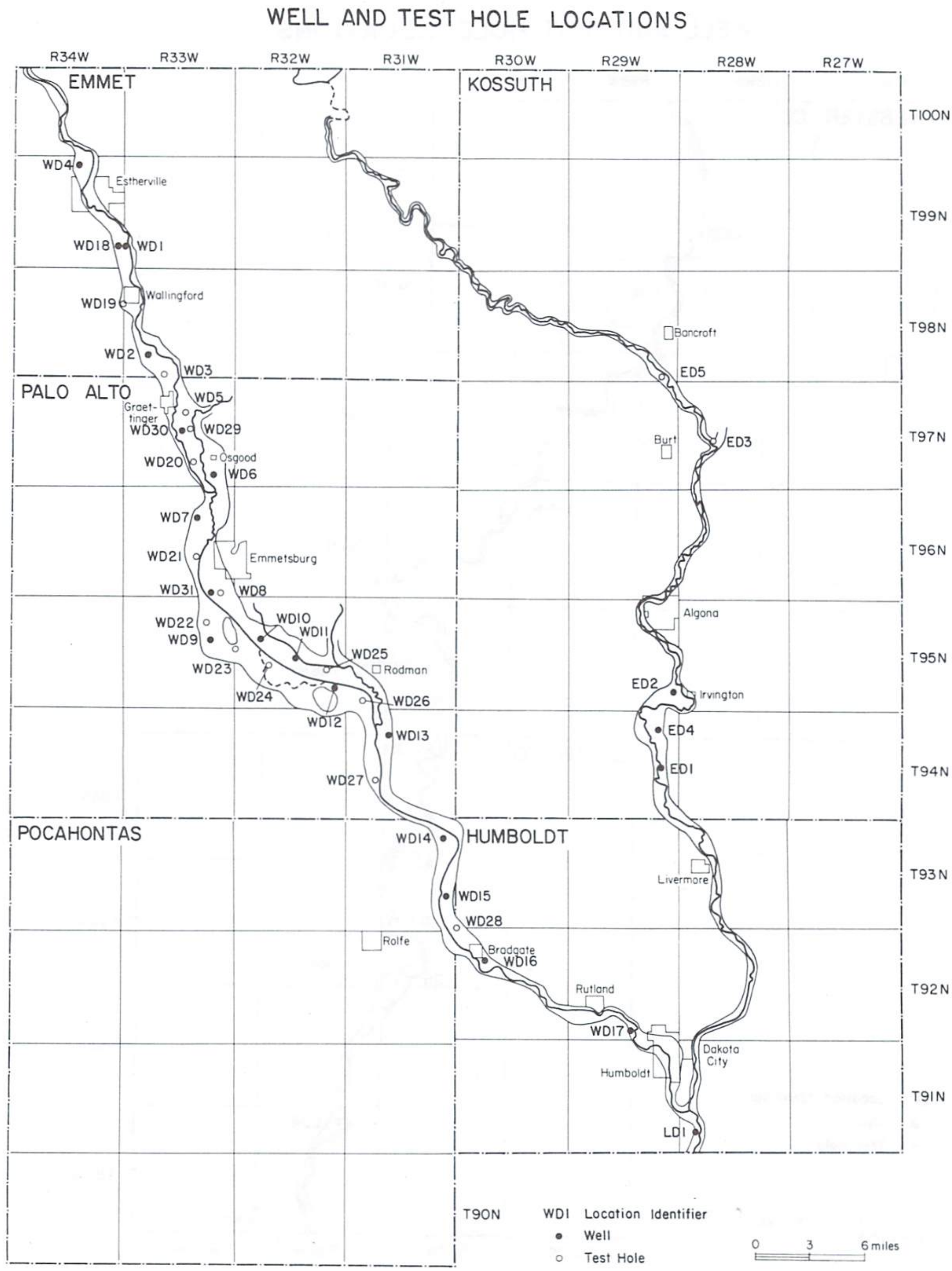


Figure 36. Well and test hole locations: East and West Fork.

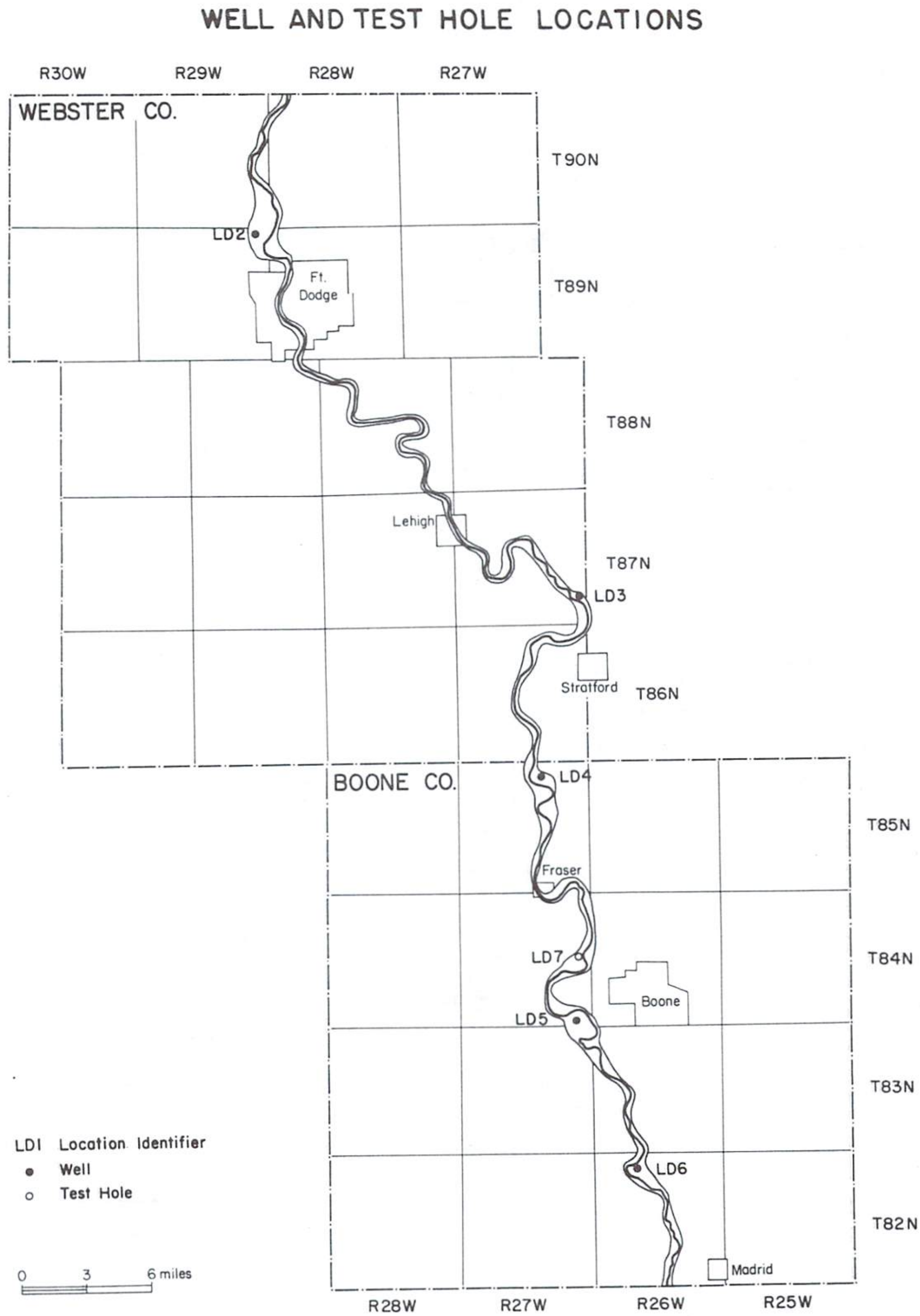


Figure 37. Well and test hole locations: Lower River.

Table 1. Summary of Well and Test Hole Information.

Well No.	Hole Depth (ft)	Surface Elevation	Elevation of Unit Tops (All elevations in ft. above sea level) Pleistocene	Cretaceous	Pennsylvanian	Mississippian
WD4	31	1310	1283			
WD1	21.5	1268	1248			
WD18	41	1273	1248			
WD19	221	1293	1259	1131		
WD2	25	1240	1220			
WD3	41	1240	1228			
WD5	21	1233	1222			
WD29	21	1226	1214			
WD30	21	1228	1211			
WD20	41	1214	1196.5			
WD6	40	1225	1198			
WD7	41	1212	1174			
WD21	61	1206	1161			
WD31	41	1200	1162			
WD8	49	1202	1157			
WD22	60	1195	1147			
WD9	56.5	1188	1133			
WD23	41	1188	1150			
WD10	41	1187	1151			
WD24	41	1183	1158			
WD11	41	1176	1140			
WD25	41	1174	1135.5			
WD12	56	1170	1136			
WD26	41	1165	1128			
WD13	41	1155	1118			
WD27	56	1152	*	1104		
WD14	41	1138	1107	1104		
WD15	41	1127	1110	1090		
WD28	89	1124	*	1104		
WD16	21	1116	1111.5			
WD17	61	1089	*	1074.5		
ED5	61	1147	1146			
ED3	41	1130	1124			
ED2	93	1130	1125	1083	*	1038
ED4	94.5	1115	*	1061		
ED1	34.5	1096	*	1063		
LD1	21	1083	1069			
LD2	21	1020	*	*	*	1013
LD3	30	930	904			
LD4	61	938	932			
LD7	21	940	*	*	*	932
LD5	56	900	*	*	850	
LD6	20	860	*	*	844.5	

*Unit absent

in the alluvial aquifer.

GEOPHYSICAL LOGGING

Geophysical logs were run for the majority of the wells and test holes drilled for the alluvial project. These logs and their interpretations are available for inspection at the Iowa Geological Survey. More detailed information on log theory, methods, or applications can be found in Keys and Mac Cary (1971).

Electrical Logging

Resistivity logs using a single-point device, and spontaneous potential logs were obtained on test holes drilled in the study area. A spontaneous potential log measures the difference in the natural potentials developed between the drilling fluid and the natural fluid in the rocks. It is commonly used for geologic correlation, bed-thickness determinations, and defining zones of higher porosity and/or zones of highly-mineralized water. The resistivity log measures resistances over a small sphere near the well electrode and near the surface electrode (ground). The main applications for resistance logging are geologic correlation and determination of bed boundaries. No quantitative analyses can be done with the electric logs in this study, as the log devices are not calibrated. The logs have been qualitatively analyzed for lithologies which are indicated on the log. Deflections to the left on the SP curve may indicate intervals at higher porosity. The resistivity log generally forms a reversed image of the SP. Bed boundaries on the SP curves are at inflection points on the curve.

Gamma-Ray Logging

Gamma radiation results from the emission of photons by the disintegration of radioactive elements such as uranium, thorium, or potassium. The emission of gamma rays is statistically random, and the radiation count, therefore, is a statistical quantity. A time-constant circuit is used to average, over a given time interval, the background fluctuation of the gamma radiation. The logging speed, or rate the tool is raised in the hole, also will smooth the count rate. The parameters used for all logs in this study were: logging rate (25'/minute), time constant (8 seconds), and count rate (100 counts/second).

Gamma-ray logging is primarily used for lithologic identification and correlation applications. Of the common rock types in the study area, shale is by far the most radioactive and gives the highest gamma counts (50-600 cps). The clay minerals in shales tend to concentrate radioactive elements by cation exchange and sorption. Carbonates and clean quartz sandstones show the lowest levels of radioactivity, although the sandstones in the study area (8-30 cps) are often interbedded with thin shales and may contain feldspars or heavy minerals. Tills are matrix-dominated in the study area with clay minerals forming about 15-25% of the matrix. Large particles (clasts >2 mm) comprise less than 4-8% of the till and are variable in mineralogy, but are mostly shale and carbonate. In the upper reaches of the river, above the Mississippian outcrop area, the larger boulder-sized material contains many igneous rocks. Thus, the tills show radioactive counts (25-50 cps), intermediate between the sand and gravels and the shales. The sands and gravels are outwash sediments, and tend to have varying amounts of clay, silt, and heavy minerals.

An attempt was made to differentiate sand and gravel lithologies along stretches of the river. The two forks (east and west) and the downstream segment could not be differentiated on the basis of the gamma-ray counts. This is probably due in part to the lack of log data for the east fork and the downstream segment. Most of the logs are for holes located on the west fork, and there is a slight trend noticed among these logs (Figure 38). Logs from the upper reach of the west fork (above Wallingford, Emmet County) have slightly higher ranges in counts per second than do those from the rest of the west fork. This may be related to two factors. The sands and gravels may be "dirtier," i.e., have a higher clay content, or they may contain a larger fraction of heavy minerals. The difference may be related to a change in the depositional environment of the two areas. The upper reach of the river was ice marginal during deposition of the Algona Moraine. During this time, dirty ice blocks falling into the valley and abundant debris flows resulted in rapid

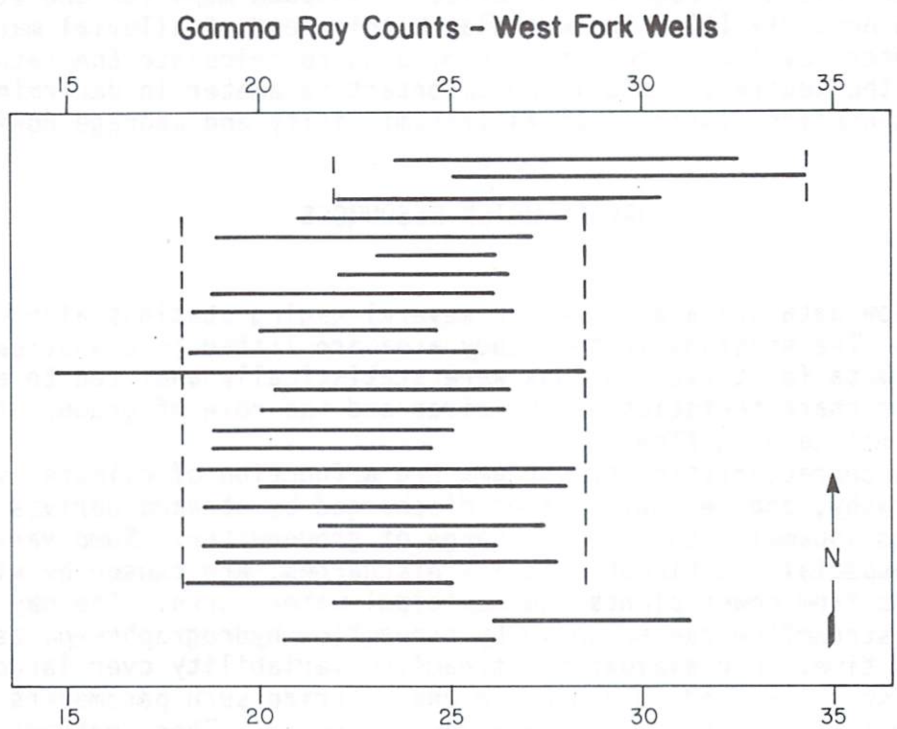


Figure 38. Gamma ray counts plotted against location for West Fork wells.

deposition and variable sorting of the deposited material. Under these conditions, clays and cobbles may have been deposited together. Further downstream the river was farther from the ice front resulting in a higher degree of sorting and winnowing out of fines. The gamma-ray patterns may then be indicative of a real difference in the clay mineral contents of these two areas. Further analysis of the cuttings did not reveal significant differences in clay or heavy mineral contents. However, rotary drilled cuttings do not necessarily reflect the true nature of the material present. Analysis of sand and gravel pit sections along the river are needed to fully test this hypothesis.

GEOLOGY OF THE DES MOINES RIVER ALLUVIAL AQUIFER

The preliminary geologic information combined with the seismic and test-hole information from this study has been used to obtain a more comprehensive picture of the Des Moines River alluvial aquifer geology. The hydrologic properties of the aquifer differ depending on the properties of the materials below. When the alluvial aquifer rests on limestone or sandstone, significant recharge from, or discharge to these units can occur. If the substrate is till or shale, the alluvial aquifer is essentially an isolated system. Bedrock elevation and geology are shown in Plates I and II. Isopach maps show the thickness of the sand and gravel deposits. Figure 39 is an example of such a map for Palo Alto County. A series of isopach maps for the study area is located in Appendix III. The calculated thickness of alluvial material along with water-level measurements can be used to calculate the saturated thickness of the aquifer. This is an important parameter in determining other hydrogeologic characteristics such as transmissivity and storage coefficient.

SURFACE-WATER RESOURCES

Streamflow data are available for several gaging stations along the Des Moines 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.

The flow characteristics of streams are a function of climate, vegetation cover, topography, and geology. Water discharged by streams derives from precipitation and snowmelt, and the discharge of groundwater. Some variations in streamflow, especially noticeable at low discharges, are caused by withdrawals and discharges from power plants and municipal water works. The day to day variation in streamflow can be shown by streamflow hydrographs--plots of discharge versus time. For evaluating streamflow variability over larger 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 streams 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 the physical characteristics of the stream's watershed. Streams having well integrated, efficient drainage networks have a very rapid flow

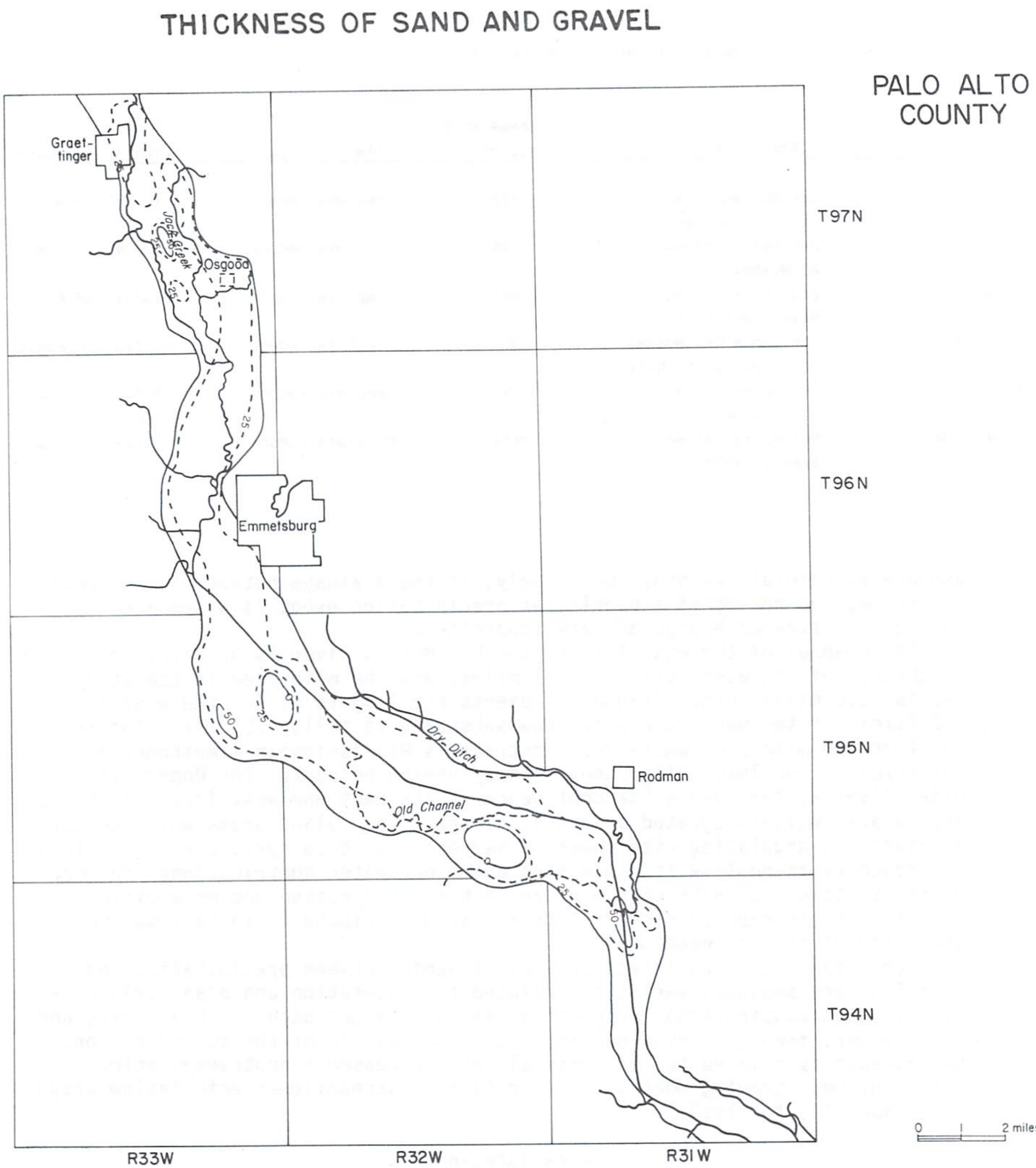


Figure 39. Isopach map for Palo Alto County.

Table 2. Streamflow-gaging stations on the Des Moines River

Station No.	Station Name	Drainage Area (sq. mi.)	Station Type	Years of Record
05-4765.00	Des Moines River at Estherville	1372	Complete record	10/51 - Present
05-4767.50	Des Moines River at Humboldt	2256	Complete record	10/64 - Present
05-4780.00	East Fork Des Moines River near Burt	462	Complete record	10/51 -9/74
05-4790.00	East Fork Des Moines River at Dakota City	1308	Complete record	3/40 - Present
05-4805.00	Des Moines River at Fort Dodge	4190	Complete record	10/46 - Present
05-4813.00	Des Moines River near Stratford	5452	Complete record	4/20 - Present

response to rainfall events. Conversely, if the drainage network is not well integrated, the result of a particular precipitation event is attenuated and peaks on the streams hydrograph are suppressed.

The channel of the west fork of the Des Moines River is 80 miles long, the channel of the east fork is 108.3 miles, and the main stem in the study area is 71.6 miles long. Channel gradients are 1.33 ft/mi for the east fork, 1.92 ft/mi for the west fork where the substrate is till, 3.51 ft/mi for the west fork and main stem where the substrate is Mississippian limestone, and 1.57 ft/mi in the lower river above Pennsylvanian bedrock. The Upper Des Moines River system, above the confluence of its east and west forks, is not a particularly well-integrated drainage network. The upland areas which border the river are undulating with numerous swales which trap surface runoff. In this reach overland flow is diminished and groundwater contributions are more important, thus the peaks of the hydrograph are suppressed and more diffuse. These same hydrograph characteristics are also attributable in part to the large size of the drainage basin.

Other factors which affect the relationship between precipitation and streamflow are seasonal variations related to evaporation and plant transpiration (evapotranspiration). Highest stream discharges occur in the spring and early summer, then gradually decrease over the balance of the summer season. The decrease is related to less rainfall and increased evapotranspiration during the peak growing months. Figure 40 is a streamflow-precipitation graph for Estherville for 1969.

Flow Duration

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. The shape of the flow-duration curve is used to assess the variability of streamflow, and to compare the flow characteristics of one drainage area with another. A steep slope on the duration curve denotes a highly variable stream--one whose flow is largely controlled

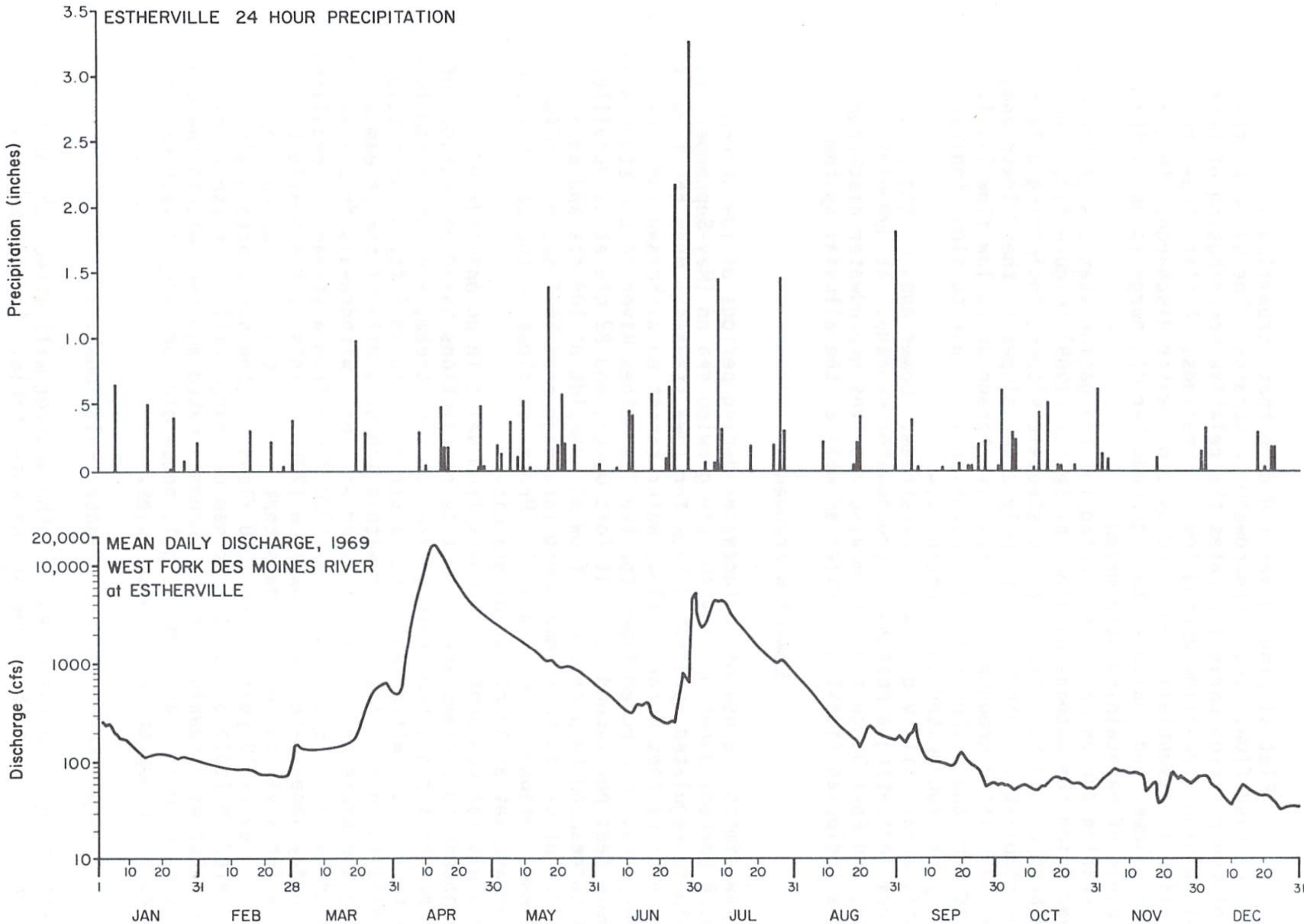


Figure 40. Streamflow - precipitation graph for Estherville for calendar year 1969.

by surface runoff. Flat sloping curves indicate that streamflow is 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 gaging stations of the Des Moines River using the methods outlined by Searcy (1959) (Figure 41). The curves for Burt and Estherville have the steepest slopes, indicating a fair amount of variability. Both have extremely steep slopes in their lower end, indicating that little groundwater is held in storage above low flow level. The river at Burt and Estherville will occasionally cease to flow, indicating the inability of groundwater to maintain flow.

Streamflow variability decreases downstream. Lower ends of the curves are flattened indicating a reasonable groundwater storage. At Humboldt, Dakota City, and Fort Dodge the stream also receives groundwater discharge from the Mississippian limestone aquifer as well as the alluvial system.

Low-Flow Frequency

Iowa law limits the use of surfacewater during periods of low stream flow. The 84 percent duration flow for the growing season (May-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. Protected flows for the Des Moines River in the study area are 220 cubic feet per second (cfs) at Fort Dodge, and 22 cfs at Estherville. This would correspond to a protected flow at Humboldt of 109 cfs and an approximate flow of 64 cfs near Emmetsburg (drainage area 1674 sq. mi.) (Jim Wiegand, DWAWM, personal communication). Protected flows on the East Fork Des Moines River are set at 42 cfs at Dakota City.

Withdrawals for consumptive purposes from wells 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 low-flow characteristics. Withdrawals from a stream draining fifty or more square miles or wells in an alluvial aquifer within 1/8 of a 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 smallest average flow for seven consecutive days that is expected to occur on the average of once every 10 years. The 7Q10 flows for the study area gaging stations are listed in Table 3. If the stream discharge falls to these levels, 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.

Groundwater and Surfacewater Relationships

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

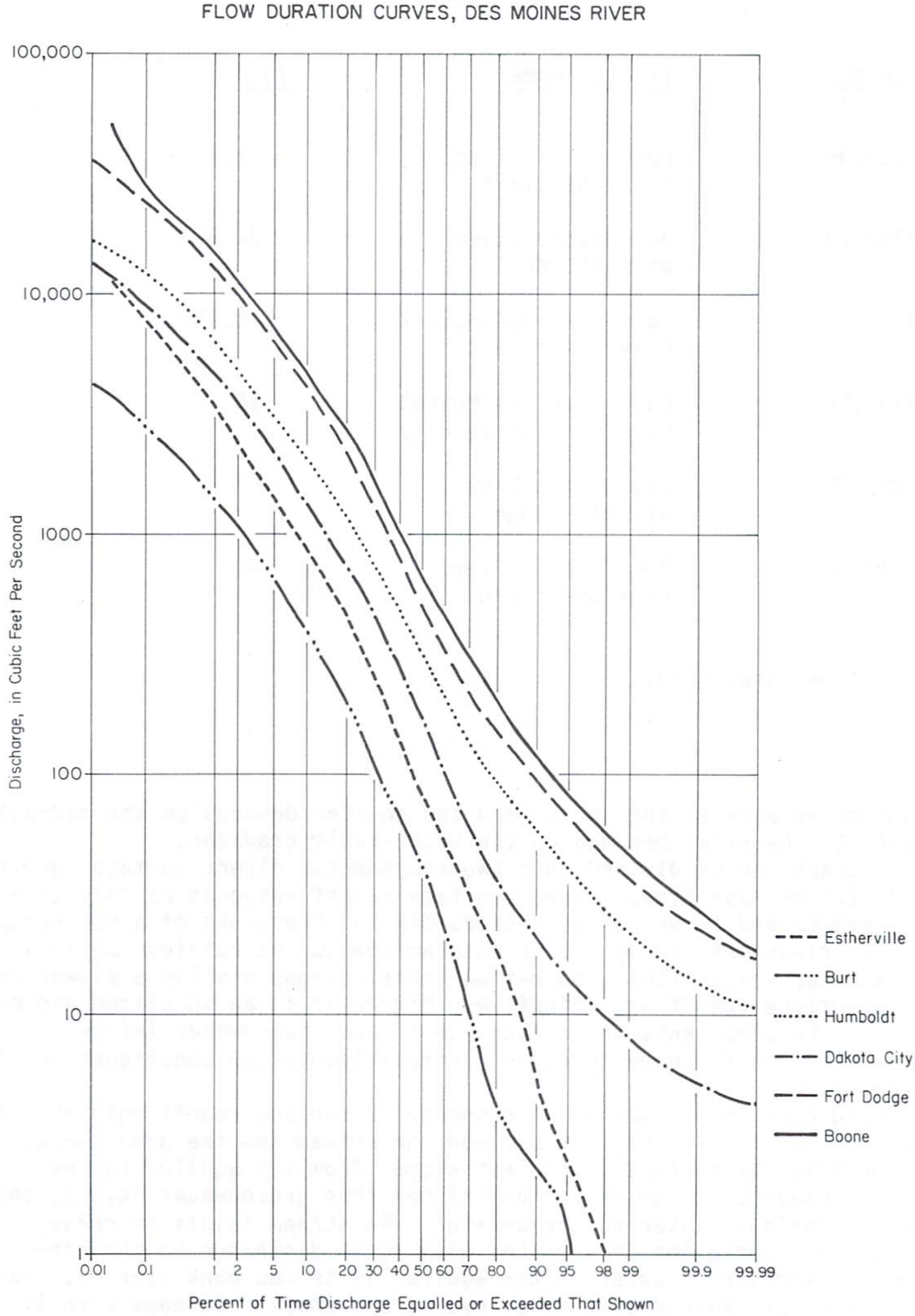


Figure 41. Flow duration curves - Upper Des Moines River.

Table 3. Seven day, ten year low flow frequencies for gaging stations on the Des Moines River.

Station No.	Station Name	7Q10 (cfs)
05-4765.00	Des Moines River at Estherville	1.4
05-4767.50	Des Moines River at Humboldt	28.0
05-4780.00	East Fork Des Moines River near Burt	0.28
05-4790.00	East Fork Des Moines River at Dakota City	10
05-4805.00	Des Moines River at Fort Dodge	38
05-4813.00	Des Moines River near Stratford	43

Information from Lara, 1979.

water transferred between the stream and the aquifer depends on the hydraulic conductivity of the streambed and on the water-table gradient.

A hydrograph can be divided into two components; direct surface runoff and groundwater or base flow. Direct surface runoff responds rapidly to precipitation events and is primarily responsible for the peaks of a hydrograph. Base-flow contributions supply most of streamflow during rainless periods. Since groundwater moves slowly, base-flow contributions display a slower response than surface runoff and interflow. Figure 42 is an idealized hydrograph showing the components of surface runoff and groundwater inflow. Integration under these curves provide the relative volume contributions of each component.

The rapid rise in streamflow in response to surface runoff and interflow may reverse the hydraulic gradient between the stream and the groundwater system. Normally the hydraulic gradient slopes from the aquifer to the stream. If, however, stream levels are higher than groundwater levels, the stream will contribute water to the aquifer. As stream levels decrease, the gradients again reverse and groundwater will again discharge to the stream. This temporary storage of water in the aquifer is termed bank storage. Bank storage can have pronounced effects on hydrograph shape. Streams with little bank storage will have large steep-sided peaks. Hydrographs for streams with significant bank storage capacity will have lower peaks and the recession curve will be less steep. This is shown schematically in Figure 43.

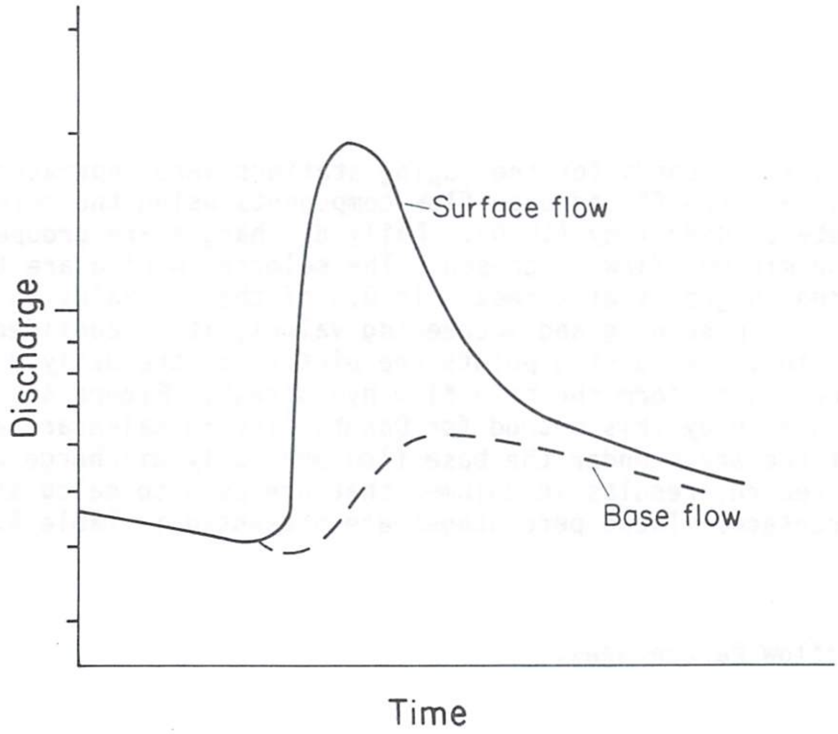


Figure 42. Idealized hydrograph illustrating the relative relationships of surface runoff and groundwater flow.

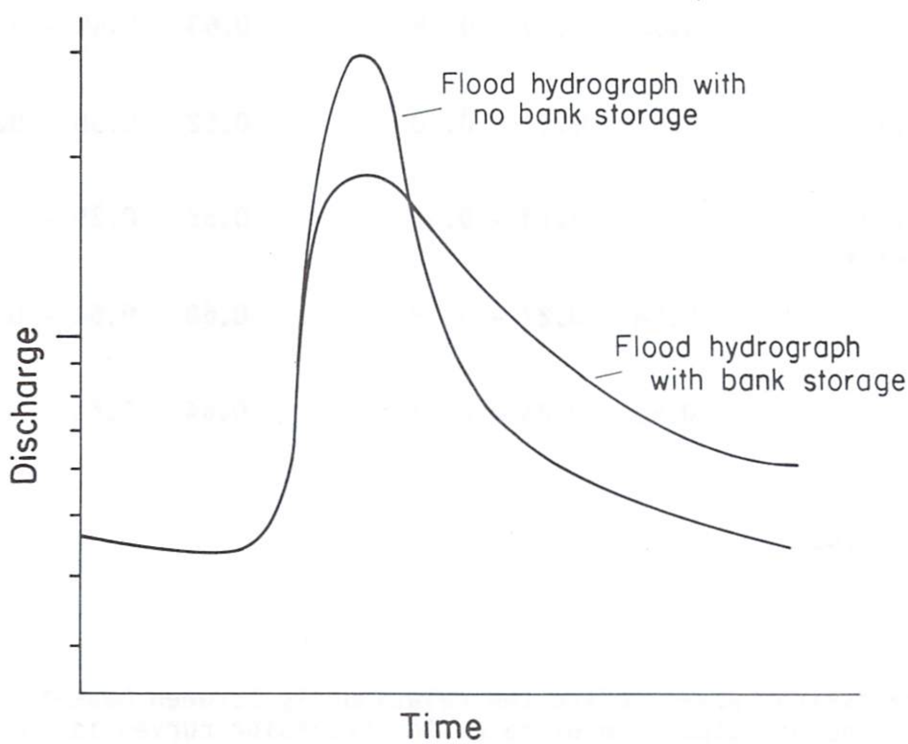


Figure 43. Idealized hydrograph showing the effects of bank storage.

The hydrograph records for the gaging stations were separated into surface and subsurface runoff and base flow components using the method developed by the Institute of Hydrology (1980). Daily discharges are grouped into sets of five and the minimum flow is chosen. The selected minima are then sequentially evaluated in groups of threes. If 0.9 of the mid-value in the group of 3 is less than its preceding and succeeding values, it is considered a base-flow turning point. The turning points are plotted on the daily discharge graph and connected to form the base-flow hydrograph. Figure 44 is a base-flow separation made by this method for Dakota City in calendar year 1961. Integration of the areas under the base flow and daily discharge curves, over the period of record, results in volumes that are used to calculate an average base flow percentage. These percentages are presented in Table 4.

Table 4. Baseflow Percentages.

Station	Average and Range (period of record up to 1980		Average and Range (period of record from 1964 - 1980	
Des Moines River at Estherville	0.54	0.19 - 0.79	0.57	0.21 - 0.77
Des Moines River at Humboldt	0.63	0.40 - 0.78	0.63	0.40 - 0.78
East Fork Des Moines River near Burt*	0.47	0.17 - 0.70	0.52	0.35 - 0.70
East Fork Des Moines River at Dakota City	0.53	0.18 - 0.67	0.58	0.35 - 0.68
Des Moines River at Fort Dodge	0.58	0.22 - 0.79	0.60	0.51 - 0.79
Des Moines River near Stratford	0.58	0.25 - 0.81	0.64	0.51 - 0.81

* Record only to 1974.

Base-flow recession curves define the relationship between base-flow discharge and time. The principal use of base-flow recession curves is to forecast low flows, especially during the growing season when most low flows occur and when water demand is highest. The curves provide estimates of normal streamflow recession rates, providing that no appreciable precipitation occurs during the period. The reliability of the curves decreases after about twenty days and depends, in part, on the variability of streamflow and groundwater inflow. Figure 45 shows the curves developed for the study area gaging stations.

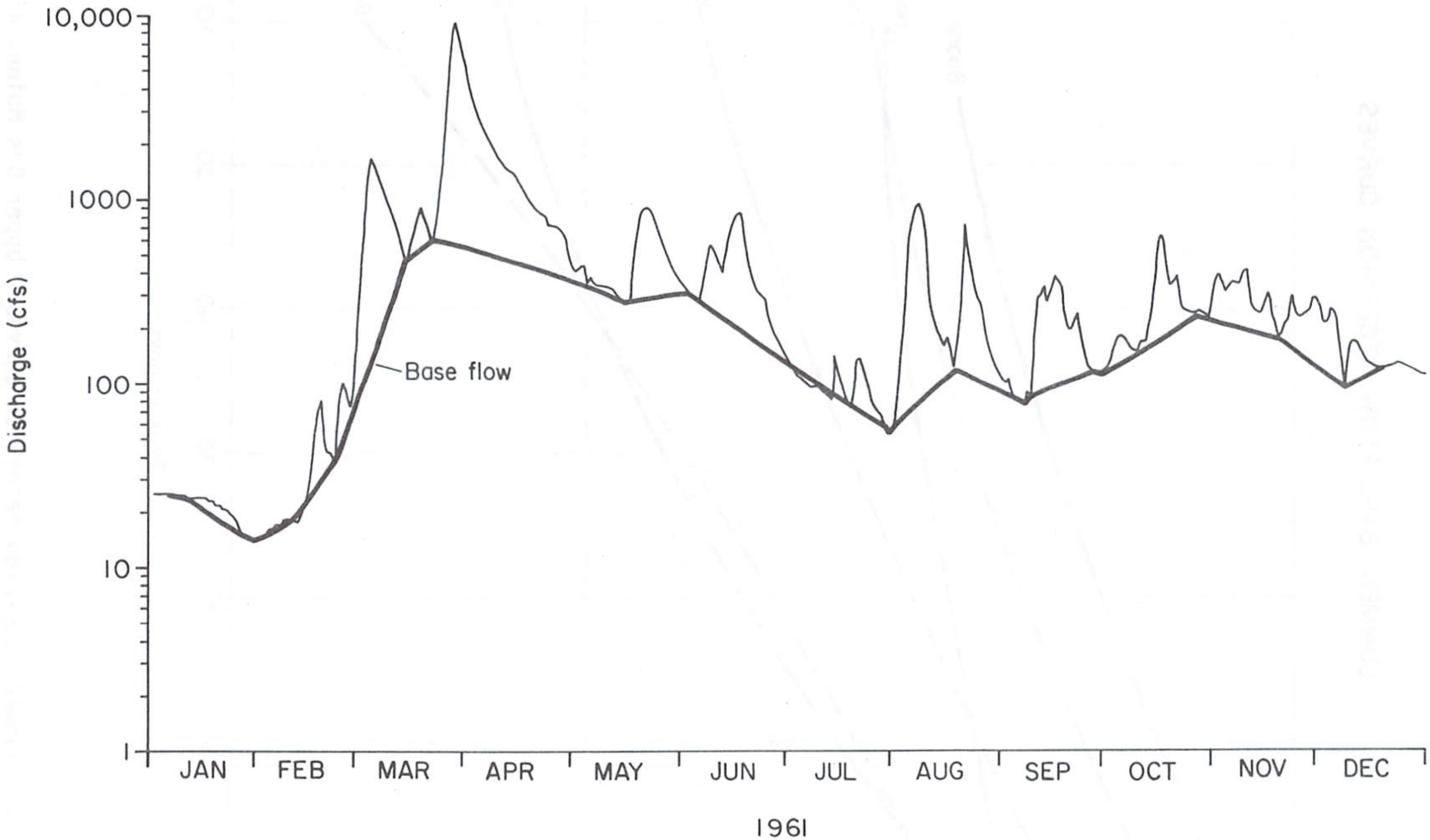


Figure 44. Dakota City hydrograph showing baseflow separation by the method discussed in the report.

SUMMER BASE-FLOW RECESSION CURVES

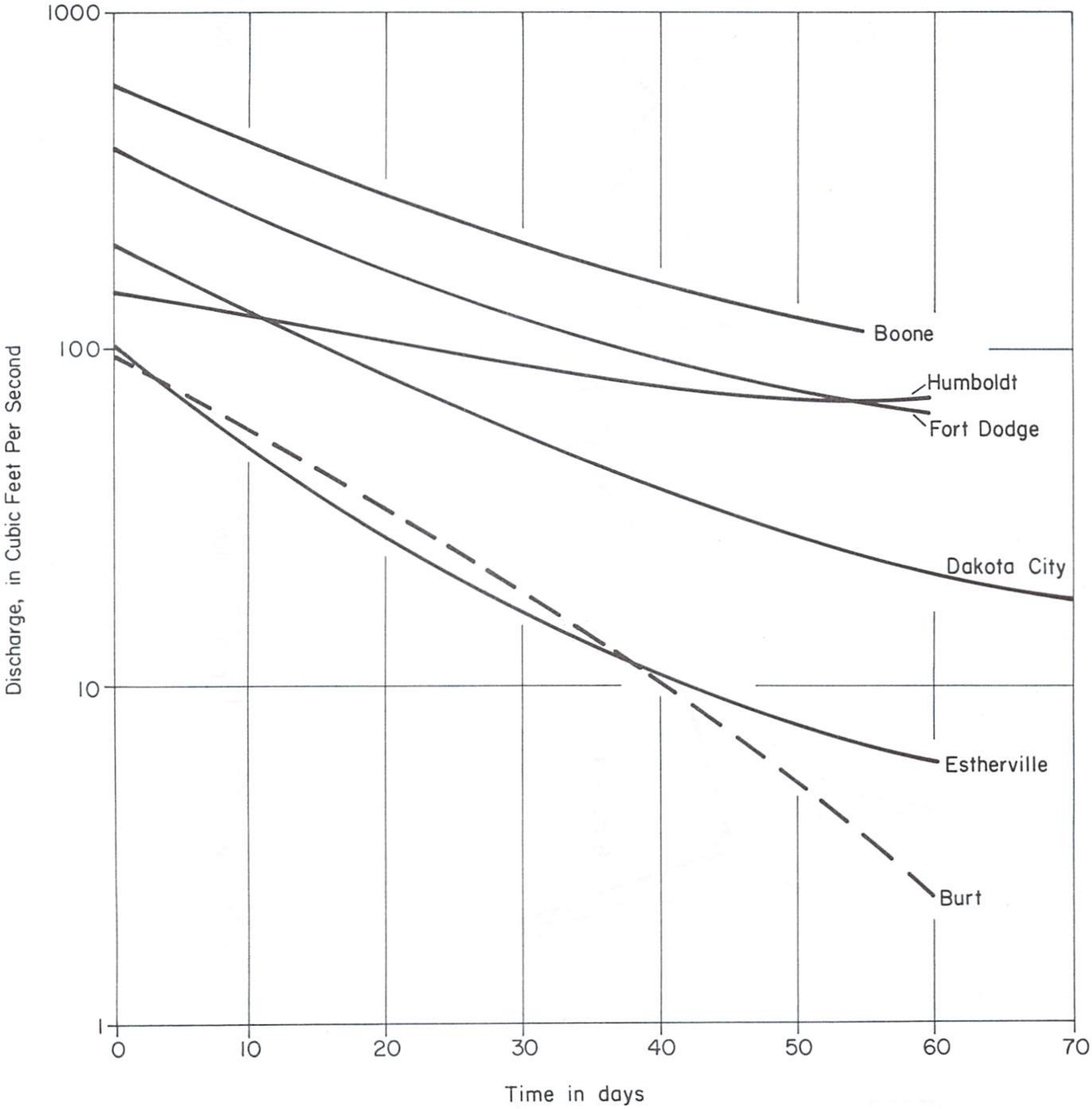


Figure 45. Summer base-flow recession curves - Upper Des Moines River.

Streamflows at Estherville and Burt are highly variable and groundwater discharge is not significant. Flows of less than 1 cubic foot per second (cfs) occur several times over the period of record. The curves shown are for average flow years for the summer months. If antecedent conditions are such that flow is greatly diminished, both of these stations will have much steeper curves especially below 10 cfs. The flow at Estherville in dry years will go from 10 cfs to less than 1 cfs in a period of 10-15 days.

The curve for Humboldt shows a relatively high flow being maintained even over an extended rainless period. The average baseflow percentage for Humboldt is the highest in the basin with a range of 40 to 78 percent. This could be related to the geology. Flow at Humboldt will be partly maintained by discharge from the Mississippian Aquifer which is less affected by short term climatic changes. Flows at Dakota City and Fort Dodge, however, should also show similar effects if groundwater discharge is responsible. Therefore, the anomalously high base flows at Humboldt are probably related to the period of record examined. Sixteen years of data was analyzed for Humboldt (1964-1980) which is not representative for a long term flow analysis. This is shown in Table 3. If the years of record are equalized, average baseflow percentages and the low ends of the ranges all increase.

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 Des Moines River originated as stream deposits laid down during and subsequent to the melting of the Des Lobe glacier. The saturated sand and gravel is unconfined, meaning that it is not overlain by material which retards the downward flow of water. In a few areas a thin layer of clay is present, but this is not laterally persistent.

The top of the alluvial aquifer is defined as the water table and is the level to which water will freely rise in a well or open hole. The surface of the stream defines the water table at that point. The water table generally slopes from the high areas toward the stream, although this can be reversed during time of high stream stages. The source of groundwater in the alluvial system is precipitation which infiltrates through the soil. Groundwater levels thus change noticeably throughout the year in response to precipitation, being highest in late spring and winter. Another source of groundwater in the alluvial system is seepage from streams which cut through the aquifer. Pumping will result in lowering of the water table and in induced infiltration from the river.

Figure 46 shows how groundwater levels are affected by pumping. When a well is pumped, water is withdrawn from storage in the immediate vicinity of the well. As pumpage continues, more water is withdrawn from storage over larger areas. Water levels may eventually be lowered below the stream surface causing influent seepage from the stream, which recharges the aquifer. According to Glover and Balmer, 1954 most of the water (70% or greater) being supplied to a pumping well at equilibrium in an alluvial situation is from streamflow. 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.

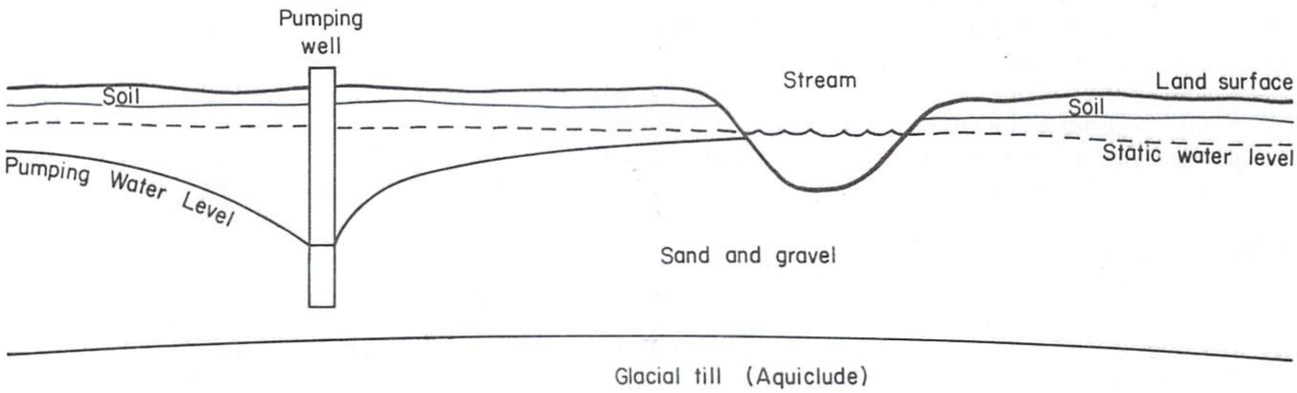


Figure 46. Schematic showing relationship between static and pumping water levels.

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

Not much is known about the hydrogeologic properties of Iowa's alluvial aquifers. Only a few pumping tests which are necessary to establish values, have been done. Table 5 lists value of S, K, and T for alluvial wells in Iowa. The variability of the numbers is a reflection on the variability of the aquifer and its geology. Low specific yields signify semi-confined conditions and probably indicates 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 situation. Often the floodplain adjacent to the river will be covered with a Holocene silt, while further away from the river the sands and gravels may be immediately below the soil.

The thickness of the sands and gravels is variable and this creates different flow patterns and affects storage capability. Other geologic effects can be related to differences in grain-size in layers such as alternating fine or coarse materials or differences related to arrangement of the grains, called isotropy, which affect the flow direction. All of this variability in

Table 5. Hydrogeologic values for alluvial wells in Iowa. Values are from IGS files on pumping tests.

Alluvial Wells	T (gpd/ft.)	S	Discharge [Q] (gpm)	Thickness (ft.)	K (gpd/ft^2)
Missouri River	300,000-400,000	0.05-0.25	1,000-2,000	100-120	2,500-4,000
Ames-Skunk River	200,000-400,000	0.12-0.11	500-1,000	60-100	4,000-6,500
Cedar Rapids-Cedar River	<150,000	.1	1,000-2,000	70-80	1,850-2,150
Muscatine Island-Mississippi River	150,000-300,000	0.15-0.24	1,000-1,500	40-140	1,100-2,100
Jefferson-Hardin Creek	50,000-70,000	.00038-00044	900-1,350	70	700-1,000
Olin-Wapsipinicon River	300,000	.0005	1,800-2,200	100	3,600
Dubuque-Mississippi River	350,000	.0025	1,500-2,500	100-200	1,800-2,500
Redfield-Racoon River	50,000-200,000	.0004-.6	400-500	15-20	?
Des Moines-Des Moines River	50,000-100,000	.005-.05	500-1,000	40-60	1,250-1,650
Merrill-Floyd River	71,600	.0001	650	25	2,860

the geology affects the hydrologic properties of the aquifer. Thus, an unconfined alluvial aquifer is difficult to characterize. The numbers presented here are a general guide to the availability of water. Potential development sites need to be evaluated by test-drilling and pumping to determine the aquifer characteristics for that site.

Water Levels

Water levels were measured during the 1984 water year at numerous well and river locations along the Des Moines River (Figure 47 and 48). Water level data are also available from a series of wells installed and monitored by the Iowa Department of Water, Air, and Waste Management (for July 1981 to June 1983). Wells and river locations along the west fork were surveyed to obtain more accurate estimates of water table position. Water level data are presented in Appendix 4. Some wells could not be measured during winter because

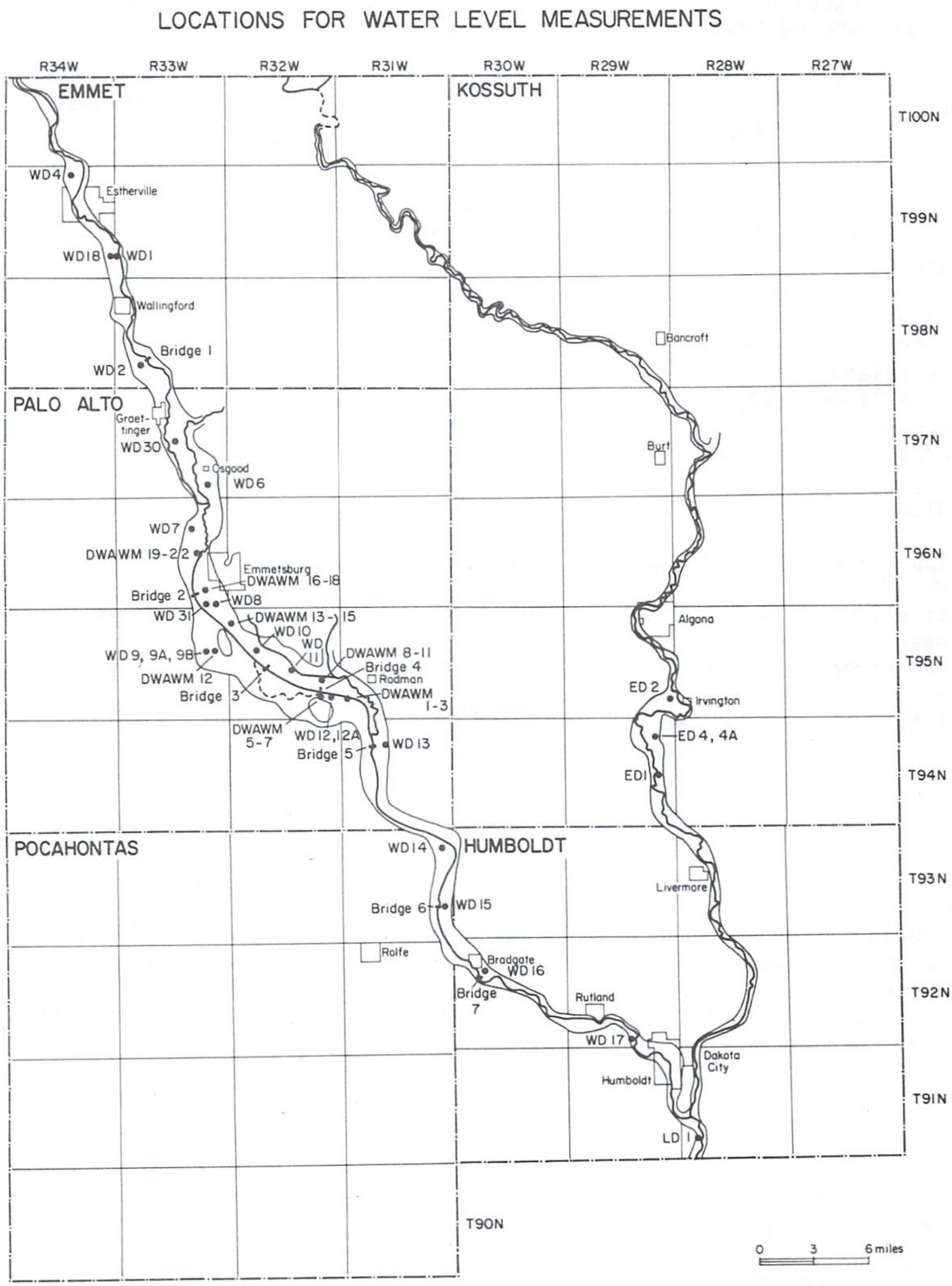


Figure 47. Locations for collections of water level data: East and West Fork.

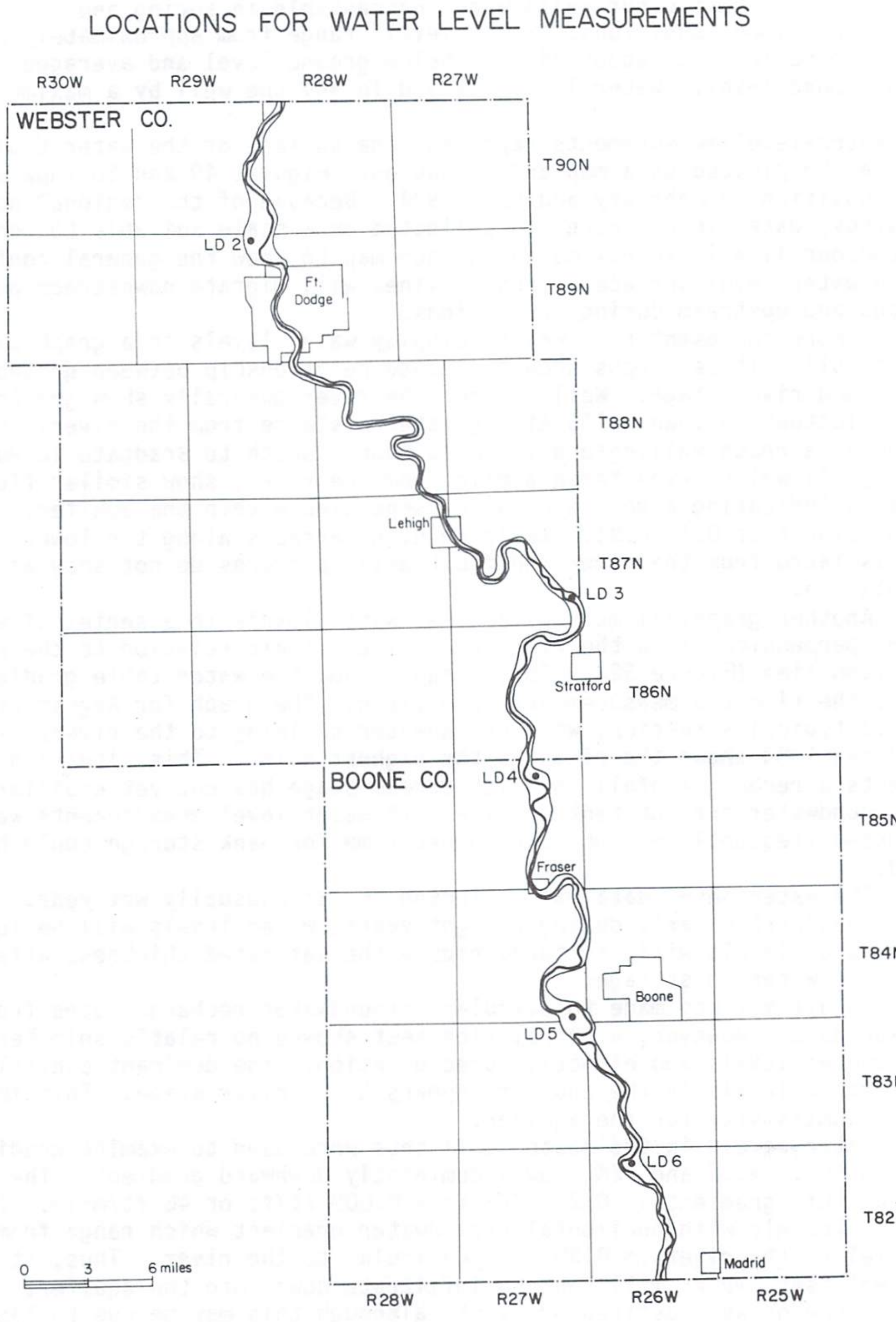


Figure 48. Locations for collection of water level data: Lower River.

of snow conditions; other wells were inaccessible in spring and early summer because of flood conditions. Water levels range from approximately 2 feet above ground level to about 24 feet below ground level and averaged six feet below ground level. Water levels varied in any one well by a maximum of 8.5 feet.

Water-level measurements represent the surface of the water table and as such can be plotted on a map and contoured. Figures 49 and 50 show water table position in February and May, 1984. Because of the regional nature of the study, water levels were not collected on a scale suitable to contouring. One contour line is approximated on each map to show the general configuration of the water-level surface. Contour lines will migrate downstream during wet periods and upstream during dry periods.

A more representative way to display water levels is a graph with time (Figure 51). These graphs show the close relationship between groundwater levels and river stage. Wells nearer the river generally show greater water-level fluctuation than wells at a greater distance from the river. However, in the area reach Wallingford in Emmet County south to Bradgate in Humboldt County, all wells, even those a mile from the river, show similar fluctuation patterns indicating a good hydraulic connection within the aquifer. (Spearman correlation test 0.75-0.8). Wells on high terraces along the lower river are more isolated from the river and fluctuation patterns do not show as close a correlation.

Another graphical method looks at water levels in a series of wells placed perpendicular to the river channel and their relation to the river at any given time (Figure 52). These graphs show the water table gradient existing at the time the measurements were taken. The graph for August of 1981 shows a typical situation, with groundwater draining to the river. The data for June, 1983 shows the river as the highest point. This situation probably reflects a recent rainfall in which stream stage has not yet equilibrated with the groundwater through bank seepage. If water level measurements were to be collected frequently enough, a response time for bank storage could be calculated.

The water level data was collected for an unusually wet year. In drier years, and particularly during drought years, water levels will be lower. Lower water levels will, in turn, reduce the saturated thickness affecting the amount of water in storage.

An attempt was made to calculate groundwater recharge rates from precipitation data. However, a correlation test showed no relationship between groundwater levels and effective precipitation. The dominant control on groundwater levels in the aquifer appears to be river stage. This implies a high tranmissivity for the aquifer.

Water levels in the nested well sets were used to examine gradients in the aquifer. WD12 and 12A show a dominantly downward gradient. The magnitude of this gradient is 0.2 ft/23 ft = 0.009 ft/ft or 46 ft/mile. This contrasts strongly with horizontal groundwater gradient which range from 0.0007 parallel to the river to 0.001 perpendicular to the river. Thus, at least for this well set, water will tend to infiltrate down into the aquifer. WD9, 9A, and 9B show no well defined gradients although this may be due to lack of data.

Water levels were also measured in the Dakota aquifer. Those from November were December show downward gradients. During April and June the gradients were upward. Thus, at times. the Dakota recharges the alluvial system while at other times the alluvial system recharges the Dakota.

WATER LEVELS FOR FEBRUARY 1984

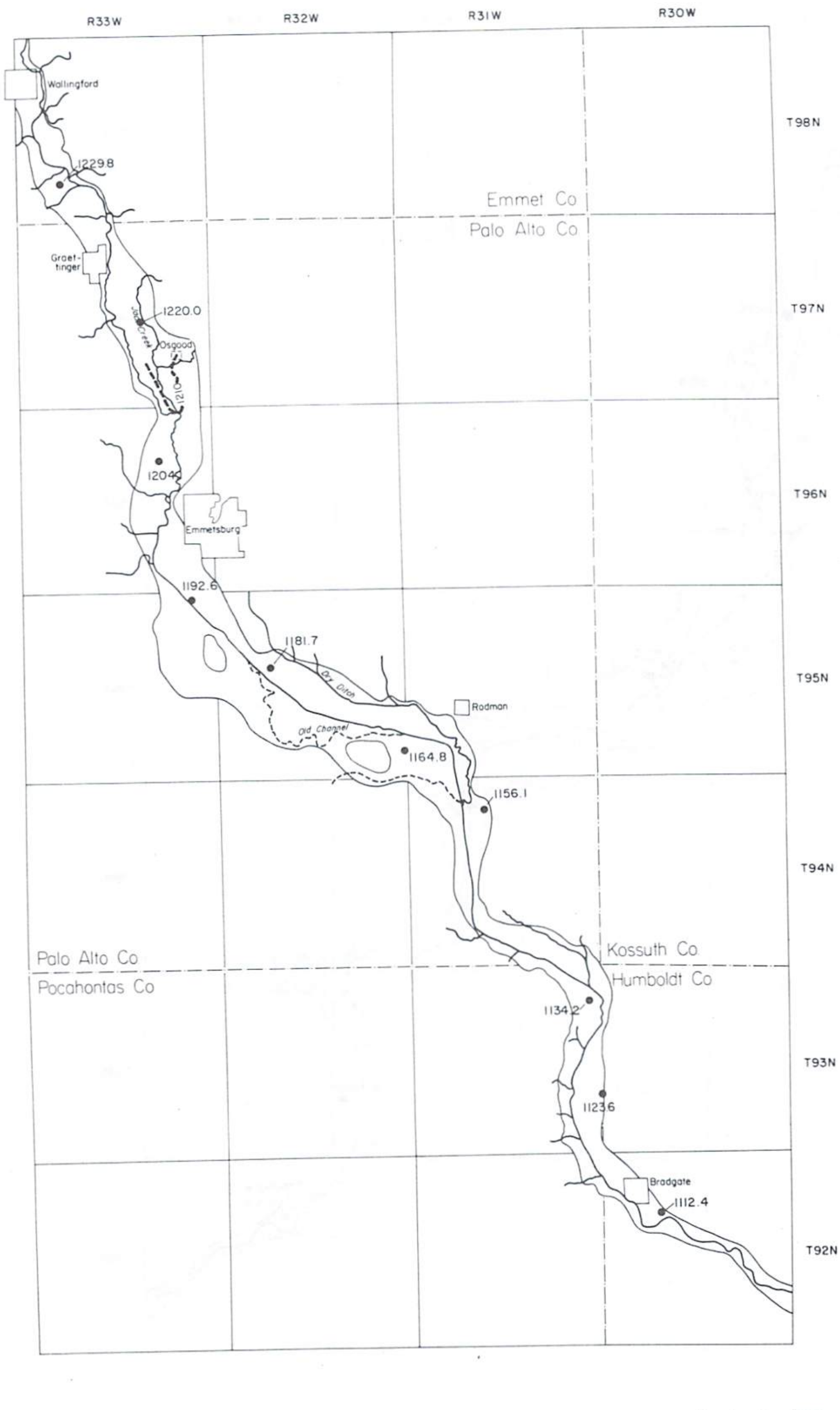


Figure 49. Water level map for February, 1984.

WATER LEVELS FOR MAY 1984

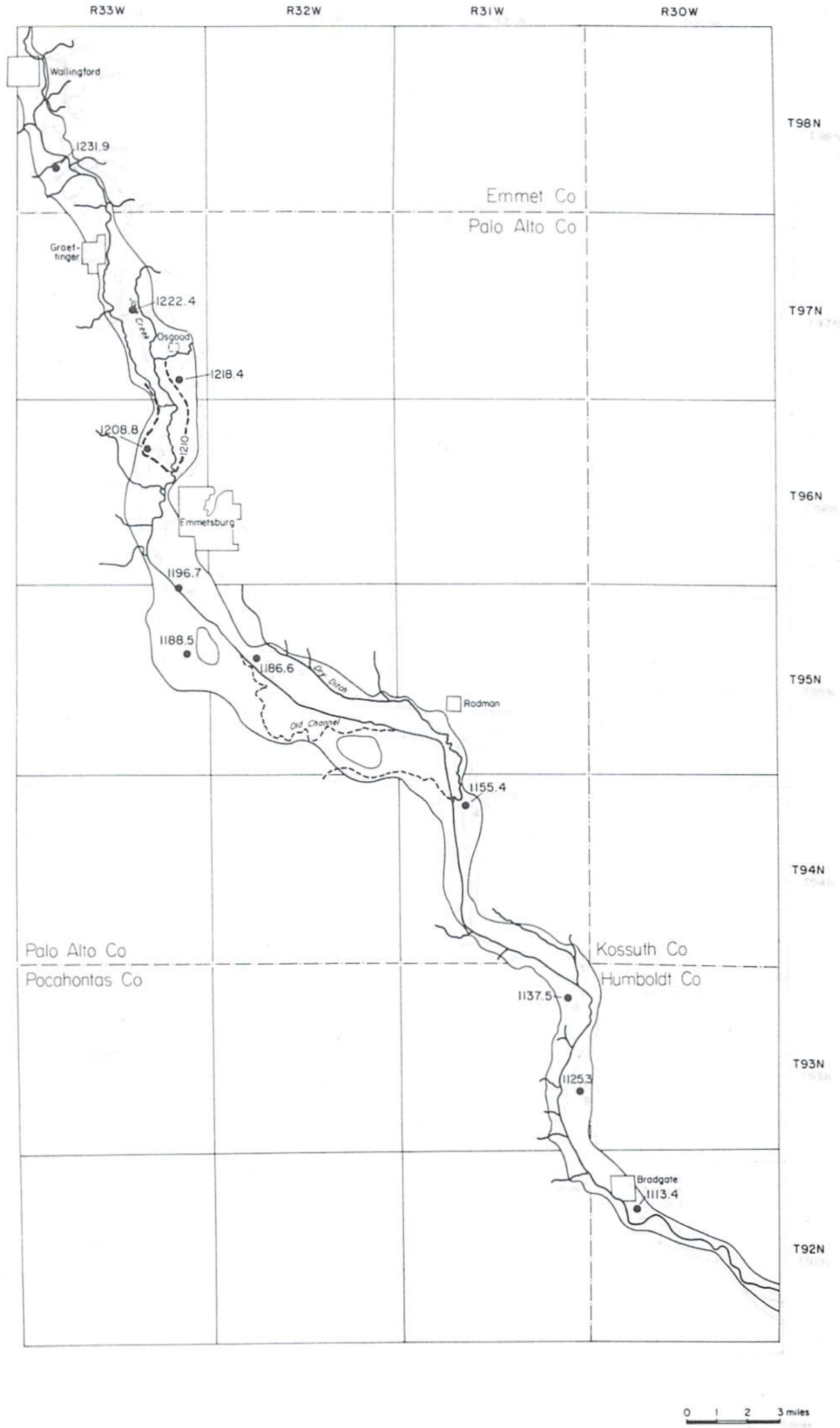


Figure 50. Water level map for May, 1984.

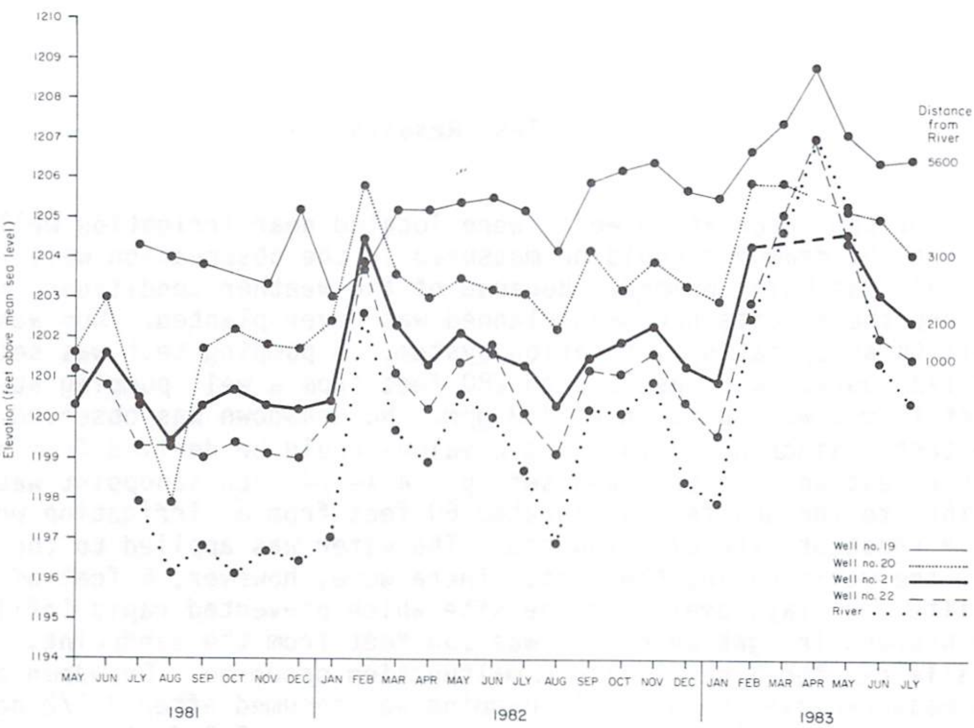


Figure 51. Static water levels with time in a selected set of wells.

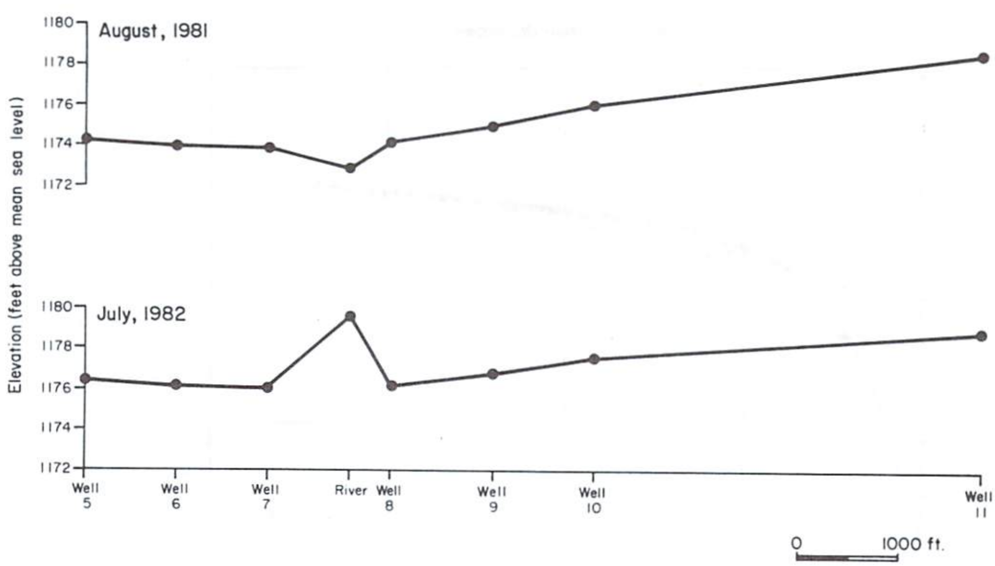


Figure 52. Static water levels at a given time for a selected set of wells.

Pumping Test Results

Several of the observation wells were located near irrigation wells. It was hoped that the drawdown could be measured in the observation well when the irrigation well was being pumped. Because of the weather conditions, most of the land where these tests had been planned was never planted. WD6 was the closest well to an operating irrigation system. A pumping test was set up and run for 22 1/2 hours. WD6 was located 280 feet from a well pumping at 400 gpm and 602 feet from a well pumping at 250 gpm. No drawdown was observed at WD6 during the test. Since no hydrogeologic values could be derived from the results of this test another test was set up. A 1-1/4 inch sandpoint was driven 25.3 feet into to the aquifer and located 60 feet from an irrigation well pumping at a constant rate of 1,100 gpm. The water was applied to the field surrounding the wells during the test. There were, however, 6 feet of alluvial silts and clays overlying the site which prevented rapid infiltration. The nearest irrigation nozzle was 150 feet from the sandpoint. The pump initially ran for 3 hours before malfunction occurred. Drawdown and recovery was measured over this time. Pumping was resumed after 2 1/2 hours, during which time water levels had recovered to within 0.2 foot of initial static level. The pump was then operated continuously for 16 hours.

The static water level was 1.7 feet below ground at the beginning of the test. Maximum pumping levels were 4.2 feet below ground. Total drawdown was 2.5 feet. Figure 53 shows the drawdown graph for the second period of pumping Several methods of analysis were applied to the data including Theis, Cooper-Jacob, and the Hantush image method (Kruseman and DeRidder, 1979). Values for T ranged from 300,000 -550,000 gpd/ft. and for storage coefficient from 0.0005 to 0.2. The higher values of T were associated with the lower values of S and may

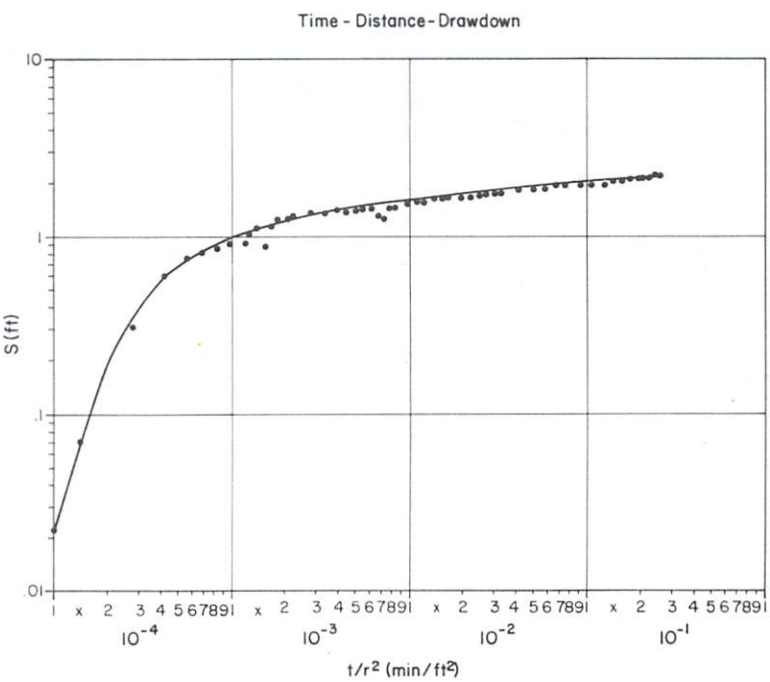


Figure 53. Time-distance drawdown curve.

be a reflection of the short time over which the test was conducted. There was little agreement between the transmissivity values derived by the various methods. All gave considerably high values of T and lower than expected values of S considering the type of aquifer. The average hydraulic conductivity ranges from 9000-15,000 gpd/ft^2. Published values for hydraulic conductivities in sand and gravel aquifers range from 100-15,000 gpd/ft^2. As an attempt to verify the high hydraulic conductivities observed, a grain size analysis was done.

Grain size of aquifer materials has been related to permeability and could be used as a check of the test values. However, grain size analysis on materials from a rotary-drilled hole does not give a true picture of the material. Normally only the finer materials are recovered when hydraulic rotary drilling methods are used. To avoid this limitation, a grain size analysis from a gravel pit face near Boone was used. The section of the pit sampled is similar to pits in the area where the pumping test was done. The assumption in making this analysis is that the aquifer materials below ground are similar to those exposed in the pits. Hazen's equation relates permeability to effective grain size, d_{10}, which is the grain size diameter at which 10% of the particles are finer and 90% are coarser. This equation yields a permeability of 6750 gpd/ft. Rose and Smith (1957) also using d_{10} in relation to permeability developed graphs which with Des Moines River data gave an estimated permeability of 11,000 gpd/ft^2. Masch and Denny (1966) relates the inclusive standard deviation σ_1 (a measure of the variability in grain size) and median grain size (D_{50}) to permeability. Their graphs, however, are only useful for sand sized particles. Attempts to extrapolate for a non-uniform gravel indicated a permeability of 75 gpd/ft^2. Bedinger (1961) working on Arkansas River alluvium found permeability to be related to median grain size. Extrapolating his chart to gravels would give extremely high permeabilities. His field measurements for a coarse sand and fine gravel ranged from 6,000-15,000 gpd/ft^2. Although the Des Moines River materials have a high percentage of extremely coarse materials, their permeability will be limited by the matrix materials which are in general a medium to coarse sand.

Thus, the calculated conductivities from the observed data are in the high range. The small drawdowns observed during the pumping test combined with a high rate of flow indicates that little water is being taken from storage, but most is being delivered to the well through the aquifer material. No boundary effects, either recharge or discharge, were observed from the pumping test data. Since the pumping test was done in an area where certain geologic conditions exist the results can only be extrapolated to areas with similar geologic conditions. Fig. 54 is a map showing the area where the calculated aquifer characteristics should hold. 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. Two estimates of specific yield were used to calculate the lower and upper ends of storage.

Area	x	Saturated thickness	x	Specific yield	x	Conversion factor	=	Storage
1.9 billion sq ft	x	26 ft	x	.01	x	7.48 g/cu ft	=	3.69 billion gal
1.9 billion sq ft	x	26 ft	x	.2	x	7.48 g/cu ft	=	73.90 billion gal

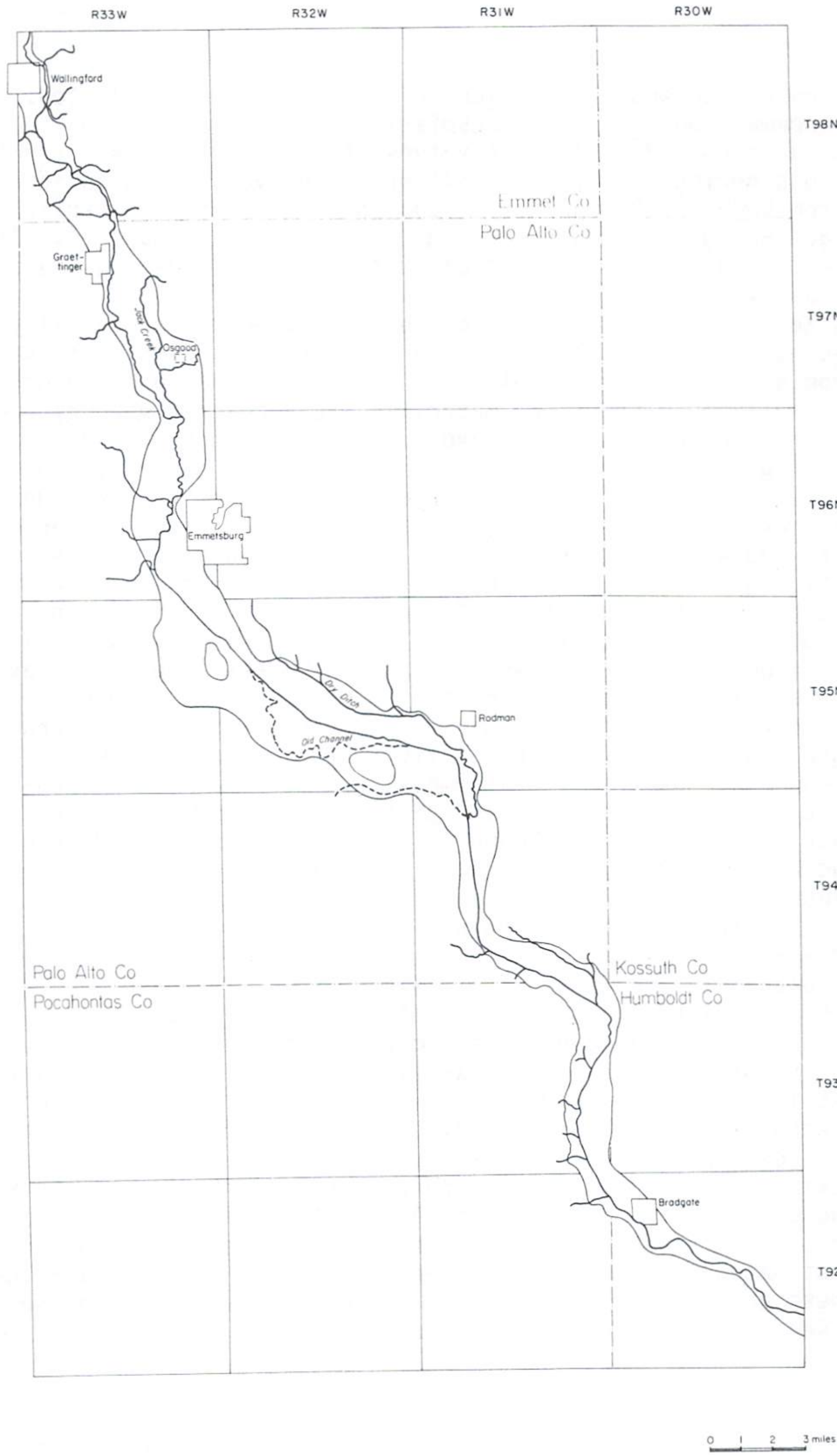


Figure 54. Area over which pumping test results can be extrapolated.

This translates to between 3 and 62 inches of water per acre in storage. This does not consider any water in the fine-grained alluvial material overlying the sand and gravel which will increase the available water. The saturated thickness values are probably high, being calculated for an extremely wet year. Normal water levels will be lower, which will decrease the amount of water in storage.

Streamflow Depletion

As previously discussed, gradients in the aquifer normally slope from the aquifer to the stream. This discharge to the stream is called base flow. During times of high river levels, these gradients may reverse and the river will supply water to the aquifer. Another situation which will cause streamflow to be diverted to the aquifer is due to pumping. The reduction of streamflow due to groundwater withdrawals is called streamflow depletion. Streamflow depletion has two components (although not necessarily separable), a) flow induced directly from the steam and b) water intercepted enroute to the stream. A method described by Jenkins (1970) was used to evaluate streamflow depletion for the Des Moines. The method computes the percentages of total pumpage attributable to streamflow based on the distance of the pumping well to the stream, the rate and length of pumping and values of storage coefficient and transmissivity. Figure 55 shows the graphs developed to provide a basis for predicting stream depletion effects along the Des Moines River.

Both graphs result from using a transmissivity value of 400,000 gpd/ft (53,200 ft^2/d). The upper curves are for a storage coefficient of 0.1 and the lower for 0.2. 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 begin taken/diverted from the stream) for a well pumping at 1000 gpm. The rate of stream depletion increases with time of pumping and decreases with distance from the river.

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

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

Field conditions never match the idealized assumptions. In the case of assumption (1) not being met, T will decrease and, therefore, streamflow depletion will decrease. 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 nonhomogeneity of the aquifer constants. T and S can vary over the aquifer. The graphs are useful, however, as a general guide to the effects of stream depletion.

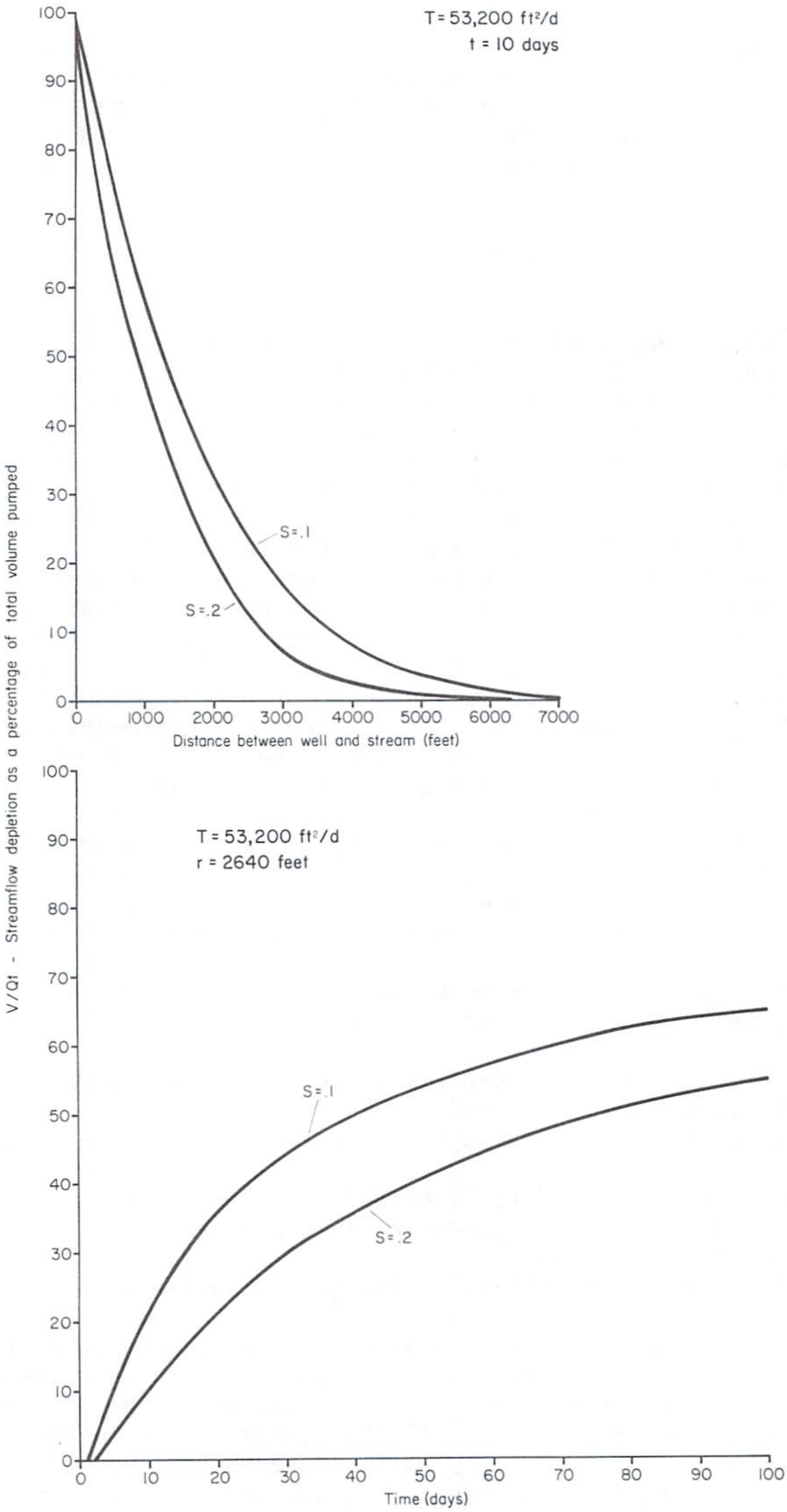


Figure 55. Stream depletion curves showing the effects of time of pumping and distance between the river and the pumped well.

Table 6. Stream depletion calculations. Assumptions are constant transmissivity (T) of 53,200 ft.^{2}/day and a constant pumping rate (Q) of 1000 gpm. Distance from the pumping well to the river (r) is constant for the first three columns while time is varied. Time is then constant over the second three columns as r is varied.

T = 53,200 ft^2/d
Q = 1000 gpm

	r = 2640 feet		+ = 10 days		
t (days)	S = 0.1 g (cfs)	S = 0.2 g (cfs)	r (feet)	S = 0.1 g (cfs)	S = 0.2 g (cfs)
0.5	0.009	0	1000	1.67	1.49
1	0.02	0.009	2000	1.19	0.85
5	0.56	0.25	3000	0.8	0.44
10	0.94	0.56	4000	0.49	0.19
20	1.24	0.91	5000	0.27	0.07
30	1.42	1.16	6000	0.15	0.02
40	1.52	1.27	7000	0.07	0.01
50	1.58	1.36			
100	1.78	1.61			

WATER QUALITY

In general, groundwater-quality data is limited for the alluvial aquifer study area. For an initial look at groundwater quality, information was drawn from several existing data sets; University Hygienic Laboratory (UHL) data, the U.S. Geological Survey's Water Storage and Retrieval System (WATSTORE), and Department of Water, Air, and Waste Management (DWAWM) data pertaining to municipal water supplies. The WATSTORE and DWAWM data sets pertain mostly to town wells and include the source of water as well as geographic location. The anlayses are done for minerals, trace metals, and radiation counts. Most of the data for the study area is from three towns along the upper reach of the west fork where the alluvial substrate is glacial till. There are also three analyses from downriver where the substrate is Pennsylvanian shale and sandstone.

The data from UHL consist of a collection of water analyses from private wells and municipal supplies. For the private well data, geologic control is poor and well locations are known only with respect to the resident's postal address. Private well analyses usually only examine water quality with respect to bacteria, nitrate, iron, and hardness. Because of the poor control on well locations, an attempt was made to better define the location of the well analyses. County plat books were used to name individuals living on the floodplain or immediately adjacent areas and only these analyses were compiled. All of the data used demonstrate some bias. Municipal wells are generally well constructed and maintained, and must attempt to meet public health standards. Private well analyses are submitted voluntarily and are usually submitted when a water-quality problem occurs (usually turbidity, taste, or odor). Thus, the water-quality data for private wells is not necessarily a true reflection of the overall quality of the groundwater system. Also, private well construction standards, especially for shallow wells, is often not comparable to those for public wells.

In addition to groundwater, surfacewater (river)-quality data was analyzed. A rationale applied was that under conditions of prolonged pumping at high rates, water quality in wells will approximate river water quality and that river water-solute concentrations tend to be inversely related to flow. Under base-flow conditions in the stream (low-stream stage), the river water may be considered to consist almost entirely of groundwater flow. The river water-quality data used was obtained from WATSTORE and from UHL. All of the background water quality data can be found in Appendix 5.

The municipal data pertaining to groundwater supplies show that typically, the groundwater in the study area can be classified as slightly alkaline fresh water with calcium and magnesium being the dominant cations, and bicarbonate the dominant anion. Total dissolved solids are usually less than 1000 mg/l and the water is characteristically hard. Nitrate values are low and cannot be related to either discharge or precipitation. The high dissolved-solids values for two Graettinger wells would suggest that these are not alluvial wells. The high dissolved-solids values for the Lehigh well implies a significant contribution from the surrounding Pennsylvanian rocks. Nitrate and bacteria data are available from 42 private samples spanning ten years from 1974 to 1983. Nitrate values range from <5 to 220 mg/l. In twenty percent (5/25) of the samples, the nitrate concentration was above 45 mg/l, the recommended health standard for drinking water. Without knowledge of local conditions, in particular the placement and construction details for wells, it is difficult to determine whether high nitrate is a local contamination problem or an indication of a more regional problem.

The river-water data provides a reasonably good base line for river-water quality. Application of this data is limited, however, as most of the samples have been collected primarily during summer and winter months. Samples collected during February of 1979 probably approximate background groundwater quality. At that time the river, shown by data for the Estherville and Humboldt gaging stations (Figures 56a and 56b), was approximately at baseflow. A water-quality study of the Des Moines River reservoirs conducted by Baumann et al., (1983) provides good river-water quality data for the lower part of the study area. Sampling station 1 near Boone, for the period between November, 1981, and January, 1983 showed nitrate concentrations ranging from 0.36 to 69.3 mg/l. Fifty-two percent of the samples (16/31) exceeded the primary drinking water standard of 45 mg/l during this time. Average daily nitrogen loadings calculated for the period 1972-1981 ranged from minimum of 17,700 lbs/day to a maximum of 284,000 lbs/day. Averaged across the basin (drainage area ≈ 5500 mi^2) and for a year the numbers range from 2 to 29 lb/acre of total nitrogen. No direct relationships were observed between nitrate concentrations and instantaneous discharge, however, a strong linear relationship was seen to exist between yearly nitrate loadings and annual discharge.

The WATSTORE data on alluvial analyses state wide was collected and statistically analyzed to see whether time trends could be observed in the nitrate results. A Kruskow-Wallis one-way analysis of variance was performed on the data, and tests the hypothesis that the samples are from different populations. The data was divided into three groups 1951-1960, 1961-1970, and 1971-1980, and proved significantly different at the .0001 level. However,

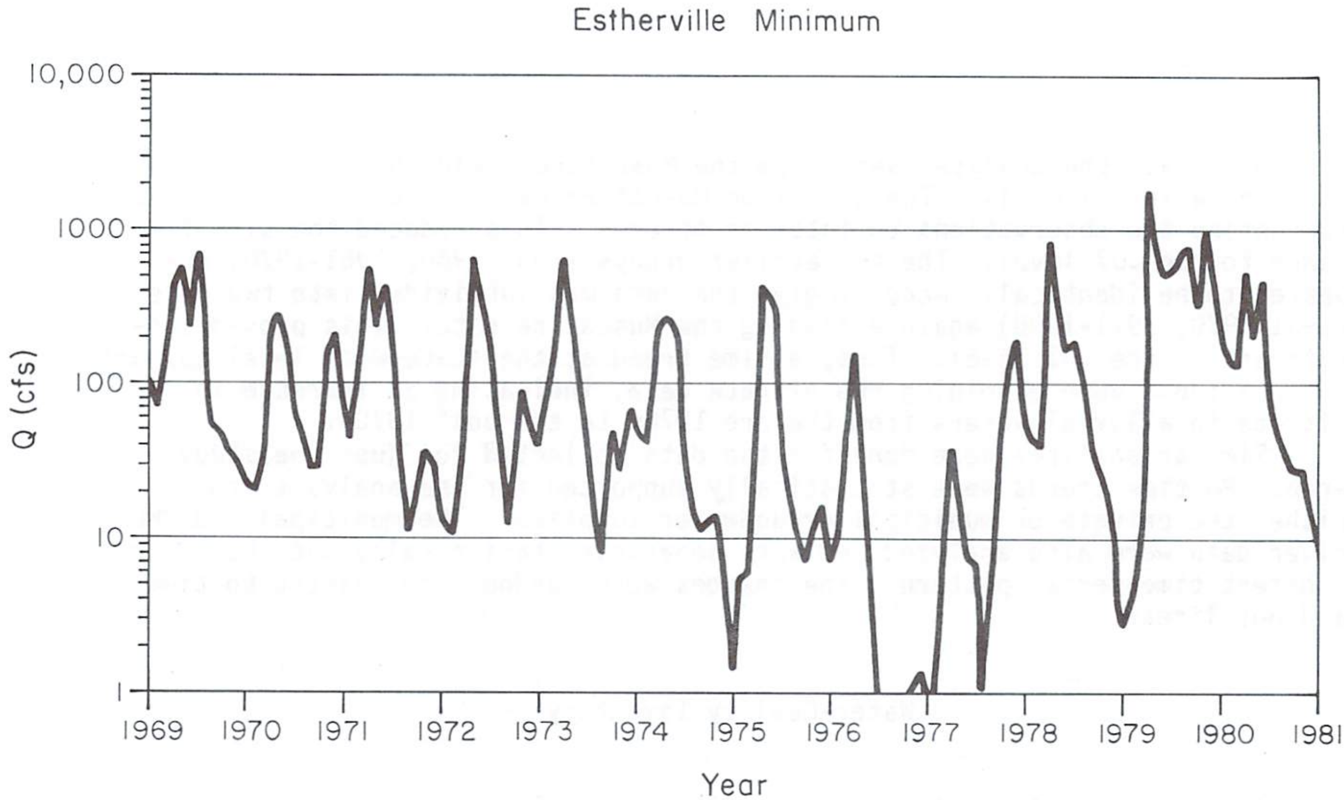


Figure 56a. Monthly minimum discharge data from Estherville (Emmet Co.) gaging station.

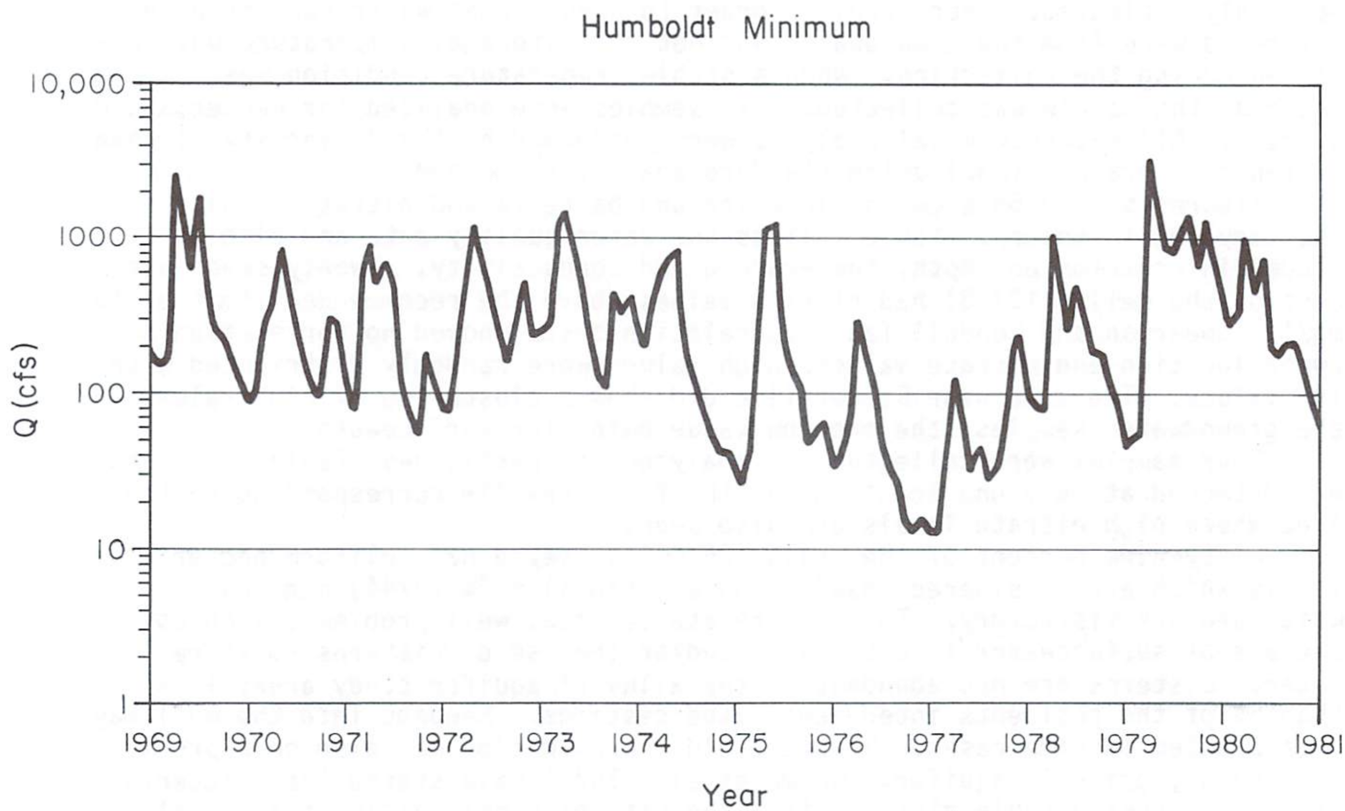


Figure 56b. Monthly minimum discharge data from Humboldt (Humboldt Co.) gaging station.

well over half the analyses were from the Muscatine field which are Mississippi River alluvial wells. The data from Muscatine was then excluded in order to confine the observations to interior streams. This reduced the significance to the .07 level. The two earlier groups (1951-1960, 1961-1970) appeared to be identical. Accordingly, the data was subdivided into two sets (1951-1970, 1971-1980) again excluding the Muscatine data. This proved significant at the .03 level. Thus, a time trend at the state-wide level appears to be evident when examining the nitrate data, indicating an increase in nitrate in alluvial waters from the pre 1970s to the post 1970s.

Similar analyses were done for the data collected for just the study area. No time trends were statistically supported for the analyses from either the private or municipal groundwater supplies. The municipal and UHL river data were also analyzed and were separable statistically but showed no coherent time-series pattern. The changes were random with respect to time and not linear.

Water-Quality Inventory

To further evaluate the water quality of the Des Moines River alluvial aquifer and to aid in placement of the monitoring network, a preliminary water-quality survey was done the week of August 22-26, 1983. Forty-eight water samples were collected from private, commercial, and municipal sources. Information about the depth and size of casing was not available and depths were only estimated. Therefore, in order to assure that water samples being collected were from the groundwater and not from storage, temperature was monitored during the collection. When a stable temperature condition was reached, the sample was collected. All samples were analyzed for bacteria and nitrate. All water-chemical analyses were performed by the University of Iowa Hygienic Laboratory (UHL) using standard analytical methods.

Figures 57 and 58 show the location and bacteria and nitrate results for the sampling inventory. Table 7 lists the water-quality data and also includes information on depth, temperature and conductivity. Twenty-seven percent of the wells (13/48) had nitrate values above the recommended limit of 45 mg/l. Spearman and Kendall Tau B correlation tests showed no correlation between location and nitrate values; high values were randomly distributed with low values. The area near Estherville did show a clustering of high values in the groundwater samples, the one low value being for surfacewater.

Four samples were collected and analyzed for pesticides (Table 8). Lasso was detected at only one location, north of Estherville corresponding to the area where high nitrate levels are also seen.

Fifty-nine percent of the wells (26/44) surveyed had coliform bacteria levels which are considered unsafe. An additional 6.8% (3/44) had analyses which are unsatisfactory. This may relate to local well problems, such as seepage of surfacewater into the well and/or the use of cisterns to store water. Cisterns are not abundant in the alluvial aquifer study area; less than 5% of the residents interviewed used cisterns. Seepage into the well may be a problem in some cases. Septic field contamination may also be a problem in a sandy, gravelly aquifer. Bouma et al. (1972) have stated that bacteria may move a considerable distance from the site of septic effluent disposal. Many of the well sites are located in areas subject to flooding. In areas of sandy, loamy soil bacteria may not be filtered as the water table drops after

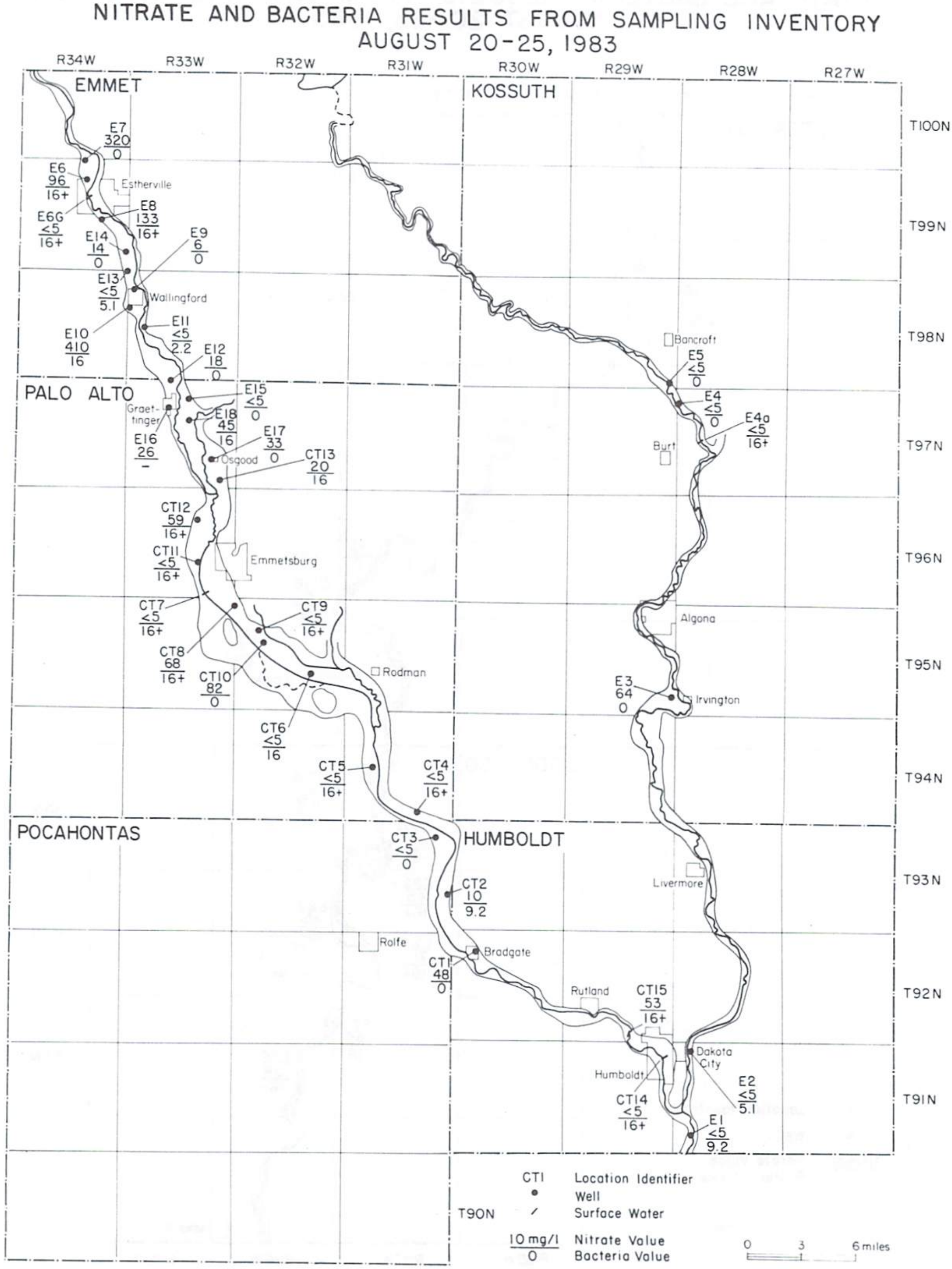


Figure 57. Water quality sampling locations and results from preliminary inventory: East and West Fork.

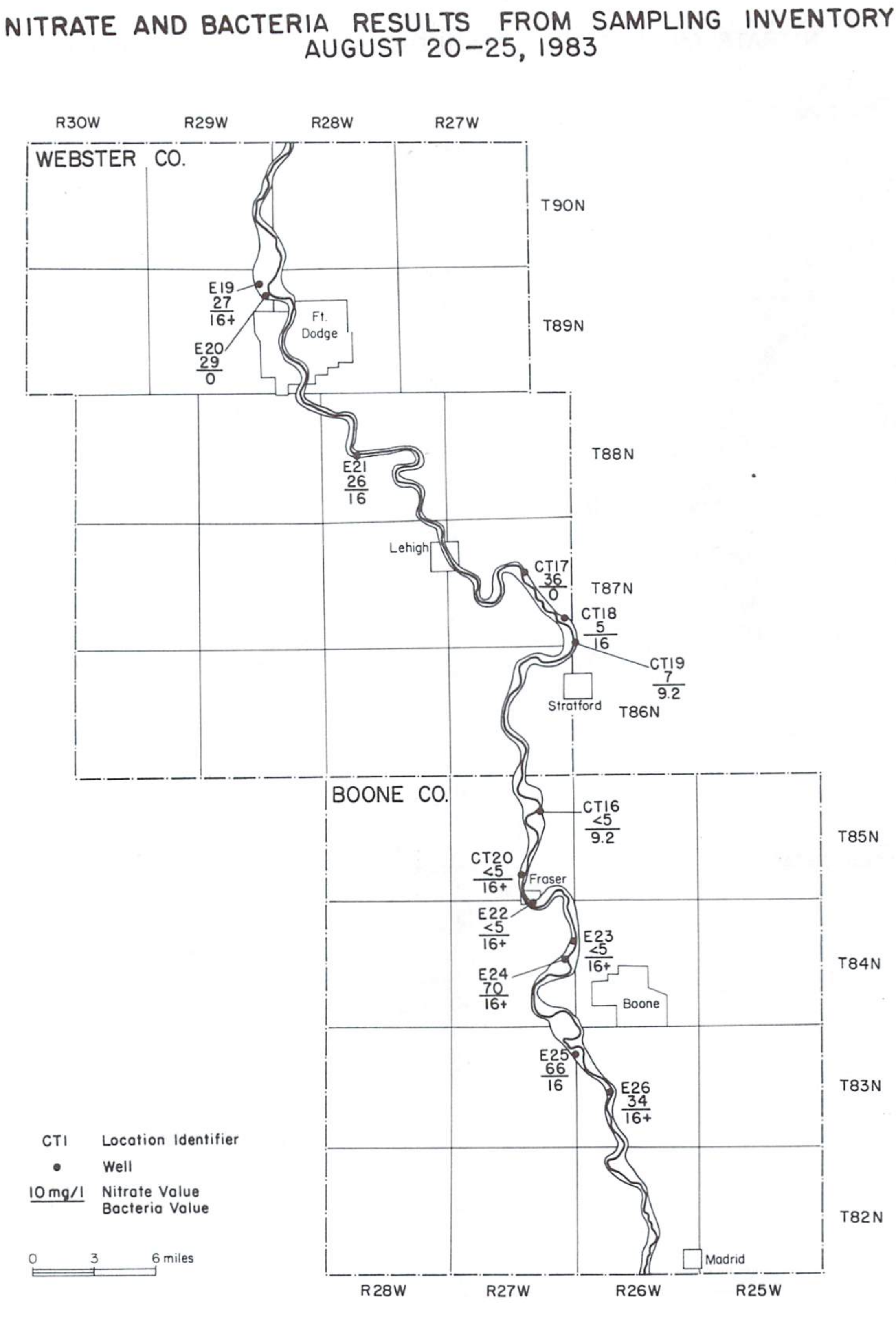


Figure 58. Water quality sampling locations and results from preliminary inventory: Lower River.

Table 7. Results from Sampling Inventory, August 20-25, 1983.

Location Identifier	Depth (ft)	Temperature (°F)	Conductivity	Nitrate (mg/l)	Bacteria
CT1	18	63	950	48	0
CT2	20	55.5	725	10	9.2
CT3	13	53	1150	<5	0
CT4	32	54	650	<5	16+
CT5	??	57	790	<5	16+
CT6	??	65	680	<5	16+
CT7	Surface	77	820	<5	16+
CT8	30	65	920	68	16+
CT9	14	52	750	<5	16+
CT10	18	68	945	82	0
CT11	18	67	690	<5	16+
CT12	38	54	705	59	16+
CT13	??	54	600	20	16+
CT14	Surface	--	740	<5	16+
CT15	Surface	--	440	53	16+
CT16	28	59	1825	<5	9.2
CT17	29	57	1650	36	9
CT18	??	69	775	5	16
CT19	30-40	65	1690	7	9.2
CT20	??	51	765	<5	16+
E1	??	--	630	<5	9.2
E2	40	--	760	<5	5.1
E3	18-21	--	2200	64	0

Location Identifier	Depth (ft)	Temperature (°F)	Conductivity	Nitrate (mg/l)	Bacteria
E4	20-30	--	1200	<5	0
E4a	Surface	--	----	<5	16+
E5	30	--	700	<5	0
E6	6	--	640	96	16+
E6a	Surface	--	---	<5	16+
E7	15	--	0	320	0
E8	16	--	1220	133	16+
E9	15	--	650	6	0
E10	30	--	820	410	16
E11	30	--	705	<5	2.2
E12	12	--	660	18	0
E13	30	--	720	<5	5.1
E14	14	--	840	14	0
E15	30	--	520	<5	0
E16	30-40	--	780	26	--
E17	14	--	525	33	0
E18	18	--	795	45	16
E19	20	--	630	27	16+
E20	??	--	1950	29	0
E21	21	--	1625	26	16
E22	??	--	890	<5	16+
E23	20	--	850	<5	16+
E24	??	--	840	70	16+
E25	20	--	1550	66	16
E26	40	--	835	34	16+

Table 8. Pesticide Analysis from four alluvial wells.

Concentration in Parts per Billion (micrograms/L)

Date Collected	Location	Atrazine	Lasso	Bladex	Treflan	Furadan	Dyfonate	Chlorinated Hydrocarbon Pesticides
8/26/83	E4	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
8/26/83	E7	N.D.	0.70	N.D.	N.D.	N.D.	N.D.	N.D.
8/26/83	CT10	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
8/24/83	CT1	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.

N.D. = None Detected

flooding and can, therefore, infiltrate to the groundwater. There bacteria can perist for some time.

Soils charts were compiled for the study area and list information on hydraulic group, drainage class, permeability, and limitations pertaining to septic tank effluent disposal (Table 9). This information was obtained for county soil survey reports and SCS technical releases. The majority of the soils in the study area have moderate to high infiltration rates and are generally not favorable for septic tank effluent fields. The risk of contamination of the shallow groundwater from septic sources is moderate to high in many of these soils. In others the poor filtering capacity may allow the effluent to travel considerable distances.

Water Quality Monitoring

Drilling sites were chosen to give a reasonable distribution of wells throughout the study area. The sites are in ditches along county and state roads. Mineral scans were done on samples collected from each well shortly after completion. The results of these analyses, listed in Table 10, are in agreement with the background municipal data in Appendix 5. A few of the wells show elevated sulfate concentrations which may indicate areas of recharge from the Dakota aquifer. Over the year of monitoring, two of the wells frequently emitted a sulfurous odor indicating that reducing conditions exist in the deeper parts of the alluvium. Nitrate values were low in the upper river except for WD16 and WD17. Several of the lower river values were elevated. Nitrate results will be discussed in a later section. Nine of the monitoring wells were sampled in early November and analyzed for pesticides. None were detected in any of the samples including those wells, which consistently showed elevated nitrates (WD16 and ED4A).

Table 9. Soils Information

	Hydrologic Group	Drainage Class	Permeability	Septic Tank Disposal field limitations	Parent Material
Alluvial land	---	variable	moderate to rapid	very severe	recent alluvium
Ankeny sandy loam	A	somewhat excessive	rap. to mod. rapid	severe	sandy local alluvium
Billet fine sandy loam	A	well	med. rapid or rapid	severe, poor filtering capcity	sand deposited by wind & water
Biscay clay loam, deep	B/D	poor	mod. to med. slow	severe, danger of GW contamination	loamy alluvium over sand & gravel
Buckney fine sandy loam	B	excessive	rapid	slight, poor filtering capacity, danger of GW contamination	alluvium
Calco silty clay loam	B/D	poor	mod. slow	severe marginal percolation	alluvium
Coland silty clay loam	B/D	poor	mod. slow	severe	alluvium
Colo silty clay loam	B/D	poor	mod. slow	severe, marginal percolation	alluvium
Cylinder loam, med. deep	B	somewhat poor	mod. to rap.	moderate, GW contamination high	loamy alluvium over sand & gravel
Cylinder loam, deep	B	somewhat poor	mod. to rap. to very rap.	moderate, danger of GW contamination	loamy alluvium over sand & gravel
Dickinson fine sandy loam	B	somewhat excessive	mod to rapid	slight, poor filtering capacity	dominantly eolian sand
Dickman fine sandy loam	A	excessive	rapid	slight	loamy sand and silt
Dorchester silt loam	B	Mod. well	moderate	---	calcareous alluvium

	Hydrologic Group	Drainage Class	Permeability	Septic Tank Disposal field limitations	Parent Material
Esterville sandy loam	B	somewhat excessive	mod. rap. to very rap.	slight	sandy and gravelly glacial deposits
Flager sandy loam	B	somewhat excessive	mod. rap. to very rap.	slight	alluvim
Hanlan fine sandy loam	B	mod. well	mod. rapid	mod. to severe	sandy local alluvium
Hanska	C	---	mod. to rapid	severe	outwash sand
Havelock clay loam	B/D	---	mod.	severe	loamy alluvium
Huntsville silt loam	B	well to mod. well	med.	severe	alluvium
Kato loam	B/D	impe. feet	med.	---	glacial outwash
Linder sandy loam	B	somewhat poor	mod. rapid to rapid	severe, poor filtering capacity	loamy alluvium over sand & gravel
Mayer loam	B/D	poor	mod. to very rapid	severe	calcareous sand & gravel
Moingona loam	C	med. well	med.	mod.	loamy alluvium
Okoboji	B/D	poor	slow	severe	local alluvium
O'Neill loam			not rated		
Pierce fine sandy loam			not rated		
Ridgeport sandy loam	B	somewhat excessive	mod. rapid to rapid	severe, poor filtering capacity	loamy sandy alluvium
Salida sandy loam	A	excessive	med. rapid to rapid	moderate, danger of GW contamination	sandy & gravelly glacial deposits
Saltre loam	B	well	mod. to very rapid	severe, poor filtering capacity	loamy alluvium over sand & gravel

	Hydrologic Group	Drainage Class	Permeability	Septic Tank Disposal field limitations	Parent Material
Sioux fine sandy loam			not rated		
Sparta loamy fine sand	A	excessive	very rapid	slight, poor filtering GW contamination danger severe	Eolian sand
Spillville loam	B	mod. well to somewhat pooly	moderate	severe	loamy alluvium
Talcot clay loam, deep	B/D	poor	mod. to mod. rapid	severe, danger of GW contamination	loamy alluvium over sand & gravel
Terril loam	B	mod. well	mod.	slight	local alluvium
Truman	B	well	mod.	slight	silty glacial sediments
Turlin	B	somewhat poor	moderate	severe	alluvium
Wabash silty clay loam	D	very poor	very slow	severe	clayey alluvium
Wadena loam, mod deep	B	well	mod.	slight, danger of GW contamination	loamy alluvium over sand & gravel
Watseka	B	somewhat poorly	rapid	severe	coarse textured alluvium
Waukegon silt loam	B	well	mod. to rapid	slight, danger of GW contamination	silty alluvial materials over sand
Zook silty clay loam	C/D	poor	slow to very slow	severe, unsatis-factory percolation	fine textured alluvium

HYDROLOGIC SOIL GROUPS:
If two letters are given, the first letter is the for tile drained soils, the second is for soils in their natural state.
A - Low runoff potential, high infiltration rates even when wetted; B - Moderate infiltration rates;
C - Slow infiltration rates when wetted; D - High runoff potenial, slow infiltration rates.

Table 10. Chemical Analyses from the Des Moines River alluvial wells. All analyses in milligrams per liter except: pH standard unit, Conductivity micromohs.

Well No.	Ca^{++}	Mg^{++}	Na^{+}	K^{+}	Mn^{+}	Fe	HCO_3^-	$SO_4^=$	Cl^-	NO_3^-	F^-	SiO_2	Hardness	Alkalinity	TDS	Conductivity	pH
WD18	81	27	50	3.2	0.20	2.9	317	120	12	0.8	0.3	27	319	260	578	730	7.75
WD2	130	38	8.4	3.2	0.38	0.17	520	56	8	0.7	0.3	22	482	427	539	870	7.5
WD30	110	35	9.4	4.6	0.65	0.05	289	150	28	5.2	0.15	20	425	237	556	810	7.5
WD6	82	25	4.4	1.8	0.30	0.49	275	73	14	0.2	0.2	25	309	226	355	600	7.15
WD7	77	24	28	5.2	0.29	0.40	293	76	10	1.5	0.2	26	292	240	386	640	7.6
WD8	150	48	87	9.1	0.55	2.1	324	94	260	0.2	0.2	26	569	266	972	1500	7.6
WD31	150	48	13	3.1	0.41	1.4	302	96	37	0.9	0.1	27	565	248	911	1200	7.5
WD9	63	19	47	4.9	0.21	0.63	265	95	18	0.5	0.4	26	237	217	404	660	7.7
WD10	77	25	14	3.4	0.40	1.3	245	73	20	0.1	0.2	24	298	201	368	590	7.5
WD11	160	48	24	3.6	0.97	4.5	277	350	18	0.1	0.25	28	607	227	788	1100	7.4
WD12	170	53	69	5.1	0.76	3.2	396	410	6.5	0.2	0.3	21	650	325	998	1300	7.3
WD13	96	31	17	3.8	1.80	3.0	329	110	22	0.2	0.2	28	376	270	514	770	7.4
WD14	95	34	16	4.6	0.29	0.33	324	92	24	0.2	0.2	20	378	266	426	730	7.7
WD15	64	18	9.9	5.1	0.40	1.2	237	30	10	1.2	0.2	28	237	194	282	460	7.6
WD16	75	23	4.5	1.9	0.02	0.14	229	36	4	55	0.2	23	282	188	326	540	7.7
*WD17	100	27	5.8	4.0	0.06	1.3	321	49	14	61	<0.1	24	373	263	502	740	7.5
***ED4	72	23	4.3	1.4	0.11	0.73	295	43	1.0	0.3	0.2	21	276	242	309	530	7.5
ED1	100	32	6.3	2.5	0.42	0.20	339	70	26	2.0	0.2	27	382	278	445	710	7.4
LD1	88	27	7.1	1.6	0.09	1.6	251	27	26	93	0.2	28	334	206	471	680	7.3
**LD2	120	36	6.8	2.8	0.50	0.99	345	96	22	8.2	0.4	17	438	283	493	750	7.75
LD3	120	27	16	2.6	0.11	0.09	407	68	12	9.7	0.25	24	411	333	419	790	7.5
LD5	120	35	57	4.4	0.20	1.2	380	160	35	0.4	0.4	23	446	310	631	910	7.5
LD6	100	31	9.6	2.6	0.08	0.71	397	52	6.5	11	0.2	26	379	325	441	730	7.2

* Finished in sandstone
** Finished in Mississippian Limestone
*** Finished in Cretaceous Dakota sandstone

To fully evaluate water-quality in the alluvial aquifer, a year-long monitoring program was undertaken. From the drilling sites a monitoring network was developed which concentrates on the area where the aquifer is most variable, but also includes a reasonable sampling of the rest of the river. Figures 59 and 60 show the wells and surfacewater sites chosen for the sampling network. Table 11 gives information for each well in the monitoring network including well depth, screened interval, and nature of and depth to the substrate. Included in the network are several nested-well sites (ED4, WD9, WD12). ED4 is open to the Cretaceous Dakota Sandstone, while ED4A is open to the alluvial sand and gravel. This allows a check on water quality in the Cretaceous aquifer where it is overlain directly by alluvial sands and gravels. Both WD9 and WD12 sets are open to different intervals within the alluvial sand and gravel. Monthly samples were collected for nitrate and bacteria, weather permitting. Some occasional sampling of private residences or other river sites was also done.

Weather conditions during the period for which water quality samples were collected was extremely atypical. September and October, 1983 were characterized by above normal precipitation and an early snowfall in October. Precipitation in November was the fourth greatest on record for the state and the second greatest in northwest Iowa. December brought the coldest temperatures of record with snowfall twice as heavy as normal. January and February were moderate, although much blowing and drifting of snow occurred. March snowfall was twice normal and contributed to the rising stream levels. April was the wettest on record with late, heavy snow occurring in the northwest. May precipitation again exceeded normal.

Table 12 lists total precipitation, departure from normal and snowfall for the stations in the study area.

Streamflows were also high during the 1984 water year. Figure 61 shows monthly mean river discharge for the Des Moines River at Fort Dodge compared to previous minimums and maximums. Discharge was near maximum throughout the year and set new record highs in May and June. These high streamflows led to damaging floods; up to five feet of downcutting occurred in some areas as the river attempted to scour new channels.

The heavy snows and cold temperatures hampered water collection efforts during the winter months. Many of the monitoring wells could not be reached, others were buried under large snowdrifts. Crop planting was delayed because of standing water in fields. The record streamflows and high water table in June again hampered collection efforts. Roads were flooded and many of the wells were in or covered by standing water. Normal planting and fertilization schedules could not be followed, in fact, crops in many fields were either drowned or never planted. In Palo Alto County, total land area in the Des Moines river valley is approximately 35,000 acres. Of this, about 16,000 acres were not planted in 1984. Some of this land is never planted, but probably 1984 crop losses approached 40%. Of the remaining crop area, approximately 20% is in corn with the rest in beans. This, compared to the county average of 52% corn and 48% bean, shows the depletion of the corn crop for this year. These depletions may have had an effect on the water quality, particularly with regard to the nitrate data.

MONITORING SITE LOCATIONS

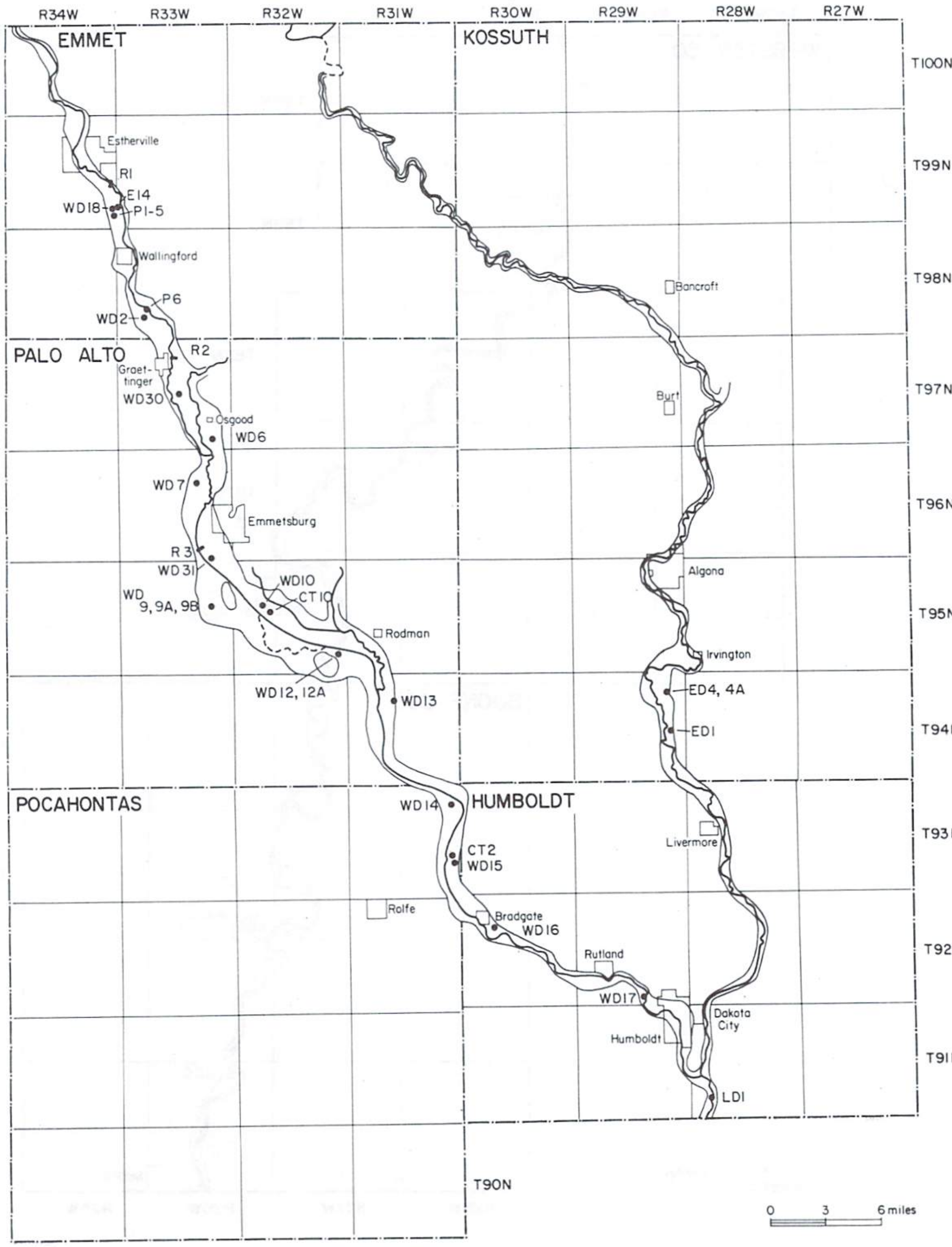


Figure 59. Monitoring well locations: East and West Fork.

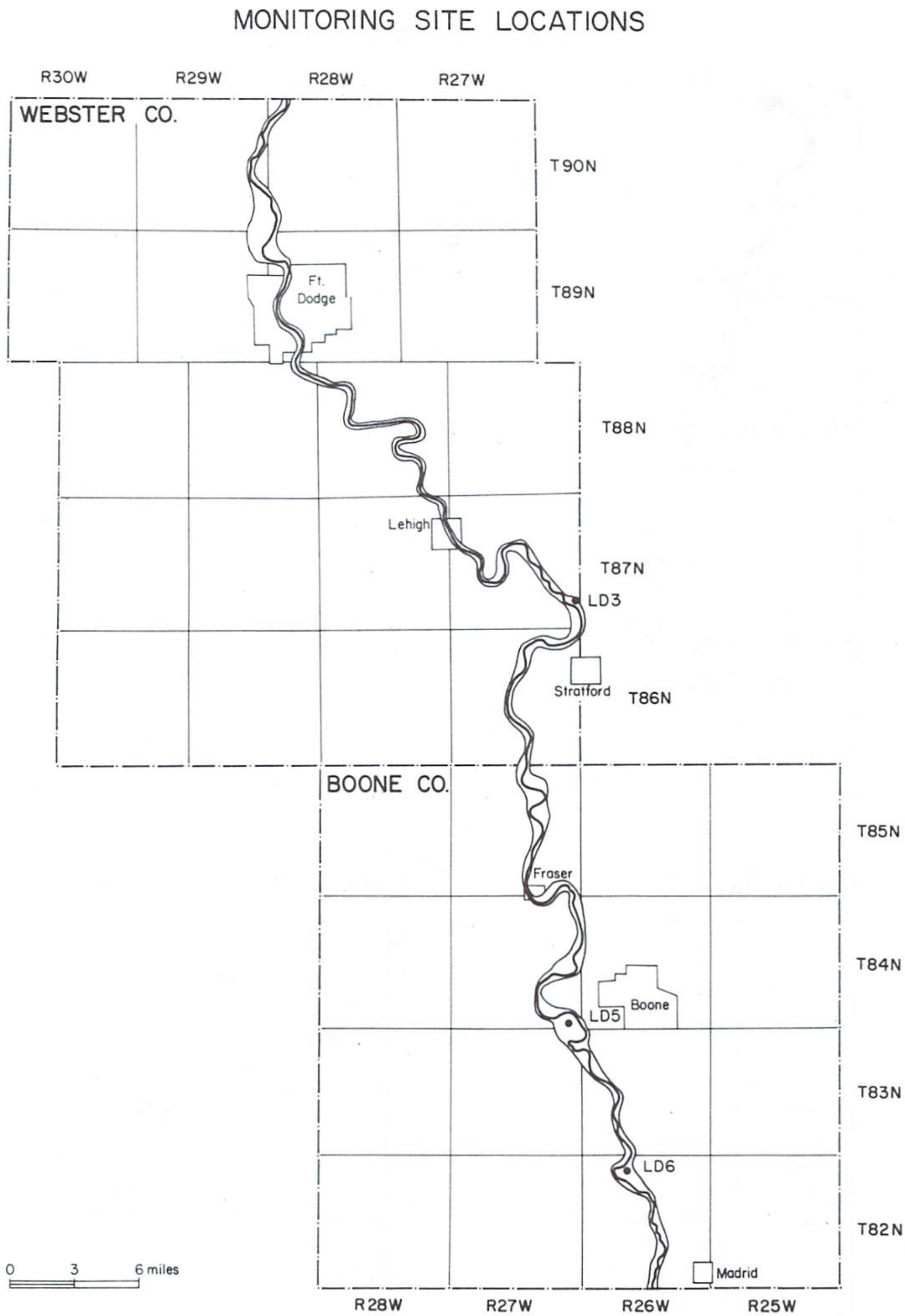


Figure 60. Monitoring well locations: Lower River.

Table 11. Monitoring Network Well Data

Well No.	Elevation (ft. above mean sea level)	Well Depth (ft)	Screened Interval (ft)	Substrate Lithology	Thickness of Alluvium (ft)	Base of Alluvium (ft)	Average Depth below Water Table (ft.)
WD4	1310	25	22.5-25	Till	25	27	6
WD1	1268	19	16.5-19	Till	16	20	Dry
WD18	1273	24	21.0-24	Till	20	25	16
WD2	1240	25	18.0-20	Till	15	20	9
WD30	1228	17	15.0-17	Till	15	17	6
WD6	1225	27	24.5-27	Till	25	27	19
WD7	1212	37	34.0-37	Till	36	38	29
WD8	1202	42	38.0-42	Till	39	45	35
WD31	1200	38	35.0-38	Till	31	38	30
WD9	1188	48	44.0-48	Till	53	55	41
WD9A	1188	17	15.0-17	Till	53	55	12
WD9B	1188	34	31.0-34	Till	53	55	28
WD10	1187	32	29.0-32	Till	34	36	24
WD11	1176	34.5	31.0-34.5	Till	34	36	29
WD12	1170	48	28.0-32	Till	31	34	25
WD12A	1170	25	22.5-25	Till	31	34	19
WD13	1155	36	33.0-36	Till	27	37	27
WD14	1138	31	28.0-31	Till	29	31	24
WD15	1127	17	15.0-17	Till	15	17	12
WD16	1116	14.5	13.0-14.5	Till	11.5	14.5	7
WD17	1089	58	50.0-58	SS	13.5	14.5	43
LD1	1083	14	13.0-14	Till	7	14	1
LD2	1020	21	18.0-21	LS	2	7	12
LD3	930	26	24.0-26	Till	20	26	16
LD4	938	37	34.0-37	Till	0	--	12
LD5	900	50	46.5-50	Shale	45	50	37
LD6	860	14.5	13.0-14.5	Shale	5.5	15.5	5
ED1	1096	33	30.0-33	LS	22	33	24
ED4	1115	94	90.0-94	SS	51	54	75
ED4A	1115	29	27.5-29	SS	51	54	12
ED2	1130	93	87.0-93	Till	4	5	59

SS = Sandstone

LS = Limestone

Table 12. Weather Summary for Monitoring Year

Station No.	Total Precipitation (in)	Departure from Normal	Snowfall (in)
September, 83			
1	2.32	-0.87	0
2	M	M	0
3	5.97	3.09	0
4	4.42	1.28	0
5	3.32	-0.02	0
6	3.42	0.07	0
October, 83			
1	2.04	0.25	2
2	M	M	M
3	2.82	0.95	T
4	2.96	1.06	T
5	3.88	1.81	0.5
6	4.90	2.59	T
November, 83			
1	3.20	1.94	14.3
2	4.16	2.86	14.2
3	3.63	2.28	18.0
4	3.52	2.26	8.5
5	3.64	2.25	14.5
6	5.50	4.08	7.0
December, 83			
1	0.30	---	13.0
2	0.64	-0.31	7.1
3	0.82	-0.02	11.0
4	0.83	-0.01	9.3
5	0.90	-0.06	10.5
6	0.78	-0.27	7.3
January, 84			
1	1.14	---	5.8
2	0.52	-0.26	6.0
3	0.47	-0.25	6.0
4	0.70	0.00	7.0
5	0.42	-0.45	5.0
6	0.66	-0.32	6.0
February, 84			
1	M	M	12.0
2	0.65	-0.50	7.5
3	0.62	-0.35	8.0
4	0.73	-0.19	0.5
5	0.77	-0.27	3.5
6	0.77	-0.36	1.0

Station No.	Total Precipitation (in)	Departure from Normal	Snowfall (in)
March, 84			
1	1.57	---	14.0
2	1.13	-1.24	9/5
3	0.74	---	10.0
4	2.48	-0.47	12.0
5	1.62	-0.62	14.0
6	1.65	-0.49	13.8
April, 84			
1	4.10	1.42	9.5
2	4.58	1.89	14.0
3	5.66	3.11	8.0
4	6.63	3.71	M
5	7.36	4.33	4.0
6	7.37	4.05	0.5
May, 84			
1	3.68	-0.01	0
2	4.07	0.37	0
3	3.82	0.11	0
4	2.93	-0.82	0
5	4.46	0.79	0
6	4.98	0.47	0
June, 84			
1	9.39	5.05	0
2	8.19	2.10	0
3	8.79	4.68	0
4	10.20	5.66	0
5	7.97	2.91	0
6	6.48	1.31	0
July 84			
1	1.92	-1.45	0
2	2.74	-0.82	0
3	3.44	-0.31	0
4	4.30	0.25	0
5	5.86	1.61	0
6	3.18	-0.64	0

M = missing data; T = trace
STATIONS: 1 - Estherville; 2 - Emmetsburg; 3 - Algona; 4 - Humboldt; 5 - Fort Dodge; 6 - Boone

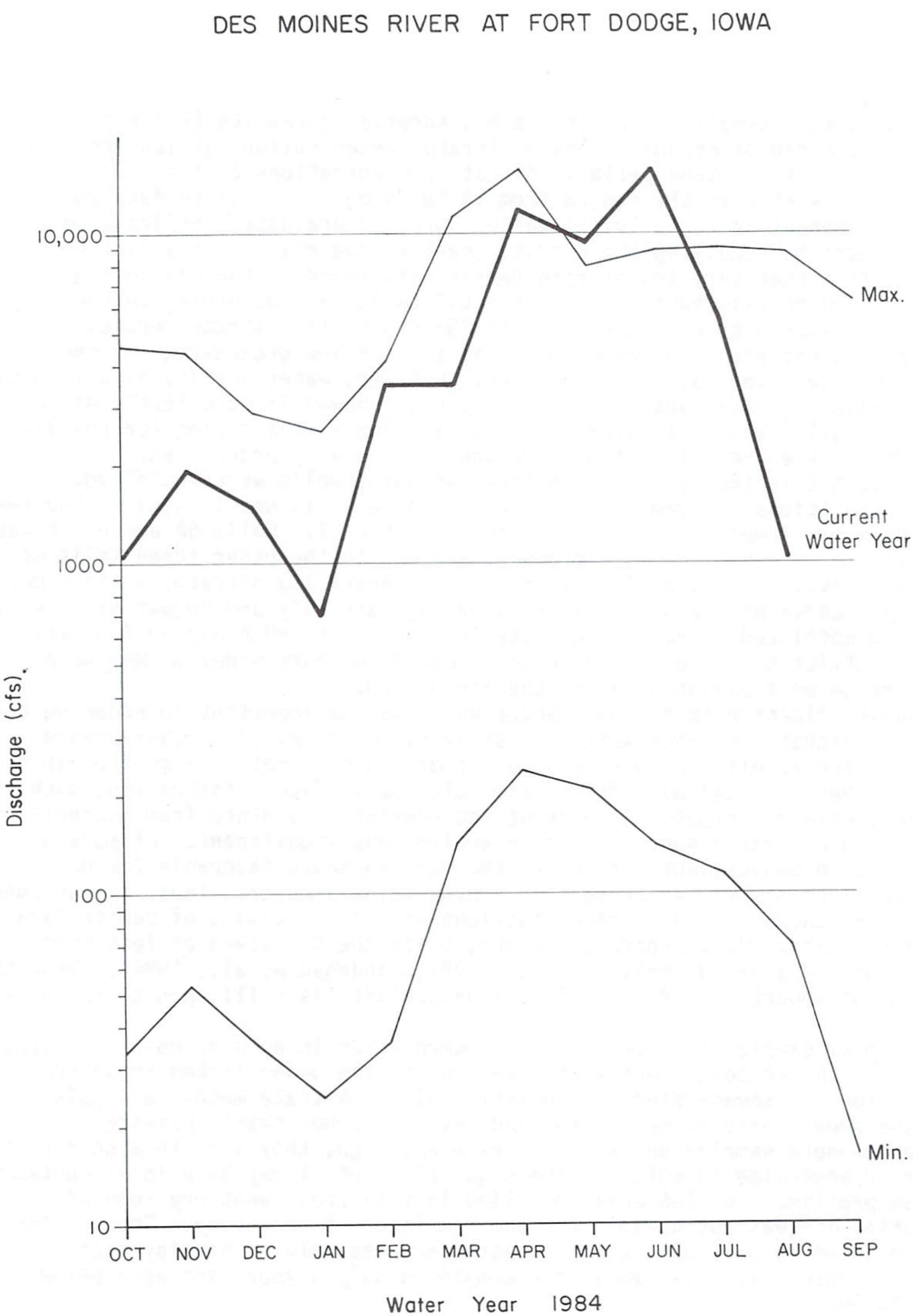


Figure 61. Mean monthly discharge at Fort Dodge showing previous maximums and minimums.

Nitrate Data

The monthly sampling for nitrate had surprising results (Table 13). West fork wells, north of Bradgate showed nitrate concentrations of less than five mg/l for the entire study period. Nitrate concentrations in the river during the fall and winter months ranged from 14 to 26 mg/l. Since surface runoff is a minor component in the alluvial valley north of Bradgate, infiltration and baseflow must be supplying the nitrate loads to the river. This fact combined with the fact that very low nitrate levels were found in the monitoring wells led to the hypothesis that vertical stratification was occurring in the aquifer. Research by Wehtje et al., (1983) showed that strong vertical gradients in nitrate as nitrogen occur in the shallow groundwater of the central Platte River valley in Nebraska. However, water-quality data from the upper levels of nested sets in this study also showed nitrate levels of less than five mg/l. Thus, if vertical stratification is the reason for the low level of nitrate, then the stratification must be very pronounced.

To test this theory, a few shallow sandpoint wells were installed. Weather conditions delayed installation of these wells until August. The results from two sampling dates are listed in Table 14. Wells 6A and 6B showed high nitrate levels. Concentrations of nitrate in the other three wells were less than five. The river at this time also showed low nitrate, <5 to 9 mg/l. Possibly because of the dry conditions during late July and August nitrate was not being mobilized. The high nitrate levels at site WD-6 may be from increased infiltration due to irrigation. Fields on both sides of WD6 were being irrigated frequently during the dry period.

Denitrification is another factor which may be important in reducing the levels of nitrate in groundwater. A study by Hendry et al., (1983) found a sharp decline in nitrate concentration at depths of 1 meter below the water table. Other chemical parameters, also tied to surface infiltration, such as chloride, were distributed throughout the aquifer. Evidence from isotopic studies proved that dispersion in the aquifer was significant. Dissolved oxygen and Eh measurements indicated that environments favorable for denitrification to occur were present at depths below 1 meter. Thus, it was concluded that the observed nitrate distribution was the result of denitrification activities. Most reports, however, place the N evolved as less than 5% of the total N applied (Rolston et al, 1981, Goodroad et al., 1984). Thus the question of importance of denitrification activity is still open to speculation.

Several samples from private wells were taken in an area north of Estherville. P1 showed consistently high values and the owner linked these to applications of sewage sludge in nearby fields. A trace metals analysis was done and showed only normal background levels. Other nearby private residences were sampled and while nitrate was high, they were in accord with the prior area-wide inventory. The high values at P1 may be a local contamination problem. The IGS well installed in this area, went dry soon after installation and was not useable for the remainder of the study. The aquifer in this location is part of a terrace system and has only a thin layer of saturated material. Most wells are completed only a short distance below the water table.

Well WD16 is similar. The saturated thickness varied from 7 to 11 feet over the past year, which places the well only 6 to 10 feet below the water table. WD17, however, is a deep well consisting of a thin alluvial section (15 feet) over a very fine-grained sandstone. There is, apparently, a channel in the Mississippian limestone in this area. Downward flow gradients may be pronounced since high nitrate levels were observed even though the well is completed at 58 feet.

Table 13. Nitrate Monitoring Results

	11/18-19/83	12/13-14/83	1/23-24/84	2/27-28/84	3/19-22/84	5/23/84	6/4,7/84	6/12/84	7/3/84	8/9/84	8/15/84	10/15/84
WD18	<5	<5	<5	<5	<5	<5	--	--	--	--	<5	
WD2	<5	<5	<5	<5	<5	<5	--	<5	<5	--	<5	
WD30	<5	<5	<5	<5	<5	<5	--	<5	<5	--	<5	
WD6	<5	<5	<5	<5	<5	<5	--	<5	<5	<5	--	
WD7	<5	<5	<5	<5	<5	<5	--	<5	<5	--	<5	
WD31	<5	<5	<5	<5	<5	--	--	<5	<5	--	<5	
WD9A*	<5	<5	--	--	--	<5	<5	--	--	<5	--	
WD9B**	<5	--	--	--	--	<5	<5	--	--	<5	<5	
WD9***	<5	--	--	--	--	--	<5	--	--	<5	<5	
WD10	<5	<5	<5	<5	<5	--	--	<5	<5	--	<5	
WD12A*	<5	<5	<5	<5	<5	--	<5	--	--	<5	<5	
WD12***	<5	--	--	--	--	--	<5	--	--	<5	<5	
WD13	<5	<5	<5	<5	<5	--	<5	<5	<5	--	<5	
WD14	<5	<5	<5	<5	<5	--	--	--	--	--		
WD15	<5	<5	<5	<5	<5	<5	--	--	<5	--	<5	
WD16	36	24	20	8	13	--	--	24	<5	--	5	
WD17	69	74	75	77	78	--	<5	65	16	--	65	
ED1	--	<5	--	--	12	--	<5	--	--	--	--	
ED4A***	230	184	--	--	--	--	240	--	--	--	--	
ED4A*	<5	--	--	--	--	--	<5	--	--	--	--	
LD1	--	--	--	--	--	--	103	103	--	--	--	
LD3	6	--	--	--	--	--	--	--	--	--	--	
LD5	<5	--	<5	<5	<5	--	--	<5	--	--	--	
LD6	--	--	11	12	--	--	--	--	--	--	--	
R1	14	17	14	24	20	--	--	--	--	--	--	
R2	--	--	--	--	--	--	--	28	--	9	--	
R3	--	23	16	26	21	--	19	29	--		--	<5
P1	400	380	270	270	260	--	--	--	--	--	--	
P2	--	<5	--	--	--	--	--	--	--	--	--	
P3	--	--	--	69	--	--	--	--	--	--	--	
P4	--	--	--	75	--	--	--	--	--	--	--	
P5	--	--	--	60	--	--	--	--	--	--	--	
P6	--	--	--	--	--	81	--	--	--	--	--	
CT10	--	--	--	--	--	28	--	--	--	--	--	
E14	--	--	--	--	--	<5	--	--	--	--	--	
CT2	--	--	--	--	--	12	--	--	--	--	--	

*Upper; **Middle; ***Lower

Table 14. Monitoring Data from Sand Point Wells

Well No.	Screened interval below water table	Nitrate	Bacteria	Conductivity
		Sampling date 8/8-9/84		
6A	0 - 1	14	16+	655
6B	1 - 3	93	16+	615
9D	0 - 1.5	<5	0	540
9E	1 - 3	<5	0	585
10A	2.7 - 4.7	<5	2.2	720
		Sampling date 8/23/84		
6A	3 - 5	101	2.2	
6B	5 - 7	88	16+	
9D	2 - 4	<5	0	
9E	5 - 7	<5	16+	

Of the two east fork alluvial wells, ED1 occasionally showed nitrate while ED4A displayed consistent high concentrations. Textures in the sand and gravel are finer in the east fork however the geology at ED4A is fairly complex. The site is adjacent to the Algona moraine and in addition is open to the underlying Cretaceous sandstones. The vertical gradient is not consistent, being downward in fall and winter and upward in spring and summer. The high nitrate values at this site are not explainable without further investigation.

On the main stem of the Des Moines, two wells showed elevated nitrate. LD1 has an extremely thin saturated thickness of only 1-4 feet, thus the water sampled was from just below the water table. LD6 is finished in limestone, but again is only five to six feet below the water table.

In general, it appears that the wells completed less than 10 feet below the water table show elevated nitrate concentrations. Exceptions to this were WD2 and WD30 which have average depths below the water table of 9 and 6 feet respectively and the sand points at WD9 and 10 which even at the water table showed no nitrate. Conversely, WD17 which averages 43 feet below the water table, consistently yielded water high in nitrate.

Some further studies were done the last week of October. The well sets at 6, 9, and 12 were resampled for nitrate, chloride, and pesticides. In addition, dissolved oxygen, temperature, and specific conductance were measured in the field. The field measurements along with data on depth below the water table and the nitrate results are presented in Table 15. Pesticide analyses are not yet available. In wells 6A and 6B where nitrate is found, dissolved oxygen (DO) levels are high. In the other wells, DO levels are low, one of the conditions necessary for denitrification.

Soil samples were taken from the fields adjacent to WD6 and WD9. These samples are being analyzed for nitrate. Detailed descriptions of the soils showed notable differences. Although both soils are sandy loam in texture and derived from the alluvium there are important differences. The soil at WD-9 is poorly drained and is calcareous nearly to the surface, suggesting very limited leaching by infiltrating water. This may be due to a persistent high water table in this area reducing infiltration. By contrast, WD6 is leached throughout the 38 inch core and is highly oxidized indicating significant infiltration. This may explain the nitrate distribution at these two sites. Leaching at WD6 carries the nitrates down to the groundwater and to some, as yet undetermined, distance within the aquifer. Water entering the section at WD9 is held up in the soil where abundant organic matter and microbes are present. Reducing conditions are indicated both by soil color and the apparent water-logged soil conditions. Thus, the environment at WD9 is entirely favorable for denitrification which is the probable explanation for the lack of nitrates at this site. Further investigations are underway in an attempt to define the flow paths in the Des Moines alluvial system. Some redesign of the monitoring well network is being done to test shallow sections of the aquifer.

Table 15. Monitoring Data 10/30/84

Well No.	T.D. (ft.)	Water Level (ft.)	Depth of open interval below water table (ft.)	Dissolved oxygen ppm	Specific Conductivity Micromohs/cm	Temperature F°	NO_3 (mg/l)	Bacteria	Cl
9	48	1187.4	41.8 - 45.8	0.6	500	10.5	<5	16+	10
9B	34	1187.4	28.5 - 31.5	0.4	520	10.5	<5	16+	22
9A	17	1187.4	12.5 - 14.5	0.6	520	10.5	<5	16	16
9E	11.4	1187.7	3 - 5	0.1	550	--	<5	16+	17
9D	7.1	1187.5	0 - 2	0.9		--	<5	16+	16
6	27	1216.5	18.5 - 21	0.55		12		--	--
6B	15.2	1217.0	5.7 - 7.7	9.8	510	12	94	0	14.0
6A	10.2	1219.9	1.5 - 3.5	9.2	520	12	87	0	7.5
12	48	1163.0	24 - 28	1.25	1050	12	<5	16+	7.5
12A	25	1163.0	16.7 - 19.2	1.25	615	12	<5	16+	16

Bacteria Results

Water samples from the monitoring network were also analyzed monthly for coliform bacteria (Table 16). The data are reported as the most probable number (MPN) of total coliform individuals per 100 ml of water. The MPN classes are 0, 2.2, 5.1, 9.2, 16, and 16+. Values of 2.2 are unsatifactory, values >2.2 are considered unsafe. Surfacewaters sampled during the study were always 16+.

The data from the first sampling period in November and December is meaningless as the samples were contaminated during collection. The wells were all subsequently chlorinated in late December and pumped. Values from wells WD9, 9A, 9B, and WD12 and 12A may be meaningless after the 6/4/84 sampling period. These wells were completely submerged during high water periods and surfacewater would have entered the wells through the casing. Offsetting this however, is the fact that the wells are pumped at rates of approximately 100 gpm for three to five minutes to ensure that the samples are from the groundwater. Samples from the above periods and wells will be ignored in the following discussion.

Forty-seven percent of the samples showed coliform levels over 2.2 (58/81). Another 10 percent had levels at 2.2 (8/81). Again there appears to be a relationship between depth below the water table and bacterial presence. High bacterial counts seem to be related to periods of high stream stage. Bacterial counts rose in many of the wells during the June and July high water periods. Thus it appears that bacterial problems are not confined to local system contamination problems, but are a problem in the aquifer itself.

Temperature Monitoring

Temperatures were measured when groundwater samples were collected (Table 17). The temperatures are typical for shallow alluvial systems. Those measured in November show a larger variation, but were measured with a Fahrenheit thermometer which was not as accurate as the Centigrade instrument used during the remainder of the study.

WATER USE

The major categories of water use in the Des Moines River alluvial aquifer are rural-domestic and livestock, municipal, and irrigation. Some industrial useage occurs, but there are no numbers available. For some uses, most notably irrigation, the water use is consumptive. Consumptive water use is defined as water not returned to the system, but transpired by plants and/or evaporated from the soil. Consumptive water use depletes the available water resource and is only replaced through natural recharge.

Table 18 lists water use by category for each county in the study area. Statistics used for population and livestock numbers were obtained from the 1982 Iowa Statistical Profile. Rural populations in the alluvial valley were estimated by multiplying the total rural population of the county by the percentage of the county in the alluvial valley. An average consumptive figure of 70 gallons per day per capita was used to calculate water use. Estimates for livestock use were calculated in a similar way using consumptive figures from Herrick (1978). Livestock estimates are high, because in general there

Table 16. Bacteria Monitoring Results

	11/18-19/83	12/13-14/83	1/23-24/84	2/27-28/84	3/19-22/84	5/23/84	6/4,7/84	6/12/84	7/3/84	8/9/84	8/15/84
WD18	9.2	2.2	0	0	0	0	--	--	16+	--	2.2
WD2	2.2	0	--	0	0	0	--	0	16	--	0
WD30	16+	16+	--	16+	16	5.1	--	5.1	5.1	--	0
WD6	--	--	--	--	--	0	--	2.2	2.2	16	--
WD7	2.2	0	0	0	0	0	--	16+	16+	--	16
WD31	9.2	2.2	0	0	0	--	--	0	0	--	0
WD9A*	16+	9.2	0	--	--	16+	0	--	--	16+	16+
WD9B**	16+	--	--	--	--	16	0	--	--	16+	9.2
WD9***	16+	--	--	--	--	0	--	--	--	16+	16+
WD10	16+	16+	5.1	0	0	0	--	0	16+	--	16+
WD12A*	16+	16+	16+	16+	16+	--	0	--	--	16+	16+
WD12***	16+	--	--	--	--	--	0	--	--	16+	16+
WD13	16+	0	0	0	0	--	--	0	16+	--	9.2
WD14	0	0	0	0	0	--	--	--	--	--	--
WD15	16+	16	16+	9.2	2.2	0	--	--	16+	--	16+
WD16	16+	0	0	2.2	16	--	--	2.2	2.2	--	9.2
WD17	16+	16+	16	16+	16+	--	16+	0	16+	--	16
ED1	--	9.2	--	--	9.2	--	0	--	--	--	--
ED4A***	16+	5.1	--	--	--	--	2.2	--	--	--	--
ED4A*	16+	--	--	--	--	--	0	--	--	--	--
LD1	--	--	--	--	--	--	16+	16+	--	--	--
LD3	16+	--	--	--	--	--	--	--	--	--	--
LD5	16+	--	0	0	0	--	--	2.2	--	--	--
LD6	--	--	0	9.2	--	--	--	--	--	--	--
R1	16+	16+	16+	16+	16+	--	--	--	--	--	--
R2	--	--	--	--	--	--	--	16+	--	16+	--
R3	--	16+	16+	16+	16+	--	16+	16+	--	16+	16+
P1	0	0	0	0	0	--	--	--	--	--	--
P2	--	0	--	--	--	--	--	--	--	--	--
P3	--	--	--	0	--	--	--	--	--	--	--
P4	--	--	--	0	--	--	--	--	--	--	--
P5	--	--	--	9.2	--	--	--	--	--	--	--
P6	--	--	--	--	--	16+	--	--	--	--	--
CT10	--	--	--	--	--	0	--	--	--	--	--
E14	--	--	--	--	--	0	--	--	--	--	--
CT2	--	--	--	--	--	0	--	--	--	--	--

*Upper; **Middle; ***Lower

Table 17. Temperature (°C) Monitoring Results

	11/18-19/83	12/13-14/83	1/23-24/84	2/27-28/84	3/19-22/84	5/23/84	6/4,7/84	6/12/84	8/15/84
WD18	10.0	10.0	10.0	9.5	9.0	10.0	---	---	9.0
WD2	10.5	11.0	10.0	9.0	9.0	8.5	---	9.0	11.0
WD30	11.6	11.0	10.0	9.0	9.0	8.0	---	9.0	11.0
WD6	---	---	---	---	---	10.0	---	---	---
WD7	10.0	10.0	10.0	9.5	10.0	10.0	---	10.0	10.5
WD31	8.8	10.0	10.0	10.0	10.0	---	---	10.0	9.0
WD9A*	16.5	10.0	---	---	---	10.0	10.0	---	9.0
WD9B**	9.4	---	---	---	---	10.0	10.0	---	9.0
WD9***	9.4	---	---	---	---	10.0	10.0	---	9.0
WD10	8.8	9.0	10.0	10.0	9.0	10.5	---	10.0	10.5
WD12A*	11.1	11.0	11.0	10.0	9.0	---	10.0	---	10.0
WD12***	10.0	---	---	---	---	---	10.0	---	10.0
WD13	10.5	10.0	10.0	9.5	9.5	---	10.5	10.0	10.0
WD14	11.1	11.0	11.0	10.0	10.0	---	---	---	---
WD15	12.2	11.0	10.0	9.0	9.0	10.5	---	---	10.0
WD16	11.7	11.0	10.0	10.0	8.0	---	---	9.0	10.0
WD17	10.5	10.0	10.0	9.0	9.5	---	10.0	11.0	10.0
ED1	---	---	---	---	---	---	11.0	---	---
ED4A***	10.0	9.0	---	---	---	---	10.0	---	---
ED4A*	8.9	---	---	---	---	---	10.0	---	---
LD1	---	---	---	---	---	---	10.0	12.0	---
LD3	12.8	---	---	---	---	---	---	---	---
LD5	11.1	---	10.0	10.0	9.5	---	---	12.0	---
LD6	---	---	11.0	10.0	9.0	---	---	---	---

*Upper; **Middle; ***Lower

Table 18. Water Use by County and Category

County	Water Use (mg/yr) Municipal	Rural-Domestic	Livestock	Irrigation	Total
Emmet		4.1	15.7	42.4	62.2
Palo Alto	333.2	11.5	47.5	2685.1	3076.3
Pcahontas		1.5	6.8		8.3
Humbolt	3.9	3.9	12.4		20.2
Webster	47.1	8.4	38.1		93.6
Boone	730.0	6.8	17.7		754.5
Kossuth		4.5	14.9		19.4
	1114.2	40.7	153.1	2727.5	4034.5

are few animals in the valley. Most livestock production occurs in the uplands.

The numbers cited for irrigation are the total amount which is permitted. 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. Irrigation useage in 1984 was quite small owing to the minimal corn crop caused by early summer flooding.

Future Water Use

As can be seen in Table 18, irrigation is potentially the largest user of alluvial water, even though confined to a relatively small area. There are no projections available to forecast future useage. Another drought, such as that during 1975-77, could stimulate renewed interest in irrigation.

Future population estimates were compiled and represent the expected change in total county population (Table 19). Also listed are the changes in rural and total populations for the period 1970-1980. In general, the rural population is decreasing faster than the total county population. Since most of the estimates are for increased population, some increases in water useage for rural-domestic and livestock can be expected.

RESOURCE ASSESSMENT

The Des Moines River alluvial aquifer from Boone County north to the Minnesota border is an aquifer of several contrasts. In Boone, Webster, and Humboldt counties the aquifer consists of thinly saturated terrace deposits. These deposits sit at varying levels above the present day floodplain and are underlain by either a thin layer of till or Pennsylvanian or Mississippian bedrock. The volume of water in these deposits is generally insufficient for all but light rural-domestic use. Storage tanks are usually required to

Table 19. Population Projections

County	Estimated Population on floodplain	Projected percent change total County (1995)	Percent Change 1970-1980 Rural	Percent Change 1970-1980 Total
Kossuth	177	10.8	-7.7	-4.6
Emmet	158	5.2	-1.4	-4.8
Palo Alto	448	11.0	-11.4	-4.3
Pocahontas	59	-3.8	-11.1	-11.1
Humboldt	153	4.7	-5.1	-2.2
Webster	327	1.2	-3.5	-5.9
Boone	267	-1.4	-2.9	-1.1

ensure an adequate water supply. These terrace deposits can be pumped dry and are recharged slowly from either the river or other sources. Water quality is variable and is dependent in large part on the infiltration capability of the soils. If infiltration does occur, then surface pollutants will be carried down to the water table through the overlying oxidized sand and gravel deposits. Several of the terrace wells sampled during the study showed high concentrations of nitrate.

Deposits of alluvium also occur directly under the floodplain and these can be quite thick in meander loops such as the one west of Boone. These deposits can be a source of water, although most water produced by wells will be supplied by the river. Supply, therefore, is dependent on the flow characteristics of the river. Except for dry years, the river will provide adequate supplies of water. Water quality at least to high pumpage wells will approximate that of the surface water.

The east fork of the Des Moines River is generally underlain by till. From Irvington down to the junction, the river valley averages 3/4 miles wide and displays a flat valley floor. Alluvial thicknesses range from 20 to 50 feet deep, static water levels are from 4 to 15 feet below the surface, and saturated thicknesses are from 20 to 40 feet. The storage capacity of the system is not large because of the narrow valley width and high pumpage wells will impinge on the river. There is adequate volume to meet rural-domestic and livestock needs. Water quality appears variable, but little is known as only two sites were sampled. The high water table may prevent rapid infiltration and thus prevent nitrate from leaching to the groundwater. Very little alluvium is present along the east fork north of Irvington and the resource is not significant.

The primary area of water availability from the upper Des Moines alluvial system occurs along the west fork between Bradgate and Wallingford. Valley widths range from 1/2 to greater than 2 miles. Storage in this area was calculated to be between 4 and 74 billion gallons. Alluvial thicknesses range from 20 to 60 feet and average about 26 feet. Most of this thickness is saturated and the aquifer in this area is highly transmissive. Wells up to a mile from the river mimic river-stage fluctuation patterns indicating a close hydraulic tie. Yields suitable for irrigation, industrial, and municipal useage can be obtained. Water quality, in general, is good. There are scattered locations where reducing conditions allow the formation of hydrogen sulfide gas. The water can be aerated or filtered to remove the sulfur odor. Nitrate distribution appears to be related to soil type and depth below the water table. Soils with a high infiltration capacity in areas where the water table is not too near the surface, will permit leaching of nitrate to the aquifer. Denitrification appears to be an important factor in reducing nitrate levels in the alluvial system. Wells located ten feet or more below the water table show little or no nitrate contamination.

In general, adequate yields can be obtained for domestic use at any location along the river. Yields do vary, however, because of the variation in alluvial thicknesses over a short distance. Test drilling is still necessary to locate the most favorable sites for high capacity wells. Water quality should be checked for nitrate and bacteria levels. Test kits are available from extension agents or from the University of Iowa Hygienic Laboratory.

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Appendix I

Preliminary Geologic Information

Well Logs
Sand and Gravel Pits
Bridge Borings

Part I.

Wells Logs

No.	W-Number	Location	Elev. (ft.)	T.D. (ft.)	From	To	Lithology
1	10262	SE SE NW SE Sec. 10 T99 R34	1280	756.3	0	1	Soil
					1	10	Gravel
					10	135	Till
					135	280	Graneros shale
2	596	SE/C Sec. 10 T99 R34	1299	350	0	34	Gravel
					35	145	Till
					145		Cret sh
3	7730	NW NW NW NE Sec. 14 T99 R34	1295	770	0	2	Soil
					2	20	Gravel
					20	160	Till
					160	225	Cret Graneros shale
4	17152	NW NW NE NE Sec. 15 T99 R34	1282	750	0	5	Fill
					5	10	Till
					10	15	Gravel
					15	125	Till
					125	225	Cret sh
5	15954	SW SE NE NW Sec. 36 T99 R34	1288	42.5	0	5	Soil
					5	10	Silt
					10	32	Till
					32	42	Gravel
6	10759	SE NE Sec. 4 T97 R33	----	32	0	2	Soil
					2	20	S & G
					20	26	Till
					26	30	Gravel
					30	32	Till
7	4330	NE SW NE NW Sec. 9 T97 R33	1250	40	0	30	S & G
					30	40	Till
8	26647	NE NW Sec. 22 T96 R33	1212	21	0	5	NS
					5	21	S & G
9	26648	NW NW Sec. 23 T96 R33	1205	21	0	5	NS
					5	21	S & G
10	26649	NW Sec. 23 T96 R33	1204.5	42	0	5	NS
					5	25	S & G
					25	29	NS
					29	42	S & G
12	26644	SW SW Sec. 35 T95 R32	----	21	0	5	NS
					5	21	S & G

No.	W-Number	Location	Elev. (ft.)	T.D. (ft.)	From	To	Lithology
13	26645	NW SW	1196	21	0	5	NS
		Sec. 35 T96 R33			5	21	S & G
14	26646	NE SW	1199	21	0	4	NS
		Sec. 35 T96 R33			4	21	S & G
15	26643	SW NW	----	21	0	5	NS
		Sec. 6 T95 R32			5	21	S & G
16	26642	NW SW	----	21	0	5	NS
		Sec. 6 T95 R32			5	21	S & G
17	26641	SW SW	----	21	0	5	NS
		Sec. 6 T95 R32			5	21	S & G
18	26640	SE NE	----	21	0	5	NS
		Sec. 14 T95 R32			5	21	S & G
19	26639	SW NE	1183	21	0	5	NS
		Sec. 16 T95 R32			5	21	S & G
20	26638	SW SE	1181	21	0	3	NS
		Sec. 16 T95 R32			3	21	S & G
21	26637	NW NE	1181	21	0	7	NS
		Sec. 21 T95 R32			7	21	S & G
22	26636	SW NE	1181	21	0	5	NS
		Sec. 21 T95 R32			5	21	S & G
23	26635		1180	21	0	5	NS
		Sec. 21 T95 R32			5	21	S & G
24	26634	SW SE					
		Sec. 21 T95 R32	1180	21	0	5	NS
					5	21	S & G
25	26633	NW NE	1178	21	0	5	NS
		Sec. 28 T95 R32			5	21	S & G
26	26632	NE NW	----	21	0	4	NS
		Sec. 36 T95 R32			4	21	S & G
27	26631	NE NE	1167	21	0	5	NS
		Sec. 36 T95 R32			5	21	S & G
28	26630	NW NE	1166	21	0	5	NS
		Sec. 31 T95 R31			5	21	S & G
29	26629	NE NE	1163	21	0	5	NS
		Sec. 31 T95 R31			5	21	S & G

No.	W-Number	Location	Elev. (ft.)	T.D. (ft.)	From	To	Lithology
30	4724	SW NE SE Sec. 5 T94 R31	1162	505	0	30	NS
					30	35	Sand
					35	40	Till
					40	45	S & G
					45	50	Till
					50	60	Loess
					60	215	Dakota ss
					215		Dev. ls
31	11077	NE SW Sec. 34 T94 R31	----	30	0	5	NS
					5	30	S & G
32	15571	SE NE SE Sec. 31 T92 R29	1138	185	0	5	Sand
					5	50	Till
					50		Miss ls
33	10867	SW NE SW Sec. 28 T92 R29	1084	72	0	5	Soil
					5	26	Till
					26		Miss dol
34	1719	SW SW SW Sec. 35 T92 R29	1090	274	0	10	Silt
					10	65	Cret ss and sh
					65		Miss ls
35	4038	NW SW NW Sec. 2 T91 R29	1085	86	0	3	Soil
					3	40	Till
					40		S & G
36	3400	NW NW NW Sec. 1 T91 R29	1085	11	0	4	Soil, S & G
					4		Miss ls
37	3392	SE SE NW Sec. 36 T92 R29	1150	71	0	10	Soil
					10	20	Sand
					20	50	Mixed S & G, shale
					50		Miss ls
38	14369	NE NE NE Sec. 1 T91 R29	1116	302	0	5	Soil
					5	60	Till
					60		Miss ls
39	1903	NW/C SW SE Sec. 1 T91 R29	1093	870	0	5	Soil
					5		Miss ls
40	3224	SW NE SW Sec. 6 T91 R28	1126	183	0	3	Soil
					3	90	Till
					90		Cherty dol

No.	W-Number	Location	Elev.	T.D.	From	To	Lithology
41	15154	NW SW NE Sec. 6 T91 R28	1125	186	0 3 90	5 90	Soil Till Cherty dol
42	3222	SE SW NE SW Sec. 6 T91 R28	1130	1026	0 5 85 125	5 85 125	Soil Till Sand Miss dol, ls
43	5663	SW NE SW Sec. 19 T91 R28	1067	76	0 2 15 35	2 15 35	Silt Till S & G Miss ls
44	3407	SE SE SW Sec. 29 T91 R28	1059	457	0 22	22	Till Miss ls
45	3917	SE SW SE Sec. 29 T91 R28	1135	129	0 15	15	Till Miss ls
46	2570	SW NE SW Sec. 32 T91 R28	1125	109	0 20 50 75 85	20 50 75 85	Till Sand Till Sand Dol
47	2522	NE/C Sec. 32 T91 R28	1125	102	0 10 40 70 90	10 40 70 90	Till S & G Till Shale Chert
48	2399	SE NE SE Sec. 19 T98 R29	1180	208	0 50 65 125 195	50 65 125 195 208	Till Gravel Till Cret.sh Dev.CV Dolomite
49	17384	NW SW Sec. 26 T98 R29	----	152	0 70 100	70 100 140	Till Dakota ss Cret. sh
50	10442	Sec. 35 T96 R29	----	139	0 60 130 135	60 130 135 139	Gravel Dakota ss NS Chert

No.	W-Number	Location	Elev. (ft.)	T.D. (ft.)	From	To	Lithology
51	10719	NE NW NE SW Sec. 2 T95 R29	1165	145	0	5	Sand
					5	35	Till
					35	95	Gravel
					95	145	Dakota ss
52	Algona City Well #7	NW NW SW NE SW Sec. 2 T95 R29	1150	141	0	45	Clay & Gravel
					45	73	S and G
					73	74	Till
					74	140	Dakota ss
					140	141	blue shale
53	8120	SE SE Sec. 10 T95 R29	1150	225	0	40	NS
					40	80	Till
					80	100	Gravel
					100	110	Till
					110	150	Gravel
					150	225	Dakota ss
54	16400	NW NW NW SW Sec. 13 T95 R29	1147	130	0	40	NS
					40	50	Gravel
					50	80	Till
					80	130	Dakota ss
55	5653	SW Sec. 30 T95 R28	1139	57	0	10	Soil
					10	15	Clay
					15	50	Till
					50	57	Dakota ss
56	2414	NW NW NE Sec. 31 T95 R30	1143	203	0	75	Till
					75	100	Gravel
					100	155	Dakota ss
					155	203	Dev. LC dolomite
57	14026	NW NE Sec. 31 T95 R28	----	150	0	60	Till
					60	70	Gravel
					70	130	Dakota ss
					130	150	Chert
58	18347	NW SW Sec. 36 T95 R29	----	164	0	60	Till
					60	164	Dakota ss
59	6664	SE NE Sec. 2 T94 R29	1117	225	0	185	Till
					185	225	Sand
60	12261	NE NW NE Sec. 3 T94 R29	1136	80	0	5	Soil
					5	80	Till
					80	86	Dakota ss

No.	W-Number	Location	Elev. (ft.)	T.D. (ft.)	From	To	Lithology
61	11118	NE SE Sec. 23 T94 R29	----	115	0	50	NS
					0	50	Till
					50	55	Sd
					60	115	Dakota ss
62	5440	SE NW Sec. 1 T89 R29	1011	40	0	4	Soil
					4	9	Sand
					9		Dol.
63	3932	SE SW NW Sec. 1 T89 R29	1004	200	0	10	Soil
					10	12	S & G
					12	19	ss
					19		ls, dol.
64	5442	NE NE SW Sec. 1 T89 R29	1010	269	0	4	Sand
					4	15	Shale
					15		ls, dol.
65	2681	SW SE SW Sec. 1 T89 R29	998	105	0	10	S & G
					10		shale
66	City #13	NW NE SW Sec. 19 T89 R28	984	830	0	12	Sandy soil
					12	25	S & G
					25		ls
67	2373	NE SW SE Sec. 19 T89 R28	1066	404	0	15	S & G
					15	70	Till
					70	75	sand
					75		Penn. sh
67a	3218	SE NE NE SW Sec. 19 T89 R28	980	2307	0	4	Soil
					4	20	S & G
					20		Penn. sh
68	5240	NE NE Sec. 3 T84 R27	----	45	0	10	sdy sil
					10	40	S & G
					40	45	Penn sh
69	5241	NE NE Sec. 3 T84 R27	----	40	0	10	Fill
					10	20	silt
					20	40	S & G
70	5242	NE NE Sec. 3 T84 R27	---	31	0	8	silt
					8	31	S & G
71	13027	NW Sec. 1 T84 R27	1100	658	0	110	S & G
					110	275	Till
					275	285	Gravel
					285	370	Penn sh
					370		Miss ls

No.	W-Number	Location	Elev.	T.D.	From	To	Lithology
72	146	SE SE SW Sec. 13 T84 R27	935.29	324	0 15	15	S & G Penn sh, ss, ls
73	11862	SE NE SE Sec. 17 T83 R26	----	33.9	0 10 25	10 25 34	Soil silt gravel
74	3175	SE NE SE Sec. 17 T83 R26	870	30.8	0 14 30	14 30 31	Soil Gravel Penn sh

Part II.

Sand and Gravel Pit Tests

No.	Location	From	TO (ft.)	Lithology
S1	SE Sec. 34 T100 R34	0	1	Black Loam
		1	12	S & G
S2	SE NW Sec. 34 T100 R34	0	15	S & G
S3	NE Sec. 3 T99 R34	0	24	S & G
		Highly variable		
S4	SE NE Sec. 23 T99 R34	0	14	S & G
S5	E 1/2 Sec. 25 T99 R34	0	2	Sandy loam
		2	14.5	Clay
S6	NE SE Sec. 26 T99 R31	0	2	Loam
		2	17	S & G
S7	SW NW Sec. 4 T97 R33	0	2	Loam
		2	14	S & G
S8	SW Sec. 23 T96 R33	0	8	Loam
		8	12	Sand
S9	NW SE NE SW Sec. 5 T94 R31	0	2	Loam
		2	40	S & G
S10	SE NE Sec. 16 T92 R30	0	10	Soil, S & G
		10		Mississippian Meramec Ls
S11	NE/C Sec. 23 T92 R30	0	5	Soil, S & G
		15		Mississippian St. Louis Ls
S12	SE SE Sec. 29 T92 R29	0	4	Loam, clay
		4		Dolomite
S13	SW SW Sec. 27 T92 R29	0	6	Loam
		6	17.5	S & G
S14	SW NW Sec. 35 T92 R29	0	16.5	Loam, S & G
				Mississippian Ls
S15	E 1/2 Sec. 24 T91 R29	0	25	S & G in pit
		0	11	S & G in holes
				Till
S16	NW Sec. 32, T91 R28	0	3.5	Dirt
		3.5	10	S & G
				Clay

No.	Location	From	To (ft.)	Lithology
S17	SE NW Sec. 7 T97 R28	0	3	Loam
		3	12	Sandy clay
		12		Till
S18	SE NE SW Sec. 30 T95 R28	0	5	Gravel
		5		Till
S19	E 1/2 Sec. 31 T95 R28	Gravel ranges from 10 to 30 feet thick		
S20	Sec. 36 T95 R29	0	2.5	Clay, Loam
		2.5	1.9	Gravel
S21	Sec. 36 T95 R29	0	10	Sand and gravel
		10		Till
S22	SW Sec. 2 T94 R29	0	1	Loam
		1	14	Sand and gravel
S23	NE Sec. 25 T90 R29	0	3	Loam
		3	14	S & G
		14		LS
S24	NW SW Sec. 36 T90 R28	0	4	Generally loam
		4	18	S & G
S25	SE NW Sec. 1 T89 R29	0	5	Overburden
		5	27	Sand
		27		LS
S26	SW SW Sec. 14 T88 R28	0	18	S & G
S27	SE Sec. 21 T88 R28	0	18	S & G
S28	NW SE Sec. 16 T87 R27	0	1.5	Sandy Loam
		1.5	13	S & G
S29	Central Sec. 36 T87 R27	0	1	Soil
		1	17	S & G
		17		Till
S30	NE Sec. 9 T86 R27	0	17	Sandy loam/S & G
S31	NE Sec. 3 T85 R27	0	5	Silty loam
		5	20	S & G
		20		Clay
S32	NE SW Sec. 3 T85 R27	0	12	Gravel
S33	Sec. 10, 11, 14, 15, T85 R27	Gravel ranges from 11 to 44 ft. thick		

No.	Location	From	To (ft.)	Lithology
S34	SW Sec. 13 T84 R27	0	1.5	Soil
		1.5	11	S & G
		11		Shale
S35	Sec. 26/27 T84 R27	0	12	S & G
		12		Penn sh
S36	SW Sec. 26 T84 R27	0	29	S & G
		29		Penn sh
S37	SW NE Sec. 36 T84 R27	0	30	S & G
		30		Penn sh
S38	NE SE Sec. 30 T84 R27	0	4	Soil
		4	32	S & G
S39	SW Sec. 4 T82 R26	Gravel ranges from 19 to 31' thick		
S40	E SW Sec. 22 T82 R26	Gravel ranges from 18 to 36' thick		
S41	Sec. 34/27 T82 R26	0	6	Gravel
		6		Penn sh
S42	SW NE Sec. 34 T82 R26	0	11	S & G
		11		Clay
S43	Sec 34/35 T82 R26	0	16	S & G
		16		Penn sh

Part III.

Bridge Borings

No.	Location	Elev. (ft.)	From	To	Lithology
B1	T100 R34 Sec. 21/28 (W)	1271	0	5	Fill
			5	12.2	Clay,silt
			12.2	23.5	S & G
					Clay
	T100 R34 Sec. 21/28 (E)	1271	0	3	Fill
			3	13	Clay, silt
			13	25	S & G
					Clay
B2	T100 R34 Sec. 24 (W)		0	6	Fill
			6	15.7	Clay
			15.7	29	Sandy clay
	T100 R34 Sec. 24 (E)		0	20.5	S & G
			20.5	25	Sandy clay
B3	T99 R34 Sec. 10 (W)		0	15.1	Fill
			15.1	20.1	Clay
			20.1	23.1	Sand
					Till
	T99 R34 Sec. 10 (E)		0	13	Fill
			13	18	S & G
					Till
B4	T99 R34 Sec. 14 (W)	1251.6	0	6	Clay
					Till
	T99 R34 Sec. 14 (E)	1262.7	0	3	Fill
					Till
B5	T99 R33 Sec. 30/31 (W)	1132	0	2	Water
			2	13.4	S & G
					Clay
					Till
	T99 R33 Sec. 30/31 (E)	1132	0	2.6	Water
			2.6	12.2	S & G
			12.2	14.6	Clay
					Till
B6	T98 R33 Sec. 7 (W)	1248.6	0	12	Fill
			12	25	Clay
			25	38	Sand
					Till

No.	Location	Elev. (ft.)	From	To	Lithology
	T98 R33 Sec. 7 (E)	1250.5	0	15	Fill
			15	24	Sand
					Till
B7	T98 R33 Sec. 29 (W)	1215	0	2.3	Water
			2.3	9	S & G
			9	11.2	Sandy clay
					Till
	T98 R33 Sec. 29 (E)	1239.3	0	6.6	Fill
			6.6	16.8	Clay
			16.8	36.8	S & G
					Till
B8	T98 R33 Sec. 32 (W)	1148.8	0	4.5	Fill
			4.5	19	S & G
					Till
	T98 R33 Sec. 32 (E)	1148.8	0	3.5	Fill
			3.5	21	Clay
			21	57	S & G
					Till
B9	T99/100 R31 Sec. 6/31 (N)	1114.4	0	4.8	Silty clay
			4.8	7.5	Sand
					Till
	T99/100 R31 Sec. 6/31 (S)	1112	0	5	Silty clay
			5	12.5	S & G
					Till
B10	T99 R31 Sec. 9/16 (W)	1101.3	0	8.3	Silt & sand
			8.3	16.3	Sand
					Till
	T99 R31 Sec. 9/16 (E)	1115	0	7	Fill
			7	14	Clay
			14	34	Sand
					Till
B11	T99 R31 Sec. 25 (W)		0	7.5	Clay
			7.5	40	S & G
	T99 R31 Sec. 25 (E)		0	12	Clay
			12	36	S & G

No.	Location	Elev. (ft.)	From	To	Lithology
B12	T99 R31 Sec. 36 (W)	1085.4	0	3	Sand, silt
			3	9.3	S & G
			9.3	25.5	Sandy clay
					Till
	T99 R31 Sec. 36 (E)	1079.8	0	3.4	Water
			3.4	5.9	S & G
			5.9	21.4	Clay
					Till
B13	T97 R33 Sec. 14/23 (SW)		0	6	Fill
			6	22	Clay
			11	27	S & G
			27		Till
	T97 R33 Sec. 14/23 (SE)		0	3	Fill
			3	7	Clay
			7	26	S & G
			26		Till
B14	T96 R33 Sec. 14/15 (N)		0	6	Fill
			6	13	Clay
			13	44	S & G
			44		Till
	T96 R33 Sec. 14/15 (S)		0	6	Clay
			6	36	S & G
			36		Till
			0	2	Loam
B15	T95 R33/32 Sec. 7/12 (W)	1175	2	30	S & G
			30		Green clay
	T95 R33/32 Sec. 7/12 (S)	1180	0	5	Loam
			5	10	Clay
			38		Green, gray, clay
B16	T95 R32 Sec. 22-23 (W)	1175	0	2	Clay
			2	30	Sand
			30		Till
	T95 R32 Sec. 22-23 (E)	1174	0	2	Clay
			2	32	Sand
			32		Till

No.	Location	Elev. (ft.)	From	To	Lithology
B17	T95 R32 Sec. 23-24 (W)		0	4	Clay
			14		Clay
	T95 R32 Sec. 23-24 (E)		0	8	Clay
			8		Clay
B18	T95 R32 Sec. 25-26 (W)	1170	0	8	Clay
			8	39	Sand
			39		Till
	T95 R32 Sec. 25-26 (E)	1170	0	8	Clay
			8	39	Sand
			39		Till
B19	T92 R31 Sec. 2		0	5	Soil
			5	40	Red clayey sand
			40	45	Red clay
B20	T93 R30/31 Sec. 7/12 (W)		0	5	Fill
			5	14.5	Silt
			14.5	41.7	S & G
			41.7		Till
	T93 R30/31 Sec. 7/12 (E)		0	4.5	Fill
			4.5	13.4	Silt
			13.4	41.4	S & G
			41.4		Till
B21	T92 R30 Sec. 7 (W)	1170	0	12	S & G
			12		Shale
	T92 R30 Sec. 7 (E)	1230	0	5	Silt
			5	20	S & G
					Shale
B22	T92/91 R28 Sec. 34/3 (W)	1102	0	3	Loam
			3	20	S & G
	T92/91 R28 Sec. 34/3 (E)	1072	0	4	Water, mud
			4	32	S & G, clay
			32		Clay
B23	T91 R29 Sec. 1 (W)	1101	0	1	Fill
			1	25	Till
			25		LS

No.	Location	Elev. (ft.)	From	To	Lithology
	T91 R29 Sec. 1 (E)	1087	0	17	Fill
			17	20	Sdy. clay
			20	21	Till
			21		LS
B24	T92/91 R28 Sec. 31/6 (W)	1054	0	5	Clay
			5	13	S & G
			13	42	Till
			42		Ls
	T92/91 R28 Sec. 31/6 (E)	1055	0	4	Silt
			4	35	S & G
			35		Till
B25	T93 R28 Sec. 6 (S)	1087	0	9	Silt
			9	17	Clay
			17		S & G
	T93 R28 Sec. 6 (N)	1084	0	4	Silt
			4	9	S & G
			9	14	Clay
			14	66	S & G
			66		Ls
B26	T94 R29 Sec. 25/26 (W)		0	14	Fill
			14	21	S & G
			21	53	Till
			53	57	SS
			57	59	Boulders
			59		Ls
	T94 R29 Sec. 25/26 (E)		0	8	Fill
			8	23	S & G
			23	52	Till
			52		Ls
B27	T94 R29 Sec. 14/23 (W)		0	8	Fill
			8	46	Till
			46	62	Sand
	T94 R29 Sec. 14/23 (E)		0	10	Fill
			10	16	Clay
			16	32	S & G
			32	44	Till
			44	54	Sand

No.	Location	Elev. (ft.)	From	To	Lithology
B28	T95 R29 Sec. 35/36 (N)		0	10.1	Clay, silt
			10.1	36.2	S & G
			36.2	59.5	Till
	T95 R29 Sec. 35/36 (S)		0	8	Clay, silt
			8	30.8	S & G
			30.8	59.5	Till
B29	T95 R28 Sec. 30/31 (W)		0	12	Loam
			12	20	S & G
			20	22	Clay
			22	34	Sand
	T95 R28 Sec. 30/31 (E)		0	4	Fill
			4	13	Loam
			13	30	Clay
			30	43	S & G
			43	47	Clay
			47	59	S & G
B30	T95 R29 Sec. 13/14 (N)		0	8	Fill
			8	29	Clay
			29	73	S & G
			73	75	Boulder
	T95 R29 Sec. 13/14 (N)		0	6	Fill
			6	11	Clay
			11	59	S & G
B31	T95 R29 Sec. 11 (N)		0	8	Clay
			8	34	S & G
			34	41	SS
	T95 R29 Sec. 11 (E)		0	6	Clay
			6	28	S & G
			28	33	SS
B32	T95 R29 Sec. 3 (W)		0	5	Loam
			5	9	Clay
			9	46.3	S & G
	T95 R29 Sec. 3 (E)		0	3	Loam
			3	10.9	Clay
			10.9	50	S & G

No.	Location	Elev. (ft.)	From	To	Lithology
B33	T96 R29 Sec. 25 (W)	1121	0	6	Fill
			6	17	Clay
			17	37	S & G
			37	54	Till
	T96 R29 Sec. 25 (E)	1132	0	17	Fill
			17	22	Clay
			22	50	S & G
			50	78	Till
B34	T95 R28 Sec. 6 (W)		0	6	Fill
			6	14	Clay
			14	52	S & G
			52	54	Dol
	T95 R28 Sec. 6 (E)		0	6	Fill
			6	14	Clay
			14	38	S & G
			38	54	Till
B35	T97 R28 Sec. 29 (W)		0	4.5	Loam
			4.5	10.5	Clay
			10.5	28.8	Clay
			23.8	28.8	Clay
	T97 R28 Sec. 29 (E)		0	1.6	Mud
			1.6	4.1	Sd
			4.1	5.4	Clay
			5.4	7.4	S & G
			7.4	33.4	Clay
B36	T98 R29 Sec. 36 (W)		0	4	Fill
			4	12	Clay
			12	19	Sand
			19	50	Till
	T98 R29 Sec. 36 (E)		0	5	Fill
			5	12	Clay
			12	15.5	Sand
			15.5	49	Till
B37	T98 R29 Sec. 35/36 (N)		0	8	Fill
			8	14	Clay
			14	39	Sand
			39	53.5	Till

No.	Location	Elev. (ft.)	From	To	Lithology
	T98 R29 Sec. 35/36 (S)		0	8	Fill
			7	14.5	Clay
			14.5	36.8	Sand
			36.8	53.5	Till
B38	T98 R29 Sec. 26 (W)	1148.8	0	6	Fill
			6	13	Clay
			13	33	Sand
			33	44	Till
	T98 R29 Sec. 26 (E)	1148.8	0	5	Fill
			5	14	Clay
			14	31	Sand
			31	59	Till
B39	T98 R30 Sec. 8 (W)	1182	0	5	Fill
			5	16	Clay
			16	59	S & G
	T98 R30 Sec. 8 (S)	1182	0	7	Fill
			7	14	Clay
			14	44	S & G
B40	T90 N R28 W Sec. 12 (W)		0	13	Fill
			13	20	S & G
			20		LS
	T90 N R28 W Sec. 12 (E)		0	9	Fill
			9	20	S & G
			20		LS
B41	T89 R28 Sec. 24 (N)		0	12	Fill
			12	19	Sand
			19		Shale
	T89 R28 Sec. 24 (S)		0	5	Fill
			5	14	Clay
			14	22	Sand
			22	42	Sandy clay
			42	45	S & G
			45		Shale
B42	T89 R28 Sec. 24 and 30 (SW)		0	14	Silt
			14	24	S & G
			24		Shale

No.	Location	Elev. (ft.)	From	To	Lithology
	T89 R28 Sec. 24 and 30 (NE)		0	13	Silt
			13	29	Sand
			29	33	Clay
			33		Shale
B43	T89 R28 Sec. 24 and 30 (SW)		0	7	Loam
			7	11	S & G
			11		Shale
	T89 R28 Sec. 24 and 30 (NE)		0	2	Loam
			2	14	S & G
			14		Shale
B44	T89 R28 Sec. 30 (SW)		0	10	Clay
			10	16	S & G
			16		Shale
	T89 R28 Sec. 30 (NE)		0	25	Fill
			25	41	S & G
			41		Shale
B45	T87 R27 Sec. 12 (SW)		0	14	Fill
			14	30	S & G
			30		Shale
	T87 R27 Sec. 12 (NE)		0	8	Fill
			8	40	S & G
			40		Shale
B46	T86 R27 Sec. 1 (W)		0	4	Loam
			4	42	S & G
	T86 R27 Sec. 1 (E)		0	4	Loam
			4	42	S & G
B47	T86 R27 Sec. 16 and 22 (W)		0	7	Loam
			7	14	S & G
			14		Shale
	T86 R27 Sec. 16 and 22 (E)		0	8	Loam
			8	24	S & G
			24		Shale
B48	T85 R27 Sec. 14 (W)		0	18	Sandy silt
			18	40	S & G
			40		Shale

No.	Location	Elev. (ft.)	From	To	Lithology
	T85 R27 Sec. 14 (E)		0	12	Clay
			12		Till
B49	T84 R27 Sec. 2 (SW)		0	11	Silt, S & G
			11		LS
	T84 R27 Sec. 2 (NE)		0	13	Silt
			13	23	Sand
			23		Ls
B50	T84 R27 Sec. 13 (W)		0	18	S & G
			18		Penn Sh
	T84 R27 Sec. 13 (E)		0	9	Fill
			9	29	Clay
			29	69	S & G
			69		Shale
B51	T84 R26/27 Sec. 31/36 (W)		0	1.6	Loam
			1.6	37.8	S & G
			37.8		Penn sh.
	T84 R26/27 Sec. 31/36 (E)		0	12	Loam
			12	34	S & G
			34		Penn sh
B52	T83/84 R26 Sec. 31/6 (W)		0	2	Silt
			2	38	S & G
	T83/84 R26 Sec. 31/6 (E)		0	12	Clay
			12	16	Sand
			16		Shale
B53	T82 R26 Sec. 34 (W)		0	4	Silt, clay
			4	34	S & G
			34		Shale
	T82 R26 Sec. 34 (E)		0	3	Silt, clay
			3	15	S & G
			15		Shale

NS: No sample
S & G: Sand and Gravel
Ss: Sandstone
Ls: Limestone
Dol: Dolomite

Appendix II

Lithologic Descriptions for Well and Test Hole Cuttings

u.u. = unleached unoxidized
o.u. = oxidized, unleached

IGS Well No.	Identifier	Elevation	Static Water Level (ft)	Depth	Lithology
W27116	WD4	1310	15.8	0-10	Gravel and fine sand, angular
				10-27	Gravel and coarse sand
				27-31	Till, u.u., light gray, abundant gravel
W27113	WD1	1268	Dry	0-4	Soil, brown, sandy, silty, gravel
				4-10	Sand, coarse to fine, gravel
				10-20	Gravel to sand, coarse to fine
				20-21.5	Till, olive gray, u.u.
W27155	WD18	1273	4.7	0-2	Soil
				2-5	Sand, partly argillaceous to gravel
				5-8	Gravel, silty
				8-12	Gravel and sand
				12-14	Gravel, clay, calcareous
				14-20	Gravel, clean
				20-25	Sand, coarse angular
				25-36	Till, u.u., light gray
				36-41	Gravel, rounded, slightly dirty
W27156	WD19	1221		0-4	Roadbed and top soil
				4-5	Brown argillaceous silt
				5-8	Sand, fine to coarse, rounded, silty
				8-15	Sand, coarse to fine, rounded to angular, gravel
				15-18	Silt, pale yellow, calcareous
				18-34	Sand, coarse to fine,gravel
				34-85	Till, olive grey to brown, u.u.
				85-96	Clay, gray, silty, calcareous
				96-100	Silt, yellow, argillaceous, calcareous, sandy

IGS Well No.	Identifier	Elevation	Static Water Level (ft)	Lithology	
				100-106	Silt to sand
				106-117	Till, u.u., some silty calcareous
				117-162	Till, orange-yellow, o.u.
				162-188	Sandstone, orange argillaceous calcareous cement
				188-195	Shale, slightly calcareous, silty
W27114	WD2	1240	6.4	0-3	Fill
				3-20	Sand coarse to fine, some silt and clay near top, gravel at bottom
				20-25	Till, mottled, u.u.
W27115	WD3	1240		0-4	Roadbed, sandy and gravelly topsoil
				4-12	Gravel with fine sand
				12-20	Till, gray with abundant sand and gravel, u.u.
				20-36	Till, mottled brown to gray, less sand and gravel, u.u.
W27123	WD5	1233		0-1	Very sandy top soil
				1-3	Coarse sand and fine gravel
				3-6	Coarse to fine sand, gravel
				6-11	Gravel and sand, orange ferric oxide coating
				11-21	Till, mottled gray, u.u., some gravel
W27166	WD29	1226		0-4	Top soil and sandy clay
				4-12	Gravel and fine sand
				12-17	Gravel and fine sand with gray argillaceous calcareous cement
				17-20	Till, gray, u.u.

IGS Well No.	Identifier	Elevation	Static Water Level (ft)		Lithology
W27167	WD30	1228	9.5	0-2	Roadbed and top soil
				2-12	Coarse to fine sand, some gravel
				12-17	Gravel and sand
				17-21	Till, gray, u.u. with abundant sand and gravel.
W27157	WD20	1214		0-5	Roadbed and sandy top soil
				5-11	Gravel and fine sand
				11-17.5	Sand and gravel
				17.5-23	Till, mottled gray, u.u.
				23-25	Clay, dark brown to gray, sandy, silty
				25-41	Till, pale yellow gray, o.u.
W27124	WD6	1225	4.8	0-2	Sandy and gravelly top soil
				2-20	Sand, coarse to fine with gravel
				20-27	Gravel and fine sand
				27-40	Till, light gray, u.u. with gravel.
W27117	WD7	1212	4.35	0-2	Sandy, gravely top soil
				2-15	Sand fine to coarse, some gravel
				15-38	Gravel with fine sand
				38-41	Gravel grading into till, mottled gray
W27158	WD21	1206		0-4	Roadbed and sandy top soil
				4-5	Yellow-gray sandy clay
				5-30	Sand, coarse to fine and clean gravel
				30-40	Gravel to sand
				40-50	Gravel, trace coarse sand
				50-61	Till with abundant sand and gravel
W27168	WD31	1198	5.8	0-3	Top soil
				3-5	Clay, silty, sandy, some gravel.

IGS Well No.	Identifier	Elevation	Static Water Level (ft)		Lithology
				5-7	Sand, medium to fine to coarse some gravel, silty matrix
				7-30	Coarse sand, fine gravel
				30-38	Coarse sand and gravel, argillaceous matrix.
				38-41	Till, light gray, u.u., silty sandy, some gravel.
W27125	WD8	1202	3.4	0-4	Roadbed and till
				4-6	Soil, sandy, silty with gravel
				6-45	Sand, coarse to fine, gravel, dirty
				45-49	Gravel
W27159	WD22	1195		0-5	Roadbed and sandy top soil
				5-6	Yellow-gray sandy clay
				6-25	Sand, coarse to fine and fine gravel
				25-48	Gravel with argillaceous matrix, sand
				48-60	Gravel with gray argillaceous, slightly calcareous matrix
W27126	WD9	1188	0	0-2	Roadbed and top soil
				2-9	Sand, coarse to fine with rounded gravel
				9-60	Gravel with sand
W27160	WD23	1188		0-5	Roadbed and top soil
				5-20	Sand, coarse to fine, fine gravel
				20-35	Gravel and sand, coarse to fine
				35-38	Gravel and coarse sand
				38-41	Gravel with argillaceous, silty, calcareous matrix

IGS Well No.	Identifier	Elevation	Static Water Level (ft)		Lithology
W27118	WD10	1187	2.65	0-2	Sandy and gravely top soil
				2-20	Sandy, fine to coarse, gravel
				20-36	Gravel, fine sand
				36-41	Gravel, coarse sand
W27161	WD24	1180		0-4	Roadbed and top soil
				4-6	Soil, sandy, silty, calcareous
				6-12	Sand, coarse to fine, gravel to shelly debris
				12-25	Gravel to medium sand
				25-29	Till, mottled gray, u.u.
				29-39	Gravel, rounded to fine sand, slightly argillaceous
				39-41	Till, blue gray to yellow gray
W27127	WD11	1176		0-2	Very sandy top soil
				2-20	Sand, coarse to fine, rounded to angular, gravel
				20-27	Sand with abundant dark grains
				27-36	Gravel and sand
				36-41	Till, mottled, pale gray, u.u.
W27162	WD25	1174		0-5	Roadbed and top soil
				5-7	Soil, sandy, silty, argillaceous
				7-20	Sand, coarse with fine gravel, rounded to angular, clean
				20-30	Sand coarse to fine with gravel, clean
				30-38.5	Gravel with fine sand, argillaceous matrix
				38.5-41	Gravel, very argillaceous till-like sand, till, mottled gray, u.u.

IGS Well No.	Identifier	Elevation	Static Water Level (ft)	Lithology	
W27128	WD12	1170		0-3	Sandy top soil
				3-6	Sand, coarse with fine gravel, clean
				6-11	Sand, coarse to fine, rounded to angular with fine gravel
				11-20	Gravel plus fine sand
				20-34	Gravel and sand with argillaceous matrix
				34-38	Gravel and till, yellow gray, u.u.
				38-40	Sand, coarse to fine, gravel
				40-48	Sand with abundant dark heavy grains
				48-50	Gravel, very argillaceous, till, o.u.
				50-52	Gravel with till, u.u.
				52-55	Sand, fine, with gravel, rounded to angular, clean
W27163	WD26	1165		0-4	Roadbed and top soil
				4-7	Soil, sandy, silty
				7-8	Sand, coarse to fine with silty gravel
				8-13	Gravel, rounded with fine sand
				13-20	Sand, fine with gravel
				20-37	Gravel, rounded with fine sand, rounded to angular
				37-41	Gravel and sand, pale yellow calcareous till-like matrix
W27129	WD13	1162	5.0	0-6	Roadbed and till
				6-10	Soil, silty, sandy, argillaceous
				10-20	Sand, coarse to fine with gravel
				20-37	Gravel and sand, coarse to fine
				37-41	Till, pale yellow, o.u

IGS Well No.	Identifier	Elevation	Static Water Level (ft)		Lithology
W27164	WD27	1152		0-4	Roadbed and top soil
				4-8	Sand, coarse to fine, very silty and argillaceous
				8-30	Sand, coarse to fine, clean gravel
				30-48	Gravel and sand
				48-51	Shale, light gray, soft, calcareous limestone fragments
				51-56	Shale, gray, lumpy, calcareous
W27119	WD14	1138	3.65	0-2	Sandy top soil
				2-20	Sand, fine to coarse, gravel
				20-31	Gravel, coarse sand
				31-41	Gravel and coarse sand, silty calcareous matrix
W27130	WD15	1127	.5	0-2	Top soil, sandy, and gravelly
				2-17	Sand, coarse to fine, gravel
				17-37	Gravel and sand with argillaceous matrix
				37-40	Sandstone, coarse to fine, free
				40-41	Very sandy clay or shale, yellow gray
W27165	WD28	1124		0-5	Roadbed and top soil
				5-15	Sand, coarse to fine, gravel
				15-20	Gravel to sand
				20-25	Gravel with sandstone, fine to coarse, rounded to angular, silty, argillaceous
				25-50	Sandstone, fine to coarse
				50-55	Sand, coarse to fine, gravel, silty

IGS Well No.	Identifier	Elevation	Static Water Level (ft)	Lithology	
				55-60	Gravel to sand, fine, rounded to angular, silty, argillaceous
				60-70	Sand, coarse to fine with gravel
				70-75	Shale, very sandy, slightly calcareous, silty
				75-80	Gravel, rounded with sandstone, fine very argillaceous, silty
				80-84	Gravel and sand, dolomite, silty shale
				84-88	Sandstone, coarse to fine
				88-89	Dolomite
W27131	WD16	1116	4.3	0-3	Top soil, clay, sandy and gravelly
				3-7	Sand, coarse to fine, gravel
				7-14.5	Gravel and sand
				14.5-20	Till, mottled gray, u.u.
				20-21	Till, orange-brown, o.u.
W27120	WD17	1089	7.0	0-1	Sandy top soil
				1-14.5	Sand, fine to medium, gravel
				14.5-58	Sandstone, yellow fine to coarse grains rounded, not cemented, frosted
				58-61	Siltstone, gray, sand and gravel
W27133	ED5	1147		0-1	Sandy top soil
				1-11	Till, pale yellow, o.u.
				11-13	Till, olive gray, u.u.
				13-16	S.H., calcareous, argillaceous, orange gray
				16-20	Sand, fine to coarse, silty, argillaceous
				20-25	Clay, gray, silty, calcareous

IGS Well No.	Identifier	Elevation	Static Water Level (ft)		Lithology
				25-44	Sand, coarse to fine, gravel silty calcareous
				44-45	Clay, mottled gray, gravel, silty clacareous
				45-61	Till, olive gray, u.u.
W27133	ED3	1130		0-6	Roadbed and fill
				6-9	Clay, medium, dark brown, silty
				9-18	Sand, medium to fine, very argillaceous
				18-19	Sand and gravel
				19-22	Till, mottled gray, u.u.
				22-23	Gravel and sand
				23-41	Till, mottle brown gray, u.u.
W27122	ED2	1130	2.6	0-1	Black top soil
			27.9 (water level in ss)	1-3	Sand, fine to coarse, siderite
				3-5	Gravel, sand
				5-33	Till, mottled gray to olive, unoxidized, unleached
				33-34	Sand, fine to coarse, till-like matrix
				34-47	Till, mottled gray, unoxidized, unleached
				47-68	Sandstone, fine to coarse, grains round to angular
				68-71	Shale, silty, lumpy
				71-73	Sandstone, fine to coarse, rounded to angular
				73-75	Shale, gray, sandy, silty
				75-89	Sandstone, fine to coarse, rounded to angular
				89-93	Gravel, medium sand, argillaceous

IGS Well No.	Identifier	Elevation	Static Water Level (ft)	Lithology	
W27153	ED4	1115		0-1	Top soil
				1-3	Very sandy, gravelly clay
				3-40	Gravel, angular to rounded to sand, slightly dirty
				40-54	Sand, coarse to fine, rounded gravel
				54-70	Sandstone, coarse to fine
				70-80	Sandstone, coarse to fine, with gravel
				80-94	Gravel, trace sandstone
W27132	ED1	1096	4.3	0-2	Top soil, black
				2-5	Soil, dark gray, silty
				5-7	Clay, gray, silty
				7-11	Silt, yellow, argillaceous
				11-20	Sand, medium to fine, gravel
				20-33	Sand, coarse to fine, gravel
				33-34.5	Dolomite, mottled brown, grading to fine limestone, some gravel
W2734	LD1	1083	13.0	0-2	Top soil
				2-4	Silt, orange, argillaceous, slightly calcareous with fine sand
				4-7	Clay, orange, silty
				7-14	Sand, coarse to fine with gravel, slightly silty
				14-18	Till, yellow gray, o.u.
				18-21	Till, olive gray, u.u.
W27121	LD2	1020	6.65	0-2	Roadbed and fill
				2-5	Coarse sand, gravel, silty argillaceous matrix
				5-7	Gravel, dirty, sand
				7-21	Dolomite, limestone, chert

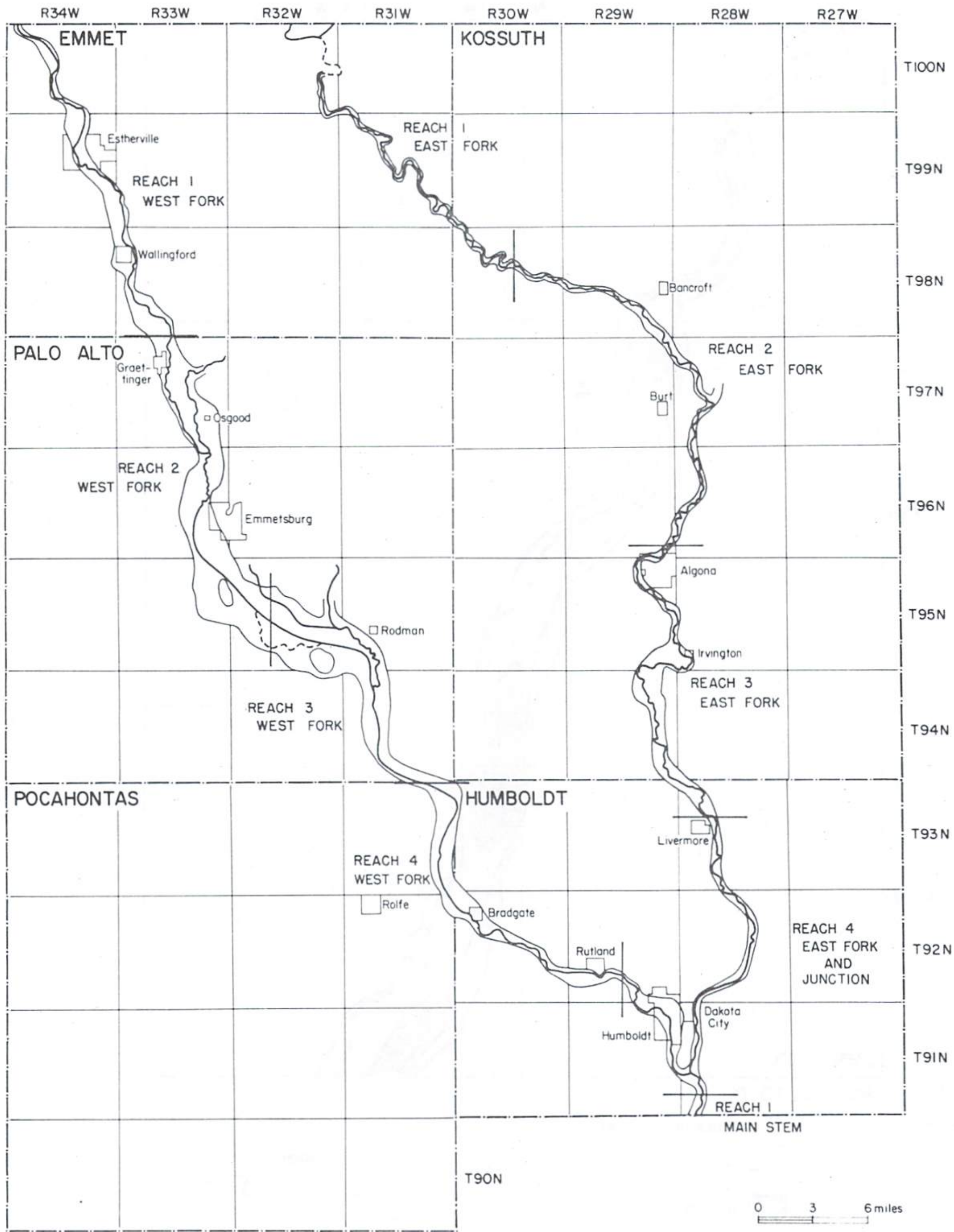
IGS Well No.	Identifier	Elevation	Static Water Level (ft)		Lithology
W27148	LD3	930	8.4	0-6	Sand, coarse to fine, very silty, argillaceous, calcareous
				6-20	Sand, coarse to fine, gravel
				20-26	Gravel and sand
				26-30	Till, brown gray, U.U.
W27149	LD4	938	24.4	0-6	Fill
				6-9	Clay, brown, silty and sandy with gravel
				9-18	till, orange gray, O.U.
				18-20	Till, pale orange, O.L.
				20-26	Sand, coarse-fine, gravel
				26-28	Till, pale-yellow, O.U. (colluvium?)
				28-33	Silt, pale-yellow, argillaceous
				33-37	Gravel and sand, silty
				37-38	Till, gray, O.U. (colluvium?)
				38-40	Sand, coarse to fine
				40-44	Till, gray, O.U.
				44-46	Till, gray, U.U.
				46-49	Sand, coarse to fine, gravel
				49-61	Till, gray, U.U., some gravel
W27152	LD7	940		0-5	Roadbed and top soil, sandy
				5-6	Sand, coarse and gravel, silty matrix
				6-8	Sand, Carse and gravel, clean
				8-9	Shale, gray orange, sandy, silty
				9-10	Dolomite, gray, silty with siderite ?
				10-15	Siltstone, very light gray, sandy, siderite nodules 12-14'
				15-17	Limestone, silty sandy
				17-17.5	Shale, lumpy, silty, calcareous

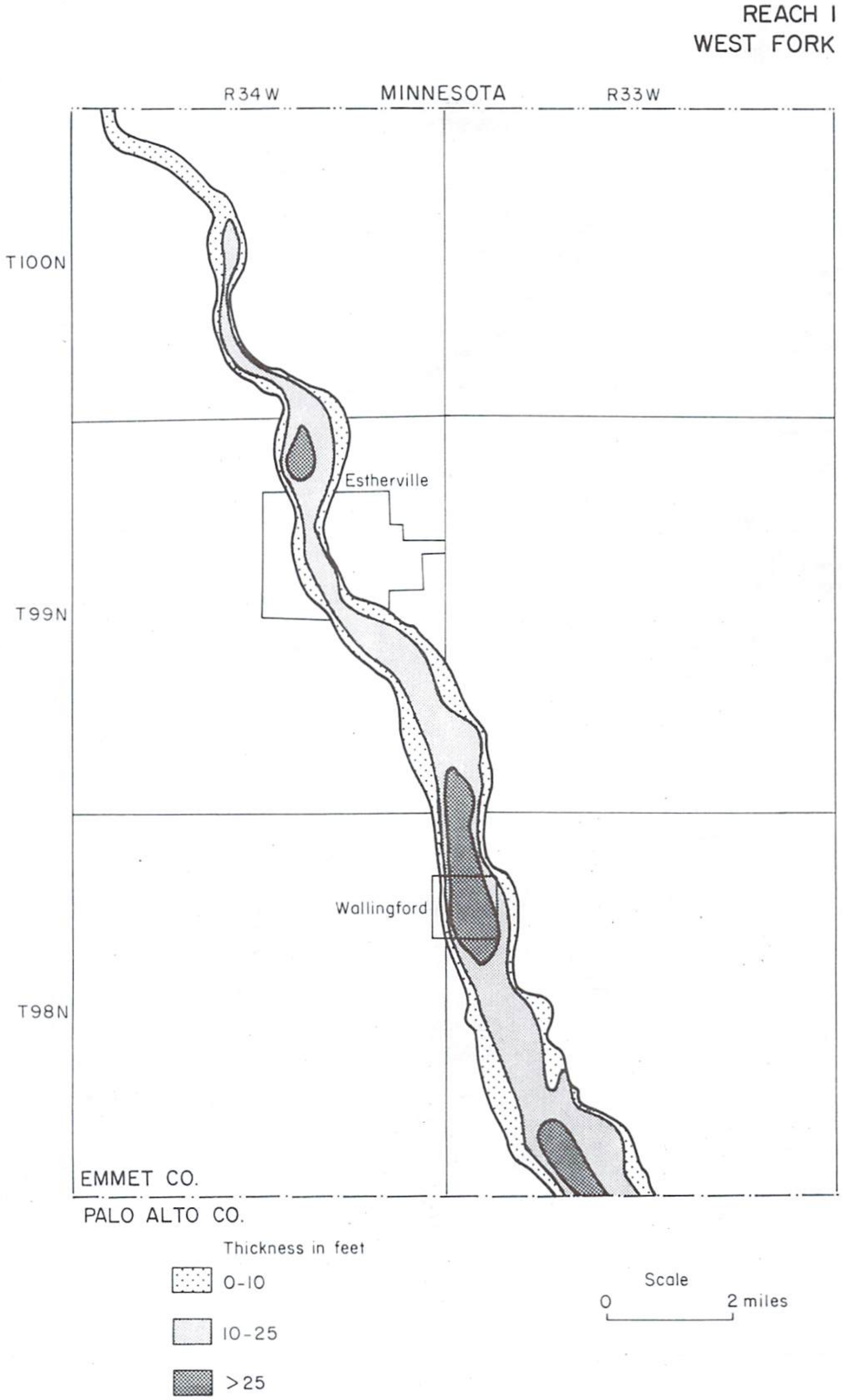
IGS Well No.	Identifier	Elevation	Static Water Level (ft)		Lithology
				17.5-18	Limestone
				18-19	Shale, sandy, calcareous
				19-20	Sandstone with calcareous cement
W27150	LD5	900		0-1	Top soil
				1-3	Silt, dark orange, argillaceous
				3-5	Silt, yelloe, calcareous
				5-38	Sand, medium to fine to coarse
				38-47	Gravel and sand
				47-50	Sand and gravel
				50-52	Shale, gray, soft, lumpy, silty, some gravel
				52-56	Shale and dolomite
W27151	LD6	860		0-3	Roadbed
				3-7	Silt, brown argillaceous, some sandy
				7-8	Sand, coarse to fine, gravel argillaceous, silty
				8-10	Silt, very argillaceous, slightly calcareous
				10-15.5	Gravel and sand
				15.5-21	Shale, gray, lumpy, silty, some gravel

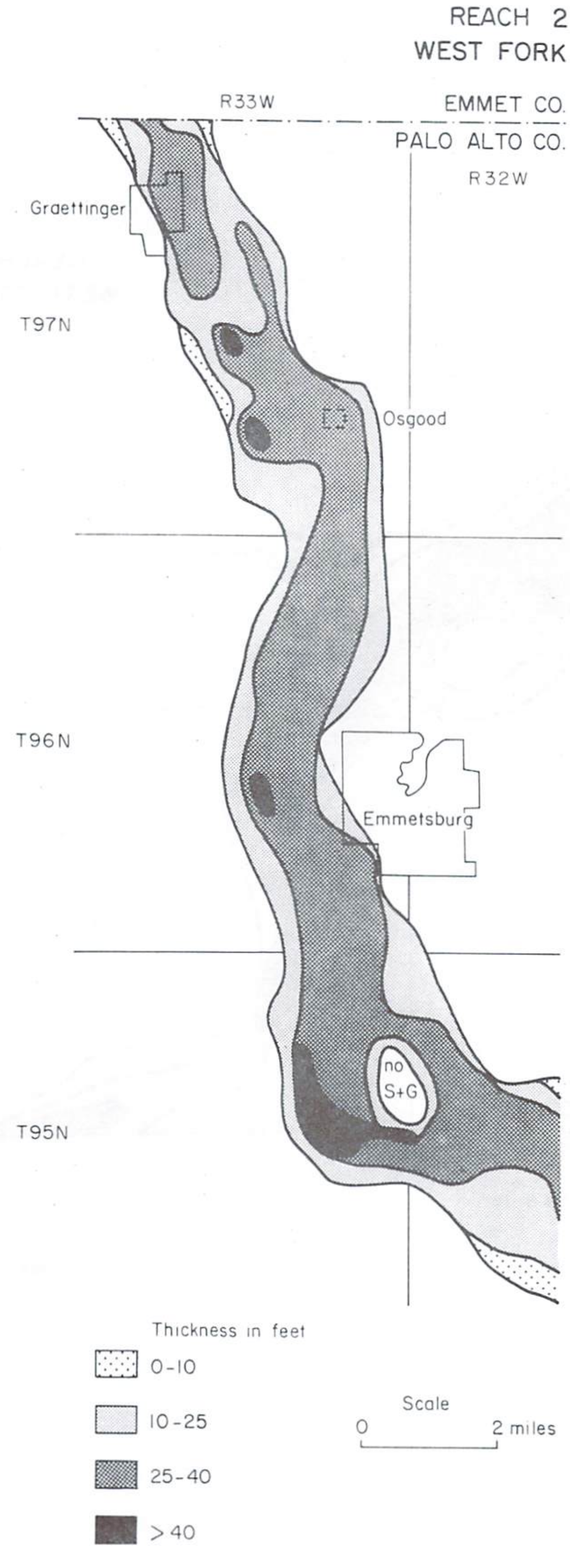
Appendix III

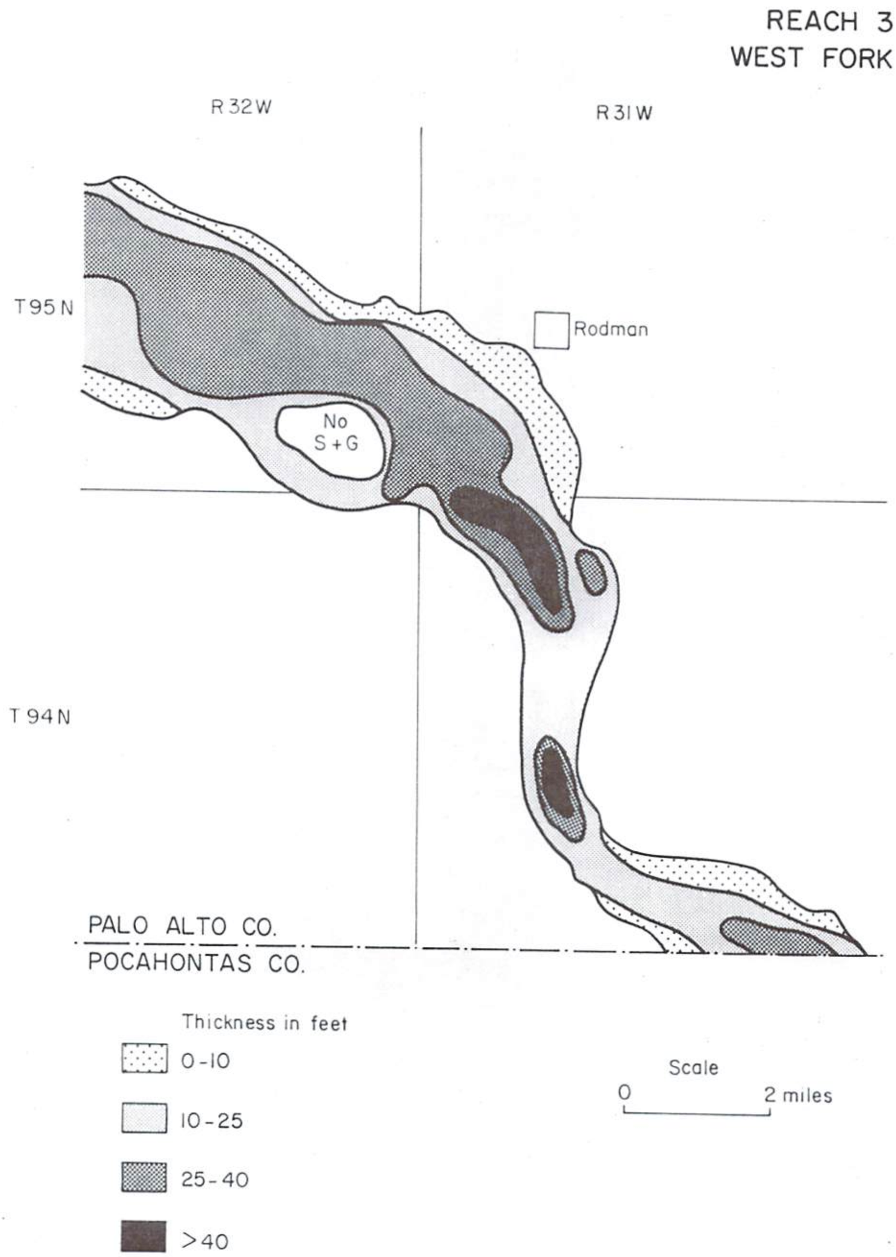
Isopach Maps

INDEX FOR ISOPACH MAPS (UPPER RIVER)

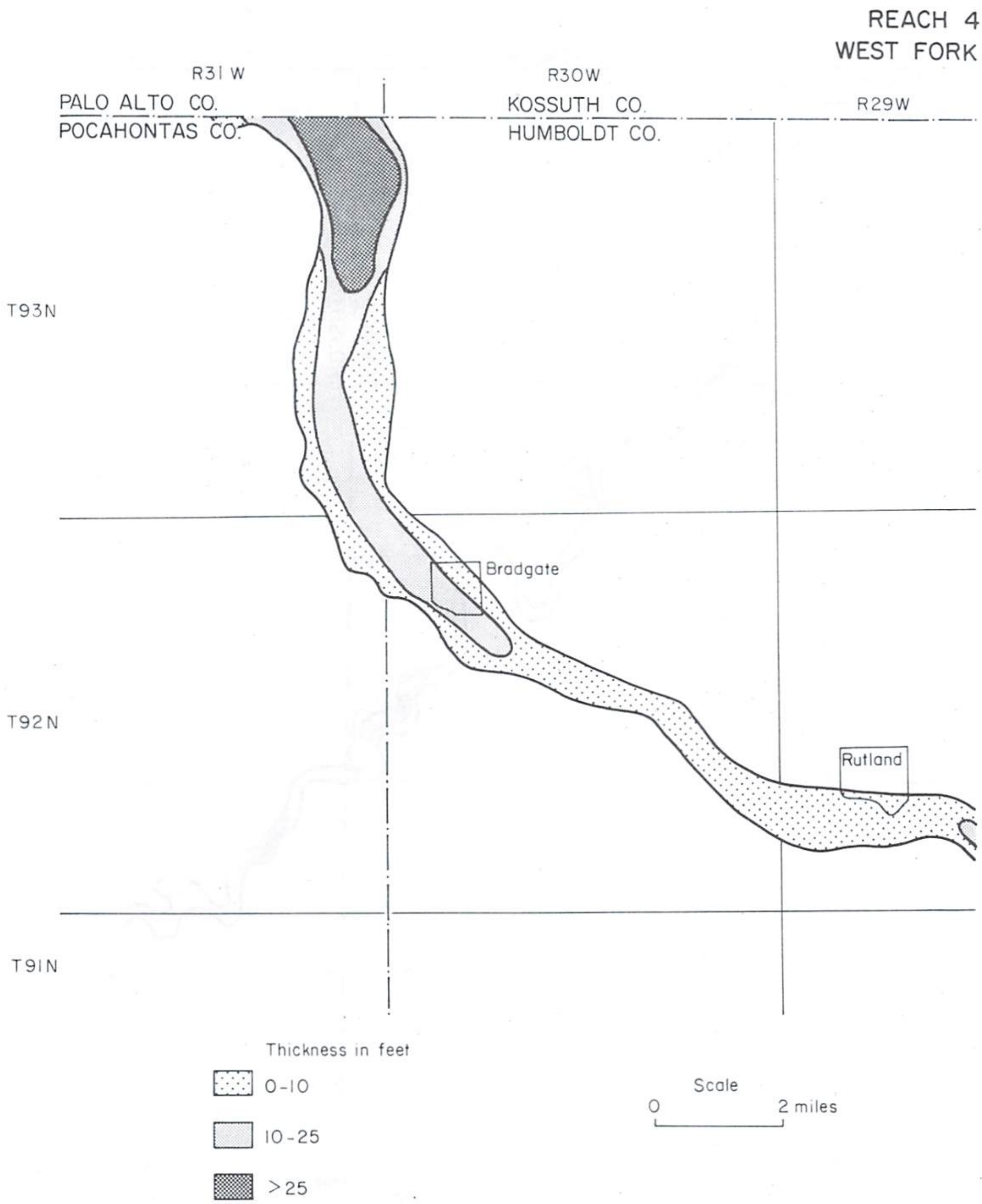


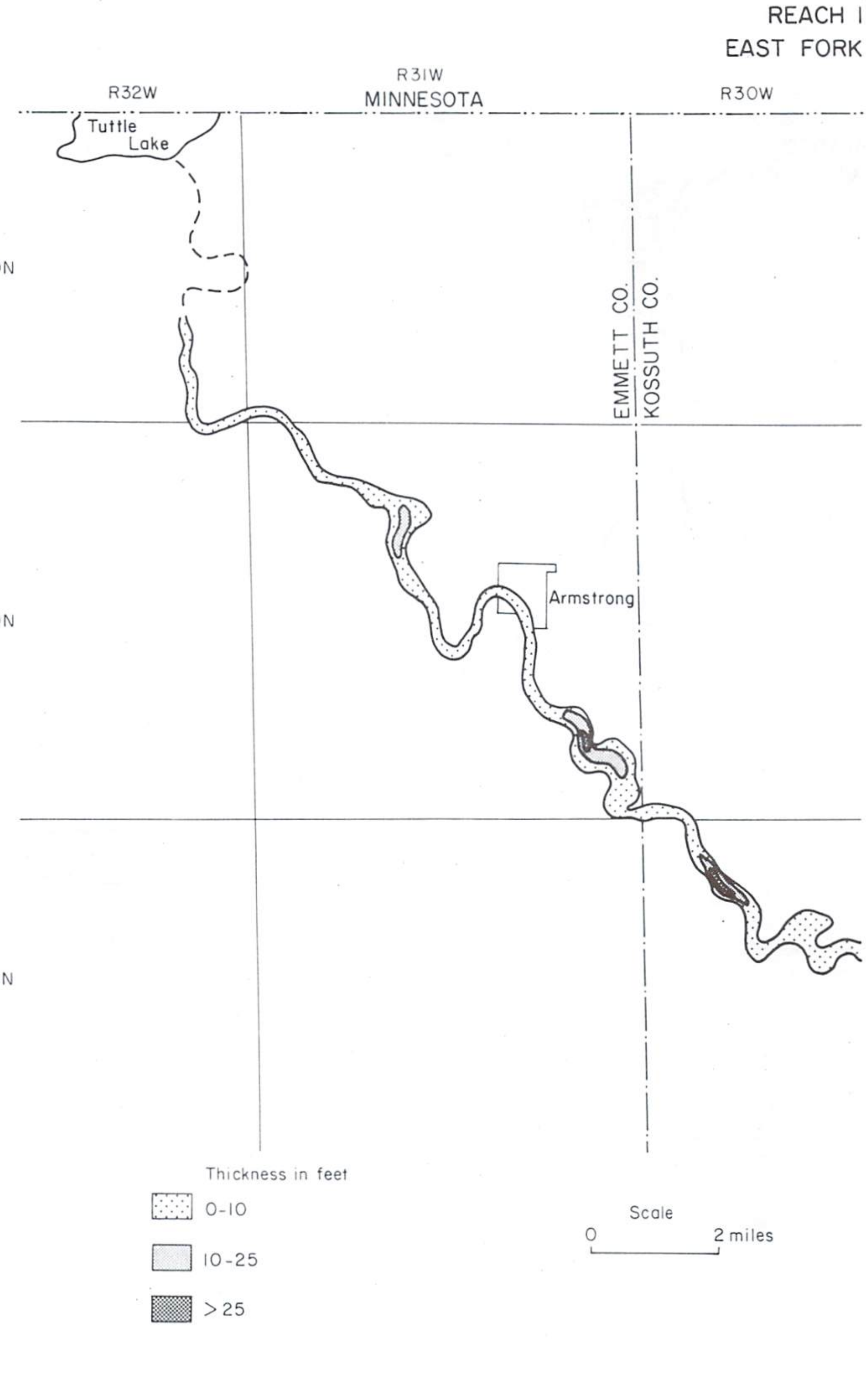

REACH I
WEST FORK
R34W
MINNESOTA
R33W
T100N
T99N
T98N
Estherville
Wallingford
EMMET CO.
PALO ALTO CO.
Thickness in feet
0-10
10-25
>25
Scale
0
2 miles


REACH 2
WEST FORK
R33W
EMMET CO.
PALO ALTO CO.
R32W
Graettinger
T97N
Osgood
T96N
Emmetsburg
T95N
no
S+G
Thickness in feet
0-10
10-25
25-40
>40
Scale
0
2 miles

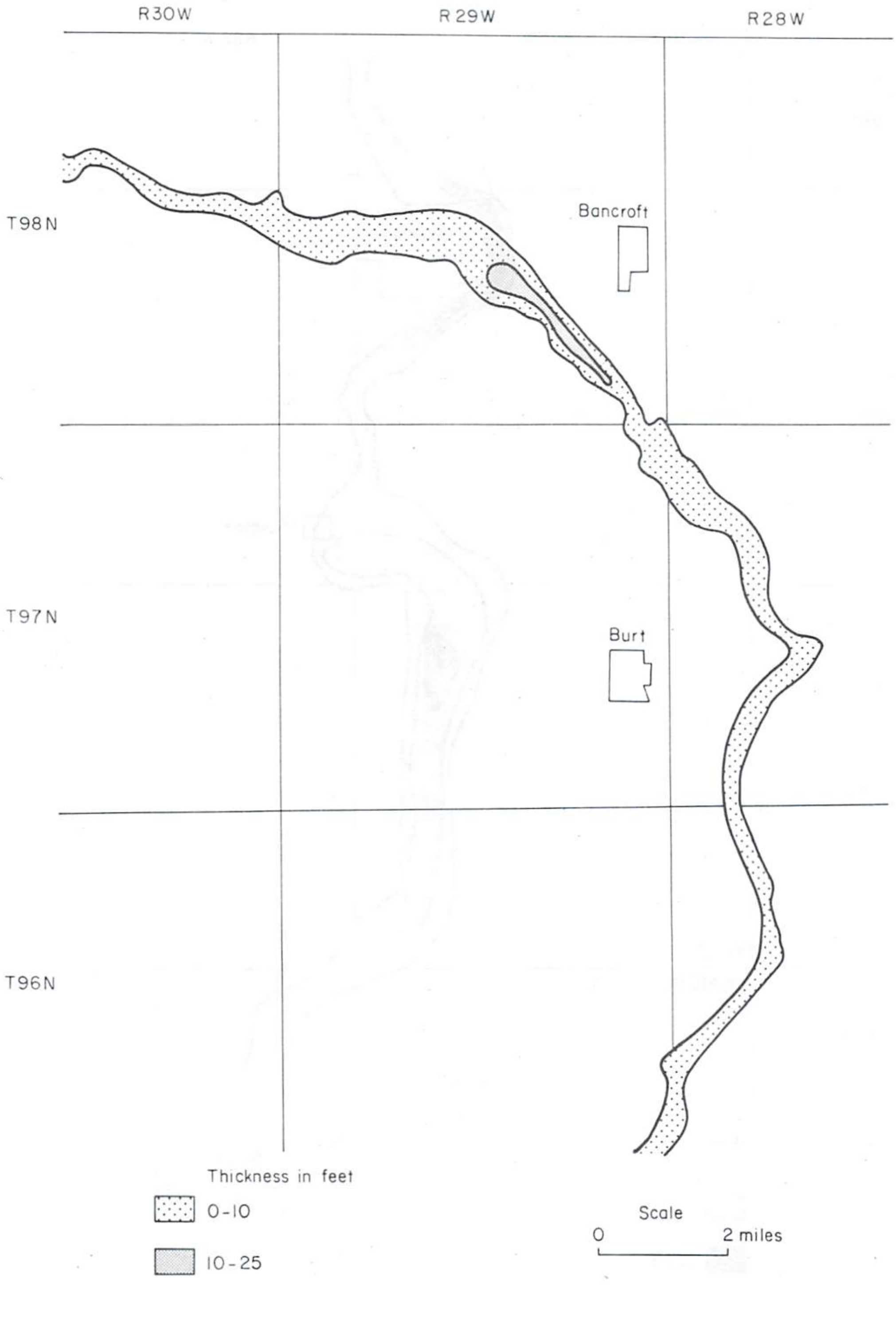


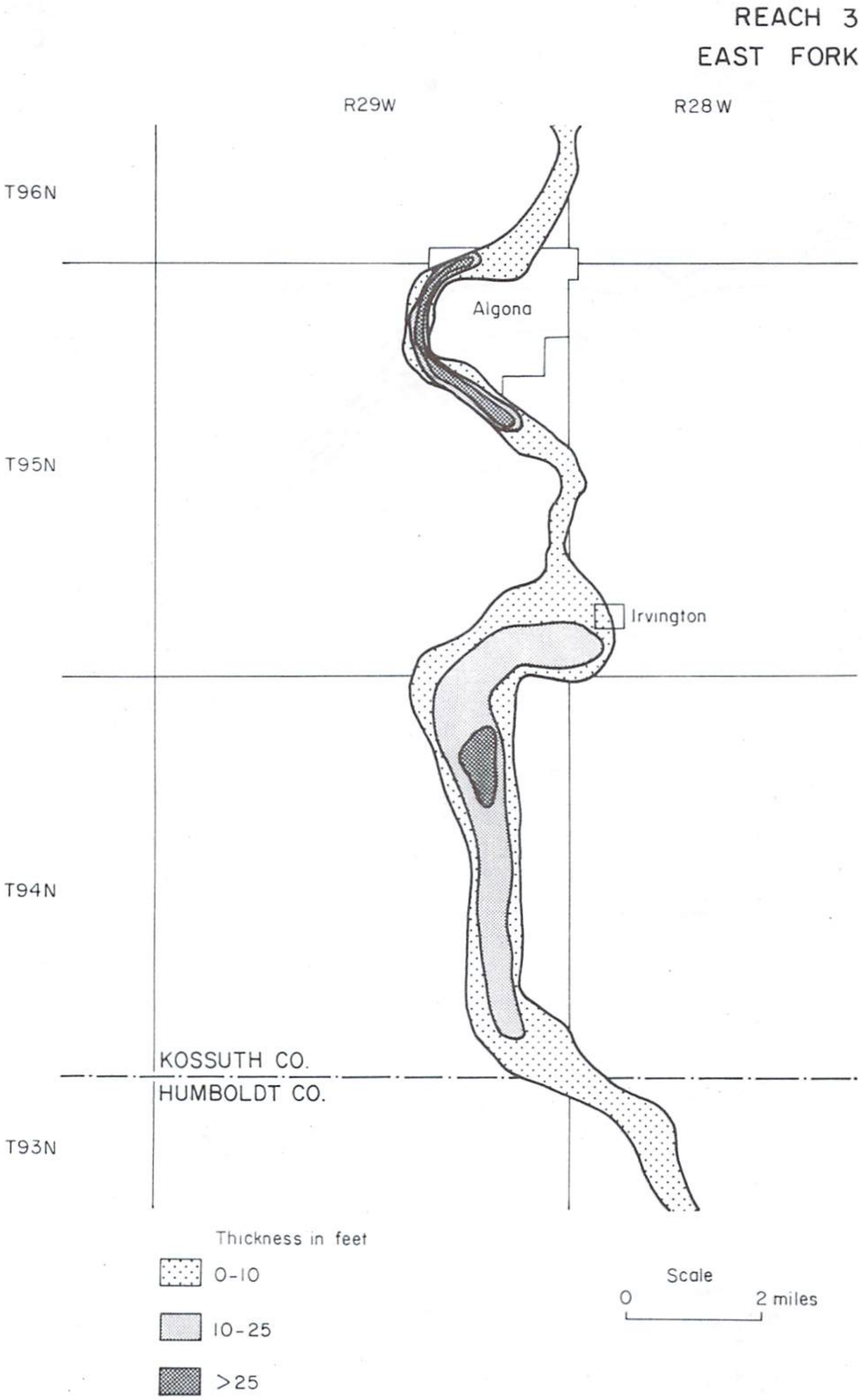
REACH 3
WEST FORK
R 32 W
R 31 W
T 95 N
T 94 N
Rodman
No
S + G
PALO ALTO CO.
POCAHONTAS CO.
Thickness in feet
0-10
10-25
25-40
>40
Scale
0
2 miles


REACH 4
WEST FORK
R31 W
R30W
R29W
PALO ALTO CO.
POCAHONTAS CO.
KOSSUTH CO.
HUMBOLDT CO.
T93N
T92N
T91N
Bradgate
Rutland
Thickness in feet
0-10
10-25
>25
Scale
0
2 miles


REACH I
EAST FORK
R32W
R31W
MINNESOTA
R30W
Tuttle
Lake
T100N
EMMETT CO.
KOSSUTH CO.
T99N
Armstrong
T98N
Thickness in feet
0-10
10-25
> 25
Scale
0
2 miles

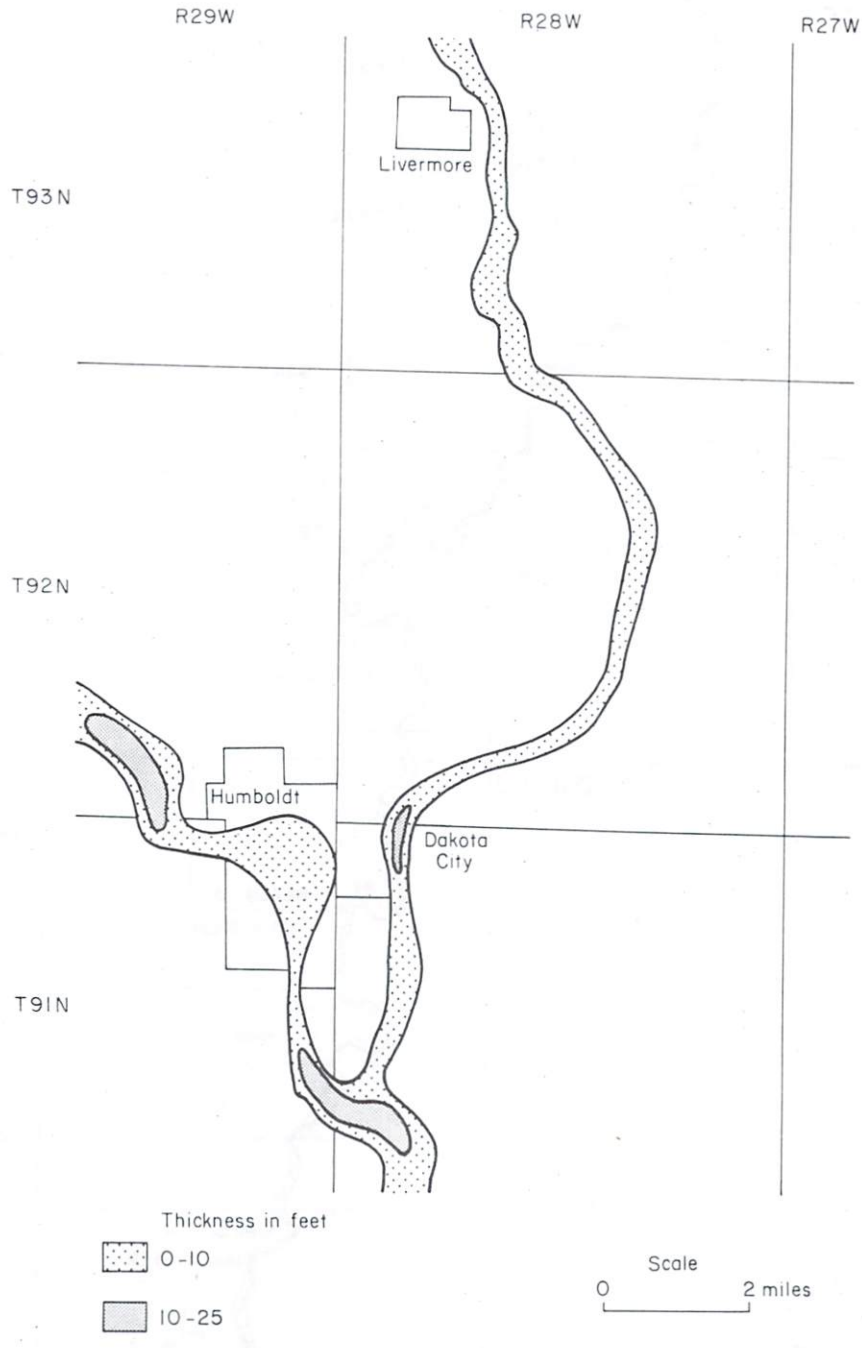
REACH 2
EAST FORK
KOSSUTH CO.



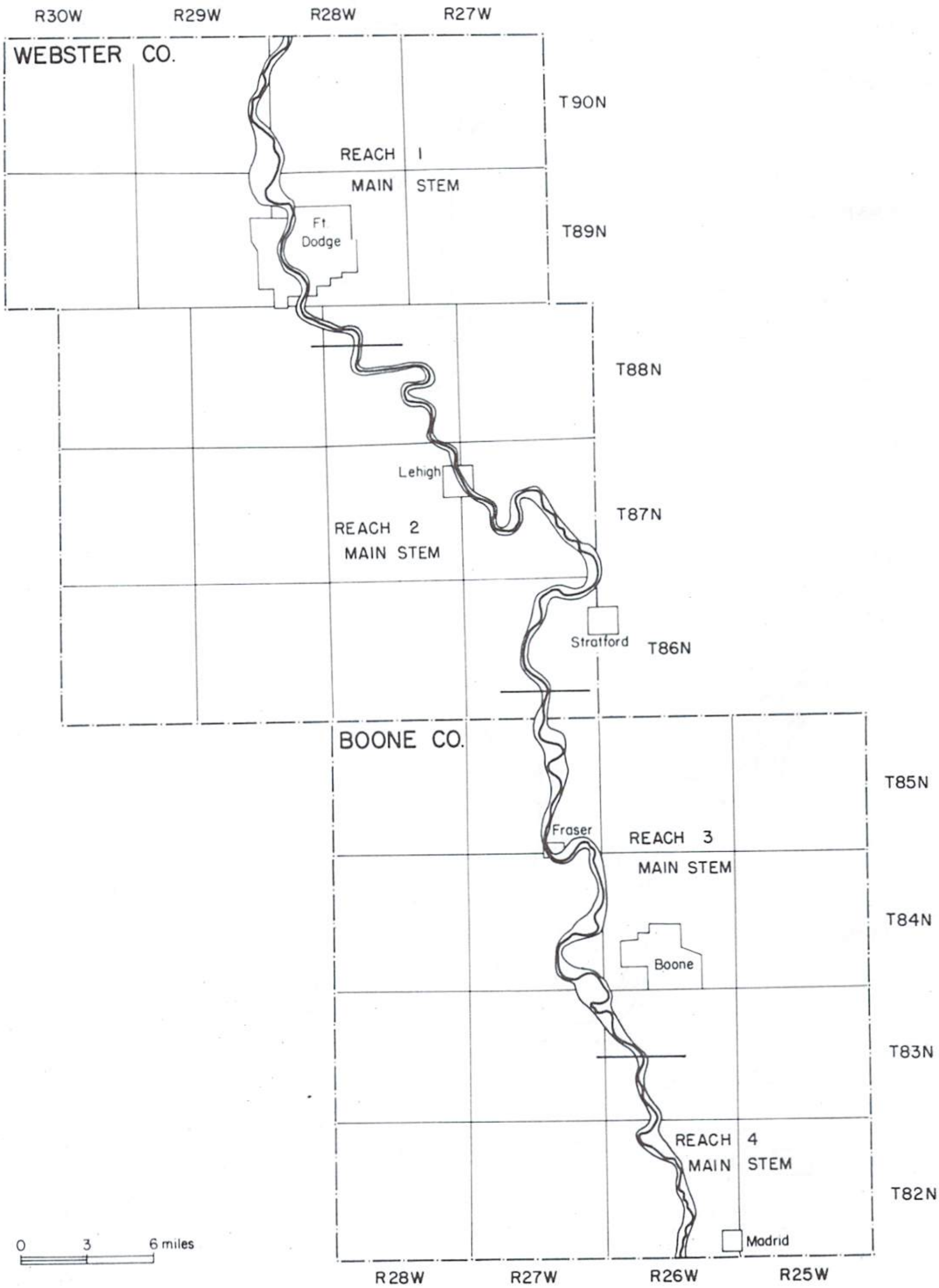


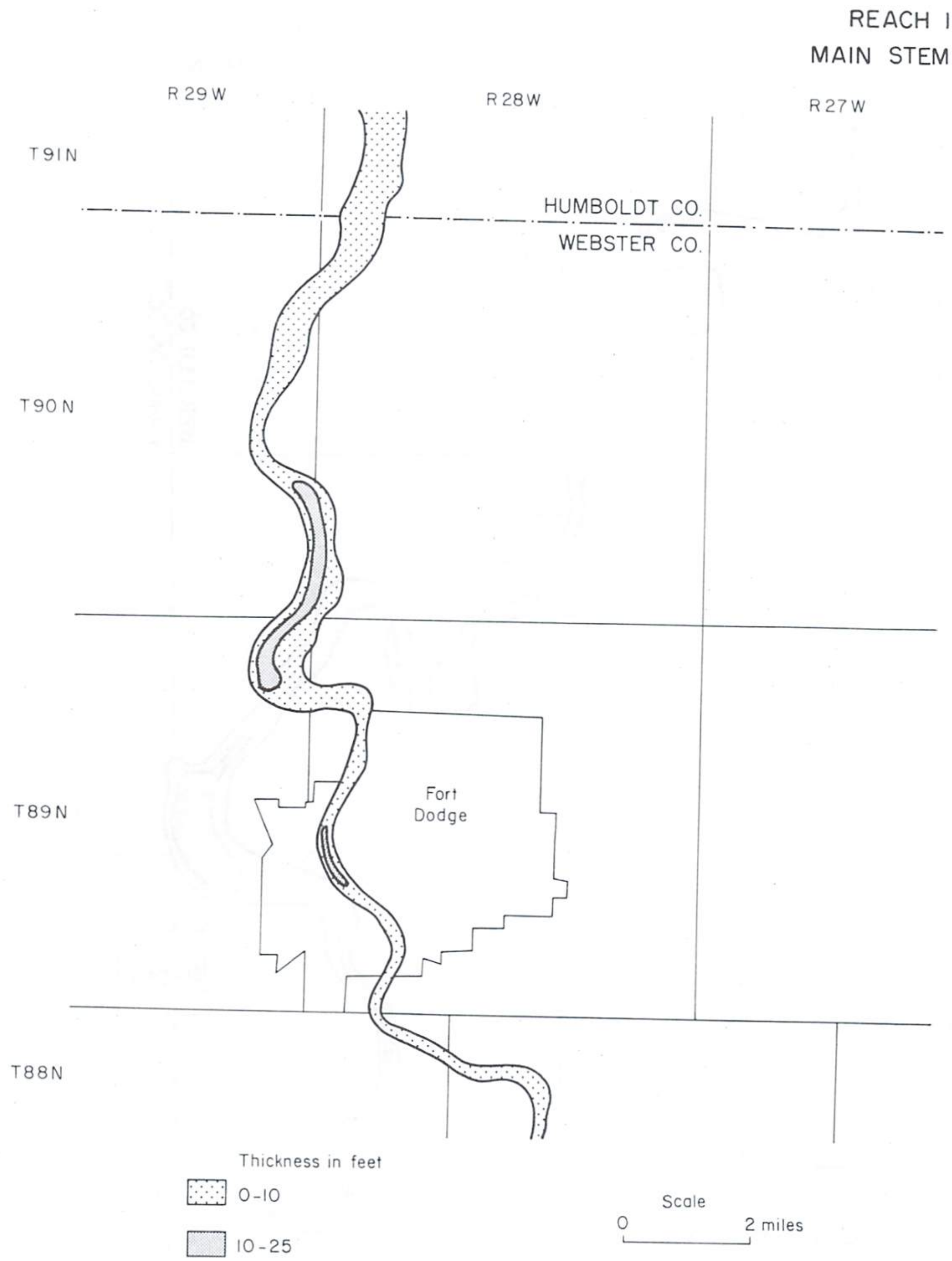
REACH 3
EAST FORK
R29W
R28W
T96N
Algona
T95N
Irvington
T94N
KOSSUTH CO.
HUMBOLDT CO.
T93N
Thickness in feet
0-10
10-25
>25
Scale
0
2 miles

REACH 4
EAST FORK AND JUNCTION
HUMBOLDT COUNTY

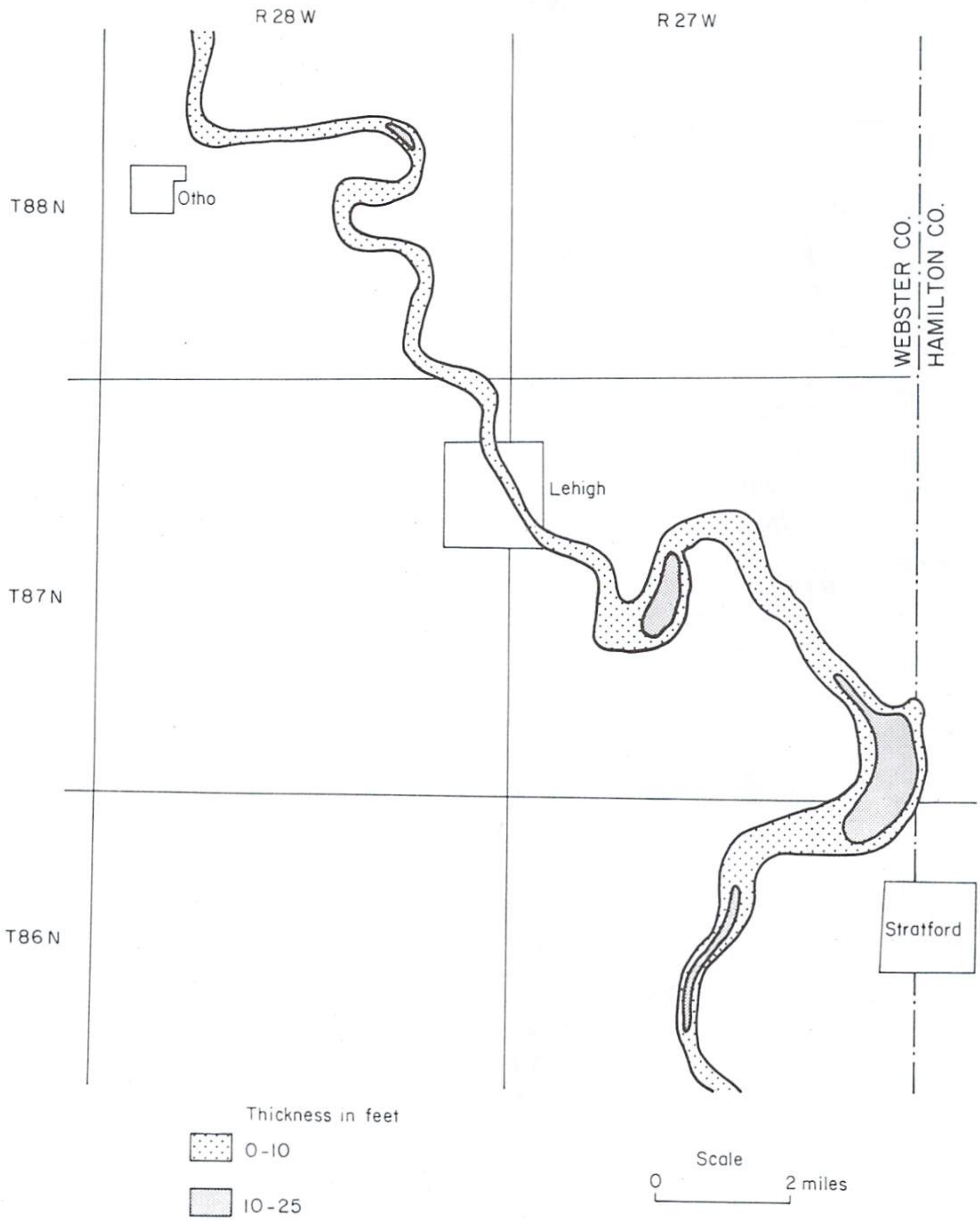


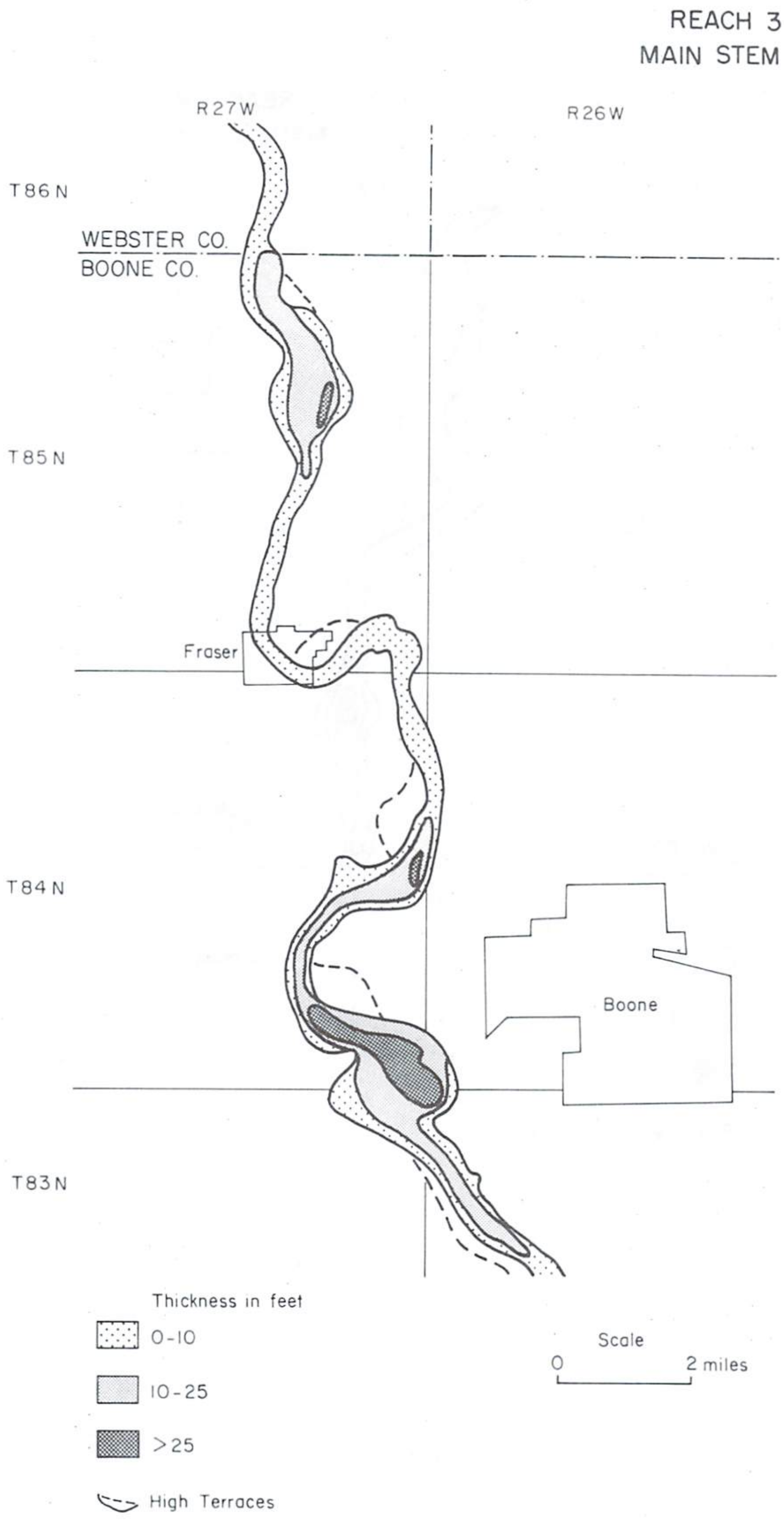
INDEX FOR ISOPACH MAPS (LOWER RIVER)

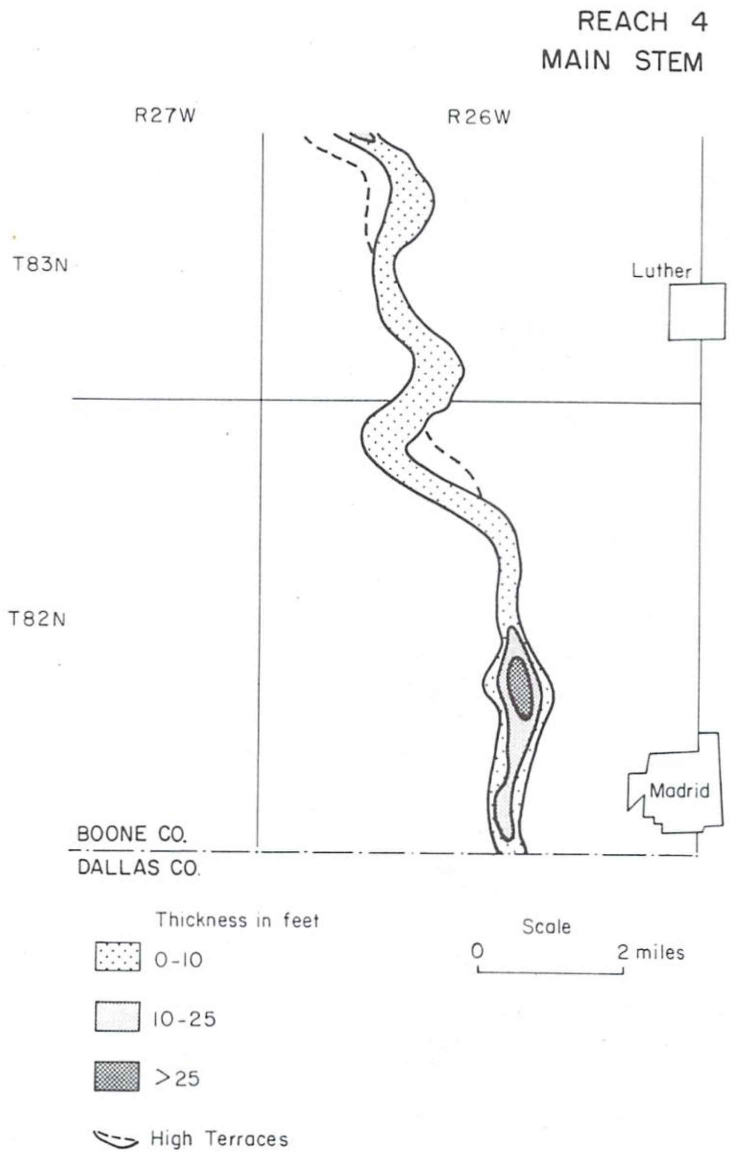



REACH I
MAIN STEM
R 29 W
R 28 W
R 27 W
T 91 N
T 90 N
T 89 N
T 88 N
HUMBOLDT CO.
WEBSTER CO.
Fort
Dodge
Thickness in feet
0-10
10-25
Scale
0
2 miles

REACH 2
MAIN STEM




REACH 3
MAIN STEM
R27W
R26W
T86N
WEBSTER CO.
BOONE CO.
T85N
Fraser
T84N
Boone
T83N
Thickness in feet
0-10
10-25
>25
High Terraces
Scale
0
2 miles


REACH 4
MAIN STEM
R27W
R26W
T83N
T82N
Luther
Madrid
BOONE CO.
DALLAS CO.
Thickness in feet
0-10
10-25
>25
High Terraces
Scale
0
2 miles

Appendix IV

Water Level Data

Appendix IV. Water Level Data

Location	Well Depth (ft)	Elevation Measuring Point	Elevation Ground Level	Date	Water Level (ft)	Elevation (ft. above sea level)	Saturated Thickness (ft)
WD4	25			9/20/83	15.8	1294	11.2
				11/17/83	Dry		
			Discontinued				
WD1	19	1269.0	1266.6	9/20/83	Dry		
				11/17/83	Dry		
			Replaced by WD18				
WD18	24	1273.6	1271.6	11/17/83	4.7	1268.9	20.0
				12/13/83	4.9	1268.7	20.0
				12/29/83	4.7	1268.9	20.0
				1/5/84	5.1	1268.5	19.9
				1/23/84	5.4	1268.2	19.6
				2/27/84	5.1	1268.5	19.9
				3/19/84	6.5	1267.1	18.5
				5/23/84	5.2	1268.4	19.8
				8/15/84	6.5	1267.1	18.5
WD2	25	1240.1	1238.2	9/20/83	6.4	1233.7	13.6
				11/17/83	8.1	1232.0	11.9
				12/13/83	8.5	1231.6	11.5
				12/29/83	8.6	1231.5	11.4
				1/5/84	8.7	1231.4	11.3
				1/23/84	8.8	1231.3	11.2
				2/27/84	10.3	1229.8	9.7
				3/19/84	10.7	1229.4	9.3
				5/23/84	8.2	1231.9	11.8
				6/12/84	7.8	1232.3	12.2
				6/14/84	8.6	1231.5	11.4
				6/16/84	8.2	1231.9	11.8
				6/21/84	8.7	1231.4	11.9
				6/27/84	7.6	1232.5	12.4
				7/2/84	8.2	1231.9	11.8
				7/10/84	9.1	1231.0	10.9
				8/15/84	10.2	1229.9	9.8
BRIDGE #1	D.M.R.	1244.7		3/27/84	14.4	1230.3	
				4/10/84	11.5	1233.2	
				6/12/84	14.8	1229.9	
				6/14/84	13.6	1231.1	
				6/16/84	13.1	1231.6	
				6/21/84	12.0	1232.7	
				6/27/84	12.4	1232.3	
				7/3/84	13.1	1231.6	
				7/10/84	14.3	1230.4	
				7/24/84	17.4	1227.3	

Location	Well Depth (ft)	Elevation Measuring Point	Elevation Ground Level	Date	Water Level (ft)	Elevation (ft. above sea level)	Saturated Thickness (ft)
WD30	17	1231.6	1229.5	11/17/83	9.5	1222.1	7.5
				12/13/83	9.3	1222.3	7.7
				12/29/83	9.4	1222.2	7.6
				1/5/84	9.7	1221.9	7.3
				1/23/84	9.9	1221.7	7.1
				2/27/84	11.6	1220.0	5.4
				3/19/84	11.6	1220.0	5.4
				5/23/84	9.2	1222.4	7.8
				6/12/84	8.4	1223.2	8.6
				6/14/84	8.5	1223.1	8.5
				6/16/84	8.3	1223.2	8.7
				6/21/84	7.3	1224.2	9.7
				6/27/84	7.5	1224.1	9.5
				7/3/84	8.1	1223.5	8.9
				7/10/84	8.5	1223.1	8.5
				8/15/84	11.1	1220.5	5.9
WD6	27	1224.3	1222.5	9/20/83	4.8	1219.5	22.2
				11/17/83	5.5	1218.8	21.5
				12/13/83	5.7	1218.6	21.3
				12/29/83	6.2	1218.1	20.8
				1/5/84	6.2	1218.1	20.8
				1/23/84	6.8	1217.5	20.2
				3/19/84	7.7	1216.6	19.3
				5/23/84	5.9	1218.4	21.1
				6/12/84	4.8	1219.5	22.2
				6/14/84	5.3	1219.0	21.7
				6/16/84	5.1	1219.2	21.9
				6/21/84	5.3	1219.0	21.7
				6/27/84	5.6	1218.7	21.4
				7/3/84	6.1	1218.2	20.9
				7/10/84	5.9	1218.4	21.1
				8/15/84	7.4	1216.9	19.6
WD7	37	1212.9	1210.5	9/20/83	4.4	1208.5	33.6
				11/17/83	6.3	1206.6	31.7
				12/13/83	6.3	1206.6	31.7
				12/29/83	6.6	1206.3	31.4
				1/4/84	6.7	1206.2	31.3
				1/23/84	6.9	1206.0	31.1
				2/27/84	8.8	1204.1	29.2
				3/19/84	8.7	1204.2	29.3
				5/23/84	4.1	1208.8	33.9
				6/12/84	2.2	1210.7	35.8
				6/14/84	3.1	1209.8	34.9
				6/16/84	2.8	1210.1	35.2
				6/21/84	2.4	1210.5	35.6
				6/27/84	2.7	1210.2	35.3
				7/3/84	3.0	1209.9	35.0
				7/10/84	3.1	1209.8	34.9
				8/15/84	5.8	1207.1	32.2

Location	Well Depth (ft)	Elevation Measuring Point	Elevation Ground Level	Date	Water Level (ft)	Elevation (ft. above sea level)	Saturated Thickness (ft)
BRIDGE #2	D.M.R.	1213.4		3/27/84	8.3	1205.1	
				4/10/84	---	---	
				6/12/84	7.1	1206.3	
				6/14/84	6.5	1206.9	
				6/16/84	5.4	1208.0	
				6/21/84	---		
				6/27/84	4.7	1208.7	
				7/3/84	4.9	1208.5	
				7/10/84	7.9	1205.5	
				7/24/84	11.1	1202.3	
WD8	42			9/20/83	3.4	1199	39.0
			Replaced by WD31				
WD31	38	1199.8	1198.1	11/18/83	5.8	1194.0	31.0
				12/13/83	6.3	1193.5	31.0
				12/29/83	6.6	1193.2	31.0
				1/5/84	4.7	1195.1	31.0
				1/23/84	6.3	1193.5	31.0
				2/27/84	7.2	1192.6	30.8
				3/19/84	8.3	1191.5	29.7
				5/23/84	3.1	1196.7	31.0
				6/12/84	3.1	1196.7	31.0
				6/14/84	3.0	1196.8	31.0
				6/16/84	2.5	1197.3	31.0
				6/21/84	2.2	1197.6	31.0
				6/27/84	2.2	1197.6	31.0
				7/3/84	2.8	1197.0	31.0
				7/10/84	3.4	1196.4	31.0
				8/15/84	7.7	1992.1	30.3
WD9	48	1191.6	1189.6	9/20/83	0	1191.6	53.0
				11/18/83	1.4	1190.2	53.0
				12/13/83	2.9	1188.7	52.1
				3/19/84	3.6	1187.6	51.0
				5/23/84	2.0	1189.6	53.0
				6/7/84	3.4	1188.2	51.6
				8/15/84	4.5	1187.1	50.5
WD9A	17	1191.3	1189.9	11/18/83	1.6	1189.7	
				12/13/83	.8	1190.8	
				3/19/84	3.6	1188.0	
				5/23/84	2.8	1188.5	
				6/7/84	3.0	1188.3	
				8/15/84	3.9	1187.4	
WD9B	34	1191.1	1189.9	11/18/83	1.6	1189.5	
				12/13/83	1.6	1189.5	
				3/19/84	3.5	1187.6	
				5/23/84	2.6	1188.5	
				6/7/84	2.9	1188.2	
				8/15/84	4.1	1187.0	

Location	Well Depth (ft)	Elevation Measuring Point	Elevation Ground Level	Date	Water Level (ft)	Elevation (ft. above sea level)	Saturated Thickness (ft)
WD10	32	1188.6	1186.9	9/20/83	2.7	1185.9	33.3
				11/18/83	5.9	1182.7	30.1
				12/13/83	5.8	1182.8	30.2
				12/30/83	6.2	1182.4	29.8
				1/5/84	6.4	1182.2	29.6
				1/23/84	6.7	1181.9	29.3
				2/27/84	6.9	1181.7	29.1
				3/19/84	7.9	1180.7	28.1
				5/23/84	2.0	1186.6	32.0
				6/12/84	3.0	1185.6	29.0
				6/14/84	2.9	1185.7	31.1
				6/16/84	1.8	1186.8	32.0
				6/27/84	1.1	1187.5	32.0
				7/3/84	2.8	1185.8	31.2
				7/10/84	2.7	1185.9	31.3
				8/15/84	8.2	1180.4	25.8
BRIDGE #3	D.M.R.	1213.4		3/27/84	9.8	1203.6	
				4/10/84	5.8	1207.6	
				6/12/84	9.3	1204.1	
				6/14/84	7.8	1205.6	
				6/16/84	7.2	1206.2	
				6/21/84	6.0	1207.4	
				6/27/84	6.6	1206.8	
				7/3/84	8.1	1205.3	
				7/10/84	9.6	1203.8	
				7/24/84	12.4	1201.0	
WD11	34.5			9/22/83	1.8		34.0
				11/18/83	1.4		34.0
				12/13/83	2.3		33.7
				3/19/84	4.0		32.0
				5/23/84	2.8		33.2
				6/12/84	1.0		34.0
				6/21/84	1.4		34.0
				8/15/84	4.6		31.4
BRIDGE #4	D.R.M.			3/27/84	14.8		
				4/10/84			
				6/12/84	14.5		
				6/14/84	13.2		
				6/16/84	12.7		
				6/21/84			
				6/27/84			
				7/3/84			
				7/10/84	15.2		
				7/24/84	18.2		

Location	Well Depth (ft)	Elevation Measuring Point	Elevation Ground Level	Date	Water Level (ft)	Elevation (ft. above sea level)	Saturated Thickness (ft)
WD12	48	1168.6	1167.1	9/22/83	2.3	1166.3	31.0
				11/18/83	2.6	1166.0	31.0
				12/13/83	2.7	1165.9	31.0
				12/30/83	2.7	1165.9	31.0
				1/5/84	3.0	1165.6	31.0
				1/23/84	3.3	1165.3	30.7
				3/19/84	4.4	1164.2	29.6
				6/7/84	1.0	1167.6	31.0
				7/10/84	1.2	1167.4	31.0
				8/15/84	7.1	1161.6	26.9
WD12A	25	1168.8	1167.1	11/18/83	2.6	1166.2	
				12/13/83	2.7	1166.1	
				12/30/83	3.0	1165.8	
				1/5/84	3.0	1165.8	
				1/23/84	3.3	1165.5	
				2/27/84	4.0	1164.8	
				3/19/84	4.6	1164.2	
				6/7/84	2.2	1166.6	
				7/10/84	1.3	1167.5	
				8/15/84	6.3	1162.5	
WD13	36	1160.9	1158.8	9/22/83	5.0	1155.9	27.0
				11/18/83	4.9	1156.0	27.0
				12/14/83	6.0	1154.9	27.0
				12/30/83	6.8	1154.1	27.0
				1/5/84	6.7	1154.2	27.0
				1/23/84	6.9	1154.0	27.0
				2/27/84	4.8	1156.1	27.0
				3/19/84	7.6	1153.3	27.0
				5/23/84	5.5	1155.4	27.0
				6/7/84	6.2	1154.7	27.0
				6/12/84	5.2	1155.7	27.0
				6/14/84	4.9	1156.0	27.0
				6/16/84	4.5	1156.4	27.0
				6/27/84	3.9	1157.0	27.0
				7/3/84	4.7	1156.2	27.0
				7/10/84	5.6	1155.3	27.0
				8/15/84	9.1	1151.8	27.0
BRIDGE #5	D.M.R.	1164.5		3/27/84	8.7	1155.8	
				4/10/84	6.6	1157.9	
				6/12/84	8.2	1156.3	
				6/14/84	6.9	1157.6	
				6/16/84	6.4	1158.1	
				6/21/84	6.1	1158.4	
				6/27/84	6.6	1157.9	
				7/3/84	7.1	1157.4	
				7/10/84	8.3	1156.2	
				7/24/84	10.6	1153.9	

Location	Well Depth (ft)	Elevation Measuring Point	Elevation Ground Level	Date	Water Level (ft)	Elevation (ft. above sea level)	Saturated Thickness (ft)
WD14	31	1140.3	1138.6	9/22/83	3.7	1136.6	27.3
				11/18/83	3.4	1136.9	27.6
				12/14/83	3.4	1136.9	27.6
				12/30/83	3.8	1136.5	27.2
				1/5/84	3.9	1136.4	27.1
				1/23/84	4.2	1136.1	26.8
				2/27/84	6.1	1134.2	24.9
				3/19/84	5.1	1135.2	25.9
				5/23/84	2.8	1137.5	28.2
				6/12/84	1.9	1138.4	29.0
				8/15/84	5.3	1135.0	25.7
BRIDGE #6	D.M.R.	1135.0		3/27/84	11.2	1123.8	
				4/10/84	7.6	1127.4	
				6/12/84	11.3	1123.7	
WD15	17	1129.8	1127.6	9/21/83	.5	1129.3	15.0
				11/18/83	2.1	1127.7	14.9
				12/14/83	2.4	1127.4	14.6
				12/30/83	2.9	1126.9	14.1
				1/5/84	2.9	1126.9	14.1
				1/23/84	3.2	1126.6	13.8
				2/27/84	4.0	1125.8	13.0
				3/19/84	4.3	1125.5	12.7
				5/23/84	4.5	1125.3	12.5
				8/15/84	5.0	1124.8	12.0
WD16	14.5	1119.2	1116.6	9/21/83	4.3	1114.9	10.2
				11/17/83	4.8	1114.4	9.7
				12/14/83	4.6	1114.6	9.9
				12/30/83	5.3	1113.9	9.2
				1/5/84	5.4	1113.8	9.1
				1/23/84	5.7	1113.5	8.8
				2/27/84	6.8	1112.4	7.7
				3/19/84	7.4	1111.8	7.1
				5/23/84	5.8	1113.4	8.7
				6/12/84	3.8	1115.4	10.7
				8/15/84	7.1	1112.1	7.4
BRIDGE #7	D.M.R.	1125.0		3/27/84	11.7	1113.3	
				4/10/84	11.9	1113.1	
				6/12/84	11.3	1113.7	

Location	Well Depth (ft)	Elevation Measuring Point	Elevation Ground Level	Date	Water Level (ft)	Elevation (ft. above sea level)	Saturated Thickness (ft)
WD17	58	1087.1	1085.5	9/21/83	7.0	1080.1	7.5
				11/17/83	7.3	1079.8	7.2
				12/14/83	6.9	1080.2	7.6
				12/30/83	7.5	1079.6	7.0
				1/5/84	7.8	1079.3	6.7
				1/23/84	7.9	1079.2	6.6
				2/27/84	7.7	1079.4	6.8
				3/19/84	8.0	1079.1	6.5
				6/4/84	6.5	1080.6	8.0
				6/12/84	5.7	1081.4	8.8
				8/15/84	8.1	1079.0	6.4
LD1	14	~1083		9/21/83	13.0	1070	1.0
				11/17/83	12.1	1071	1.9
				3/19/84	12.5	1070	1.5
				6/4/84	11.9	1071	2.1
				6/12/84	10.4	1073	3.6
LD2	21	~1020		9/21/83	6.7	1013	Finished
				11/18/83	6.3	1014	in LS
			Destroyed				
LD3	26	~930		9/22/83	8.4	922	17.6
				11/18/83	7.1	923	18.9
				12/29/83	7.5	922	18.5
				1/6/84	7.3	923	18.7
				1/24/84	8.1	922	17.9
				3/22/84	8.8	921	17.2
			Inoperable from 4/84 to 6/84				
LD4	37	~938		9/22/83	24.4	914	0
				11/18/83	21.8	916	0
				12/29/83	21.3	917	0
				1/6/84	20.5	917	0
				1/24/84	21.7	916	0
				3/22/84	22.1	916	0
LD5	50	~900		11/18/83	9.2	891	40.8
				12/15/83	8.8	891	41.2
				12/29/83	11.0	889	39.0
				1/6/84	9.5	890	40.5
				1/24/84	9.8	890	40.2
				2/28/84	10.1	890	39.9
				3/22/84	11.5	888	38.5
				6/12/84	9.6	890	40.4

Location	Well Depth (ft)	Elevation Measuring Point	Elevation Ground Level	Date	Water Level (ft)	Elevation (ft. above sea level)	Saturated Thickness (ft)
LD6	14.5	~860		11/18/83	7.0	853	5.5
				12/29/83	7.7*		
				1/6/84	7.7*		
				1/24/84	7.9*		
				2/28/84	8.0*		
				3/22/84	8.6*		
ED1	33	~1096		9/21/83	4.3	1092	22.0
				11/17/83	5.3	1091	22.0
				12/14/83	5.0	1091	22.0
				12/30/83	7.5	1088	22.0
				1/23/84	5.9	1090	22.0
				3/19/84	5.9	1090	22.0
				6/4/84	4.7	1091	22.0
ED2	93	~1130		9/21/83	27.9	1102	water
				11/17/83	28.2	1102	levels
				12/14/83	28.0	1102	are for
				12/30/83	28.5	1101	Dakota
				1/23/84	28.7	1101	
				3/22/84	28.5	1101	
				6/21/84	23.2	1107	
ED4	94	~1115		11/17/83	15.4	1100	water
				12/14/83	15.3	1100	levels
				3/22/84	16.2	1099	are for
				6/4/84	14.1	1101	Dakota
ED4A	29	~1115		11/17/83	15.1	1100	38.9
				12/14/83	15.1	1100	38.9
				3/22/84	17.5	1097	36.5
				6/4/84	14.3	1101	39.7

Appendix V

Water Quality Data

Table A. Municipal Analyses
Table B. Private Alluvial Analyses
Table C. Mineral Scans - Des Moines River
Table D. Des Moines River Analyses

Table A. Municipal Alluvial Water Analyses Source: (WATSTORE, DWAWM)

IOWA GEOLOGICAL SURVEY
TABULATION OF WATER ANALYSES
(Dissolved constituents in parts per million)

Town & Well No.	Date	Depth (ft)	Diss. Solids	K	Na	Ca	Mg	Mn
Estherville #1	9/16/52	38	660	4.4	9.1	146	43.1	.8
Estherville #1	10/11/60	38	610	6.0	26.8	161	38.1	----
Graettinger #1	7/8/57	40	544	6.0	11.3	112	37.2	.47
Graettinger	7/8/57	15	603	7.1	13.0	115	36.2	<.05
Graettinger	7/8/57	35	1010	7.0	57.6	167	54.4	<.05
Graettinger #3	3/30/61	34	346	3.0	8.6	84.4	17.0	.23
Graettinger #3	11/30/70	34	473	4.0	11.0	104	31.1	.52
Graettinger #4	1/11/66	30.5	460	3.8	7.7	102	29.2	.22
Graettinger #4	11/30/70	30.5	479	4.0	11.0	109	29.1	.39
Graettinger #4	1/18/74	30.5	622	4.0	6.4	110	35.0	.22
Graettinger #4	8/4/76	30.5	355	4.4	7.1	100	35.0	.29
Graettinger #5	1/14/80	30	1710	38.0	22.0	290	83.0	.11
Emmetsburg #1	11/14/52	34	506	5.2	15.2	111.4	35.2	.27
Emmetsburg #1	12/16/54	34	510	6.1	15.1	111.6	34.8	.30
Emmetsburg #1	3/28/56	34	544	6.8	15.2	121	31.6	.38
Emmetsburg #1	10/11/60	34	542	6.3	17.5	105	37.1	.36
Emmetsburg #1	10/19/66	34	504	6.6	17.0	107	28.2	.45
Emmetsburg #1	11/3/70	34	531	7.4	25.0	124	24.3	.80
Emmetsburg #1	4/17/74	34	510	6.0	23.0	110	38.0	.32
Emmetsburg #1	7/31/74	34	----	7.2	25.0	110	39.0	.04
Emmetsburg #1	5/5/77	34	525	6.3	21.0	110	34.0	.49
Emmetsburg #2	10/11/60	38	593	5.5	14.6	109	41.8	.34
Emmetsburg #2	11/3/70	38	508	6.4	20.0	112	32.0	.37
Emmetsburg #2	5/4/77	38	520	6.0	19.0	110	36.0	.37
Emmetsburg #3	3/17/56	38	526	5.0	14.1	113	40.6	.38
Emmetsburg #3	10/19/66	38	484	5.5	17.0	105	32.3	.30
Emmetsburg #3	12/19/70	38	508	6.4	20.0	112	31.6	.37
Emmetsburg #3	8/7/74	38	425	7.8	18.0	100	33.0	.03
Emmetsburg #3	5/5/77	38	501	6.0	13.0	100	31.0	.37
Lehigh #3	4/73	34	1340	10.0	41.0	310	70.0	.93
Lehigh #3	11/6/73	34	----	----	----	264	60.8	----
Lehigh #3	3/16/77	34	1760	14.0	63.0	360	81.0	1.80

NO_3	F	Cl	SO_4	HCO_3	Fe	Hard-ness	Conduct-ance (micro-mohs)	pH
1	.25	17	175	364	.6	544	915	8.0
4	.25	19	209	454	.58	560	---	7.1
.5	.3	13	83.5	429	.14	433	770	7.4
3.9	.25	29	67.7	410	.07	436	806	7.5
.9	.2	4	374	447	15.4	668	1200	7.6
1.6	.35	8	46.7	303	.08	281	557	7.6
2.1	.25	3	63	422	.9	388	730	7.0
23.0	.25	9.5	64.6	356	.02	376	728	7.3
11.0	.25	10	82	381	.3	372	730	7.0
23.0	.25	18	81	364	<.01	396	810	7.05
8.2	.2	10	87	386	<.01	394	740	7.3
<.1	.3	9	760	387	.05	1070	2000	7.2
1.6	.4	11	72.2	444	2.6	428	756	7.7
1.5	.2	12	65.4	451.4	2.3	427	791	7.5
0	.3	8	57.4	490	2.2	437	848	7.5
<.1	.35	21	65.2	437	2.4	415	819	7.2
.7	.3	19	76	410	1.3	383	780	7.4
.4	.4	33	77	415	2.4	410	810	6.9
8.2	.25	31	71	432	1.9	450	860	7.2
3.1	.8	34	82	442	<.01	425	860	7.8
1.3	.3	23	58	454	2.5	425	810	7.0
.7	.95	21	101	407	2.3	445	797	7.2
2.3	.3	21	75	415	2.0	410	810	6.8
.1	.3	18	57	458	----	427	820	6.9
.7	.3	10	58.6	460	2.1	453	813	7.5
3.7	.3	17	69	434	2.1	396	810	7.3
2.3	.3	21	75	415	2.0	410	810	6.9
2.7	.6	30	87	368	.02	360	780	7.8
1.6	.7	35	75	349	----	391	760	7.1
3.9	.15	120	540	476	.87	1000	1900	6.9
.2	---	---	-----	----	.55	910	----	---
.6	.1	280	530	518	1.6	1240	2400	7.1

Table B. Private Alluvial Water Analyses

(Source: UHL)

No.	Location	Well Depth	Bacteria	Nitrate	Iron	Hardness	Date
1	T100 R34 Sec. 34	20'	9.2	--	---	---	11/81
2	T99 R34 Sec. 23	35'	5.1				5/76
			16+				6/76
3	T99 R34 Sec. 24	35'	0	45	<.1	540	5/76
4	T99 R34 Sec. 24	20'	16+	<5	1.9	470	8/79
5	T99 R34 Sec. 36	25'	16+	<5	<.1	390	10/75
			5.1				10/75
			0				3/76
6	T98 R33 Sec. 20	30'	2.2				5/79
			0				4/79
			16				4/79
			0	<5	5.2	300	1/81
7	T97 R33 Sec. 4	30'	0	40	<.1	310	8/76
8	T97 R33 Sec. 4	30'	0	--	---	---	1/75
9	T97 R33 Sec. 4	40'	0	<5	2.1	320	3/79
10	T97 R33 Sec. 4	30'	0	11	<.1	290	3/79
11	T97 R33 Sec. 4	25'	0	<5			8/82
12	T97 R33 Sec. 22	22'	0	18	<.1	330	1/76
13	T96 R33 Sec. 22	28'	0	<5	---	---	9/82
14	T96 R33 Sec. 25	21'	0	--	---	---	----

No.	Location	Well Depth	Bacteria	Nitrate	Iron	Hardness	Date
15	T96 R33 Sec. 25	---	0	--	---	---	4/75
16	T96 R33 Sec. 35	sd pt	-	<5	.2	400	12/79
17	T95 R33 Sec. 1	40'	16	<5	---	---	7/75
		40'	0	<5	---	---	8/75
18	T95 R32 Sec. 6	18'	2.2	108	<.1	500	5/80
		18'	0	---	---	---	2/81
		18'	---	<5	3.5	700	3/81
19	T95 R32 Sec. 8	30'	0	<5	<.1	400	7/76
20	T97 R33 Sec. 9	12'	2.2	30	<.1	340	8/74
21	T97 R33 Sec. 9	18'	16	8	.1	520	8/76
22	T98 R29 Sec. 22	25'	16+	220	---	---	4/83
23	T94 R29 Sec. 13	?	9.2	25	<.1	310	5/76
			9.2	25	<.1	310	4/76
24	T92 R28 Sec. 32	25'	5.1				6/76
			0				11/78
25	T91 R29	19'(sd pit)	0	30	<.1	440	7/76
26	T91 R29	16'	2.2	<5	.3	380	7/76
27	T91 R29	19 (sd pit)	0				3/76
28	T88 R23 Sec. 14	14'	16+	60	---	---	8/75
			0	--	---	---	8/75
			9.2	--	---	---	2/82
			2.2	103	---	---	9/82

Table C. Water Quality Analyses--Des Moines River

(Source: WATSTORE, DWAWM)

IOWA GEOLOGICAL SURVEY
TABULATION OF WATER ANALYSIS
(Dissolved constituents in parts per million)

Town-Well No. Owner	Date of coll.	°C	Diss. solids	Fe	Mn	Ca	Mg	K	Na	HCO_3	SO_4	Cl	F	NO_3	Hard-ness	pH	Cond.
Madrid	11/7/61	12°		.02	.55	109	28	6.3	22	339	78	12	1.1	11.1	340	7.4	
Madrid	11/7/61	12°		.02	.75	90	25	5.1	23	351	81	12	.9	7.1	342	7.3	
Dakota City	5/12/69	13°	406	.06	.05	78	25	3.7	7.6	251	68	18	.4	22	300	7.9	500
Humboldt	5/12/69	13°	482	.09	.05	86.4	32.1	4.9	12	227	160	16	.4	11	348	7.7	570
Humboldt Fish Hatchery	7/19/66	---	410	.09	.06	57.6	33	3.6	18	198	131	23.5	.3	.1	280	8.3	625
	7/19/66	---	452	.19	<.05	65.6	34	3.6	20.4	214	134	28	2.1	.1	304	8.4	673
	7/19/66	---	460	.56	<.05	60	34.5	3.4	23.2	190	145	32	.25	.1	292	8.4	673
Ft. Dodge #1	12/14/55	36°	600	.1	.09	99	44	4.5	42	376	132	40	.4	.3	428	8.2	914
Ft. Dodge #2	6/19/56	29°	379	.07	.13	53.6	28.7	4.7	21.6	210	113	20	.3	.3	252	7.9	568
Ft. Dodge #3	11/14/56	8°	425	.04	<.05	73.9	31.4	4.3	23.7	274	93	22	.2	.4	314	8.4	674
Ft. Dodge #4	4/30/57	18°	456	.10	<.05	73.9	30.4	5.3	24.8	229	128	23.5	.3	.2	310	8.6	676
Ft. Dodge #5	9/10/57	22°	487	.04	<.05	65.5	38.9	5.5	20.4	237	146	16	.3	.2	324	8.1	686
Ft. Dodge #6	1/7/58	2°	780	.12	<.05	133	52.5	5.4	33.2	393	244	31	.5	1.5	548	8.1	1070
Ft. Dodge #7	4/23/58	17°	485	.2	<.05	66.6	35.4	4.1	16.2	188	161	14	.35	.6	312	8.2	630
Ft. Dodge #8	6/30/58	26°	388	.16	<.05	49.9	32.9	2.9	21.2	167	133	18	.5	.3	260	8.1	587

Town-Well No. Owner	Date of coll.	°C	Diss. solids	Fe	Mn	Ca	Mg	K	Na	HCO_3	SO_4	Cl	F	NO_3	Hard-ness	pH	Cond.
Ft. Dodge #9	3/3/59	??°	1433	.08	<.05	82.3	33.6	3.7	20.8	364	76.7	13	.25	1	344	8.1	687
Ft. Dodge #10	6/2/59	17°	308	.48	<.05	52.9	17.4	2.8	5.7	164	52.3	6	.3	4.6	204	7.8	405
Ft. Dodge #11	8/25/59	28°	397	.06	<.05	72.4	20.2	5.0	21.5	237	83.7	21	.4	.6	264	8.1	535
Ft. Dodge #12	11/24/59	??°	576	.12	<.05	116	33.5	3.2	19.5	373	110	21	.45	5.4	428	8.35	835
Ft. Dodge #13	2/16/60	??°	630	.08	<.05	119	41.3	4.2	24.2	371	156	23.5	.4	2.6	468	8.05	873
Ft. Dodge #14	4/12/60	??°	290	.18	<.05	50.4	17.0	5.3	4.5	159	61.3	5	.25	2.5	196	8.1	488
Ft. Dodge #15	6/28/60	??°	523	.04	<.05	102	33.0	4.2	12.1	288	117	13	.55	5.2	392	8.3	732
Ft. Dodge #16	9/26/60	18°	496	.16	.05	87.2	31.6	4.6	15.4	222	140	17	.3		350	8.4	681
Ft. Dodge #17	1/4/61	1°	723	.16	<.05	136	45.7	5.0	32.0	393	215	31.5	.5	1.2	528	8.0	1020
Ft. Dodge #18	6/1/61	19°	518	.08	<.05	101	36.9	4.0	11.9	273	182	4	.5	2.0	404	8.3	780
Ft. Dodge #19	11/29/61	3°	551	.10	<.05	112	36.0	2.3	15.2	349	110	14	.5	3.5	428	8.3	789
Ft. Dodge #20	1/30/62	3°	660	.08	.05	123	43.7	3.9	26.0	437	146	26	.5	2.5	488	7.85	972
Ft. Dodge #21	6/4/63	22°	314	.12	<.05	54.4	17.5	2.1	6.8	171	54.9	5	.3	17	208	7.6	414
Ft. Dodge #22	2/4/64	1°	602	.08	.05	109	39.9	4.3	34.8	361	146	35	.35	5.3	436	7.9	920
Ft. Dodge #23	10/1/64	22°	428	.06	<.05	81.6	26.2	5.5	12.8	273	91.4	14	.35	8.0	312	8.05	638
Ft. Dodge #24	6/7/65	16°	302	.14	.05	88	28.7	4.7	21.6	210	106	8	.4	18	340	8.1	654
Ft. Dodge #25	3/28/66	6°	415	.10	.06	84.8	26.2	3.2	11.6	271	95.1	11.5	.4	16	320	8.1	637
Ft. Dodge #26	4/19/66	14°	675	.06	<.05	118	46.2	6.8	44.0	461	168	17	.75	3.5	485	7.35	1040

Town-Well No. Owner	Date of coll.	°C	Diss. solids	Fe	Mn	Ca	Mg	K	Na	HCO_3	SO_4	Cl	F	NO_3	Hard-ness	pH	Cond.
Ft. Dodge #27	4/3/67	10°	379	.08	.12	71.2	21.9	5.2	14	228	88	17	.3	3.5	270	8.0	590
Ft. Dodge #28	7/17/67	22°	600	.08	.05	101	37.9	3.5	18	271	180	18	.5	4	410	8.4	790
Ft. Dodge #29	1/15/68	2°	727	.29	.09	134	48.6	5.6	45	509	160	44	.4	1.2	540	7.9	1100
Ft. Dodge #30	6/16/68	2°	536	.29	.09	48.6	48.6	5.6	45	509	160	44	.4	1.2	727	7.9	110
Ft. Dodge #31	8/31/69	20°	428	.06	.05	86.6	26.2	5.5	12.8	273	91.4	14	.4	8	310	8.0	638

Table D. Water Quality Analyses--Des Moines River (Source: UHL)

(All values in mg/l unless otherwise specified)

County	No.	Location	Date	Temp (C°)	pH	Nitrate N	Nitrite N	Org. N	Amm. N	Tot. Alk.	Tot. P	Cl	Turb.	Diss. Oxygen	Fecal/100 ml Coliforms
Emmet	1	T100 R34 S34	8-24-71	25	8.0	<.1	.003	1.9	.01	201	.14	---	88	10.5	5,100
			1-11-72	0	7.6	.9	.031	.79	.63	318	.22	43	2	6.9	20
			6-5-73	17	8.2	4.8	.051	2.1	<.01	230	.13	---	70	8.2	150
			7-11-73	23.5	8.1	1.4	.036	1.9	.07	186	.1	31	47	6.5	500
			8-14-73	20	7.3	.2	.006	2.0	.06	179	.11	114	19	5.9	230
			1-8-74	0	7.75	4.6	.086	.93	.57	335	.19	57	3	7.5	40
Emmet	2	T99 R34 S10	8-24-71	25	7.9	<.1	.004	2.0	<.01	---	.16	---	172	7.4	1,300
			1-11-72	0	---	.9	.036	.83	.59	---	.2	---	2	7.6	10
			2-13-79	0	7.4	1.4	----	.62	3.2	416	.39	100	5.1	3.8	100
Emmet	3	T99 R34 S14	8-24-71	26	7.7	.1	.067	2.4	2.2	---	.74	---	56	3.7	810,000
			1-11-72	0	7.5	.7	.043	1.6	2.1	348	.76	160	8	6.9	98,000
			2-13-79	0	7.6	1.4	----	.44	3.6	430	.36	110	4.8	4.5	70
Emmet	4	T99 R33 S30/31	6-5-73	17	8.2	5.0	.053	2.3	.12	230	.18	---	88	8.1	2,300
			7-11-73	25	8.0	1.7	.1	1.8	.25	196	.25	56	47	5.7	8,400
			8-14-73	21	7.8	.4	.2	2.2	1.8	213	.78	76	26	4.5	18,000
			1-8-74	0	7.7	3.2	.13	1.1	1.3	347	.42	90	4	7.5	26,000
			2-13-79	0	7.5	8.6	----	1.1	2.8	403	1.6	350	6.2	6.6	13,300
Emmet	5	T99 R33 S6	8-24-71	26	7.6	.2	.098	2.1	.92	---	.46	---	88	7.2	33,000
			1-11-72	0	7.6	.7	.070	2.9	3.6	352	1.3	---	10	3.7	40,000
Emmet	6	T98 R33 S7	1-11-72	0	7.5	8.2	----	1.9	2.6	392	1.6	280	5.8	5.5	30,000
			2-14-79	0	7.6	.9	.074	1.3	2.4	340	.78	---	3	3.1	7,100

County	No.	Location	Date	Temp (C°)	pH	Nitrate N	Nitrite N	Org. N	Amm. N	Tot. Alk.	Tot. P	Cl	Turb.	Diss. Oxygen	Fecal/100 ml Coliforms
Emmet	7	T98 R33 S29	6-5-73	17	---	---	----	---	---	---	----	---	----	8.1	2,300
			7-11-73	24	7.8	2.3	.12	2.0	.23	212	.25	50	53	7.6	1,200
			8-14-73	21	8.1	.4	.056	2.5	.14	209	.33	1	20	9.7	390
			1-8-74	0	7.65	5.2	.12	.83	1.0	342	.41	61	3	7.6	3,900
Palo Alto	8	T97 R33 S9	8-24-71	26	8.0	.5	.096	2.1	.01	---	.3	---	88	12.2	800
			1-11-72	0	---	.8	.053	.97	1.8	---	.47	---	2	2.0	540
Palo Alto	9	T97 R33 S27	6-5-73	17	---	---	----	---	---	---	----	---	----	8.0	2,800
			7-11-73	24.5	8.0	2.7	.051	2.2	.03	216	.19	40	45	9.8	700
			8-14-75	22	8.3	<.1	.01	2.9	.04	185	.29	70	27	13.1	700
			1-8-74	0	7.65	4.8	.08	.88	.59	333	.28	52	3	7.0	270
			2-14-79	0	7.5	4.6	----	.86	2.4	385	.85	170	6.2	3.7	2,200
Palo Alto	10	T96 R33 S14/23	1-11-72	0	7.7	.9	.061	1.0	1.7	324	.38	---	2	5.8	30
			2-14-79	0	7.7	5.3	----	1.2	2.4	356	.87	190	4.9	5.9	1,600
Palo Alto	11	T96 R33 S35	6-5-73	16	8.1	6.2	.005	2.0	.01	234	.18	---	68	8.5	1,900
			7-11-73	24	8.0	4.2	.052	.21	.01	232	.18	35	100	9.2	700
			8-14-73	21	8.1	.1	.006	2.1	.02	161	.19	54	23	11.6	230
			1-8-74	0	7.7	5.2	.09	1.1	.39	125	.21	49	3	7.4	340
			2-14-79	0	7.7	4.1	----	.74	2.0	358	.69	160	3.5	5.7	910
Palo Alto	12	T95 R33/32 S12/7	1-11-72	0	7.7	1.1	.065	.88	1.6	316	.37	---	4	9.1	1,610
			2-14-79	0	7.7	4.3	----	.37	1.8	342	.57	160	4	6.5	750
Palo Alto	13	T95 R32 S21	6-5-73	17	8.2	6.2	.048	2.1	.04	230	.2	---	88	8.4	1,500
			7-11-73	24	8.1	3.8	.046	2.0	<.01	238	.2	37	58	10.0	500
			8-14-73	21	8.15	.1	.006	2.2	.02	166	.22	50	22	12.4	400
			1-8-74	0	7.65	5.0	.099	.82	.44	324	.22	42	3	6.8	420

County	No.	Location	Date	Temp (C°)	pH	Nitrate N	Nitrite N	Org. N	Amm. N	Tot. Alk.	Tot. P	Cl	Turb.	Diss. Oxygen	Fecal/100 ml Coliforms
Palo Alto	14	T95 R31 S29	1-11-72	0	---	1.1	.055	.88	1.2	---	.27	---	3	9.9	60
Palo Alto	15		6-5-73	17	---	---	----	----	---	---	----	---	----	8.9	650
			7-11-73	25	8.2	3.1	.038	2.1	<.01	242	.16	31	60	10.7	300
			8-14-73	22	8.2	<.1	.005	1.8	.02	164	.18	43	22	12.9	270
			1-8-74	0	7.65	4.8	.085	.69	.39	316	.22	15	4	6.5	340
			2-14-79	0	7.7	3.1	----	.63	1.3	313	.28	100	3.8	7.3	250
Pocahontas	16	T93 R31 S1	1-11-72	0	---	1.3	.061	.81	1.0	---	.22	---	2	8.4	300
			6-5-73	16.5										8.7	600
Pocahontas	17	T93 R31 S24/25	2-14-79	0	7.6	2.6	----	.33	1.1	313	.35	100	2.6	4.7	160
Humboldt	18	T92 R30 S23	1-11-72	0	---	1.9	.051	.57	.59	---	.22	---	1	10.2	90
			6-5-73	17	---	---	----	----	----	---	----	---	----	8.7	700
			7-11-73	25	8.2	5.1	.03	1.7	.01	258	.27	25	60	9.5	760
			8-14-73	23	8.2	<.1	.006	1.7	<.01	187	.10	62	18	13.6	100
			1-8-74	0	7.7	5.6	.079	1.3	.39	320	.21	66	5	7.8	600
			2-14-79	0	7.7	3.0	----	.86	2.7	318	.26	62	3.1	5.7	310
Humboldt	19	T92 R29 S34	6-5-73	17										9.1	580
			7-11-73	25	8.1	5.2	.032	18	<.01	248	.13	24	53	11.0	200
			8-14-73	22.5	8.0	<.1	.007	2.3	.04	174	.14	29	27	8.7	100
			1-8-74	0	7.75	5.6	.072	.96	.24	318	.17	34	3	10.1	620
Humboldt	20	T91 R29 S1	1-11-72	0	7.8	2.8	.045	.49	.48	296	.22	---	1	13.2	2,530
			2-14-79	0	7.6	3.4	----	.76	1.5	304	.16	57	2	11.1	50
Humboldt	21	T91 R29 S24/19	6-5-73	18	8.2	5.4	.032	1.5	.01	248	.18	---	84	9.5	700
			7-11-73	26.5	8.1	5.2	.027	1.9	<.01	230	.17	24	60	10.7	1,100
			8-14-73	25.5	8.3	<.1	.006	2.0	<.01	159	.15	28	22	16.0	3,800

County	No.	Location	Date	Temp (C°)	pH	Nitrate N	Nitrite N	Org. N	Amm. N	Tot. Alk.	Tot. P	Cl	Turb.	Diss. Oxygen	Fecal/100 ml Coliforms
			1-8-74	0	7.85	6.4	.068	.73	.29	315	.22	34	4	13.3	1,400
			2-14-79	0	7.8	3.5	----	.18	.67	304	.19	54	1.8	10.2	2,600
Emmet	22	T99 R31 S9/16	6-4-73	18	8.1	4.4	.077	2.2	<.01	160	.06	----	65	10	160
			7-10-73	29	7.8	3.4	.046	3.1	.01	154	.1	29	85	11.4	240
			8-13-73	28.5	8.3	.1	.01	2.3	<.01	164	.08	32	28	14.1	500
			1-7-74	0	7.8	4.8	.086	1.3	.52	275	.1	42	4	11.9	220
Kossuth	23	T98 R30 S6	6-4-73	18	---	---	----	----	----	---	----	----	---	8.4	550
			7-10-73	28	8.0	4.4	.047	3.0	.01	190	.14	28	120	9.8	250
			8-13-73	25.5	8.1	<.1	.01	3.4	<.01	180	.18	42	42	11.0	540
			1-7-74	0	7.8	5.6	.077	1.2	.41	289	.11	42	4	10.7	100
Kossuth	24	T98 R29 S22	6-4-73	----	---	---	----	----	----	---	----	----	---	9.0	310
			7-10-73	28.5	8.1	4.7	.041	2.9	<.01	186	.14	28	120	11.5	530
			8-13-73	25	8.0	<.1	.01	3.2	<.01	218	.15	26	39	8.7	1,000
			1-7-74	0	7.75	6.4	.069	1.1	.35	296	.12	38	5	10.2	120
Kossuth	25	T97 R28 S17/20	6-4-73	18	---	---	----	----	----	---	----	----	---	9.3	280
			7-10-73	27	8.1	5.8	.06	2.4	<.01	238	.2	28	110	10.4	900
			8-13-73	24.5	8.0	.1	.01	3.3	<.01	255	.18	27	34	11.7	1,700
			1-7-74	0	7.75	5.9	.068	.88	.34	311	.14	38	4	9.9	2,700
Kossuth	26	T96 R29 S25	6-4-73	18	---	---	----	----	----	---	----	----	---	9.0	240
			7-10-73	26	8.1	7.7	.065	2.1	<.01	258	.14	26	65	9.7	100
			8-13-73	25	7.8	.2	.027	2.3	.12	257	.18	26	28	8.8	250
			1-7-74	0	7.7	6.4	.058	.62	.19	329	.15	32	4	10.6	530
Kossuth	27	T95 R28 S30	6-4-73	18	---	---	----	----	----	---	----	----	---	9.3	140
			7-10-73	26	8.1	8.3	.062	1.5	.01	272	.22	26	70	8.6	300
			8-13-73	22.5	8.0	.5	.059	1.8	.18	285	.33	28	25	8.3	1,200
			1-7-74	0	7.7	6.5	.06	.57	.28	335	.18	32	3	9.9	4,900

County	No.	Location	Date	Temp (C°)	pH	Nitrate N	Nitrite N	Org. N	Amm. N	Tot. Alk.	Tot. P	Cl	Turb.	Diss. Oxygen	Fecal/100 ml Coliforms
Kossuth	28	T94 R29 S25	6-4-73	19	---	---	----	----	----	---	----	----	----	9.1	280
			7-10-73	26.5	8.1	8.4	.053	1.5	<.01	270	.22	29	70	8.9	300
			8-13-73	23	7.9	.7	.019	1.8	.02	283	.25	27	27	9.5	310
			1-7-74	0	7.7	6.6	.056	.6	.27	331	.17	32	2	9.7	1,400
Humboldt	29	T93 R28 S17	6-4-73	19	---	---	----	---	----	---	----	----	----	9.1	2,400
			7-10-73	25	8.0	8.4	.043	1.6	<.01	282	.25	26	70	8.0	300
			8-13-73	22.5	8.0	.3	.014	1.7	.02	287	.18	33	22	9.9	260
			1-7-74	0	7.7	6.4	.052	.41	.21	332	.20	32	2	10.0	1,800
Humboldt	30	T92 R28 S10	6-4-73	18	8.1	10	.076	1.2	.01	248	.22	----	40	8.4	60
			7-10-73	24	8.0	8.9	.044	1.7	<.01	278	.22	25	80	8.1	800
			8-13-73	22	7.9	.2	.011	2.0	.02	262	.14	40	21	8.6	120
			1-7-74	0	7.7	6.6	.045	.37	.19	336	.19	29	3	9.8	1,500
Humboldt	31	T91 R28 S6	6-11-73	24	7.85	9.6	.052	1.4	.04	248	.16	28	76	9.7	<100
			7-10-73	24	7.9	8.2	.035	1.9	.03	272	.22	23	75	7.9	1,300
			8-6-73	22.5	7.7	1.6	.029	2.3	.12	194	.1	25	12	12.7	70
			1-7-74	0	7.75	6.7	.048	.55	.15	351	.26	31	9	9.9	390
Webster	32	T90 R29 S12	1-15-74	0	7.7	6.0	.065	.52	.28	314	.18	28	10	11.2	430
Webster	33	T88 R28 S17	1-15-74	0	7.7	6.5	.075	.56	.71	326	.25	35	3	12.0	940
Webster	34	T88 R28 S35	1-15-74	0	7.75	7.0	.07	.51	.68	328	.27	34	3	11.4	960
Webster	35	T87 R27 S25	1-15-74	0	7.7	7.2	.08	.48	.39	350	.17	21	3	11.2	840
			1-15-74	0	7.7	8.5	.065	.33	.23	332	.16	33	2	10.3	950
Webster	36	T86 R27 S21	1-15-74	0	7.75	7.8	.07	.45	.35	337	.16	18	3	11.0	820

County	No.	Location	Date	Temp (C°)	pH	Nitrate N	Nitrite N	Org. N	Amm. N	Tot. Alk.	Tot. P	Cl	Turb.	Diss. Oxygen	Fecal/100 ml Coliforms
Boone	37	T84 R27 S13	1-15-74	0	7.75	7.5	.075	.41	.35	336	.18	28	3	10.9	800
Boone	38	T84 R26 S31	1-15-74	0	7.75	7.2	.7	.33	.33	338	.18	27	5	11.1	1,300
Boone	39	T82 R26 S9	1-15-74	0	7.75	7.2	.075	.41	.33	338	.19	30	5	10.6	1,600

PLATE I

Bedrock Topography

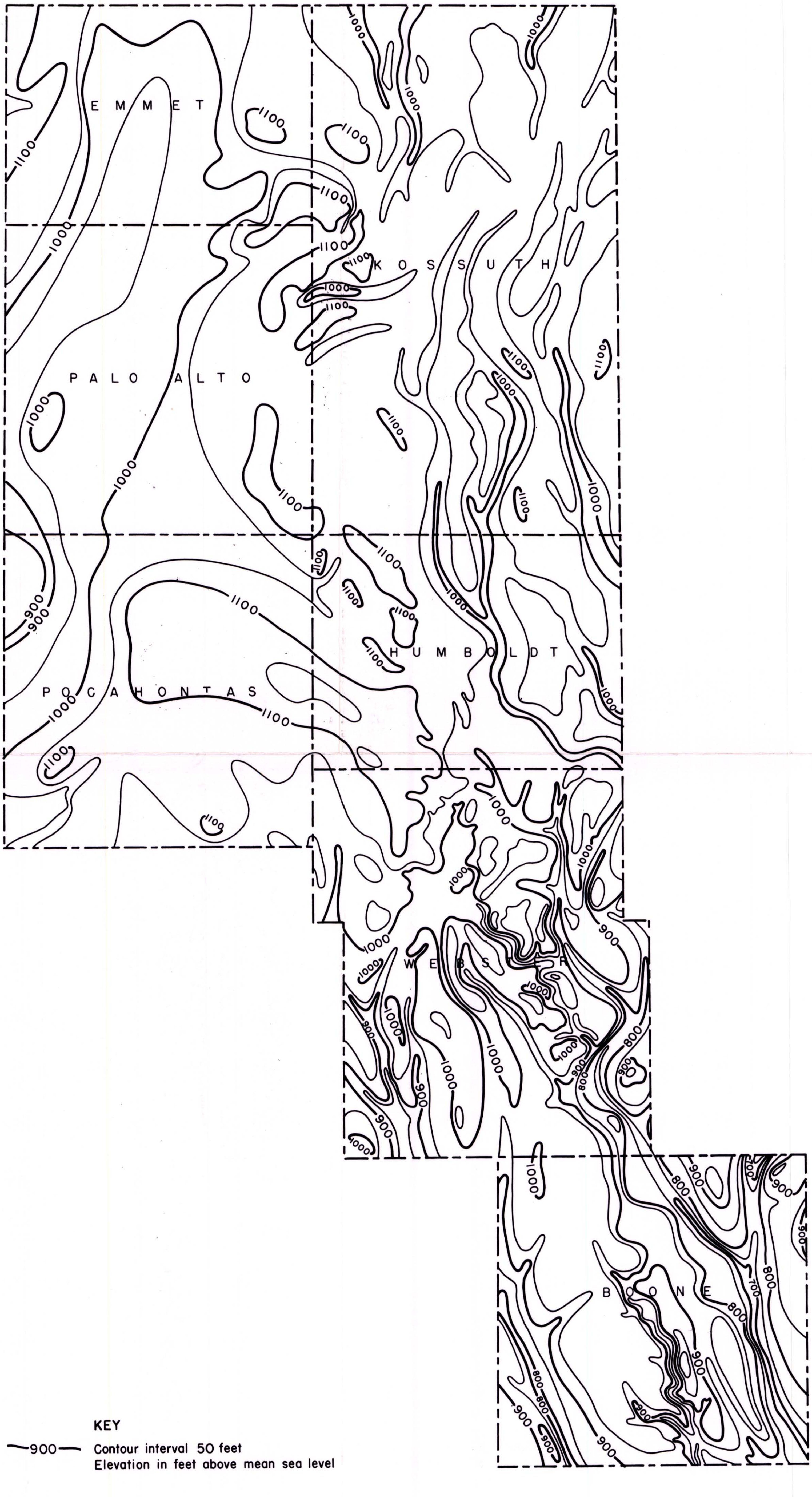


PLATE 2

Bedrock Geology