Iowa Geological Survey
Contract Report; July 30, 1980

EVALUATION OF THE EXTENT OF HAZARDOUS WASTE CONTAMINATION IN THE CHARLES CITY AREA

JAMES A. MUNTER

HYDROGEOLOGIST
GEOLOGICAL STUDIES DIVISION
IOWA GEOLOGICAL SURVEY

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Iowa Geological Survey
Donald L. Koch, Acting Director
123 N. Capitol Street
Iowa City, Iowa 52242

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INTRODUCTION

The LaBounty chemical dump site is located in the floodplain of the Cedar River in Charles City, Iowa (figure 1). From August, 1953, to December, 1977, the site was an active repository for waste material from Salsbury Laboratories, a major agricultural pharmaceutical company located in Charles City. The site contains over three million cubic feet of waste material with at least 12 toxic or hazardous wastes including an estimated six million pounds of arsenic. The site has been the subject of intensive investigation in recent years because of movement of leachate into the Cedar River and into portions of the Cedar Valley aquifer, which is a major source of well water in much of Eastern Iowa. The mechanisms, rates, and eventual impacts of such migrations have never been analyzed in detail. The purpose of this report is to provide an analysis of the available technical information and to identify the extent or likelihood of hazardous waste contamination of natural water systems in the Charles City area.

PREVIOUS WORK

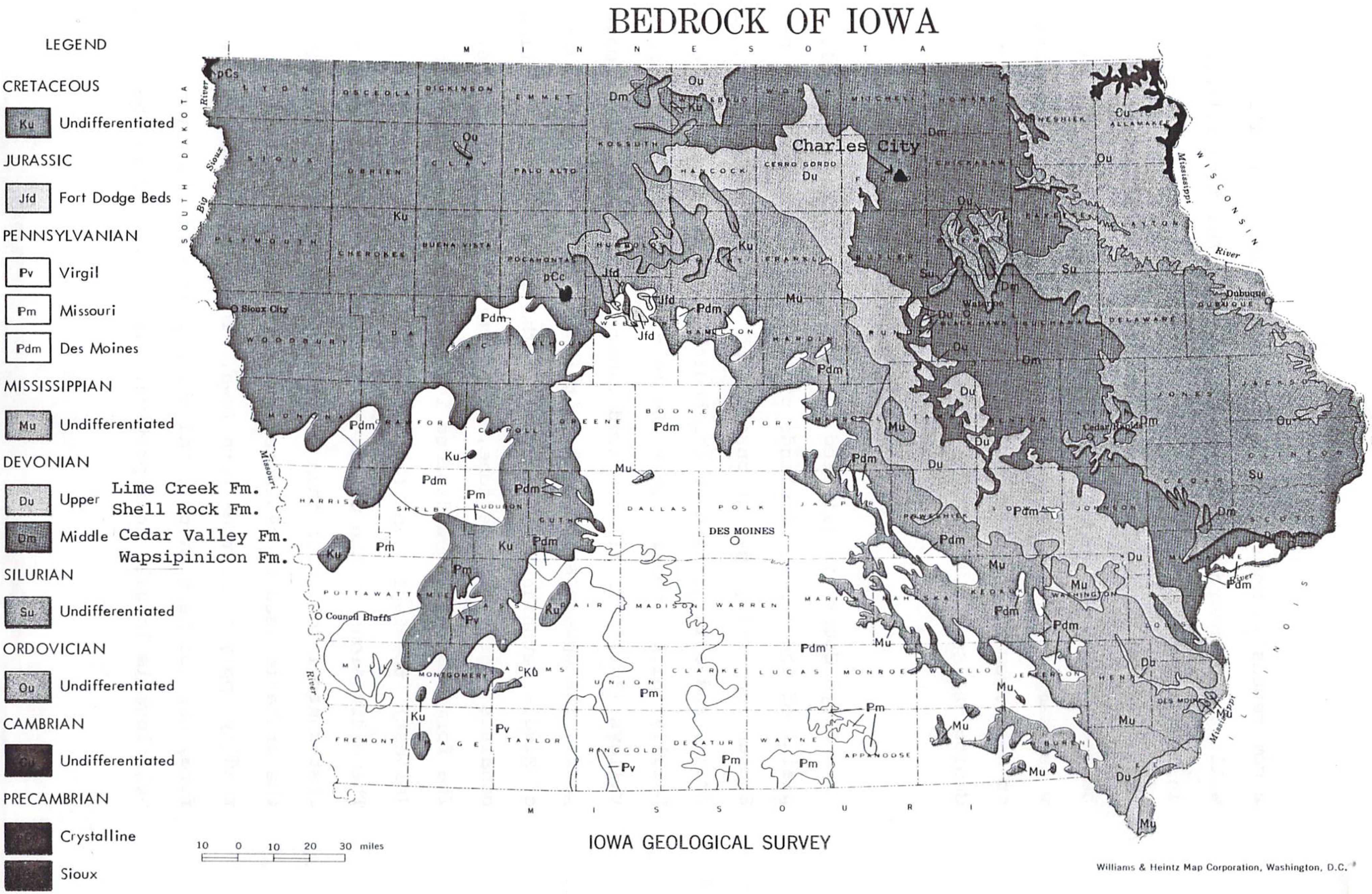
Data for this report have been derived from unpublished Iowa Geological Survey (IGS) sources and from previous field investigations of the LaBounty site. The IGS data is most useful on a regional scale. Stainbrook (1) provides the most recent synthesis of the geology of the Charles City area. His work was based mainly on outcrops and quarry exposures and is descriptive in nature. Unfortunately, many details of Middle Devonian stratigraphy in northeastern Iowa were not defined by Stainbrook, and have yet to be worked out. The IGS strip log file also contains data useful on a regional scale. This file was created by analyzing drill cuttings and logs that were supplied, for the most part, by private well drillers. The drillers logs commonly contain water level data that can be used for constructing head maps. Well locations and elevations have been field checked for accuracy. Bedrock fracture data in the vicinity of Floyd County have also been collected, but have not been previously published (2). Published maps by Hansen (3,4) present regional bedrock topography at a scale of 1:125,000.

One of the first studies at the LaBounty site included the drilling of three bedrock wells under the supervision of the IGS staff in 1975 (5). The first well has been cemented shut, the second well remains as it was originally constructed, and the third well has been rebuilt to serve as a dual piezometer for two different parts of the Cedar Valley aquifer. This well will be referred to as Rock Well #3. A series of shallow borings by Eugene A. Hickok and Associates in 1977 (6,7) provided data on the lateral and vertical extent and composition of the fill material. Arsenic was identified as a key contaminant in the fill and surrounding soils (8). Shallow borings were also drilled as part of a geophysical and thermonics study by Layne-Western Co. in 1978 (9). Seventeen piezometers were installed by the U.S. Environmental Protection Agency in 1978 (10) which provided bedrock surface and water-table elevations. Finally, in 1979, a comprehensive monitoring network consisting of 10 alluvial wells and 11 bedrock wells was installed. The data collected in 1979 and 1980 include bedrock elevations, detailed geologic logs based on cores, head measurements in both alluvial and bedrock wells, and chemical analyses of ground-water and river-water samples. Much of the latter part of this report is based on data from these wells that have been submitted to the Iowa Geological Survey.

REGIONAL SETTING

Floyd County is situated in the gently to steeply rolling plains of the central lowlands province of the continental United States. Generally thin unconsolidated deposits of loess, glacial drift, and alluvium mantle the bedrock over most of the county. Locally thick deposits (over 200 feet) occur in buried bedrock valleys (3,4). In all of Floyd County, except the westernmost parts, the uppermost bedrock unit is the Cedar Valley Formation of Middle Devonian age (figure 1). The Cedar Valley Formation consists mostly of limestone, with some shale and dolostone. The formation has been divided into three members, the Solon (oldest), the Rapid, and the Coralville (youngest) Members. These divisions of the Cedar Valley Formation were defined in east-central Iowa more than 100 miles from Charles City, and the criteria used to separate them at the type areas do not readily apply to northeastern Iowa. Their occurrence, therefore, has not been mapped, and their precise delineation in well logs is largely interpretive. Wells drilled in the Charles

Figure 1


BEDROCK OF IOWA
LEGEND
CRETACEOUS
Ku Undifferentiated
JURASSIC
Jfd Fort Dodge Beds
PENNSYLVANIAN
Pv Virgil
Pm Missouri
Pdm Des Moines
MISSISSIPPIAN
Mu Undifferentiated
DEVONIAN
Du Upper
Lime Creek Fm.
Shell Rock Fm.
Dm Middle
Cedar Valley Fm.
Wapsipinicon Fm.
SILURIAN
Su Undifferentiated
ORDOVICIAN
Ou Undifferentiated
CAMBRIAN
Cu Undifferentiated
PRECAMBRIAN
pCc Crystalline
pCs Sioux
M I N N E S O T A
M I S S O U R I
SOUTH DAKOTA
WISCONSIN
ILLINOIS
Charles City
DES MOINES
Sioux City
Council Bluffs
Dubuque
Waterloo
Cedar Rapids
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IOWA GEOLOGICAL SURVEY
Williams & Heintz Map Corporation, Washington, D.C.

City area, however, indicate that the Rapid Member is somewhat more shaley and dolomitic than the other two members. Rock Well #3 at the LaBounty site penetrated about 193 feet of Cedar Valley Formation, which is nearly the full Cedar Valley thickness in the Charles City area.

Underlying the Cedar Valley is the Wapsipinicon Formation, dominantly a carbonate unit approximately 120 feet thick, of Middle Devonian age. This rock unit is commonly considered to be part of the Cedar Valley aquifer. Underlying the Wapsipinicon Formation in Floyd County is the Maquoketa Formation, a thick unit of shale and dolostone of Ordovician age that forms the lower confining bed of the Cedar Valley aquifer. Silurian rocks are absent at Charles City.

South and west of Charles City, the Upper Devonian Shell Rock Formation and Lime Creek Formation are the uppermost bedrock units. The Lime Creek is mostly shale, and regionally forms the upper confining bed of the Cedar Valley aquifer south and west of Floyd County.

The Devonian strata in northeastern Iowa have been slightly deformed and show subtle structural features. The regional strike of the Devonian rocks is approximately S30°E and the dip is ten to twelve feet per mile to the southwest. Low amplitude folding has also been documented near Charles City (1), and the Fayette structural zone has been observed in southern Bremer County, south of Waverly. The Fayette structural zone is an area of brecciated rock that is likely to have been faulted, but has never been studied in detail.

The Cedar Valley Formation has also been modified by solution or karst processes. The formation is highly fractured in outcrop, and parts of it are nearly pure calcium carbonate. These two factors make it susceptible to dissolution by ground water. Karst processes and landforms are expressed on the surface in Floyd County by disappearing streams and sinkhole development. One example of the latter can be observed about 4 miles south of Charles City in sections 35 and 36 of T 95N, R 16W. Other sinkhole locations are listed by Stainbrook (1).

Dissolution of the Cedar Valley Formation in the subsurface also occurs. Evidence of this is the number of caves that have been discovered in Floyd County, the numerous springs which discharge to the Cedar River, and the Cedar Valley wells which sometimes yield very large volumes of water. Two wells for the city of Charles City, for example, each yield about 2,800 gallons per minute.

The Relationships of Joints to Modern and Ancient Drainage Patterns

Several well-developed and parallel stream valleys, including the Cedar River valley, crosscut Floyd County from the northwest to the southeast. This drainage pattern is prominent in much of northeast Iowa. The azimuth of the Cedar River between St. Ansgar and Nashua is typical of many area rivers, and is about S35°E. At Nashua, the river begins to flow in a more southerly direction, approximately S8°E.

A major bedrock channel, the Bremer Channel, has been mapped to the east of the Cedar River in Mitchell, Floyd, Chickasaw, Bremer and Blackhawk Counties (3,4). This buried channel intercepts the modern course of the Cedar River immediately south of Waterloo. The dominant trend of the channel between central Mitchell County and central Bremer County is north-south, with several east-west segments and branches. One notable east-west branch of the valley passes through the Charles City well field on the north side of the city.

Joint trends were measured at 17 quarries and outcrops in Floyd and surrounding counties (figure 2). Joint trends are small scale features measured at specific localities, but may be related to past regional tectonic conditions. If the joints are regionally important, then some control on regional drainage patterns might be expected. Of the 17 measured locations, only 3 were found to have major trends approximately parallel to the modern regional drainage. These are all located in the northwestern part of the study area. Five locations were identified as having major north-south or east-west trends, which are consistent with the buried Bremer Channel. This is a fairly low correlation of joint trends with regional drainage trends, and indicates that some other factors may influence modern and ancient region drainage. This does not exclude the possibility that joints have an influence on local drainage patterns, however.

Strainbrook (1) made several observations concerning regional drainge trends. He noted that most northeast Iowa rivers have larger and more numerous tributaries entering from the northeast than from the southwest. Also, most river valley walls

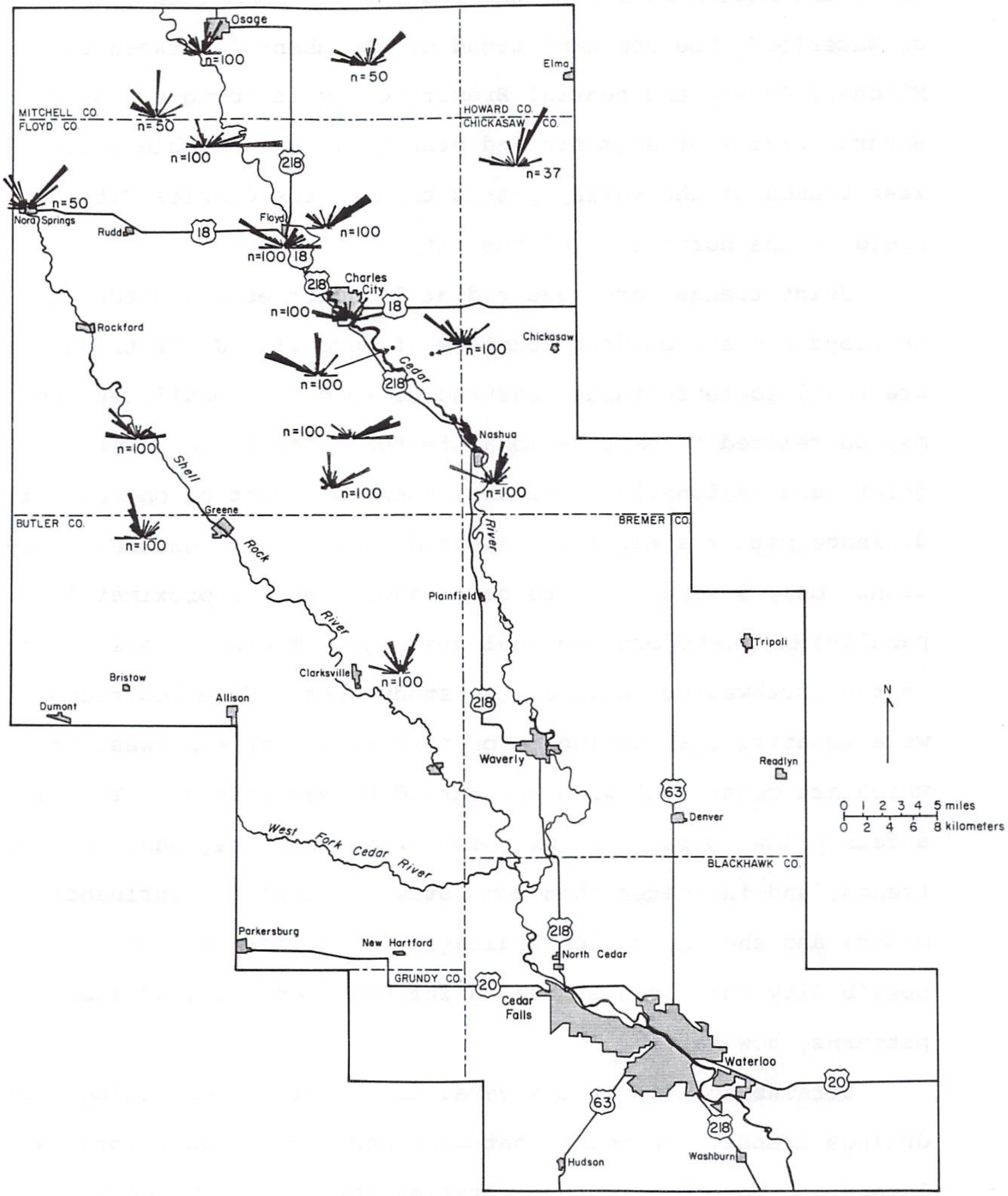

Figure 2. Joint trends in the Floyd County area.

are relatively steep on the southwestern side and gently sloping on the opposite, or northwestern side of the valley. These geomorphic features are common in terranes underlain by dipping sedimentary strata with strike controlled drainage. The features of northeast Iowa drainage noted by Stainbrook are consistent with the observation that the regional trend of the rivers (about S35°E) is nearly parallel with the regional bedrock strike (about S30°E). It is reasonable to conclude that modern regional drainage trends in the Floyd County area are strike-controlled. The reason for the orientation of the Bremer Channel is not known, however.

Extent of Confining Beds Within the Cedar Valley Aquifer

Rock Well #3 at the LaBounty site encountered shale from a depth of 104 to 121 feet. This shale is important because it is, at least at the LaBounty site, a confining bed between the upper and lower Cedar Valley aquifers. For the purposes of this report, the lower Cedar Valley aquifer will be defined as the Wapsipinicon Formation and those parts of the Cedar Valley Formation that are below the major shale in Rock Well #3. The upper Cedar Valley aquifer will be defined as the portion of the Cedar Valley Formation above the shale. Evidence that the shale is a confining bed at the LaBounty site is derived solely from Rock Well #3. Nested piezometers installed in April of 1977 have shown that a consistently upward gradient exists between the upper and lower Cedar Valley aquifers. The difference in head between the two has varied from approximately 5 feet in

1977 to approximately 15 feet in 1978 and 1979. The head difference was 12.9 feet on July 15, 1980. Because the areal extent of the shale is unknown, and its regional hydraulic effectiveness is unclear, the IGS strip log file was used to try to map the shale and evaluate it's regional significance as a confining unit.

Figure 3 is a map of bedrock topography of the Charles City area, based on strip logs. The map is at a larger scale than Hanson's maps (3,4) and incorporates more recent data. The elevation of the top of any shale unit greater than five feet thick encountered in the log is also plotted. Shale units generally ranged from 5 to 20 feet in thickness, although some logs did not describe any shale. The logs without shale may exist because the well wasn't deep enough to encounter shale or because shale cuttings were not collected, or because shale was not present at the site. The implications of these limitations of the data will be discussed in a subsequent portion of the report.

Examination of the data in figure 3 reveals that most of the wells in or near Charles City penetrated the top of a 10-20 foot thick shale bed at elevations ranging from 843 feet to 907 feet above sea level. The most reliable data point on the map is Rock Well #3, where geophysical logs have precisely located the top of the shale at an elevation of 887 feet. The data seem consistent enough to suggest that the shale encountered in Rock Well #3 is probably continuous at least in the immediate Charles City vicinity, and that deviations in elevations of the shale are related to strip log inaccuracies, local structure

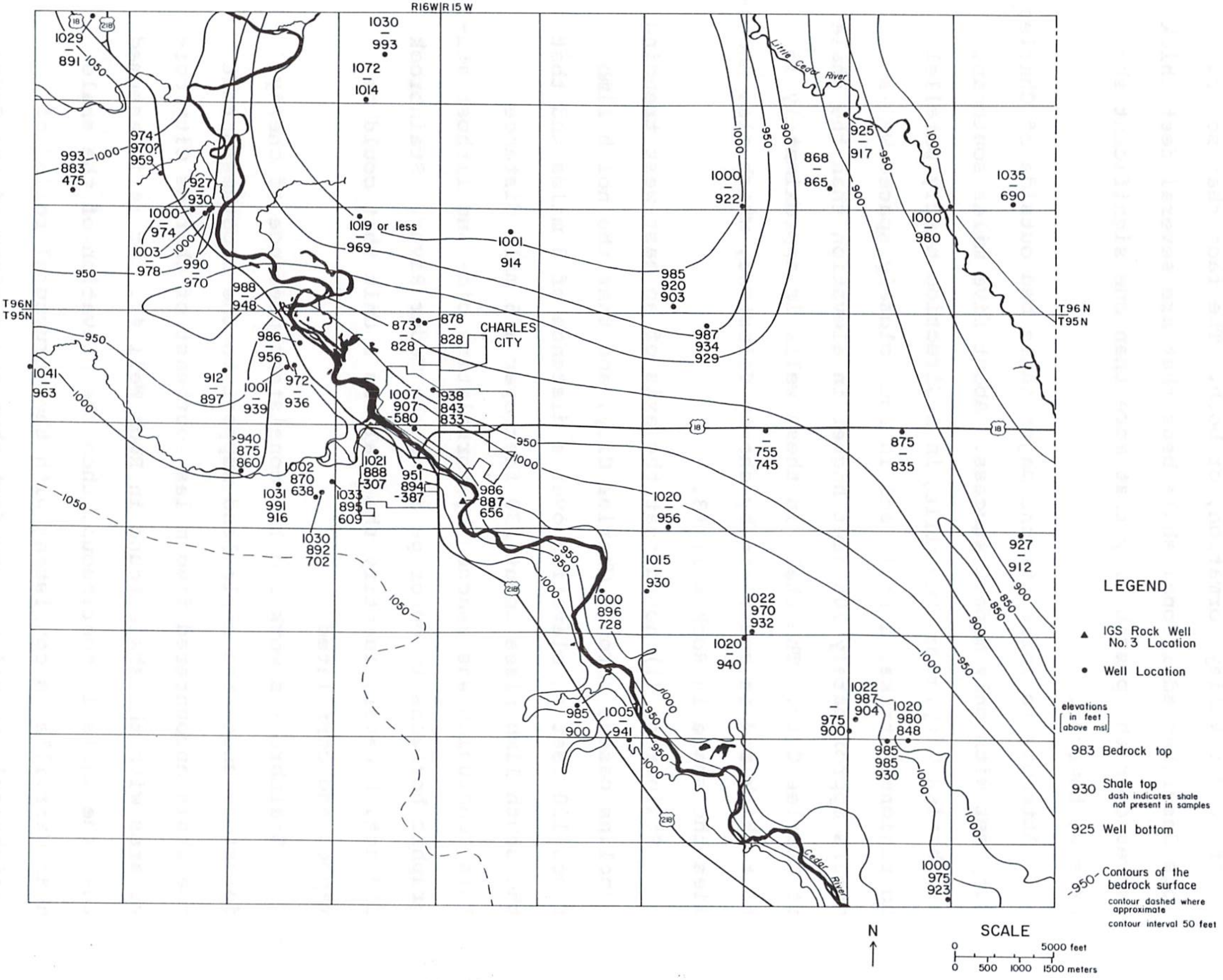

Figure 3. Bedrock topography and top of shale elevations in the Charles City area.

in the Cedar Valley Formation, or both. The fact that several logs described additional shale beds that are several feet thick leaves open the possibility that more than one significant shale exists, however.

Attempts to correlate the major shale bed outside of Charles City met with only modest success. About five miles southeast of Charles City, near Carrville, in a direction nearly parallel to regional strike, a shale bed in four closely spaced wells occurs approximately 100 feet higher in elevation than the shale at Charles City. The shale in these wells is approximately 15 feet thick and is underlain by cherty dolostone, which also underlies the shale in Rock Well #3.

Stainbrook (1) noted that the axis of an east-west trending syncline passes through Charles City, and that the north limb rises 120 feet in elevation over a distance of 8 miles and that the south limb rises about 130 feet over a 6 mile distance. This conclusion was reached by correlating bio- and lithostratigraphic horizons in outcrops along the Cedar River. Stainbrook did not, however, identify the shale as a unit that could be mapped and correlated.

Stainbrook's work and the consistent presence of cherty dolostone under the shale lend support to the hypothesis that the shale encountered five miles southeast of Charles City correlates with the shale found in Rock Well #3. If it is assumed that the shale is continuous, then the elevation of the shale near Carrville is consistent with the structural relief of Stainbrook's syncline. The fact that the surface of the Cedar

River near Carrville is about 30 feet lower (el. 965 feet) than the top of the shale only 1.5 miles to the east indicates that the shale may outcrop near the riverbank. It is almost certain that the bedrock channel of the Cedar River valley cuts through this shale.

It was not possible to correlate the shale in Rock Well #3 with any other data points in figure 3 with any degree of certainty. This is because the data are sometimes sparse or of limited value, as mentioned previously. Also, the structure of the rocks is poorly understood and correlations based solely on elevation are not valid on a regional scale. The stratigraphic position of shales noted in many logs are not accurately known. This is partly because of the fact that no deep cores exist which define the Devonian stratigraphy near Charles City. No attempt was made to map the shale beyond the boundaries of figure 3 because of these difficulties.

It is quite possible that the shale encountered in Rock Well #3 is a laterally persistent stratigraphic unit. Even if it does persist laterally, however, it is not likely to be physically continuous in the Cedar River valley. Using Stainbrook's conclusion that Charles City is in the axis of a syncline, then the shale will probably be eroded away at the base of the modern Cedar River bedrock channel approximately 3 miles downstream of the LaBounty site. The shale would then also be absent at points further downstream. If the syncline is not present, then the shale would be eroded away somewhere downstream of Charles City anyway because the Cedar River naturally incises its way into older strata southeast of Charles City (figure 1). The Geologic Map of Iowa (11), at a larger scale than figure 1, shows the bedrock surface to consist of Wapsipinicon Formation at Waverly, about 26 miles from Charles City. The shale and overlying rocks, therefore, are erosionally removed from the Cedar River valley at a minimum of 3 and at a maximum of 26 miles southeast of Charles City.

Regional Flow System of the Cedar Valley Aquifer

Figure 4 is a regional head map for the Cedar Valley aquifer from Charles City to Waterloo based on IGS strip log data. The map indicates on a regional scale that the aquifer discharges to the river along the entire mapped interval. The generalized nature of the data and of the contours precludes the delineation of local zones where the ground-water gradient could be reversed. Such reversals would be most likely to occur near pumping wells, dewatered quarries, or artificial reservoirs.

Figure 5 is a more detailed potentiometric surface of the Cedar Valley aquifer in the Charles City area. Notice that some of the static water levels on the map are inconsistent with the water-level contours. The contours were slightly generalized to allow for irregularities in the data collection process, local heterogeneity in the aquifer, and the fact that the data were collected over many years. It is apparent that the trends of the data are consistent, and that the data are useful for describing the flow system.

Similar to the flow system depicted in figure 4, the Cedar River is a discharge point of the flow system, and recharge is

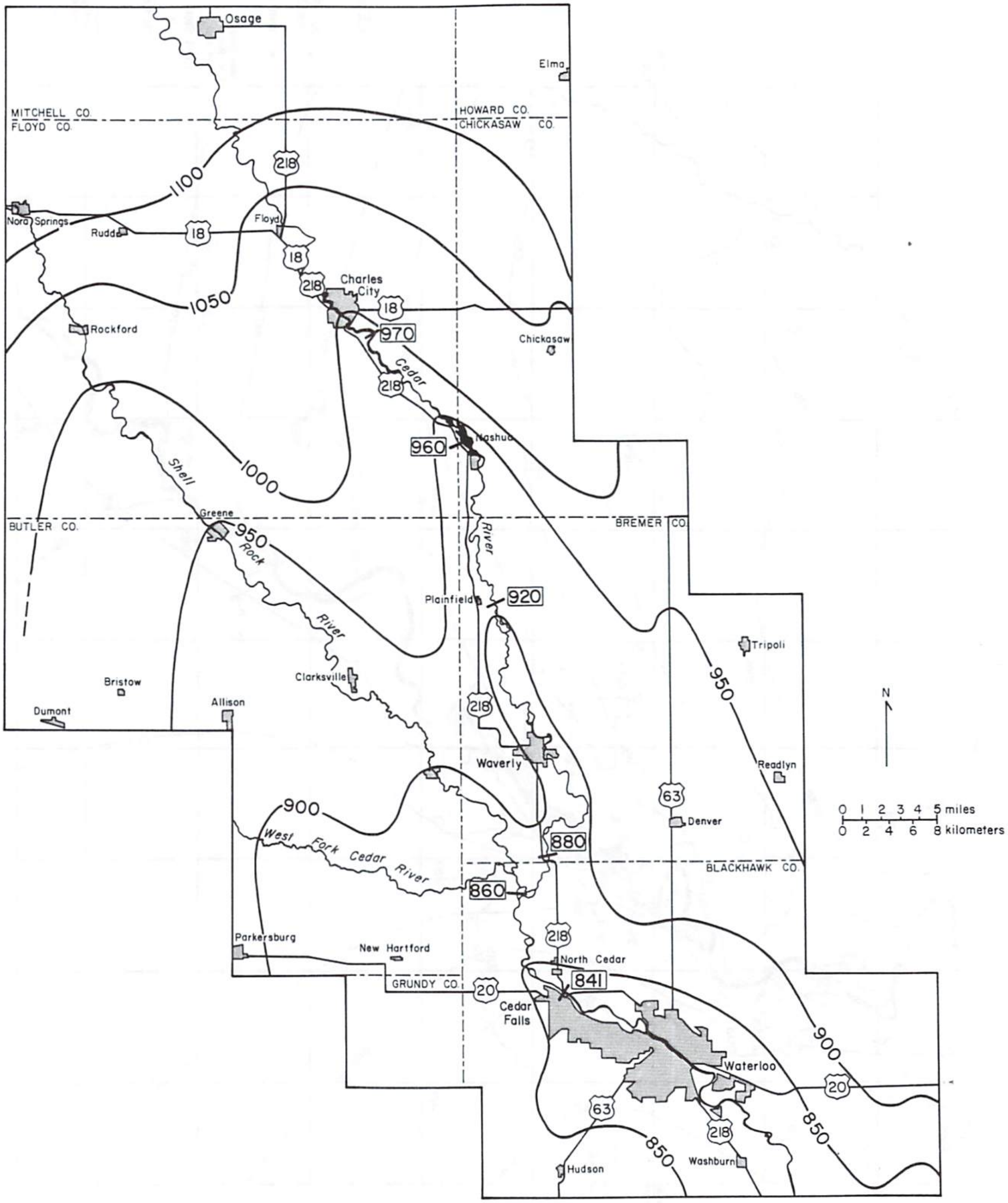

Figure 4. Regional potentiometric contours of the Cedar Valley aquifer. Contour interval is 50 feet. Datum is mean sea level.

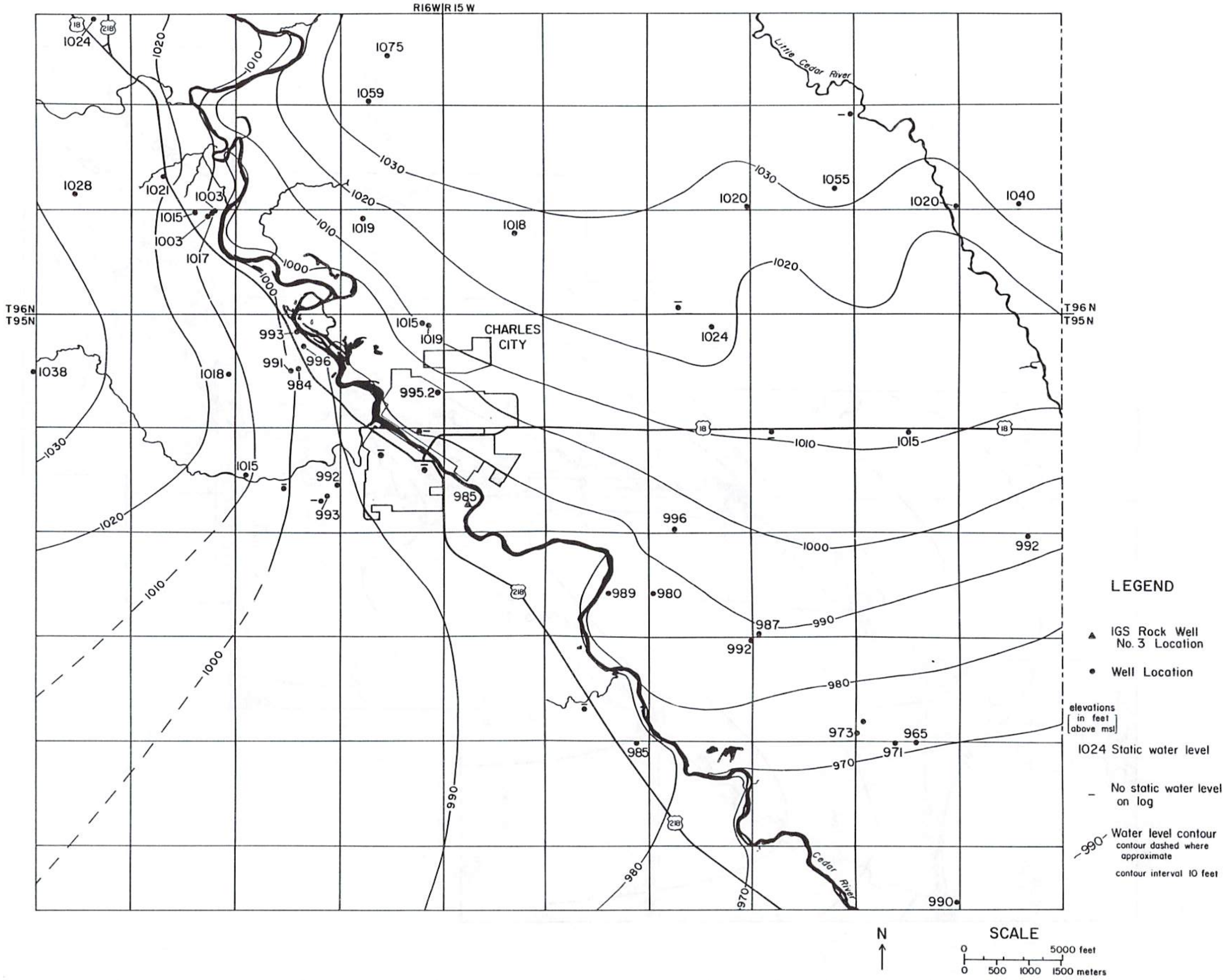

Figure 5. Head map of the Cedar Valley aquifer in the Charles City area.

in the interstream divide areas. It is important to remember that this is only a two-dimensional representation of a three-dimensional flow system. One feature common to such flow systems is that ground water gradients have a downward vertical component in recharge areas and an upward vertical component in discharge areas. Thus, it is not surprising that Rock Well #3 at the La Bounty site has a higher head in the lower part of the aquifer.

A flow net to compute the volume of ground water discharging to the Cedar River was not constructed because of the lack of aquifer transmissivity data. Transmissivities from quantitative and controlled pumping tests are rare in the Cedar Valley aquifer (12, Table 1), are highly variable, and have questionable applicability to regional flow nets in carbonate aquifers. Transmissivity data derived from specific capacity data are similarly variable (Table 2) and of lesser quality.

Assessment of Regional Contamination Potential

The Cedar Valley aquifer is not currently in danger of regional contamination from the LaBounty site because the site is located in the discharge zone of an active ground-water flow system. Regional contamination of the aquifer from the Cedar River is unlikely for the same reason. The flow system is active because of the humid climate, thin soil, and permeable nature of the aquifer near Charles City. The shale in Rock Well #3 has the efect of retarding the natural upward flow of ground water to the Cedar River. The shale should not be thought of as a "lid" sealing the aquifer from downward percolation of

Table 1. Transmissivity Data from the Devonian/Silurian aquifer* in Eastern Iowa (from P. J. Horick, unpub. IGS data, 1980)

(Sec.-Twp.-Rng.)	Transmissivity (gpd/ft) Pumping Well	Observation Wells	Thickness (ft)
1. NE¼ SW¼ 26-100N-20W Worth County	49,000	87,000 50,000 112,000	270
2. SE¼ NW¼ 25-96W-25W Hancock Co.	24,000-27,000	92,000	344
3. NW¼ 21-92N-14W Bremer Co.	1,900,000-2,700,000		98
4. Center 4-99N-18W Mitchell Co.	400,000	370,000 525,000-675-000 350,000 466,000	184
5. NE¼ NW¼ 13-89N-13W Blackhawk Co.	129,000		262
6. Center NW¼ 19-90N-13W Blackhawk Co.	1,760,000		268
7. NW¼ NW¼ 35-86N-9W Benton Co.	7,220	5,520	290
8. SE¼ NW¼ 22-80N-6W Johnson Co.	2,820	4,680 8,000	137

*Wells derive all or most of their water from the Cedar Valley and Wapsipinicon Formations.

Table 2. Transmissivity data--Charles City area [Modified from (9)].

LIST OF AQUIFER TRANSMISSIVITY OF THE CEDAR VALLEY AQUIFER FOR WELLS IN THE CHARLES CITY AREA

Sec.-Twp.-Rng.	TRANSMISSIVITY	THICKNESS
4-95-15	7,500 gpd/ft.	50 feet
7-95-15	30,000 "	60 "
9-95-15	6,200 "	65 "
15-95-15	2,500 "	90 "
16-95-15	5,400 "	85 "
1-95-16	24,000 "	100 "
1-95-16	15,000 "	65 "
1-95-16	130,000 "	100 "
1-95-16	44,000 "	50 "
2-95-16	50,000 "	30 "
2-95-16	15,000 "	40 "
11-95-16	3,600 "	300 "
11-95-16	73,000 "	300 "
11-95-16	270 "	80 "
11-95-16	2,900 "	110 "
	409,370	
AVERAGE	27,291	

Calculations based on: Transmissivity (gpd/ft) = C x Specific Capacity (gpm/ft) where C is am empirical constant. C = 2500 was used for this table.

contaminants. Where the shale is not present below the river, natural upward ground-water flow would also be expected to occur, providing an effective hydrodynamic barrier to downward contaminant migration.

Man-induced stresses can alter the natural flow system on a local scale, however. Areas of primary concern would be near large pumping wells close to the Cedar River. Cones of depression around pumping wells may intercept the river and induce recharge from the river to the aquifer. Where the aquifer is fractured or cavernous limestone, the travel time of contaminants will be short, and attenuation of contaminants will be minimal. An alluvial aquifer offers slightly more retardation of contaminant movement because of the adsorptive capacity of the clays commonly associated with alluvial deposits.

An artificial impoundment is another source of hydraulic stress on the aquifer. Increasing the head of the river behind a dam could reverse the natural discharge of ground water to the river and cause water to move into the aquifer. Again, the effects would be localized because the bulk of the water would migrate back into the river below the dam. As previously noted, the available data are not sufficiently detailed to permit delineation of any areas of local recharge to the aquifer.

Recommendations for additional data needs that will aid in assessing the mechanisms of regional contaminant migration are listed below in priority order.

1. Monitor Rock Well #3 on a weekly basis as part of the regular monitoring program to establish a relationship

between water levels and climatic fluctuations.

2. Monitor recent sediments and the ground-water flow system at Nashua, where the impoundment of the Cedar River may have an effect on contaminant migration.
3. Periodically measure non-pumping water levels in Charles City wells for which IGS strip logs exist to observe changes in the ground-water flow system caused by natural or artificial stress on the aquifer.
4. Drill a deep core (to the base of the Wapsipinicon Formation) in or near Charles City to define Devonian stratigraphy. Construct nested piezometers to monitor ground-water conditions.
5. Examine and describe outcrops along the Cedar River southeast of Charles City and/or drill shallow holes to attempt to locate the shale found in Rock Well #3 and in the four wells near Carrville.
6. Identify wells downstream of Charles City that have shown ONA contamination and install monitoring wells between the contaminated wells and the river.

LABOUNTY SITE

Physical Description

The LaBounty site is located on the south side of Charles City on the floodplain of the Cedar River (figure 6). Immediately north and west of the site, the Cedar River is nearly straight, has a very narrow floodplain and bedrock is known to be near the surface. It can safely be concluded, therefore,

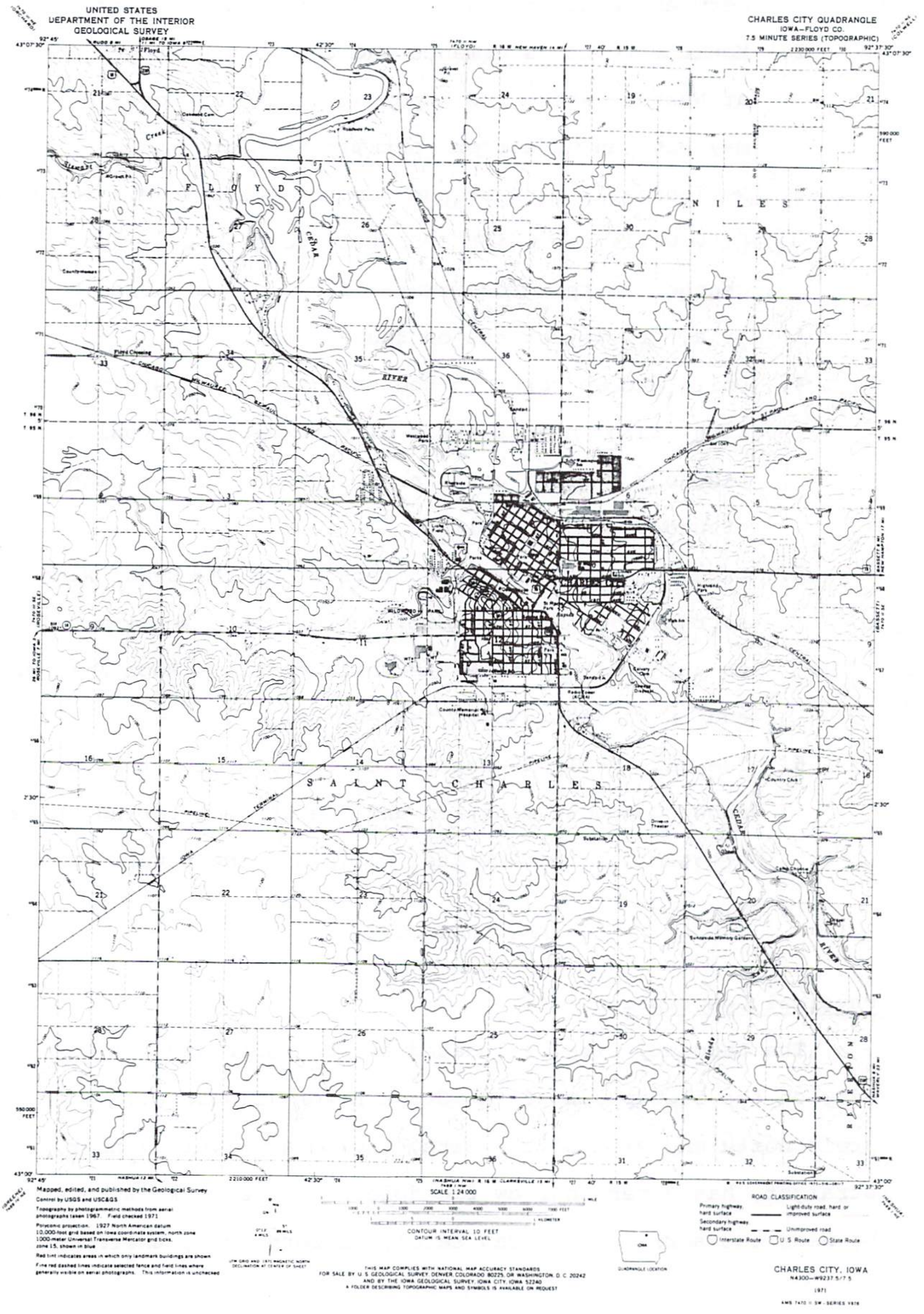

Figure 6. Location of the LaBounty site.

that that segment of the river is largely confined by bedrock. At the site and below, however, the floodplain becomes much wider and the river starts to meander within an alluvial plain, indicating that bedrock no longer confines the floodplain.

The uppermost bedrock unit at the LaBounty site is the Coralville Member of the Cedar Valley Formation, and it lies at a depth of 0-40 feet below land surface. Figure 7 is a detailed map of bedrock topography at the site. A major bedrock channel nearly coincides with the present course of the Cedar River, and a minor channel is present under the fill material. Each channel trends approximately S55°E, which is parallel to the direction of the Cedar River immediately north of the site.

Examination of the major joint trends (figure 2) reveals that several locations near Charles City have dominant joint systems that are nearly parallel to both the river and the two bedrock channels at the LaBounty site. This strongly suggests that joint trends in the Cedar Valley Formation had a significant influence on the course of the Cedar River immediately north of the LaBounty site. It is not likely, however, that the river valley is joint controlled immediately east and south of the site because the floodplain is no longer bedrock controlled.

The stratigraphy of the LaBounty site can be seen in the cross sections in figures 8-11. The sections are principally based on the drilling and rock coring performed at the site during 1979. Borings penetrating the fill material are described in Hickok and Associates (7). IGS Rock Well #3 is also

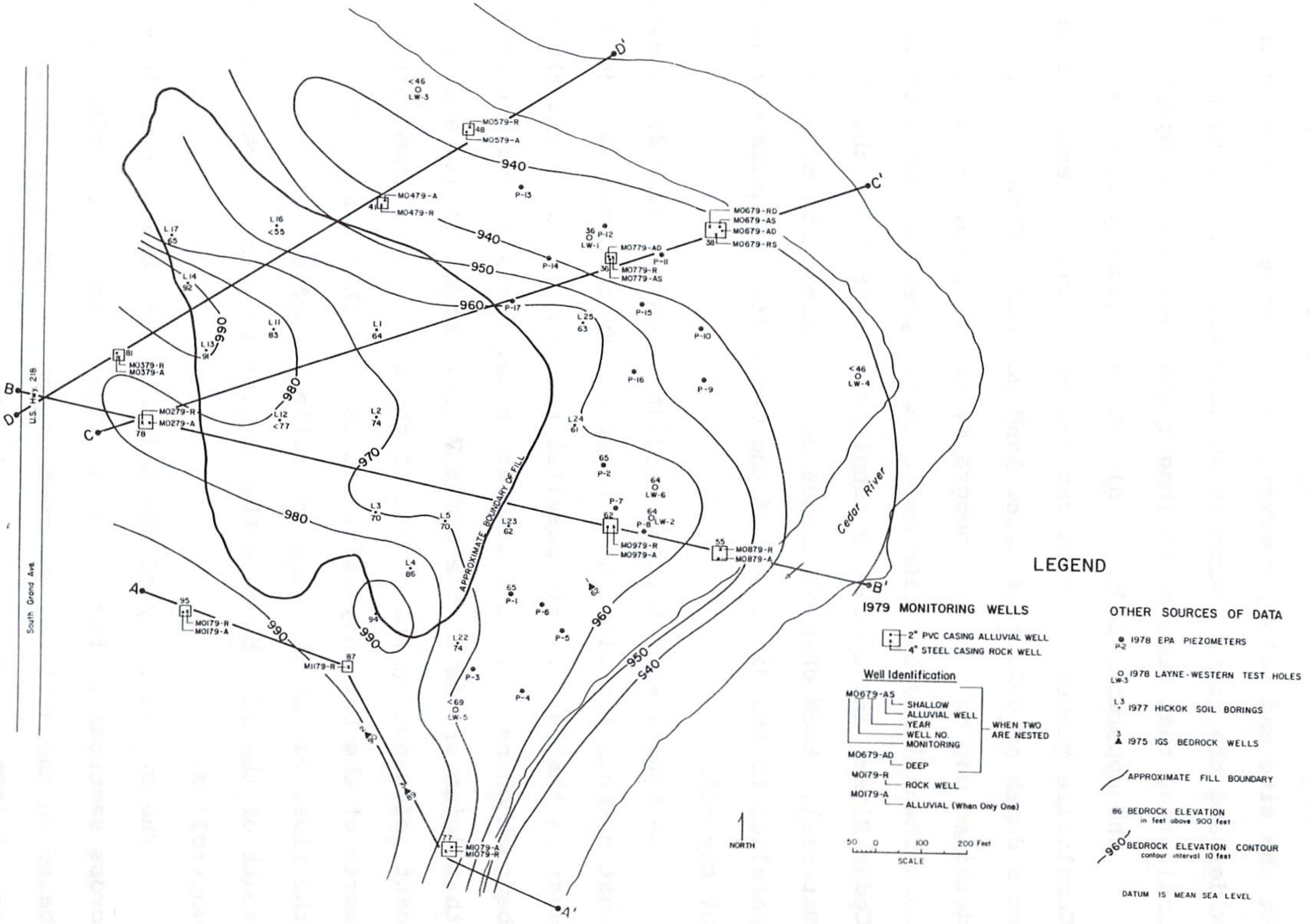

Figure 7. Bedrock topography at the LaBounty site.

illustrated in figure 8. Only the dominant lithology of units greater than one foot thick were distinguished on the cross sections, although more detailed descriptions are in the Appendix.

The chemical and physical characteristics of the fill material were described by Hickok and Associates (7) and will not be detailed here. It is interesting to note, however, that the material was not deposited on the floodplain surface, but appears to have been deposited in excavations in the river alluvium. This is relevant because of the importance of the position of the water table in the fill material.

The river alluvium at the LaBounty site exhibits a wide range of grain sizes, from clay to gravel, but is dominantly a medium-grained sand with some gravel (6). Measured hydraulic conductivities range from 1.4×10^{-2} cm/sec to 7×10^{-8} cm/sec (6). Freeze and Cherry (13) note that clean sand should have a hydraulic conductivity between 10^{-4} cm/sec and 1 cm/sec. Laboratory determinations of hydraulic conductivity are commonly lower than field determinations.

In general, the alluvial deposits in Iowa are coarser textured at greater depths. The sequence of alluvial deposits usually consist of a silty to fine-sandy upper unit of variable thickness, which overlies a unit of coarser sand and/or gravel which fills the base of the valley. Thus, the coarser-grained sands and gravels with grater hydraulic conductivities tend to be located at the base of alluvial deposits. The significance of this will be discussed in the flow system description.

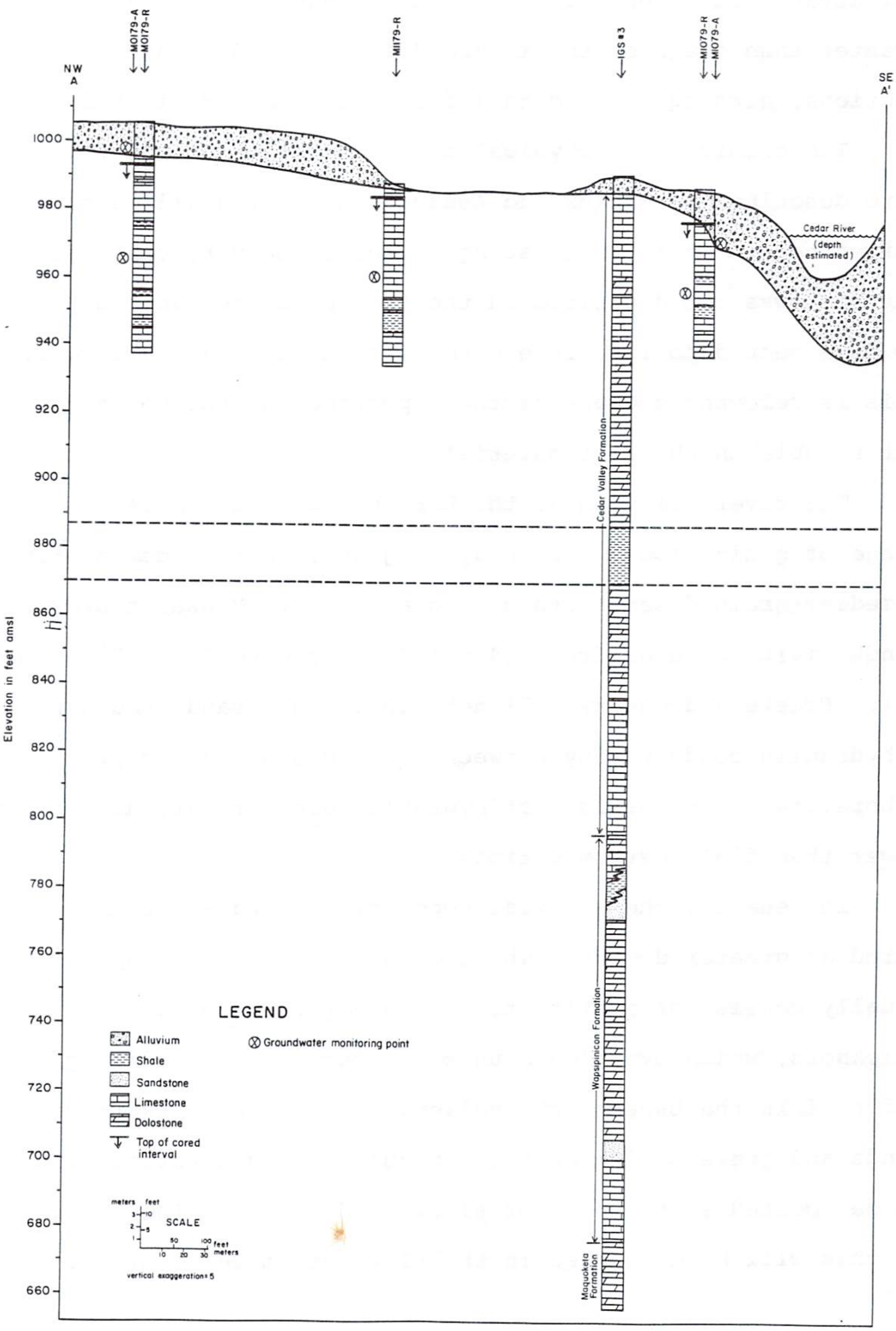

Figure 8. Geologic cross section A-A' at the LaBounty site.

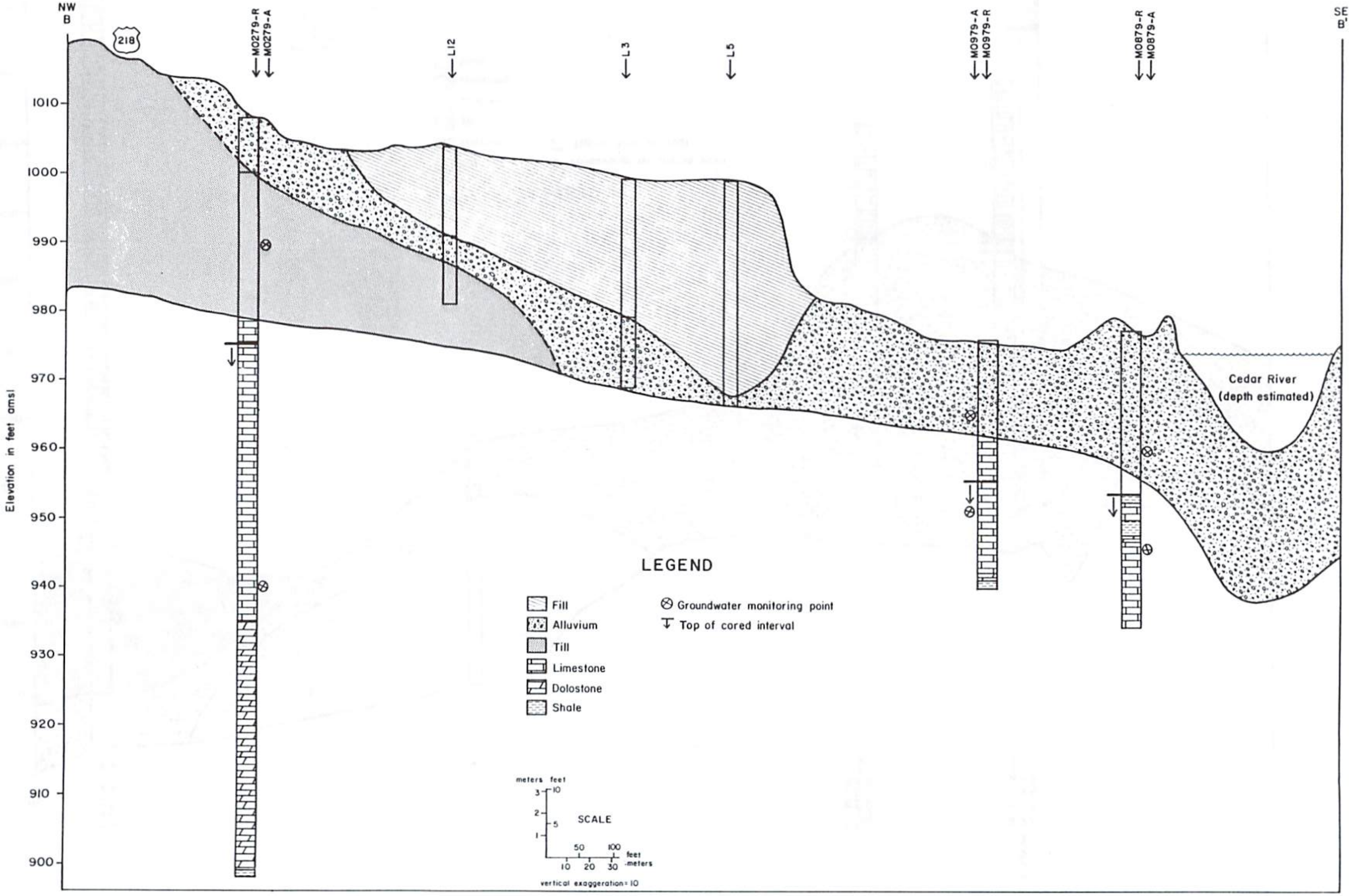

Figure 9. Geologic cross section B-B' at the LaBounty site.

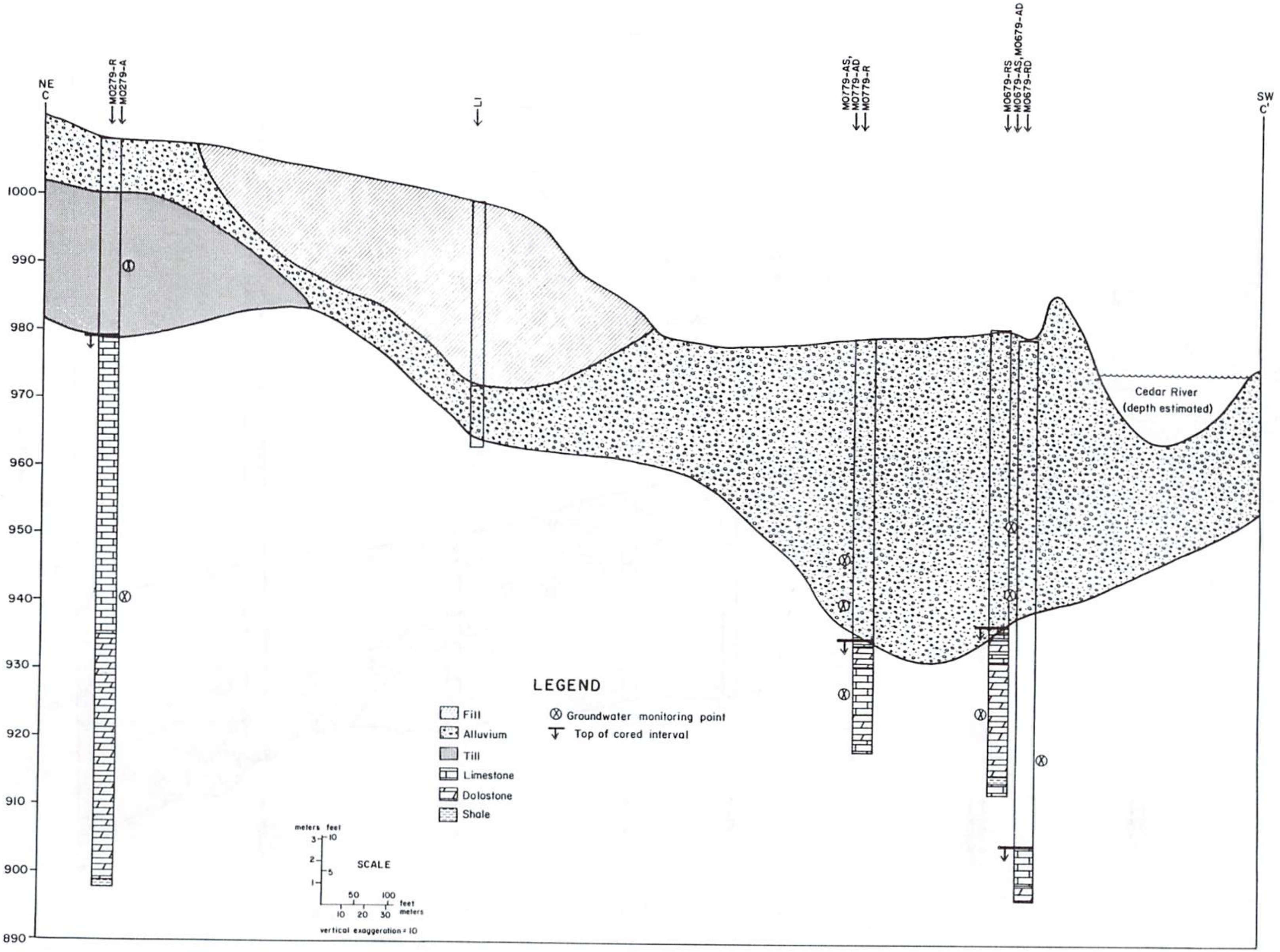

Figure 10. Geologic cross section C-C' at the LaBounty site.

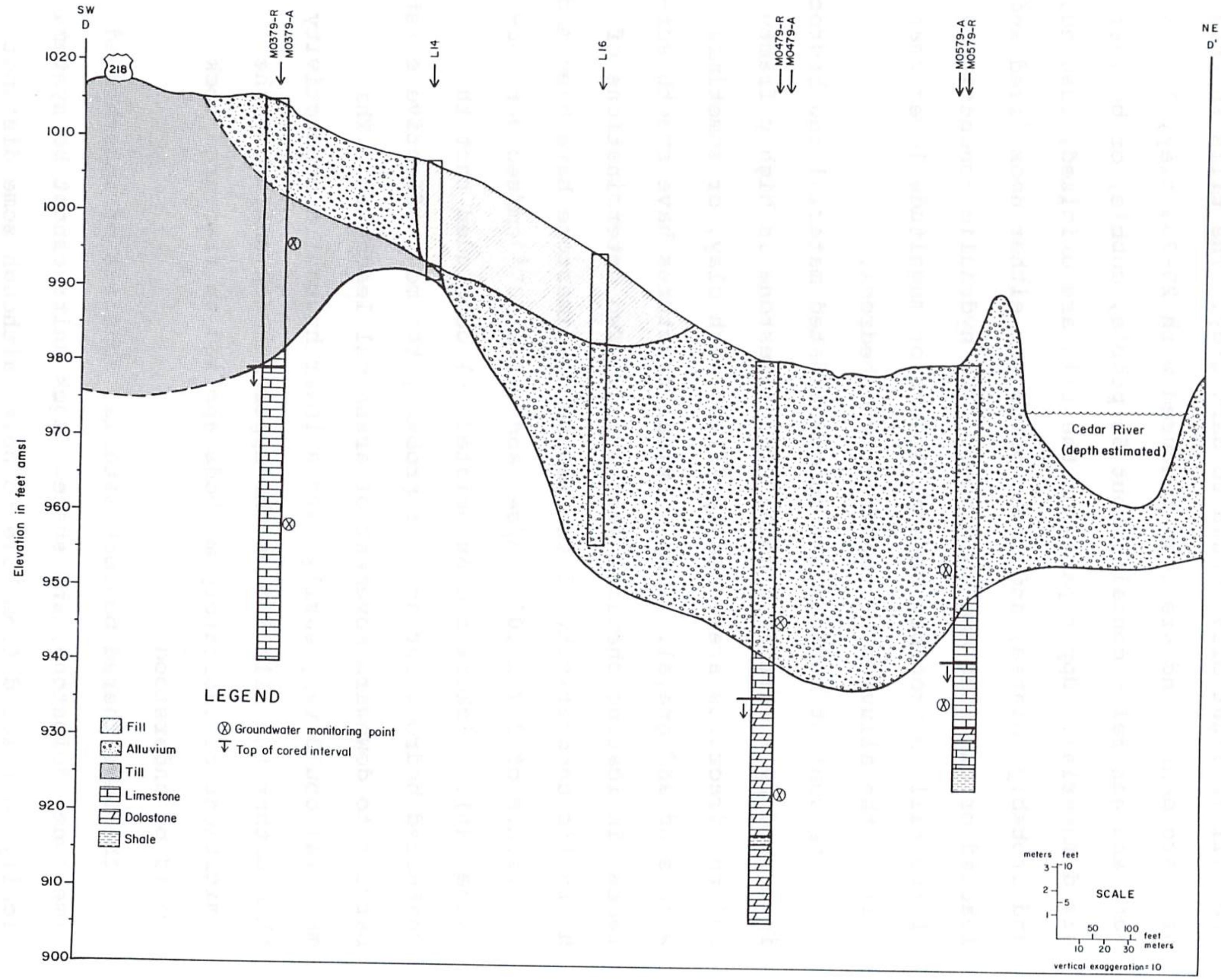

Figure 11. Geologic cross section D-D' at the LaBounty site.

Glacial till was also encountered at the LaBounty site. The till is light olive brown to dark grey. The tills in this area are dense, and are loam textured with 20-25% clay, 35-45% sand and generally contain about 5% pebble, cobble, or boulder sized material. Upper parts of the till are oxidized, leached, and probably jointed, and lower parts are either unoxidized and leached or oxidized and unleached. The hydraulic conductivity of the till is probably several orders of magnitude lower than that of the alluvium or the fractured bedrock.

The contact between the unconsolidated material and bedrock is marked by a weathered zone. The limestone is highly fractured, and the fractures are commonly filled with clay, or sometimes with sand and gravel. Some vertical fractures have smooth surfaces, indicating chemical weathering. Two determinations of hydraulic conductivity of the weathered limestone have been made, and values of 2.2×10^{-5} cm/sec and 1.3×10^{-5} cm/sec were obtained (6). Hickock and Associates (6) concluded that the weathered bedrock surface "is probably the most effective existing barrier to downward movement of arsenical leachate". This material could very easily have a lower hydraulic conductivity than either the alluvium or the upper bedrock units but the limitations of laboratory methods applied to fractured rock should be understood.

The unweathered bedrock material consists of interbedded limestone, dolostone, and shale. Rock units cannot be systematically correlated from hole to hole, although some distinct sequences can be recognized in several wells. A transition from dominantly limestone to dominantly dolostone occurs at an elevation of 935 feet in several holes. This horizon is usually considered to be the contact between the Coralville Member and the underlying Rapid Member of the Cedar Valley Formation. IGS Rock Well #3 in figure 8 illustrates the deeper stratigraphy of the site, including the shale separating the upper and lower Cedar Valley aquifers and the change from dolostone to limestone lower in the Cedar Valley Formation which is usually considered to be the contact between the Rapid and Solon Members.

Porosity and permeability in the upper Cedar Valley aquifer in the form of vugs, fractures, solution channels, and brecciated zones has been noted (see Appendix). This indicates that the hydraulic conductivity is likely to be intermediate in magnitude between that of the till and the Cedar River alluvium.

Ground-Water Flow System

The ground-water flow system is depicted areally in figures 12 and 13 and in cross section in figures 14-17. Head measurements made on April 24, 1980, were used because very little precipitation occurred in the preceeding weeks, and the flow system was very close to being at steady state. The water table was at a relatively low position. River elevations at the lines of cross sections were linearly interpolated from gage readings made at the USGS Charles City station and at the railroad bridge near the south end of the site. A river slope of 1:2,300 or 0.00043 was used.

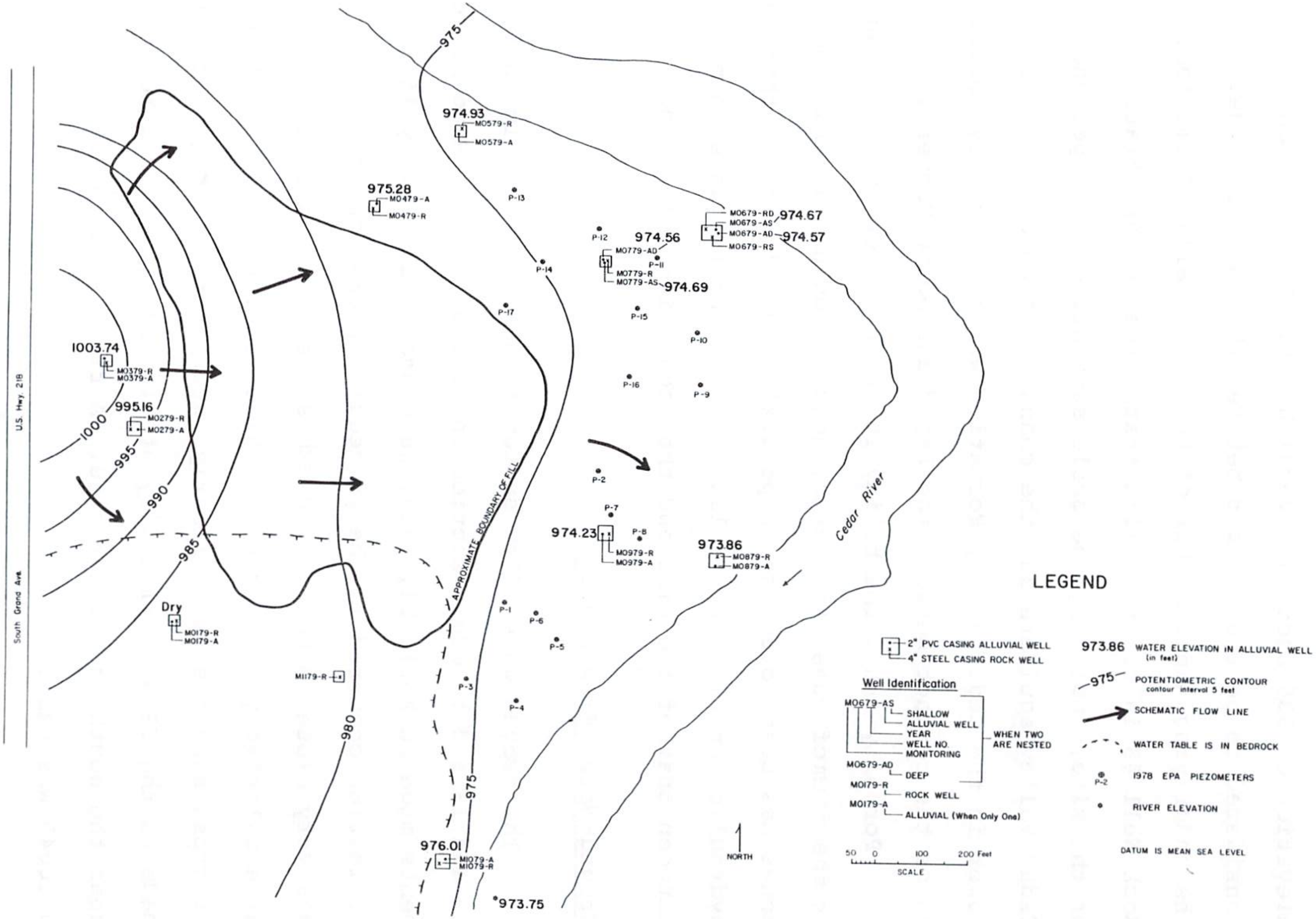

Figure 12. Water-table map - alluvial wells, April 24, 1980.

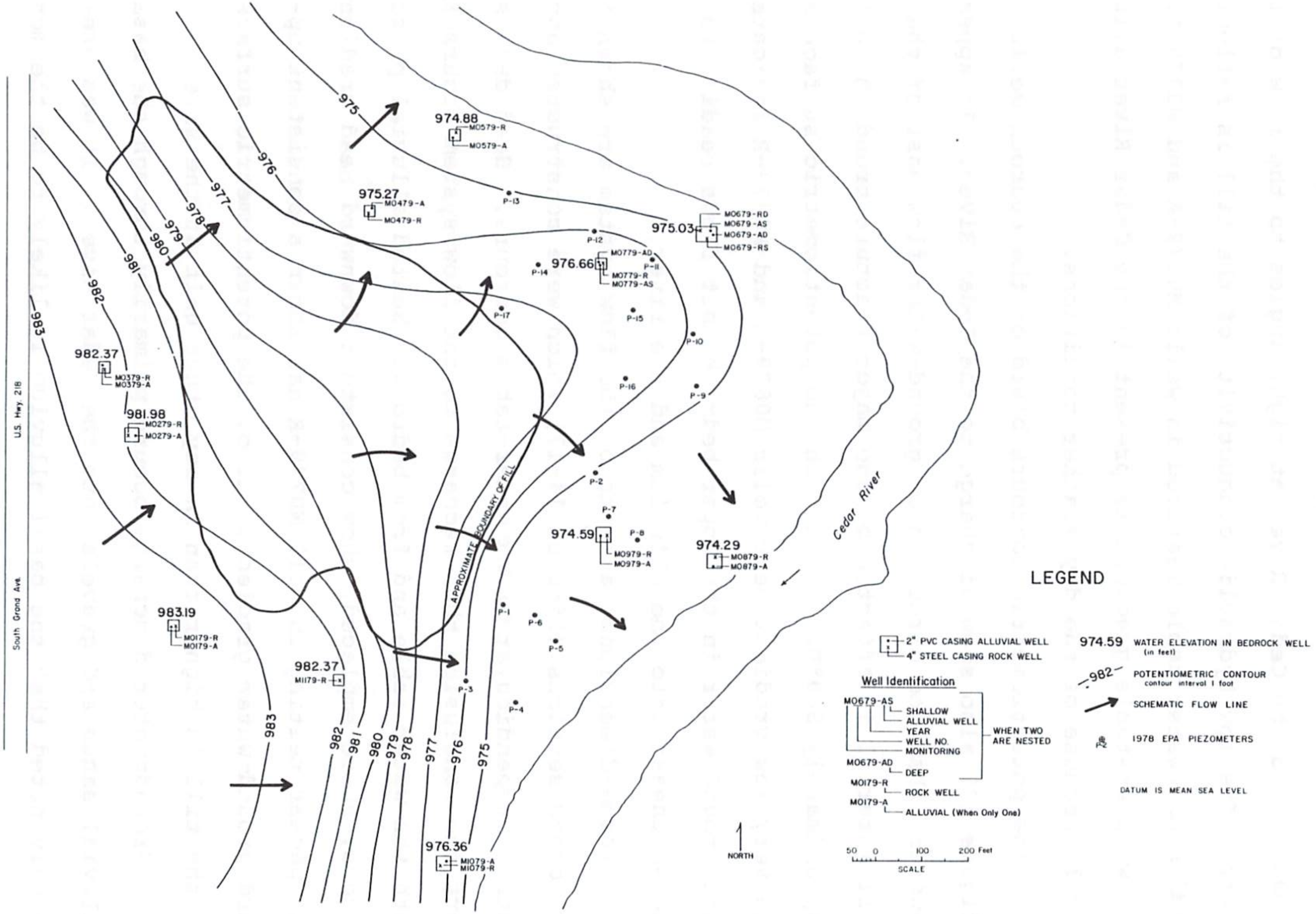

Figure 13. Potentiometric map - bedrock wells, April 24, 1980.

The water-table map (figure 12) shows that ground water flows toward the Cedar River at right angles to the flow of the river. The low hydraulic conductivity of the till is reflected in the high water table measured in wells M0279-A and M0379-A. A low water-table gradient is present in the Cedar River alluvium, partly because of the dry weather conditions.

The potentiometric contours based on the bedrock wells (figure 13) also show discharge to the Cedar River. It appears however, that the direction of ground-water flow east of the fill material is affected by the major fracture trend which is approximately S60°E. A ridge in the potentiometric surface and the very low gradient near wells M0879-R and M0979-R indicate that ground water in the upper bedrock unit flows readily to the southeast into the alluvium and the river.

Three-dimensional aspects of the flow system are shown in the cross sections (figures 14-17) which were constructed approximately perpendicular to the water-table contours. Head data support the conclusion that recharge to the flow system occurs from both the water table and from bedrock. Nested alluvial piezometers, where emplaced, show consistent downward head gradients, and packer testing in well M0279-R has shown a consistent upward ground-water gradient. Also, the potentiometric surface in the till is higher than in any other unit at the site.

Ground-water discharge occurs primarily through the basal alluvial sands and gravels into the Cedar River. It was previously noted that the basal alluvium is likely to be the most permeable, which is consistent with the observation that the

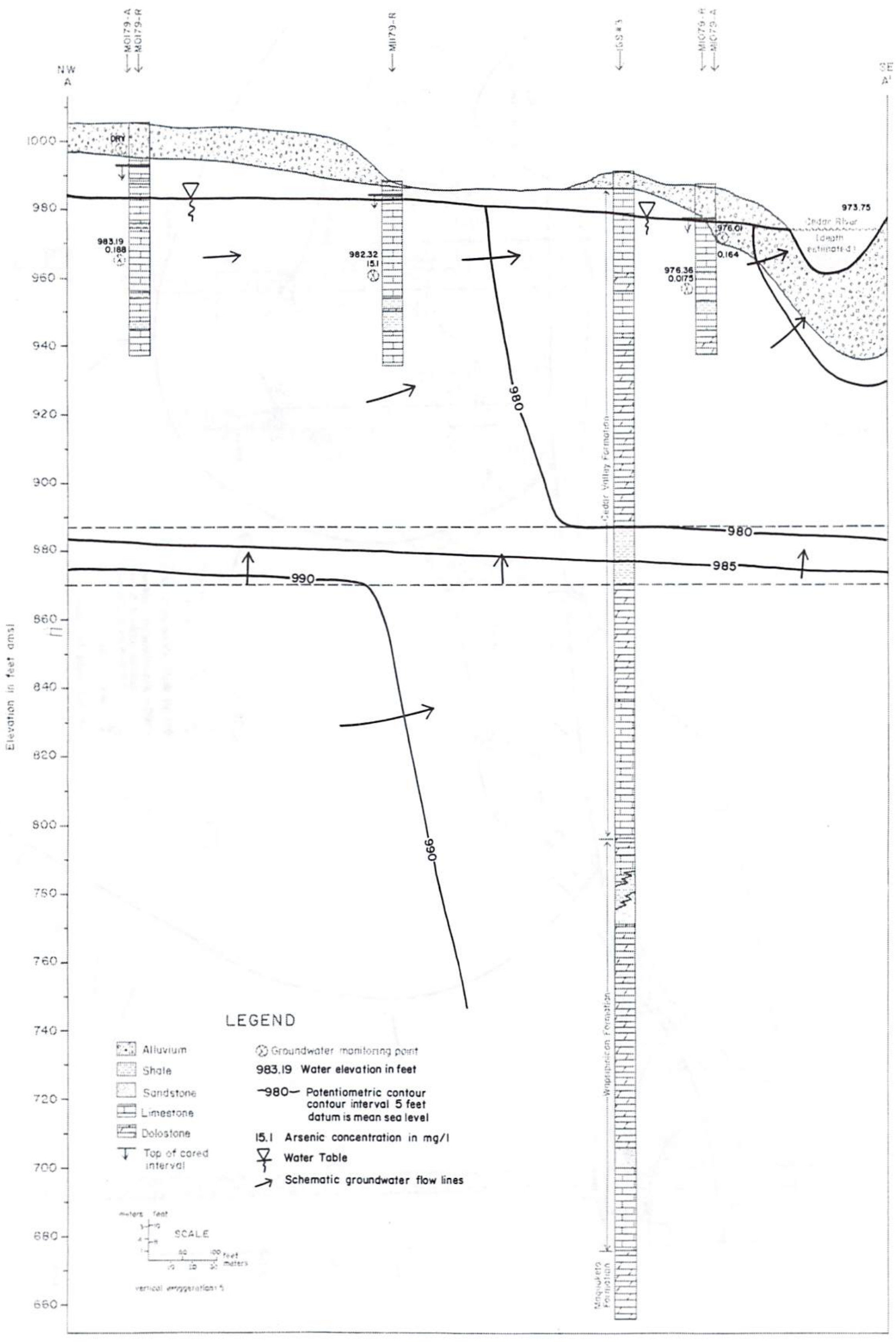

Figure 14. Potentiometric cross section A-A', April 24, 1980.

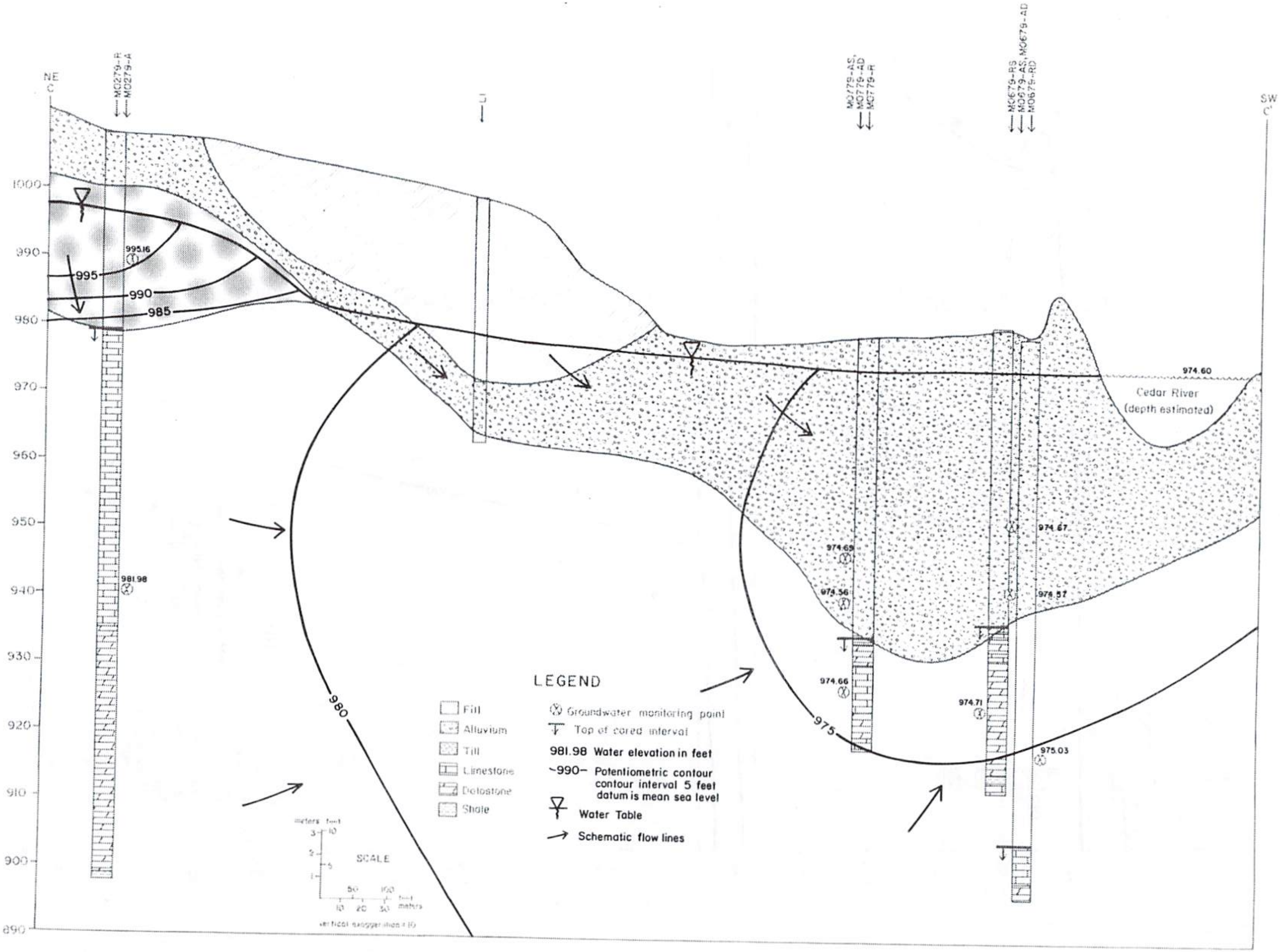

Figure 16. Potentionmetric cross section C-C', April 24, 1980.

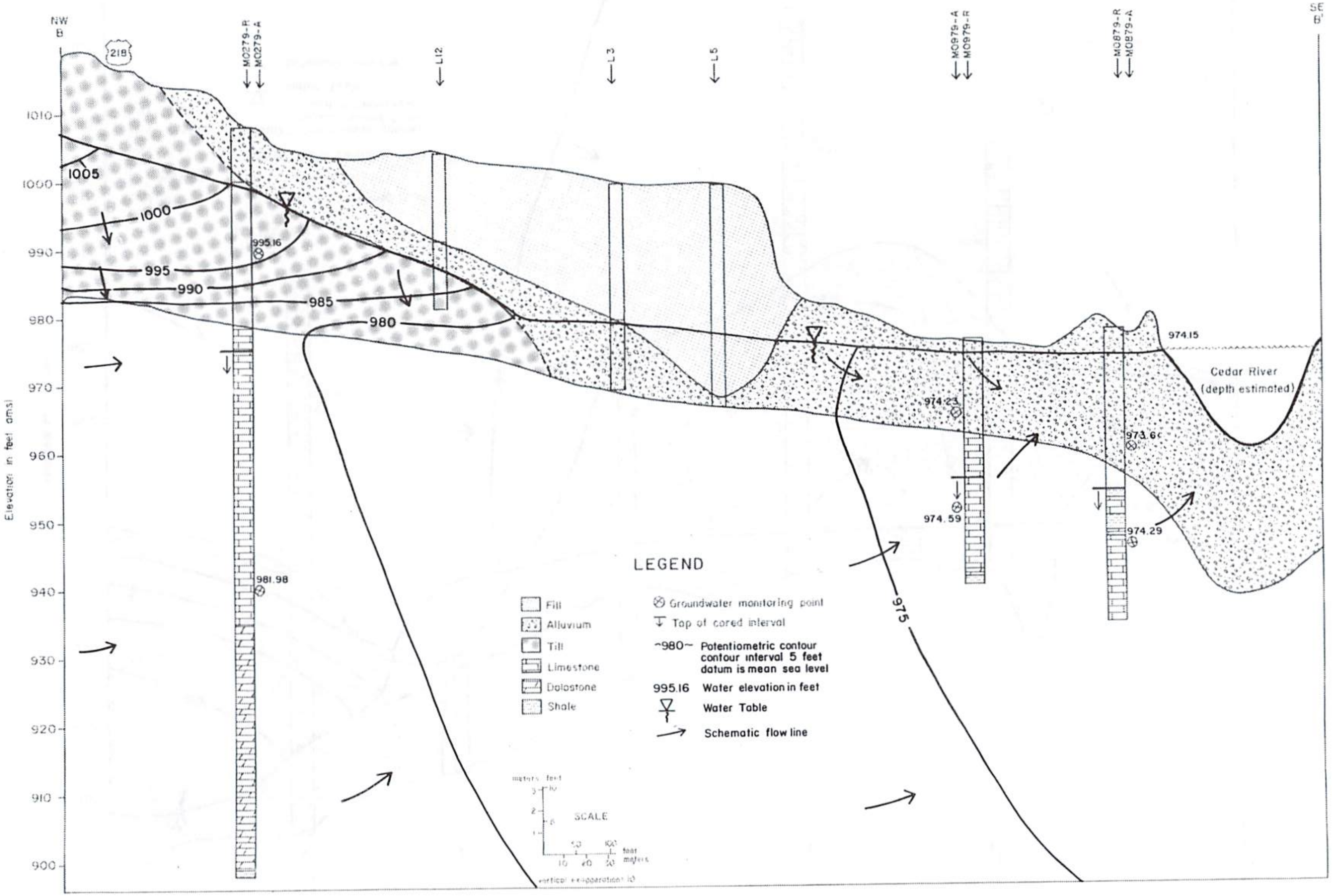

Figure 15. Potentiometric cross section B-B', April 24, 1980.

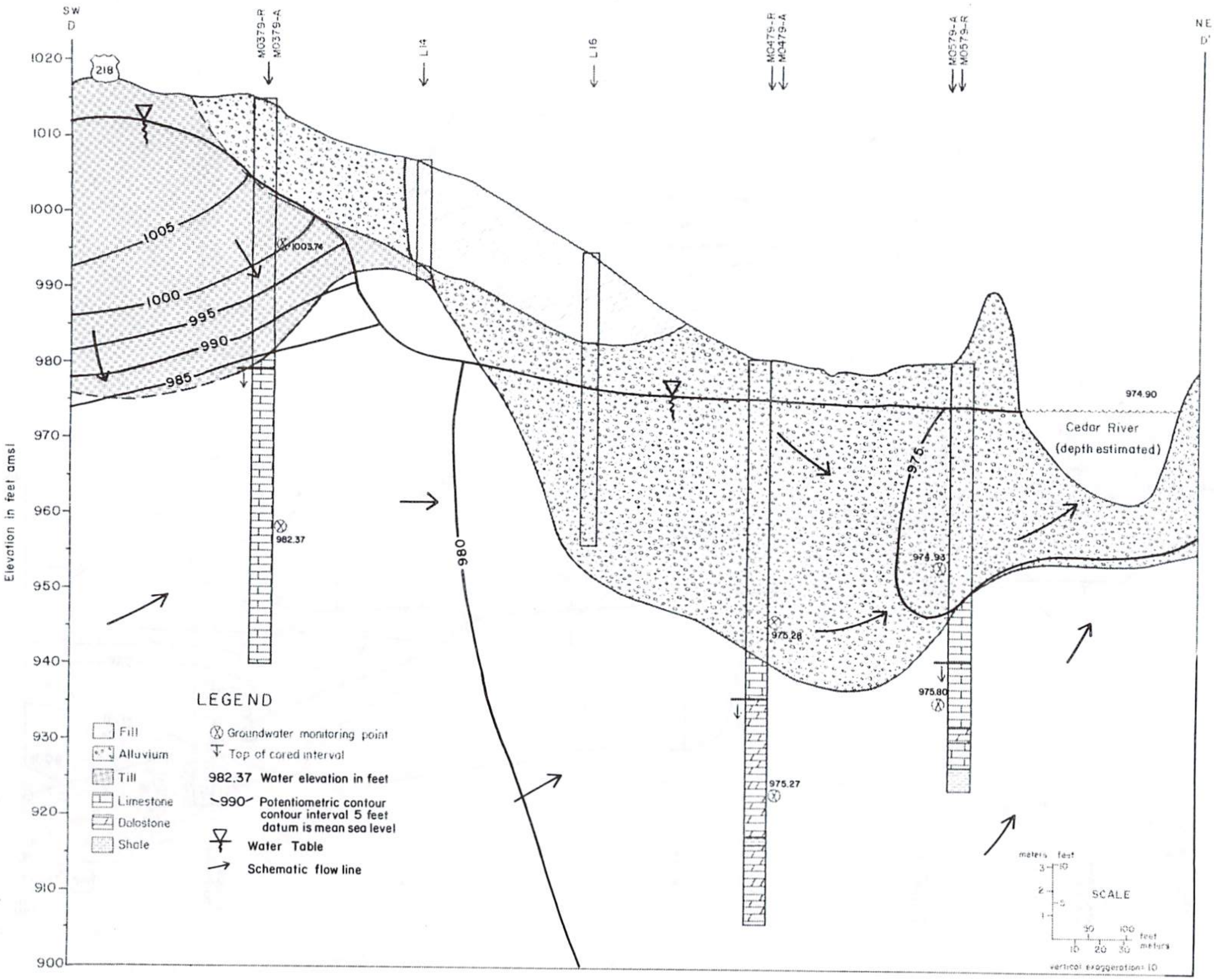

Figure 17. Potentiometric cross section D-D', April 24, 1980

lowest heads in the flow system are in the basal alluvium adjacent to the river.

An anomaly seems to be present in cross section B-B' and C-C', where the river elevation is higher than the water levels in the deep alluvial wells. This discrepancy could be because of any one of four reasons, or a combination of all four. It is not possible to completely resolve the issue, however. The three most likely possibilities are: 1. A rise in river stage was not reflected in the alluvial wells; 2. the linear interpolation procedure used to derive the river elevation was inaccurate; or, 3. there was a consistent discrepancy in the reported elevations of the alluvial wells and/or the staff gage at the railroad bridge.

A fourth possibility is that the direction of ground-water flow in the area of wells M0679-AD and M0879-A is actually in a southward direction, parallel to the axis of the bedrock channel, and that discharge is to the Cedar River at some downstream location. This possibility is difficult to evaluate because the accurate river elevation in the area is not known, and the effectiveness of the hydraulic connection between the river and the permeable parts of the alluvium is not defined. A southward direction of ground-water flow would be favored if materials with relatively low hydraulic conductivity are present between M0679-AD and the river. The ultimate effect of this possibility would be minor, however, because the river remains the discharge point of the flow system.

An important item to note in the potentiometric cross sections is the position of the water table with respect to the waste material. Cross sections B-B' and C-C' show that significant amounts of waste are below the water table, whereas all of the waste in cross-section D-D' is above the water table. It is also important to consider that the water table configuration shown represents a dry period of time, and that significantly more waste is saturated during wet periods. It is unlikely, however, that significant amounts of waste material are ever fully saturated along line D-D'.

Figure 18 illustrates the response of the flow system to transient conditions. This figure is based on data from the 1978 piezometers as reported in (10). The large number of alluvial monitoring points in a small area makes it possible to map the water table in detail. This type of mapping is difficult with the 1979-1980 data because of the smaller number of alluvial wells. Water levels were originally measured with respect to the elevation of IGS Rock Well #1, but were converted to elevations with respect to sea level so that the river elevation could be included.

Two important conclusions can be drawn from figure 18. First, the wells were measured shortly after a rise in river level, and had not yet come into equilibrium with the river. Water was recharging the alluvium from the river both to the northeast and to the southeast of the dump site. This is commonly called bank storage because this water returns to the river after the river level drops.

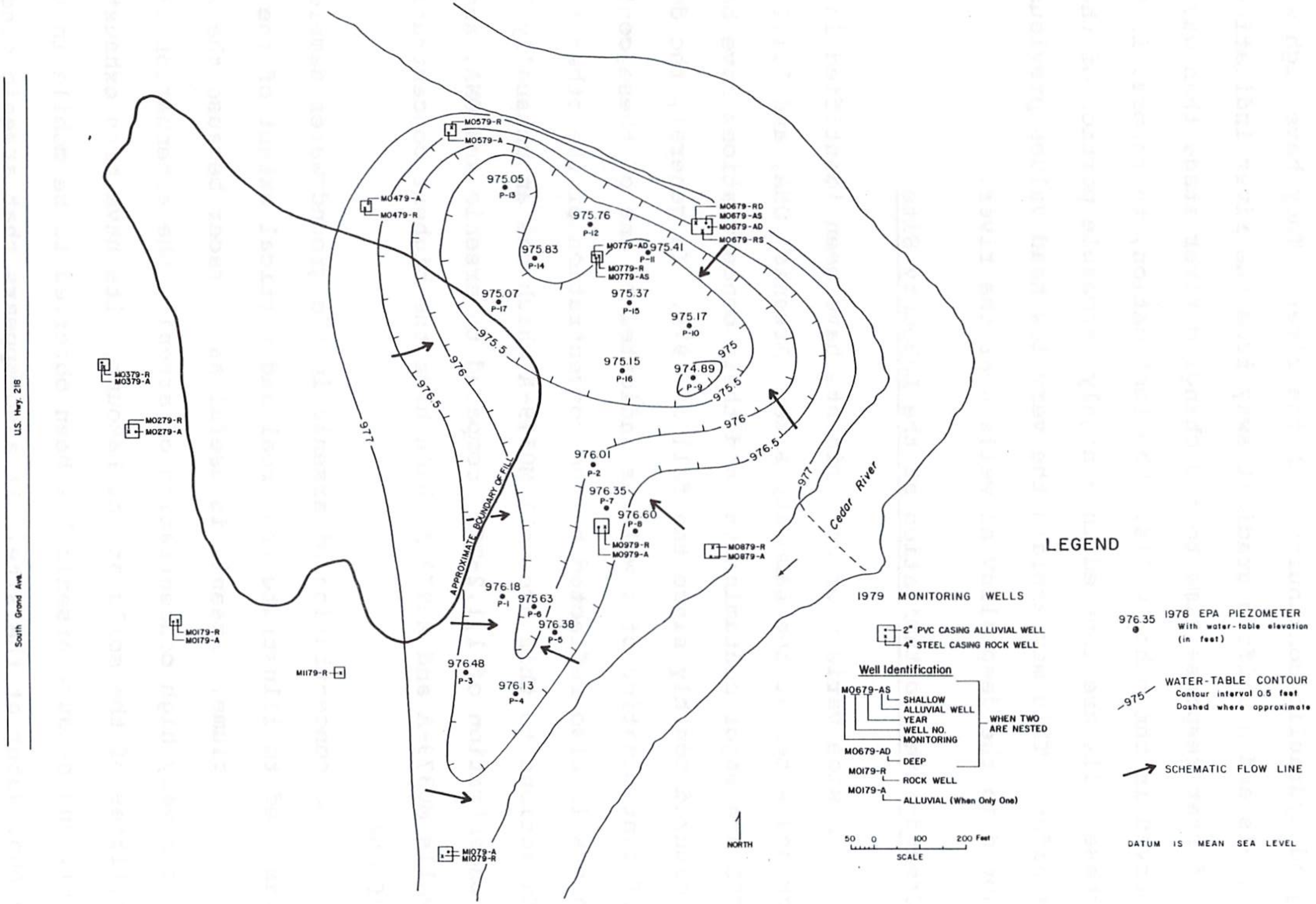

Figure 18. The transient flow system, July 6, 1978, based on EPA piezometers.

Second, wells numbered P-2, P-7, and P-8 appear to be in good hydraulic continuity with the river. They have high water levels and a uniform gradient away from the river indicating a faster response time to the changing river stage than was observed in the other wells. The implication, therefore, is that these wells are located in a highly permeable portion of the aquifer. This may explain the very low head values previously noted in the deep alluvial wells near the river.

Ground-Water Contamination at the LaBounty Site

A wide variety of contaminants have been identified in the ground water at the LaBounty site. Arsenic, ONA, and 1,1,2-TCE are major contaminants, and their concentrations have been measured monthly since the fall of 1979. In general, the degree of contamination of a well as indicated by one of these contaminants is also reflected by the concentration of the other two. Exceptions to this are well M0579-A which has an unusually high concentration of 1,1,2-TCE, compared to arsenic and ONA, and wells M0879-A and M0979-A which have the highest concentrations of ONA.

The concentration of arsenic in the ground-water samples was used to illustrate the areal and vertical extent of the contaminant plume. Arsenic is useful as a tracer because the waste has a very high concentration of arsenic, the attenuation capabilities of the soils at the LaBounty site have been exhausted (6), and because arsenic has been observed to be mobile in the ground water at the site. It also appears that arsenic concentrations are somewhat less variable than ONA and 1,1,2-TCE and give a better definition of the contaminant plume.

Arsenic is not an ideal tracer, however, mainly because the various chemical species containing arsenic at the LaBounty site are not known. A number of arsenic oxides, ion complexes, and other compounds are likely to be present. The chemical and physical controls on arsenic migration, therefore, are not understood.

Figures 19 and 20 show the areal distribution of arsenic in the alluvial and bedrock wells in April, 1980. By far the highest concentrations are in the alluvial wells immediately east of the fill material. Of the bedrock wells, the highest concentrations are also immediately east of the fill.

Figures 21 through 23 and figure 17 show the vertical distribution of arsenic. The highest concentrations are at the base of the alluvium immediately down gradient of fully saturated portions of the waste. The lack of high arsenic concentrations in the ground water down gradient of unsaturated waste strongly suggests that the bulk of the contamination results from the mobilization of contaminants by ground water below the water table. Ground water passing through the fill would be in direct contact with the fill for a period of weeks or months, which is probably long enough for the water to become fully saturated with a wide variety of undesirable chemical species.

The relative importance of the saturated zone versus the unsaturated zone for the production of leachate is currently not known. If leachate is not currently being produced in significant quantities in the unsaturated zone (i.e. above the water

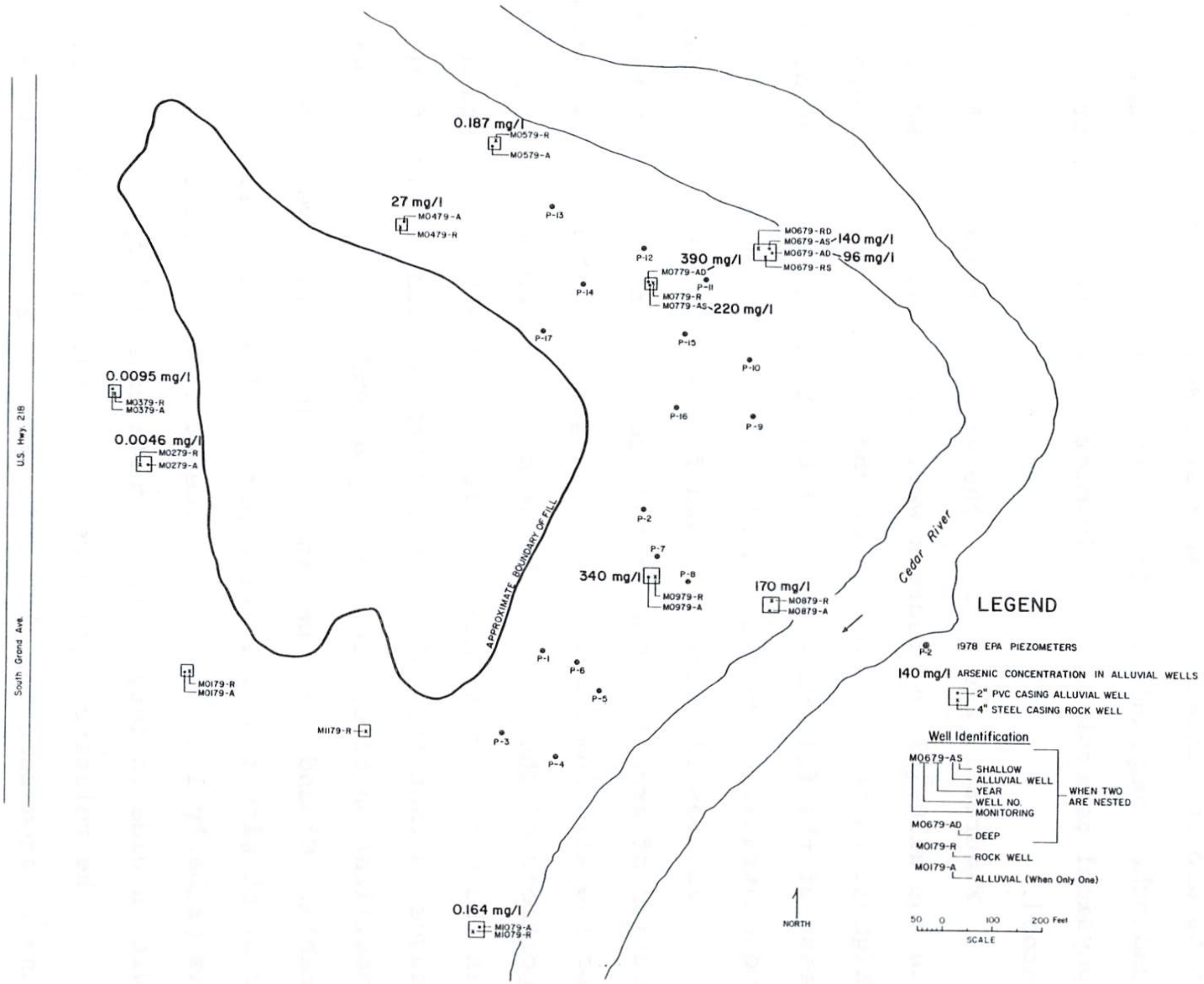

Figure 19. Areal distribution of arsenic in alluvial wells.

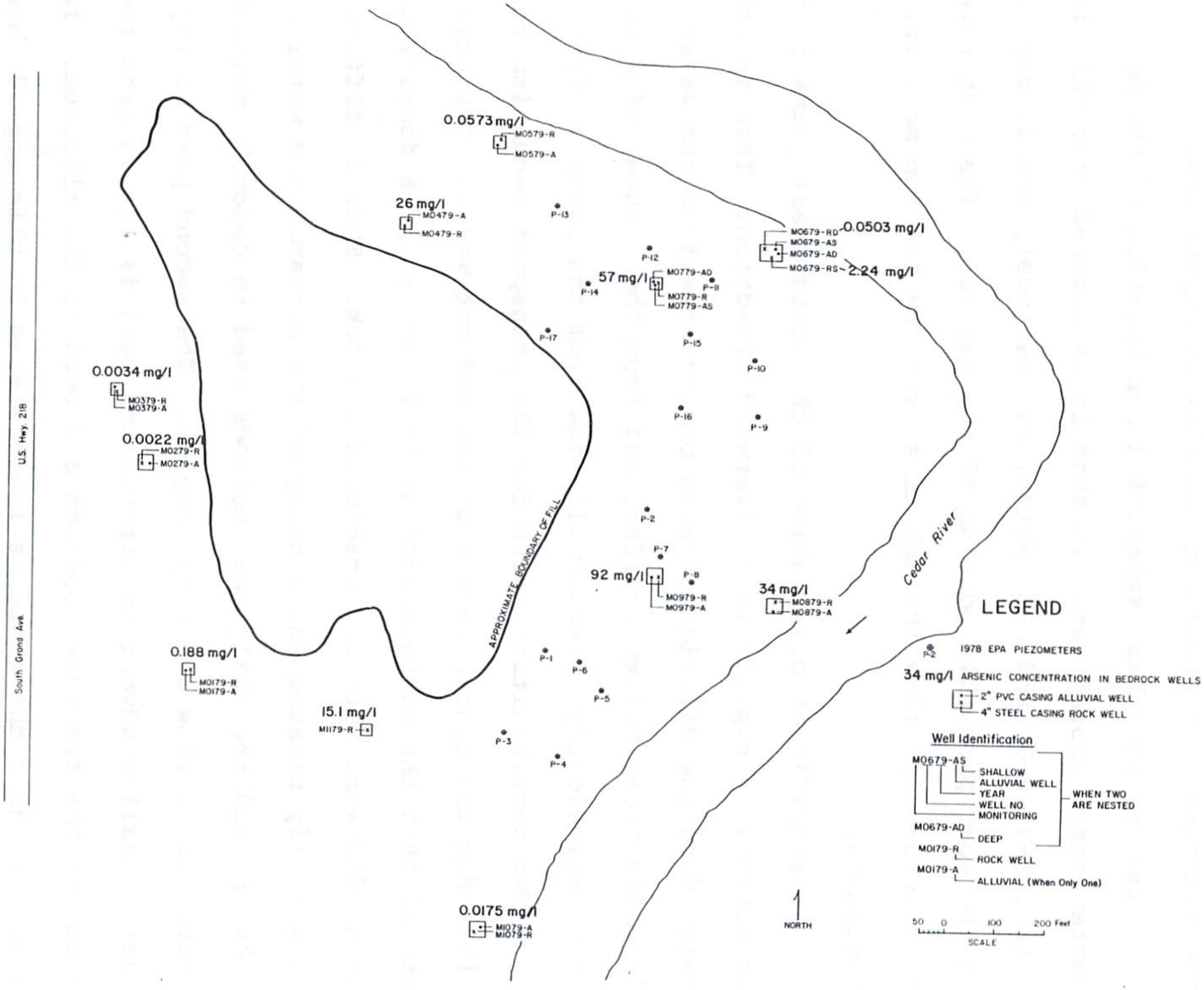

Figure 20. Areal distribution of arsenic in bedrock wells.

table), then the elimination of the downward percolation of water through the waste will have little effect on ground-water quality. This aspect of the LaBounty site should be considered during the planning of contaminant containment strategies.

Another possible explanation for location of the most highly contaminated ground water is that it is located near EPA piezometers P-2, P-7, and P-8, which, as previously noted, may be in the most permeable portion of the aquifer. The high rates of ground-water flow through this area may tend to mobilize contaminants.

A significant observation of the contaminant plume is that it attenuates rapidly in a riverward direction. This is probably related to the dilution effects of recharge from the water table, from the Cedar Valley aquifer, and from the volumes of water that periodically enter the alluvium from the river as bank storage.

Two possibilities exist for the transport mechanism responsible for the contamination of the bedrock wells. One possibility is that the contaminated water is driven by a density gradient downward into the fractured bedrock. This is difficult to quantify because the density of the contaminated water is unknown, and the analytical methods used to describe multiphase ground-water flow are very complex. The second possibility is that a shallow advective circulation cell is active from the waste to the fractured bedrock and back to the alluvium. The head data near the waste is inconclusive in this regard, however.

The possible existence of a density gradient in the contaminated ground water below the site is significant, however,

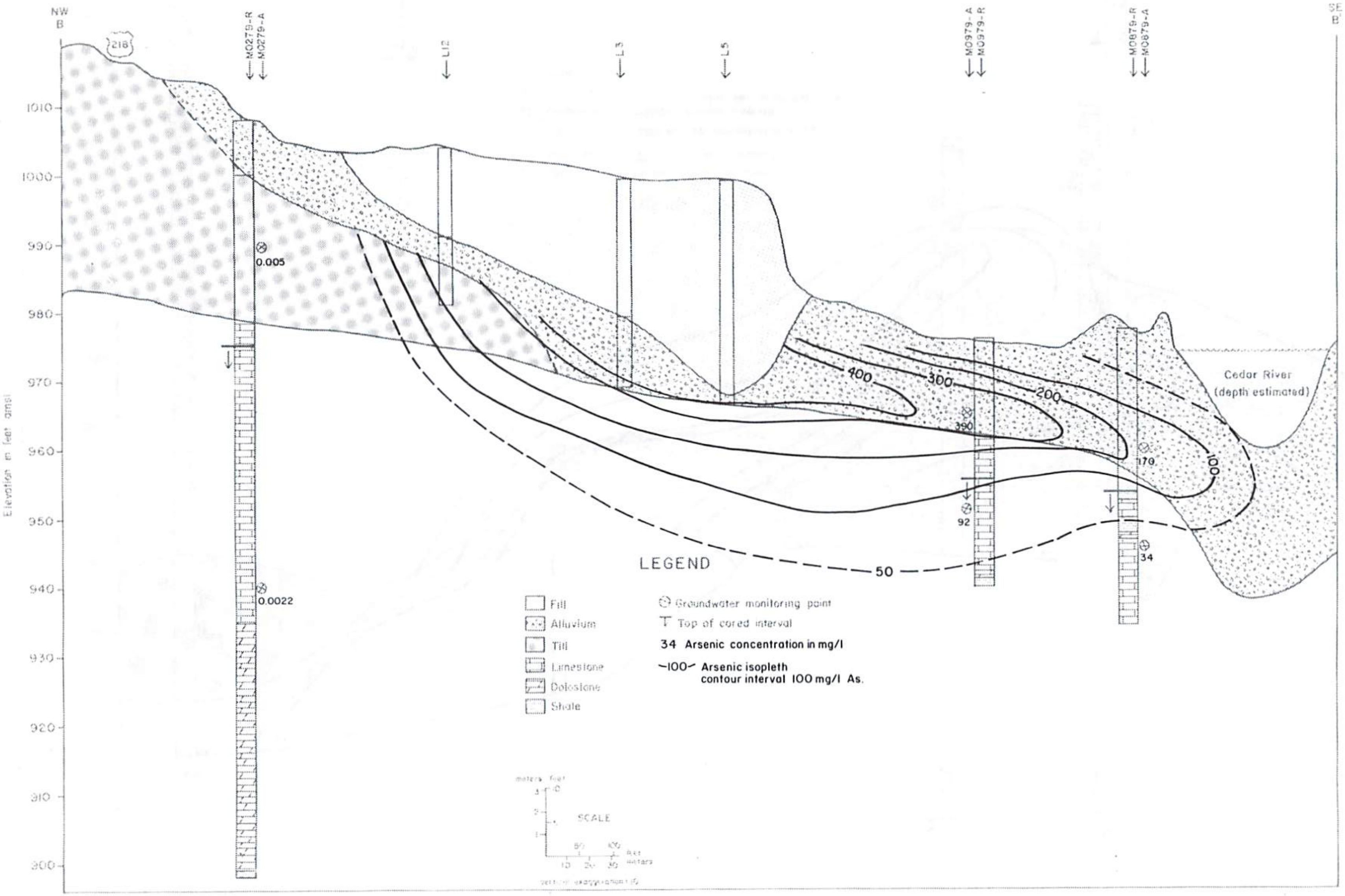

Figure 21. The leachate plume in cross section B-B'.

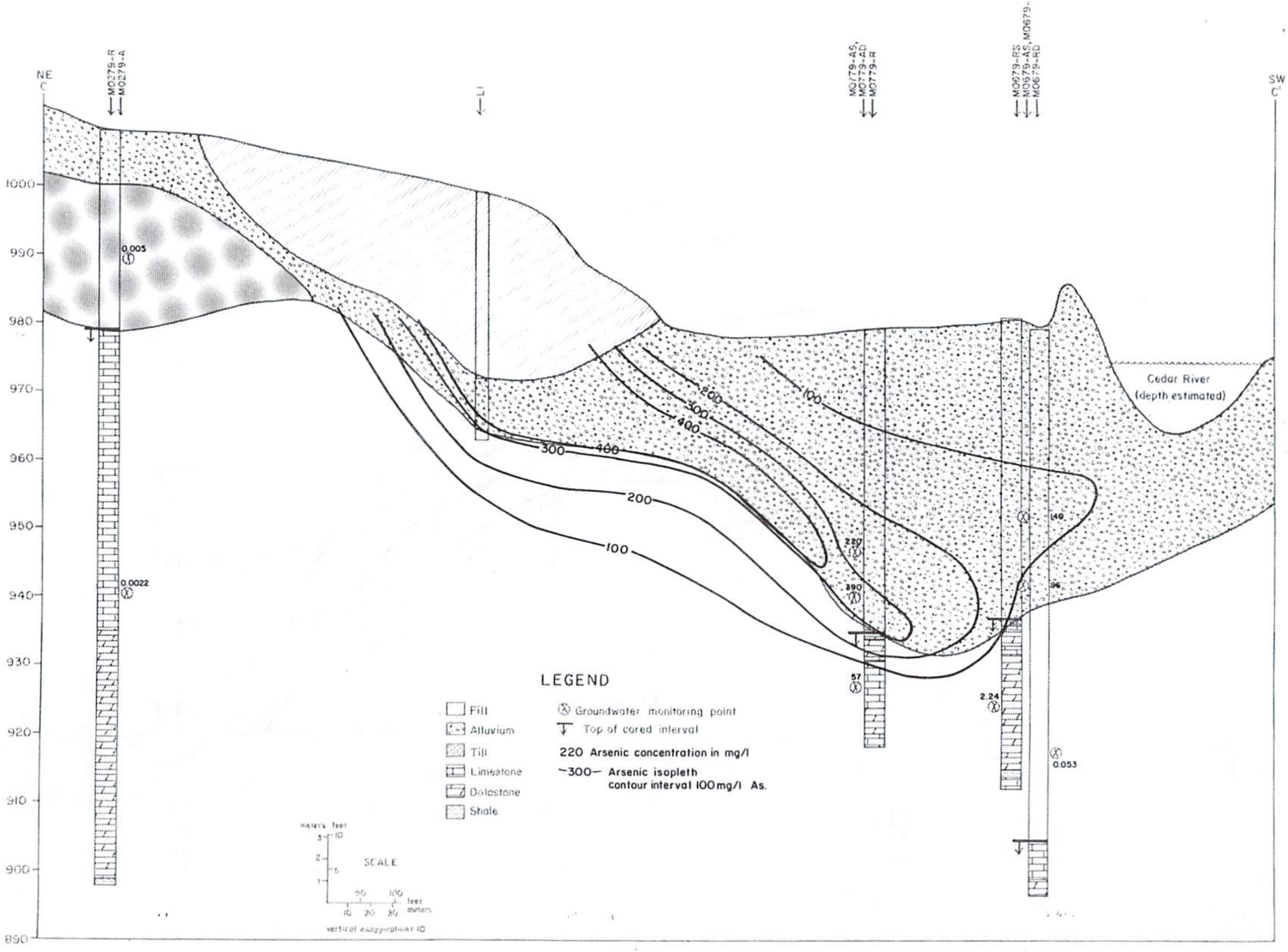

Figure 22. The leachate plume in cross section C-C'.

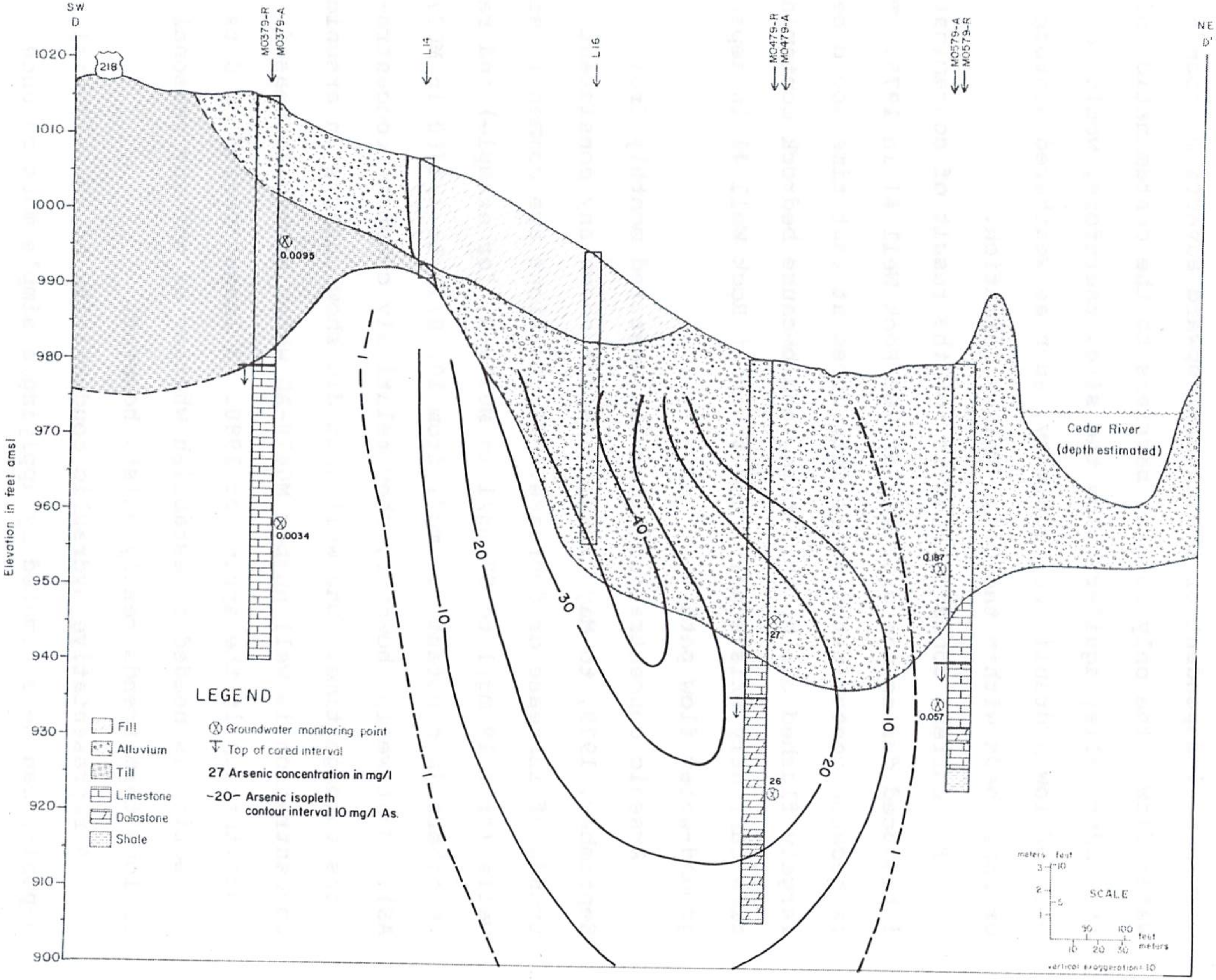

Figure 23. The leachate plume in cross section D-D'.

because it would mean that contaminated ground water could flow downward, independent of the natural upward advective ground-water flow. The only natural barriers to the contamination of the Cedar Valley aquifer below the site, therefore, would be ones of low hydraulic conductivity, such as weathered bedrock or shale beds within the Cedar Valley Formation.

The current contamination is not the result of contamination introduced during the drilling of IGS Rock Well #1 in 1975. This is because contaminated water introduced at that time would be largely flushed out by this time, and because bedrock contamination currently exists north and south of Rock Well #1 in separate ground-water flow paths.

Arsenic concentrations in wells measured monthly from September, 1979, to May, 1980, have not shown any consistent trends of increase or decrease. Fluctuations are common in some wells (from 19 mg/l to 57/mg/l in M0779-R, for example) and rare in others (a constant 190 mg/l from 10/18/79 to 1/4/80 in M0779-AS). Most wells, however, show relatively constant concentrations through time. One well that did show changes in arsenic concentration is well number M0679-AD which showed increased contamination in the spring of 1980. A longer period of data collection is needed to establish whether or not any seasonal or long term trends really exist, however.

A representative hydraulic conductivity of the alluvial deposits can be estimated by applying a simple mass balance equation and Darcy's law to the available data. These equations are: (Note: Bracketed quantities denote units; M=mass, L=length, T=time.)

(1). $Z = C \times Q$ where:

Z = Load of arsenic supplied to the Cedar River from the LaBounty site ground water [M/T];

C = average concentration of arsenic in the ground water [M/L^3]; and

Q = volumetric rate of flow of ground water to the river [L^3/T].

(2). $Q = K \times I \times A$ where:

Q = as above

K = hydraulic conductivity [L/T];

I = ground-water gradient towards the river [Dimensionless]; and

A = cross-sectional area perpendicular to flow [L^2].

These equations can be combined and solved for K to yield $K = Z/(C \times I \times A)$ (equation 3). All of the items on the right hand side of this equation can be estimated with some accuracy from the available data. The load to the Cedar River (Z) has been calculated by measuring the concentration of arsenic in the river water and the rate of flow of the river both upstream and downstream of the LaBounty site, and taking their product. The average of five such calculations between 10/2/79 and 5/8/80 is 45 lbs/day (0.235 g/sec), with a range of 34.1 to 65.9 lbs/day. To obtain estimates of the remaining variables, it is convenient and reasonable to assume that all of the contaminated ground water enters the Cedar River in a leachate plume 800 feet (244 m) wide, 20 feet (6.1 m) thick, with a time averaged horizontal ground-water gradient of 0.002, and with an average arsenic concentration of 100 mg/l. Substituting these values into equation 3 yields

$$K = \frac{0.235\ \mathrm{g/sec}}{0.1\ \mathrm{g/l} \times 0.002 \times 244\ \mathrm{m} \times 6.1\ \mathrm{m}} \times \frac{1\ \mathrm{m}^3}{1000\ \mathrm{l}} = 7.9 \times 10^{-4}\mathrm{m/sec} = 7.9 \times 10^{-2}\mathrm{cm/sec}$$

$$= 1{,}700\ \mathrm{gpd/ft}$$

$$= 220\ \mathrm{ft/day}$$

This value of K is very likely to be accurate to within an order of magnitude because all of the variables used to determine it are known with considerably greater accuracy. Also, it is somewhat larger than previously noted lab determinations (6) but well within the range of values commonly assigned to alluvial deposits.

In order to calculate the average linear ground-water velocity (v), it is necessary to estimate the effective porosity (n) of the alluvium. The proper formula for calculating velocity is v=(K x I)/n. K and I are defined exactly as they were for Darcy's Law. Bulk porosities for sand and gravel are typically in the range of 0.2 to 0.3, but effective porosity is somewhat less, and a value of 0.2 is commonly used. The approximation is quite good in comparison with another parameter in the formula, hydraulic conductivity.

Substituting the appropriate values into the equation yields

$$v = (7.9 \times 10^{-2}\text{cm/sec} \times 0.002)/0.2 = 7.8 \times 10^{-4}\ \text{cm/sec} = 2.2\ \text{ft/day}$$

This means that it takes approximately 6 months for a volume of ground water to travel from the dump site to the river 400 feet away. By similar reasoning, it would take ground water at least 100 days to reach the nearest 1979 monitoring well, M0979-A, which is about 220 feet away from the edge of the fill. It must be remembered that these are only average velocity values, and that ground water velocities are likely to vary with different flow paths, at different places along the same flow path, and with different water-table conditions.

SUMMARY AND CONCLUSIONS

The Devonian stratigraphy in northeastern Iowa is not well understood. Three members of the Cedar Valley Formation are defined elsewhere in the state, and can only be tentatively distinguished at Charles City. The major shale found in IGS Rock Well #3 has never been identified in outcrop, and its distribution in the subsurface is uncertain. The shale is known to be an effective confining bed between the upper and lower Cedar Valley aquifers at the LaBounty site, however. Even if the shale is a laterally persistent stratigraphic horizon, erosion has removed the shale and overlying beds from the Cedar River valley at a minimum of 3 and a maximum of 26 miles southeast of Charles City.

The regional trend of the Cedar River is most likely controlled by the regional strike of the bedrock units. The local trend of the river in Charles City, where bedrock is near the surface, is parallel to major joint trends in the area. It also appears that joints have an effect on the direction of ground-water flow in bedrock at the LaBounty site, but it is secondary to the overall control by the recharge-discharge relationships of the flow system.

The Cedar River is a regional discharge point of the Cedar Valley aquifer. Recharge is in the upland interstream divide areas. As a consequence of this flow system, upward ground-water gradients exist near the river. These gradients have been observed in IGS Rock Well #3, and in the rock well monitoring system installed at the LaBounty site in 1979. The gradients undoubtedly exist elsewhere along the river, and are the primary means by which the Cedar Valley aquifer is protected from contamination. The shale in Rock Well #3 is widespread, but is not a regionally continuous impermeable horizon providing protection for the aquifer. Should density effects be found to control migration of wastes at the LaBounty site, however, the shale will almost certainly be an effective lower limit of waste migration.

Future concern about the Cedar Valley aquifer should be focused on man-induced changes in the natural flow system. Contaminated river water will enter the aquifer where the local hydraulic gradient is reversed, such as near reservoirs, dewatered quarries, and pumping wells.

The LaBounty site is located in the alluvium of the Cedar River, which has an average hydraulic conductivity of about 7.9×10^{-2}cm/sec. Ground water in the alluvium is highly contaminated immediately down gradient of the saturated portions of the waste. Fractured limestone bedrock under the site is also contaminated. Attenuation of the contaminant plume near the river is evident, probably because of dilution from recharge.

Fluctuations in contaminant levels from October, 1979, to May, 1980, are apparent, and tend to obscure seasonal or long term trends, if they exist. The contaminant plume appears to have reached steady state at the time of this writing, however.

The effects of placing a clay cap over the fill material are likely to be twofold. Percolation through the waste will be reduced, resulting in both a decrease in the amount of leaching in the unsaturated zone, and a slight decline in the water table in or below the waste. The decrease in ground-water contamination however, could be imperceptible because the leaching of waste in the saturated zone is probably the major source of contamination, and because the decline of the water table will be slight.

If, on the other hand, the production of leachate in the unsaturated zone is the source of the bulk of the contamination, then a reduction in the downward percolation of water through the waste will have a substantial beneficial impact on ground-water quality. The importance of leaching in the unsaturated zone is currently not known. Unfortunately, any improvements in ground water quality will not be observed for a considerable length of time in the existing observation wells. Using an average linear ground-water velocity of 2.2 ft/day, ground water from the waste will not arrive in major quantities to the nearest observation well in less than 3 months, and the travel time to some other wells may be close to a year.

Another problem with observing changes in contaminant levels in observation wells is that fluctuations that have been documented are likely to continue and effectively mask small improvements in water quality. At least several months would probably be required to establish a trend at any observation well, subsequent to the arrival of ground water with lower contamination levels.

RECOMMENDATIONS

Recommendations regarding the regional setting have been listed on pages 20-21, and will not be repeated here. Several recommendations regarding the LaBounty site are listed below.

1. At least one full year should be allowed subsequent to the completion of a clay cover on the fill before a final analysis is made on it's effectiveness.
2. A well completed in the alluvium beneath the fill would help to establish the relative importance of density gradients versus natural advective flow in contaminating the bedrock aquifer by:
   a) yielding a water sample for density measurements;
   b) defining the water table in the fill material.

   Additionally, such a well would serve to identify changes in contamination levels with time in response to a clay cover or seasonal variations.
3. Laboratory studies could be done to evaluate the production and mobility of leachate in the fill material by simulating conditions that would be expected to occur above and below the water table.
4. Monitor the Cedar River elevations near the observation wells at the same time that the water observations are made in the alluvial wells.

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APPENDIX:

Geologic Logs of Test Holes

at the LaBounty Site

Preliminary Core Description

Aug. 13-14, 1979 LaBounty Disposal Site, Charles City

Hole No. 1; elev. 1005'

R. McKay IGS

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0 - 9.8	Surficial sediments, not logged
9.0 - 10.8	Reamed out top of weathered bedrock
10.8	Core begins
10.8 - 12.4	Limestone, brown, dense, calcilutite, slightly argillaceous, contains abundant redochrous cubic hematite xlts 1-2mm large, rare 1mm wide calcite filled fractures.
12.4 - 12.6	Clay and loose lms fragments .25" or less in diameter and angular, poor recov.
12.6 - 13.8	Lms - brown, dns, v.f.gr., abun Fe specks and dendrites, rare brachs
13.6 - 15.6	Lms - Stromatoporoids abun., foss. argillaceous calcilutite matrix
15.6 - 16.9	Dolo. - tan to orange, calcareous, clayey to silty, abundant liesegang
16.9 - 22.5	Lms - dense, stroms. abun., 2"-6" large, very foss. calcilutite matrix minor porosity
22.45 - 26.0	Lms - gray to brwn mottled, abundant large stroms grading to downward to finger stroms w/foss. calcilutite matrix (brachs, spicules), dense,
26.0 - 29.1	Lms - light gray, argillaceous calcilutite, finely laminated, non-foss, moderately porous
*29.1	Lost circ. - remained lost for remainder of hole
29.1 - 30.45	Shale - green and brown, interlaminated color, calcareous, wavy to horz. laminae, clayey towards base, non-foss., minor bioturbation
30.45 - 32.45	Lms - (marl), very argillaceous, some gray and grn calcareous shale laminae, iron stn in pt, mottled in pt., non-foss., moderately porous, rare calcite filled brachs
32.45 - 41.15	Lms - very fine xltn, argillaceous, light gray, dense, rare brachs, some Festn. 1" clay & lms fragment plug at 39.45', lam. to mottled at base.
41.15 - 42.05	Lms - brn, coarse xltn, good porosity, slightly argillaceous, 2-3mm pores
42.05 - 46.45	Lms - lt gry, fine-med xltn, argillaceous, rare bachs, abundant vertical and spotted dendrites, dense, at 43' '" thick brown clay w/lms fragments.
46.45 - 49.15	Lms - lt brn - lt gry, fine - med. xltn, argillaceous, w/ anastomising calcite xlt lined 2mm wide fractures and occasional xlt lined rugs, at 48 is a 4" breccia a ½" layer of dk brn organic rich lam. arg. lms., good porosity in places.
49.15 - 50.25	Shale - gray & brn, calcareous
50.25 - 51.65	Lost core

51.56 - 53.95	Lms - lt brn - lt gry, fine xltn, argillaceous abun. vertical xlt lined fractures & vugs, mod. porous, some clay filled fractures.
53.95 - 57.25	Lms - very arg. to cal. shale, extremely fractured and brecciated, clasts are lam shale and dense gray lms, many plucked clasts some cavities xlt lined, 1.6' core lost here.
57.25 - 58.05	Lms - very arg., tan, 1" zone of dk brn org. rich laminae at top and bottom, some 1-2 mm calcite filled vertical and horizontal frac.
58.05 - 60.35	Shale - brownish gray, cal, slighted bioturbated, some xlt lined fractures, grades to very arg. lms. in lower 6".
60.35 - 65.6	Lms - gray, fine xltn, arg., dense, stolytic, occasional dk brn lam., occasional xlt lined vugs near base, non-foss. modporous at base.
65.6 - 66.8	Dolo - dolomitic lms, brn, fine to med xltn, gradational top and bottom, mod. porous
66.8 - 67.7	Lms - brownish gray, arg., dense, soft.

T.D. 67.7'

Preliminary Core Description

Aug. 1979 LaBounty Disposal Site, Salsbury Labs, Charles City

Hole No. 2; elev. 1008'

Brian Witzke IGS

32.8 - 35.4	(1.8' recor'd) Limestone, calcilutite - calcisiltite, weathered to very weathered, abundant stromatoporoids; crinoid debris and brachiopods.
35.4 - 40.5	(very poor recovery) Broken into pieces less than 2"; largest piece 3" from top of run -- Dolomite, calcareous, dense, mottled, argillaceous streaks, very fine; primary limestone as above with vertical fractures noted, some filled with clay/sd.
40.5 - 44.65	(about 1' recov'd) Mostly broken into pieces less than 2"; Limestone as above solution weathered and smooth vertical fractures, partly filled clay; clay fill may also contain sand and gravel.
44.7 - 47.7	(1.4' recov'd) Limestone with clay/sand/gravel filled solutional vugs; Limestone, partly argillaceous with irregular laminations, some stylolites.
47.7 - 49.1	(less than 0.5 ft. recov'd) Limestone
49.1 - 52.95	(2.75' recov'd) Limestone, dense, crinoidal, very fine to crystalline, clay fill in weathered zone; lower 2.3' Limestone, part fractured, some vugs to pin-point porosity, very weathered and broken, clay at bottom
52.95 - 59.4	(5.4' recov'd) solutional pitting at top; top 0.8' Limestone with thin argillaceous to shaley partings and laminations; Limestone, argillaceous, shale fill at 54.3, highly weathered, marly
59.4 - 69.4	Limestone, argillaceous to very argillaceous, brecciated 62-64.6', shale fill and partings, argillaceous laminations in places, calcite-filled vertical fractures 64.6-65.6'; Limestone, sugary, pin-point porosity 67.8-68.8'; Limestone, dense, faint mottling at bottom
69.4 - 70.2 - loss	(remainder of core nearly 100% recovery)
70.2 - 71.1	Limestone, very dense, faint argillaceous mottling
71.1 - 72.4	Limestone, dolomitic, dense, slightly argillaceous; 72.4 - 73.1 Limestone, dolomitic, highly brecciated in shaley matrix
73.1 - 84.2	Dolomite, calcareous, argillaceous in top 4' becoming less argillaceous below, scattered calcite filled solutional vugs and fractures, generally dense with porous zones at 75', 77.3-77.7', and 84'.
84.2 - 85.8	Dolomite, very calcareous, argillaceous, slightly porous top ½', medium to coarse-grained, calcite void fills, irreg. arg. parts at base
85.8 - 88.0	Limestone dolomitic -- dolomite calcareous, argillaceous, becomes less argillaceous in bottom 1' where porosity develops, abundant fossil molds (<u>Atrypa</u>)

88.0 - 95.7	Dolomite, slightly calcareous, very porous with solutional vugs to 2" down to pin-point porosity, fossil molds present
95.7 - 96.4	Dolomite, slightly argillaceous - very arg. laminated, pin-point porosity to 1mm pores at base; 96.4-97.4 Dolomite, calcareous, dense, argillaceous, 1½" soft shale at top, abundant burrow mottling.
97.4 - 99.1	Dolomite, calcareous, very dense, arg.-very arg. with saccharoidal porous dolomite at base and soft shale.
99.1 - 101.1	Dolomite, calcareous, dense, pt. arg., calcite fill in vertical and horizontal fractures; 101.1-103.5 Dolomite, calc., saccharoidal, at top and 102.4'; 103.5-105.75 Limestone with abundant thin argillaceous laminations, part porous saccharoidal texture.
105.8 - 106.1	Limestone, dolomitic, slightly porous with abundant calcite fracture and void fill; 106.1-108.1 Limestone, dolomitic, argillaceous-very arg. with thin very dark gray shale partings; 108.1-110.5 Limestone, dolomitic, arg. to very arg. at base, calcite filled vertical fractures and vugs, calcite crystal filled vugs, black shale at 109.5.
T.D. 110.5	

Preliminary Core Description

Aug. 8-9, 1979 LaBounty Disposal Site, Salsbury Labs
Hole No. 3; elev. 1015'
Brian Witzke IGS

35.95 - 38.05	(1.9' recov.) Limestone, dense, sublithographic, crinoid debris, subhorizontal to subvertical fractures; clay fill abn't, soft, lt olive brown - yellow orange
38.05 - 43.0	(2.0' recov.) Driller reports hitting clays 4 times; Limestone, very dense and fractured, sublithographic, fractures may be clay filled, dendrites present; clay, light brown gray w/sand and gravel (to 1cm), non-calcareous and clay (plugged at bottom of core barrel), light olive brown, calc. w/broken limestone chunks
43.0 - 49.3	(3.0' recov.) Limestone at top broken into pieces <2", Limestone, clay, and dolomite w/liesagang bands; clay plug 1.0', light olive brown to orange brown, trace limonite, non-calcareous; Limestone, fractured to highly fractured, porous to solutional vugs to 1", some clay fill; Dolomite very fine grained w/Liesagang banding (NOTE: core catcher was stuck up in core barrel).
49.3 - 52.3	(2.4' recov.) top: Limestone, v.f., very fractured w/clay fill; 1.0' stretch of Limestone w/abn't stromotoporoids, some porosity; bottom: Limestone, stromatoporoids, vertical solution fractures, part clay filled
52.3 - 59.1	(5.7' recov.) top 0.9' Limestone, crinoidal, abn't stromatoporoids next 2.8' Dolomite, dense, trace porosity and pores to 3mm, abn't Liesagang banding, tr. dendrites, some clay fracture fill; next 0.5' Limestone, fossilif., crinoidal, vertical solution fractures, part clay filled; next 1.1' Limestone and abundant clay fill w/Ls. gravel, base w/light brown dolomitic shale; bott. 0.4' Limestone, large stromatoporoid, abundant spiriferid brachiopods, calcite void fill.
59.1 - 65.65	(4.7' recov.) Limestone, dense, slightly fractured at top down to fossilif., brachiopods, Limestone w/prominent solution fractures; Limestone, dense, abn't wavy argillaceous partings, partly brecciated at bottom (0.94'); Limestone breccia (clasts to 2 cm) in shaley matrix (0.6'); bottom 1' highly fractured weathered limestone with abundant clay fill
65.65 - 75.3	(9.4' recov.) --- Description done very quickly -- and crudely top 2½ Limestone with calcite fracture fill lower portion includes Limestone, argillaceous; breccia as above; burrow-mottled shaley dolomite, shale near bottom 2", lt. grn. gr.

Preliminary Core Description

Aug. 28, 1979 LaBounty Disposal Site, Charles City
Hole No. 4; elev. 981'

R. McKay IGS

44.7 - 49.2	Dolomite - tan, slightly broken, med. xltn, slight to moderate open vugular porosity, many vugs and horizontal calcite lined planes good porosity.
49.2 - 54.7	Lms & Dol - lms is dolomitic, 1' interbeds, dolomite is porous lms is more dense, both have abundant calcite xlt. lined or filled vugs, both dol. & lms slightly to moderately foss. At 51.7 is ½" black clay parting, calcareous, At 50' lms is styolitic
54.7 - 63.5	Dolomite - tan, medium to very coarse xltn, abundant large vugs, some vugs xlt lined, some xlt filled, excellent porosity, abundant brach and echimolds 56.2'-59.7', 1' lms at 59.7 to 64.7' then back to dolomite, dolomite is slightly arg & dense but good porosity (med xltn).
63.5 - 64.7	Shale - green, dolomitic to very arg. dolomite, laminated to bioturbated to brecciated, mottled color, dense, 1 or 2 clay partings probably washed out, well cemented, at base turns back to a medium xltn tan dolomite w/good porosity.

T.D. 74.7'

Preliminary Core Description

Aug. 22, 1979 LaBounty Disposal Site, Charles City
Hole No. 5; elev. 980' R. McKay IGS

40.2 - 42.5	Lms - brown, fine xltn, dense, hard, some calcite filled vugs and veins, rare organic rich
42.5 - 44.9	Lms - calcilutite, brn, arg, a few organic rich lam (possibly styolitic) grades to dol. below, lms is dense w/some calcite filled fractures and vugs.
44.9 - 48.5	Dolo - brown, slightly calcareous, very fine to fine grn., brach casts and molds, calcite xlt lined vugs, moderately porous, bottom 1' is very broken and porous, slightly argillaceous.
48.5 - 49.9	Dolo - brown, fine to med. xltn, sugary, abundant brach molds, moderate porosity, many calcite xlt. lined vugs, iron stning common.
49.9 - 50.6	Dolo - brown, abundant brn calcite vug and fracture fills good porosity.
50.6 - 52.1	Lms - tan to gray to brown, fine xltn, many scattered patches of brn. calcite fracture and vug fill, slightly arg., moderately dense.
52.1 - 52.7	Dolo - brown, fine xltn, many patches and lenses of brown calcite, dense, poor porosity, non-foss.
52.7 - 54.0	Lms - brown to gray, fine xltn, dense but w/½" to 1" calcite lined vugs in upper 1', non-foss.
54.0 - 55.3	Shale - green to gray, mottled color, very bioturbated?, dolomitic, slightly calcareous, 54.0'-54.2' brecciated but well cemented, 54.6-54.7 laminated calcareous zone, 55.2'-55.3' styolitic clay?
55.3-57.4	Dolomite & Shale brn, med xltn grading to vary dolomitic green shale beginning at 56.4', 56.6-56.7' 1" pure green shale, 56.4' to 57.4' bioturbated
T.D. 57.4	

Preliminary Core Description

Aug. 29-31, 1979 La Bounty Disposal Site, Charles City
Hole No. 6; elev. 981' R. McKay IGS

44.0 - 54.0	Dolomite and Dolomitic Lms - interbedded 44'-52', gray arg., moderately dense, fine xltn, many calcite lined and filled vugs, core recovered very broken, black oxide? stain coats many broken surfaces, some rare solution smoothing of fragments. 52'-54' tan med. xltn moderately abundant small foss. molds, recovered broken, dolomite w/calcite mold & vug fills, unit has overall good porosity partly due to broken nature of recovery, partly due to xltn size and vug and mold presence.
54.0 - 59.0	Dolomite - tan, fine to medium xltn, slightly calcareous in part, slightly arg. in part, many small calcite filled foss. molds, 55'-56' filled vugs, core recovered moderately to very broken, some solutionally smoothed? fragments, many broken surfaces on top & bottom were covered w/a black coating that would rub off on fingers when wet(MnO?).
59.0 - 61.6	Dolomite - tan, med-coarse grained, top 3" recovered very broken rest of core recovered in tact, abundant small foss, debris molds, extremely abundant, calcite filled vugs, good to excellent porosity, arg. toward base, pyrite xlts in top 3" on fossil casts and broken surfaces, solid bot porous rock in general
61.6 - 64.0	Dolomite - tan, med-coarse grained, abundant brach and other fossil molds, many calcite xlt lined vugs and molds many open molds, excellent porosity 62.8'-63.4' is a zone of irregularly distributed black shale laminae where the relatively solid core broke - this 6" zone correlated well w/hole #4. Core recovery good on this unit, solid but porous rock.
64.0 - 68.1	Dolomite, Shale, Lms - Dol. tan, med-coarse grained at 64.4' grades to greenish brown (mottled) dolomite at 64.65 grades to well cemented green & mottled dolomitic shale. Shale is .15' tk and has an abrupt lower contact w/sporadic green arg. coarse xltn dol. at 64.8'. 64.8-65.9 - Dol - tan, fine xltn, slightly cal., dense, .15' arg. gradation back to mottled green dolomitic shale at 65.9'.
65.9 - 67.25	Shale - green, mottled light and dark green, very slightly brecciated well cemented, 66.5-66.7 coarse grained dolomite 66.7-67.2 but well cemented, clay plug (green) at 67.2-67.25, calcareous, abrupt and irregular lower contact.
67.25 - 67.35	Lms coarse xltn, abrupt upper & lower contact
67.35 - 68.95	Lms tan, lithographic, vertical microfractures w/porosity, grades to tan dolomite, very coarse xltn, very porous.

Preliminary Core Description

Aug. 14, 1979 LaBounty Disposal Site, Charles City

Hole No. 6RD; elev. 979.51'

Brian Witzke IGS

RUN 1

75.15 - 83.15	(100% recov'd)
73.15 - 73.4	Dol., v. lt. gr., f-m, very porous, calcite fracture fill
73.4 - 75.4	Ls, v. lt. brn. gr., v. f., extremely argillaceous w/abundant dk. gr. laminations (especially in upper 1.4'), pin-point porosity developed in lower half.
75.4 - 79.1	Ls, v. lt. brn. gr. - lt. brn., v.f. - f., arg. w/scattered to abundant argillaceous laminations, pin point porosity developed becoming denser in lower 1 ft.; abundant calcite filling in top 4", less calcite fill below, calcite void common in lower 2'.
79.1 - 80.7	Ls, v. lt. brn. gr., v. f., dense, slightly argillaceous, some thin calcite fracture fill; two thin ½-1" black shale bands in top 8"; dk. brn. fr. calcareous shale fill at base.
80.7 - 81.5	Dol., v. lt. gr. - lt. gr., v. f., slightly argillaceous, calcareous, slightly porous; lower contact gradational
81.5 - 83.15	Dol., lt. gr., v. f., dense, some thin shales, scattered calcite fill.

bottom elev. 896.4

Hole #7R, elev. 979.5 ft. cored Sept. 11, 1979

Brian Witzke IGS

44.6 - 45.6	Limestone, lt. gr. - v. lt. brn. gr, dense, v.f., some vertical fractures lined w/granular calcite, dolomitic zone 2 in. above base
45.6 - 48.6	Dolomite, calc., lt. brn. gr., v.f. - f., part porous with small voids to 3mm in top 1 ft., denser in bottom 2 ft. to very slightly porous, calcite void fill w/calcite-lined geode at base, slightly argillaceous w/some argillaceous swirls above becoming argillaceous w/scattered thin dk. gr. clay streaks below.
48.6 - 55.4	Limestone, dolomitic, pale to v. lt. brn. gr., v.f., some v.f.-m., dense, slightly to very argillaceous w/scattered to abundant thin dk. gr. - lt. brn. clay streaks, some calcite void and fracture fill.
55.4 - 59.8	Dolomite, v. lt. brn. gr., v.f., very porous with voids to 2 in. diam., some calcite void fill, slightly argillaceous brachiopods (<u>Atrypa</u>), lesser echinoderm debris.
59.8 - 61.3	Limestone, dolomitic, v. lt. gr., dense, abundant dark gray argillaceous streaks, some calcite void fill (especially lower ½ ft.)

Hole # 8R elev. 977.7 Sept. 11, 1979

B. Witzke IGS

RUN 1

23.8 - 33.1	(6.6' recovered; 71% recovery) top 0.15' Ls., v. lt. brn. gr., v.f., dense, calcite void fill
23.95 - 25.0	Clay plug, v. lt. grn. gr. - v. lt. org. brn., calc., w/some sand & ls. pebbles encl.
25 - 25.8	Ls., lt. brn - v. lt. brn. gr., v.f., dense, some dk. gr - m. brn arg. streaks
25.8 - 27.3	Ls, v. lt. gr., dense, highly fractured vertically, some calcite xl lining fracs., horizontal and vertical fractures coated w/dk. gr. - blk "smelly" precipitate.
27.3 - 29.3	Sh., lt. gr. - lt. m. gr. -- Ls., v. arg., brecciated, impermeable zone, pyrite (loss at bottom?)
29.3 - 30.25	Dol.,pale crm., broken, v.f. - SL, dense
30.25 - 33.1	Clay plug or shale, lt. gr., slightly calc., abn't broken ls.

RUN 2

33.1 - 43.1	(100% recovery)
33.1 - 33.45	Ls, lt. gr., arg., w/brecc. clasts
33.45 - 34.2	Ls, v. lt. brn. gr., v.f., m. brn. - dr. gr. argillaceous streaks, calcite void fill
34.2 - 35.7	Ls., v. lt. gr., arg., some thin horiz. calcite fracture fill
35.7 - 36.1	Ls., v. lt. gr., calcite fill, numerous voids to ½" diameter; base marked by v. dk. brn. shale, slightly calcareous
36.1 - 37.4	Ls., v. arg. -- Sh., v. calc., v. lt. gr. - lt. gr., calcite-lined void 5" down from top; arg. lamination w/flat-pebbles, highly brecciated in lower half.
37.4 - 39.7	Ls., lt. gr. lt. brn. gr., arg. - v. arg., abn't arg. laminations & streaks, clacite fill and calcite xl lined geodes to over 2" in top 1.0'
39.7 - 43.1	Ls., lt. gr. - lt. brn. gr., calcite void and fracture fill, arg. - v. arg.; arg. streaks and swirls, in part dk. brn. - dk. gr.

Hole # 9R elev. 976.15 September 14, 1979

B. Witzke IGS

Run 1

20.45 - 30.45	(9.95' recovered)
20.6 - 21.1	Ls., v. lt. gr. - v. lt. brn. gr., v. f., abn't lt. brn arg. laminations becoming lt. m. brn. calc. shale at bottom
21.1 - 22.0	Ls., v. lt. brn - lt brn., v. f., dense
22.0 - 23.0	Ls. a. a. w/abn't thin argillaceous laminations and streaks, lt. m. brn. - dk. gr.
23.0 - 24.25	Ls. v. f. - f., lt. brn. - lt. m. brn. gr., dense, slightly arg., some thin calcite vein and void fill.
24.25 - 27.9	Ls., v. lt. gr. - lt. brn., highly brecciated, w/abn't lt. m. gr. brecciated ls. clasts in ls. or clay matrix, clay fill in breccia at 24.6 - 24.9 and 27.1 - 27.9; dense ls. w/ large 3" calcite-lined void at 26.5 - 26.7; swirled arg. streaks near center of unit
27.9 - 28.55	Ls. v. f. - f. lt. brn., abn't calcite void and fracture fill, partly porous
28.55 - 29.8	(right and left side of core in this interval is each of different lithology) <u>one side</u>: brecciated fill w/ ls. a.a., calcite fill becoming argillaceous in lower 7". small breccia clasts <u>other side</u>: ls., lt. gr., v.f., dense, w/dk. gr. arg. streaks and laminations, becoming slightly porous in lower 5"
29.8 - 30.45	Ls., lt. gr., dense, v.f., stylolites, partly brecciated with abn't m. gr. shale fill

RUN 2

30.45 - 36.15	(100% recovery)
30.45 - 33.6	Ls. breccia clasts to 2½" diameter, in m. gr. shale matrix, slightly calcareous
33.6 - 34.8	Dol., dense, fractured, pale cream in top 5½", argillaceous at top, very porous, rubbly dolomite zone below becoming denser and partly brecciated at base; calcite frac. fill crosses boundary of dense and porous zones
34.8 - 36.15	Shale, dol'c, v. lt. gr. - m. gr., dk. laminations and irregular swirls (bioturbated?), some vertical fractures.

Preliminary Core Description
Aug. 22, 1979 LaBounty Disposal Site, Charles City
Hole No. 10; elev. 987'
R. McKay IGS

Top of Core 10.5'

10.5 - 14.0	Lms - gray to brn, fine xltn, slightly arg., rare FeO spbs dense, 10.9' - 11.1' very arg. & broken zone, occasional thin shaley laminae.
14.0 - 18.7	Lms - brn, fn - med xltn, arg. in portions, some thin very arg. zones, occasional 1 mm wide calcite filled fractures, generally dense w/arg. zones being more porous., arg zones have greenish color
18.7 - 24.1	Lms - grey to dk brn, calcilutite, arg to very arg. 18.7 - 19.3 very arg & well lam., generally dense w/some calcite xlt. frac fill at 22' - 24'.
24.1 - 25.8	Lms - brn, calcilutite to fine xltn, very arg., some vertical calcite frac fills, grades to well lam gray & grn shale at 24.8, 25.4 - 25.8 shale is brecciated, grades back to very shaley calcilute
25.8 - 27.7	Shale - green, calcareous to arg. lms, laminated to bioturbated. At 27.1 is .4' brn clay plug in very porous tan coarse xltn lms. Overall porosity good.
27.7 - 33.8	Lms - brn, calcilutite, arg to very arg., brecciated in portions, extremely porous, large xlt lnd vugs, angular clasts (shale?) have weathered out, good recovery.
33.8 - 34.7	Lms - calcisiltite, compact but very porous, w/large 1" diameter fracture fill of 27.7-33.8 Lms.
34.7 - 38.7	Clay - tan, non-lam, calcareous, gradational to very arg. lms., very porous, bottom 7" is gray cal, non-lam clay (possible karst fill).
38.7 - 39.3	Lms - brnishgry, med xltn, very arg, porous
39.3 - 42.8	Lms & Shale - interbedded, well lam gray calcilutite w/org. rich interlaminae grading to very shaley calcilutite and to gray 1' tk cal shale, then abrupt contact at 41.2' w/.6' of coarse grn porous dolomitic lms then abrupt contact at 41.8' and back to gray arg. lam lms.
42.8 - 43.3	Breccia - dolomite clasts in coarse xltn arg. calcite matrix.
43.3 - 48.7	Dolomite - above grades to 2' (43'-45') of dolomitic lms and back to calcareous dolomite. Brnish gray, fine to med. xltn., arg to very arg., some xlt lined and filled bugs, 6" porous zone at 48'.

T.D. 48.7'

Preliminary Core Description

Aug. 22, 1979 LaBounty Disposal Site, Charles City

Hole No. 11; elev. 988'

R. McKay IGS

Top of Core 3.9'

3.9 - 6.15	Lms - gray, dense, med grn calcarenite bioturbated, Fe stnd lam, some smoothed edged solutional chunks, fos-brach, ech. debris, sparfilled fossil casts, core recovered very broken, probably good porosity due to broken nature of recovery.
6.15 - 12.0	Lms - gray to brn, calcarenite, bioturbated, slightly arg., dolomitic in part, some thin interbeds of very fine grn xltn lms (calcilutite), 11.4-12'0 is arg. lam, calcilutite w/green clay 1" plug near base, core recovered broken.
12.0 - 13.4	Shale, Calcilutite, Clay - tan - brn, all interbedded, all calcareous, slightly silty feel, green clay pebble near top, 12.6'-12.9' is green & brn clay plug, core recovered prtly broken esp. near top.
13.4 - 19.05	Lms - lt brn, muddy calcarenite, mod. amt foss. debris, dense, grades to sandy calcilutite at base w/1' zone of Fe-stng-arg-and moderately lam. calcilutite at base, moderately porous, broken along shale prtings.
19.05 - 28.85	Lms - brown to gry, muddy calcarenite grading to arg. calcilutite at 24' and arg. fn xltn lms at 27'. Core recovered intact, 3 clay plugs w/embedded lms chips in this unit, plugs are 1" to 3" long, 24'-28' has extensive calcite xlt frac. fills and lined vugs, much Fe stning, and some minor brecciation, porosity moderately high in this unit.
28.8 - 29.2	Uncon Sed - brown clay sand, lms frag, (prob. caving),
29.2 - 34.2	Lms - 29' - 30' gray, fine xltn w/Fe stn, dense grading to 30' - 31' partly broken extensively Fe stn lms w/ open vugs & calcite frac. fills, some vugs & frac are clay filled, 31 - 32' extensively broken very arg tan ls. w/grn & brown clay & ang lms fragment fills, this grades to 32-34' which is tan, brecciated fn xltn lms w/grn & brn calcareous shale to clay matrix, porosity high in this entire unit, open fractures abundant.
34.2 - 35.8	Shale - grnish grey, mostly brecciated w/6" lam sh. at 35', breccia consists of clasts of calcareous green shale & shaley lms in green cal. shale matrix, unit recovered very broken.
35.8 - 37.2	Shale - greenish gray, very calcareous, brecciated in part, laminated in part, core recovered intact.
37.2 - 38.8	Dol - tan, calcareous, arg at top grading to broken leisegang banded at 37.8'-38.4' grading to brecciated green shale at 38.8, moderately permeable.

38.8 - 41.1	Shale - greenish gray, calcareous, extensively brecciated but well cemented, clasts are calcareous shale in green shale matrix, 2-3 mm black clay near base, becomes 6" arg lms at base.
41.1 - 43.8	Shale - greenish gray, very cal, well cemented, dense, non-bioturbated non-brecciated, lam not obvious, thin black well laminated clay at base grading to very soft & mucky cal. gray clay 43.5 - 43.8'.
43.8 - 53.7	Lms - brown to gray, arg in 44-47', grading to pur fn xltn lms w/moderately abundant calcite xlt filled vugs and a few black organic lam., 53-53.7 slighted bioturbated and organic rich.
T.D. 53.7	