A GROUND-WATER STUDY USING EARTH RESISTIVITY METHODS

by

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INTRODUCTION

Purpose of Investigation

Direct current earth resistivity exploration methods have been used with considerable success in ground-water investigations in many parts of the world according to the literature. Previous use of resistivity in the Kansas River Valley of Kansas has not proven too satisfactory when compared with drilling test holes as a means of exploration.

The investigation was conducted in the Belvue-St. Marys area in an attempt to determine the usefulness of direct current earth resistivity methods in obtaining subsurface data in ground-water reconnaissance investigations. Bridge-foundation studies conducted by the Geology Section of the State Highway Commission of Kansas east and west of the study area indicate a deep channel below the alluvium in the Kansas River Valley. A deep channel was also recognized in the Blue River Valley during construction of the Tuttle Creek Dam and in several ground-water investigations in that valley. The channel, if filled with gravel, would yield large quantities of water to irrigation wells. The problem was to determine if direct current resistivity could be used to map such buried features as these deep channels.

Geography

The area of investigation is the Kansas River Valley in parts of Pottawatomie, Wabaunsee and Shawnee Counties, Kansas and from the west boundary of Range 13 East west to the west boundary of Range 11 East.

The towns of Belvue and St. Marys are within the area (fig. 1).

The area is within the Attenuated Drift Border of the Dissected Till Plains (Schoewe, 1949). The river valley is from three and one-half to four miles wide and the river flows generally southeastward.

The rainfall is approximately 32 inches a year; most precipitation occurs from April through September.

Geology

Rock units of Upper Pennsylvanian and Lower Permian Systems crop out along both sides of the Kansas River Valley (fig. 2). The uplands on both sides of the valley are partly covered by the erosional remnants of unconsolidated Quaternary sediments.

From topographic maps the altitude of the Americus limestone was determined at two locations on each side of the river valley. From this information the average dip of the bedrock units was determined to be about 16 feet to the mile to the northwest.

The relief of 250 feet has resulted from fluvial processes during the Quaternary Period. During the Early or Middle Wisconsinan Stage the Kansas River reached its maximum depth of downcutting resulting in relief of 330 feet or more. Although alluvium in the river valley is usually between 50 and 70 feet thick (fig. 3), in some areas, it exceeds 85 feet (Appendix V, F-9).

The Quaternary geology of the Kansas River Valley has been interpreted from alluvial deposits left by the Kansas River and its predecessors. Gravels of chert and limestone which now occur as small isolated remnants high on divides were dated as pre-Kansas or Early

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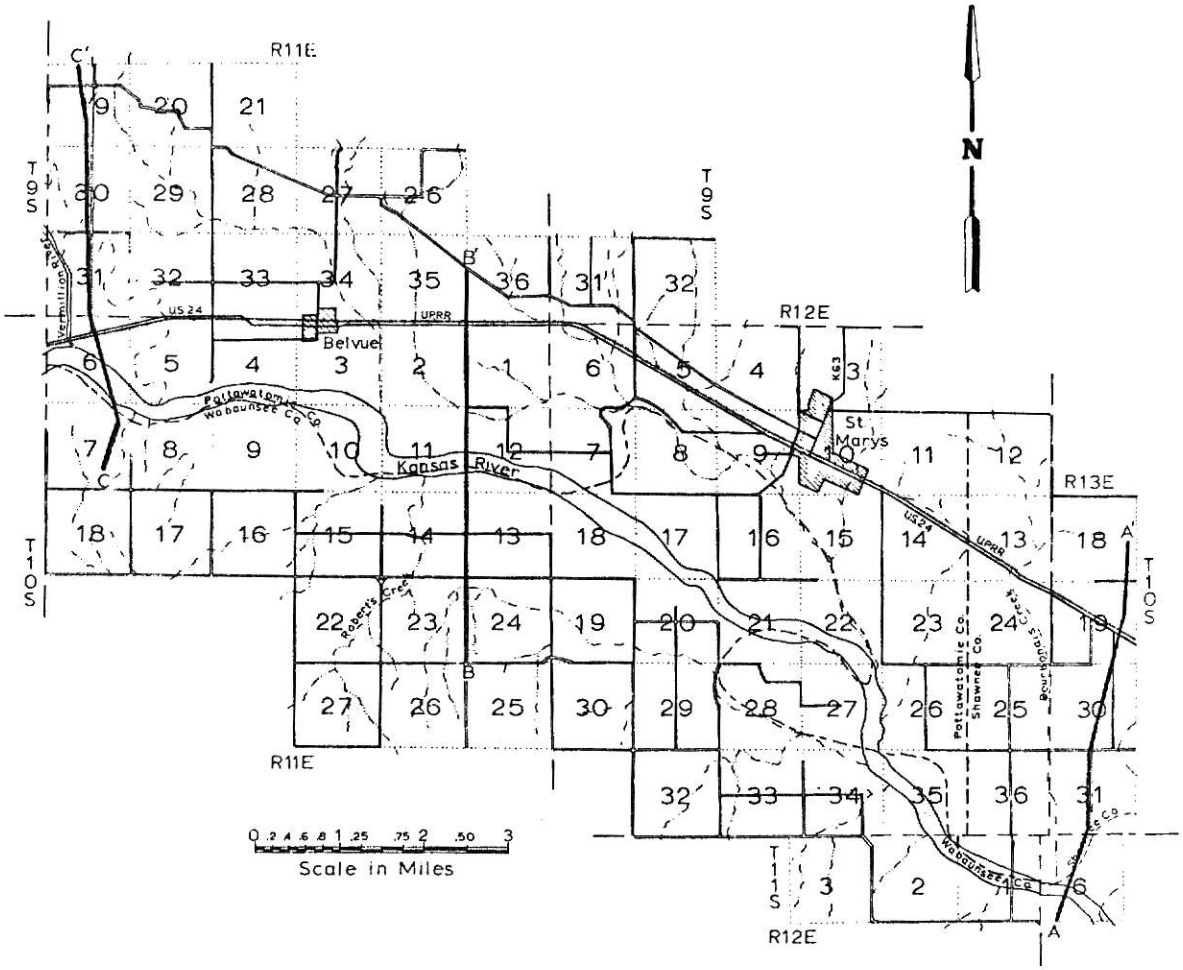
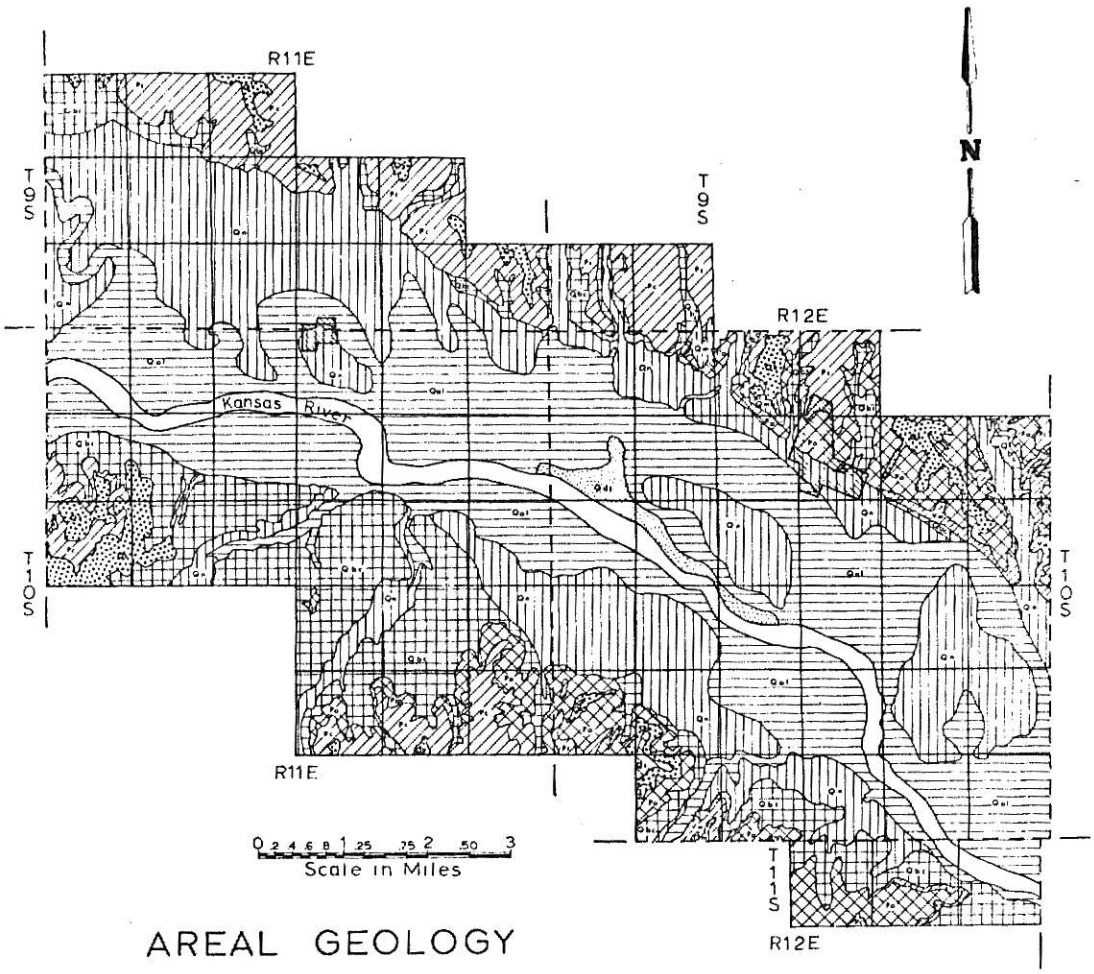


AREA OF INVESTIGATION Figure 1

EXPLANATION

- Federal or state highway
- County or township road
- Railroad
- County line
- Township line
- Section line (no road)
- Intermittent stream
- Towns



AREAL GEOLOGY

EXPLANATION

Figure 2

After Beck, 1959, plate 1

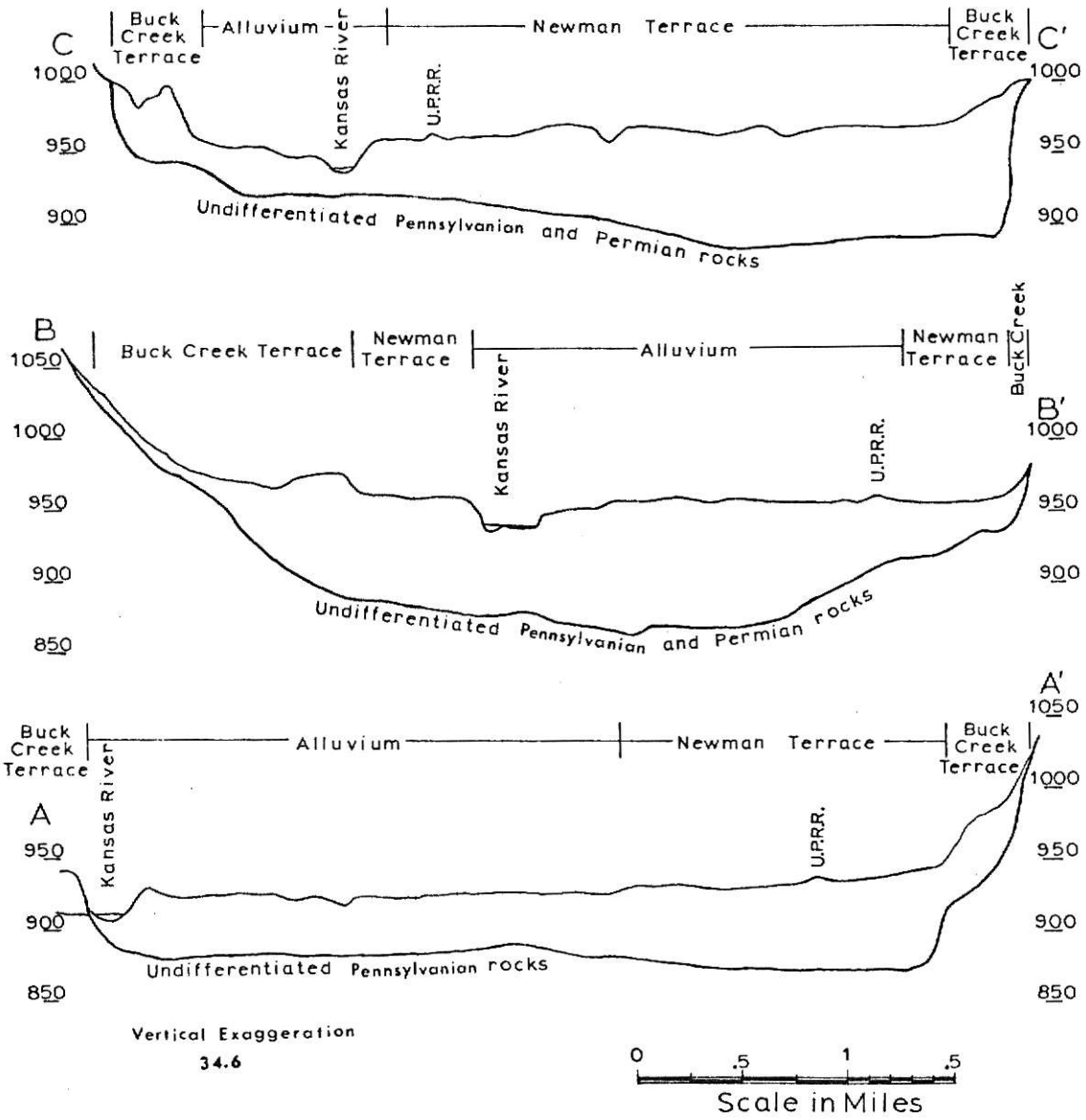
Township line

Section line

Towns

Dune Sand	Recent	PLEISTOCENE SERIES	QUATERNARY SYSTEM	
Alluvium	Late Wisconsin and Recent			
Terrace deposits (Newman)	Wisconsinan			
Peoria and Loveland	Wisconsinan and Illinoian			
Terrace deposits (Buck Creek)	Illinoian			
Terrace deposits (Menoken)	Kansan			
Kansas Till				

Council Grove Group	GEARYAN SERIES	PERMIAN SYSTEM	PENNSYLVANIAN SYSTEM
Admire Group			
Wabaunsee Group	VIRGILIAN SERIES		



CROSS SECTIONS OF THE KANSAS RIVER VALLEY IN THE AREA OF INVESTIGATION

Cross sections A-A' and C-C' are from Beck,(1959)

Figure 3

Quaternary (Beck, 1959, p. 29). These chert-limestone gravels were interpreted as alluvium left by the ancestral Kansas River which flowed on a rolling plain of low relief during pre-Kansan time (Mudge, 1955, p. 273). The bedrock surface under these gravels indicates the strath of the ancestral Kansas River ranged from 60 to 120 feet above the profile of the present stream bed. The ancestral valley was eroded by the river as the Kansan Glacier advanced from the northeast and contributed melt water to the river system (Davis and Carlson, 1952, p. 221). The valley was overrun by the glacier and covered by ice from St. George to Kansas City. Evidence of several ice-marginal lakes formed by this blockage exists as lake deposits and overflow spillways reported by Mudge (1955, p. 277). As the glacial ice disappeared, most of the pre-existing valley was reoccupied by the river. An exception was a stretch from Manhattan to east of Wamego, where the river continued to follow a spillway through the divide between Deep and Antelope Creeks (Scott, Foster and Crumpton, 1959, p. 134).

As the ice front retreated, alluvial deposits accumulated in the river valley reaching at least 80 feet above the present flood plain between Topeka and Lawrence, Kansas (Davis and Carlson, 1952, p. 212). These deposits were named the Menoken terrace and have been so extensively dissected that only isolated portions remain of the once continuous deposits. The bedrock contact under these deposits ranges from 20 to 40 feet above the present flood plain between Wamego and Topeka, Kansas (Beck, 1959, p. 40).

During Illinoian time the ancestral Kansas River went through a cycle of downcutting of bedrock and deposition of alluvium. The remains

of these deposits were named Buck Creek terrace (Davis and Carlson, 1952, p. 229). Bedrock was eroded 25 to 50 feet below the level of Kansan-age downcutting, which is to just below the level of the surface of the present flood plain. The valley was then alluviated to a level approximately 40 feet above the present flood plain of the Kansas River between Wamego and Topeka, Kansas (Beck, 1959, p. 42). It was during the Illinoian Stage that the lower Kansas River System captured the upper Republican, Smoky Hill and Saline Rivers (Bayne and Fent, 1963, p. 374). These captures resulted in the development of the present drainage system of the Kansas River.

During the Wisconsinan Stage the Kansas River extensively downcut its channel, reaching a maximum level of downcutting of 90 feet or more below the present flood plain at some time early in this stage. The early Wisconsin alluvium deposited in this bedrock channel is covered by the Middle to Late Wisconsin Newman terrace (Bayne and Fent, 1963, p. 377).

The Newman terrace surface is 4 to 15 feet above the present flood plain and has not been dissected but many meander scars are present. The present flood plain was formed by downcutting into the Newman surface in late Wisconsinan and Holocene. The channel of the Kansas River is cut into the flood plain and low water stage is 8 to 10 feet below the top of the channel (Beck, 1959, p. 42).

Ground Water

The Belvue-St. Marys area is in part of the Kansas River Valley studied for its basic ground-water and hydrologic conditions by Beck (1959). I felt that more information about the subsurface conditions

would be valuable in land use development.

The altitude of the water table fluctuates according to the amount of recharge and discharge. During Spring, 1973 several farmers stated that the water level in their wells was several feet higher than normal. This was due to the above normal amounts of precipitation that occurred during and before this investigation. According to Beck (1959, pp. 45-46) the water level in an observation well, NE¼, NW¼, Sec. 31, T. 10 S., R. 13 E., was at an altitude of 910 feet in 1954 which was approximately 6 feet below the water level of 1952. This decline of the water level was due to the below normal precipitation of the early and mid-1950's. No information is available in this area concerning the amount of recharge to the water table from precipitation. However, Nuzman (1969, p. 23) calculated the recharge as 11.5 per cent of precipitation near Manhattan, Kansas and at Lawrence, Kansas, Lohman (1941, p. 45) estimated recharge of 10 per cent. These values are used for an approximation for the study area which indicates just over 3 inches of the total precipitation (32") recharges the ground-water reservoir. Much of the recharge is from ground water in the alluvium moving into the area from upstream. The alluvium of the tributary stream valleys contributes some recharge as does the bedrock aquifers which are intercepted by the valley. According to Beck (1959, p. 47) direct recharge from the Kansas River probably occurs only during high water stage.

Ground water is discharged by evapotranspiration, wells, seepage into streams and the river, and by movement through the alluvium downstream out of the area. The water-table contours as shown by Beck (1959, plate 2) indicate that the water table slopes diagonally downstream

toward the river thus indicating that the river is the major discharge mode for the ground-water reservoir.

In most of the area the ground water has high hardness and iron concentration (Table 1). Iron staining is prevalent in the area south and southwest of St. Marys. Total iron concentration and total hardness of waters in other portions of the Kansas River Valley (Table 2) indicate water-quality problems are not unique to the Belvue-St. Marys area.

The majority of the water for household use in the area is obtained by driving sand points to a depth of 20 to 40 feet. Most irrigation wells are much deeper with many being drilled to bedrock.

Previous Experience with Earth Resistivity

While working for the State Highway Commission of Kansas, I was involved in a geoelectric sounding study using the Wenner electrode array. The instrument used was a Bay's Model ER-7, which is an alternating-current instrument, obtained by the Highway Commission in the mid-1950's.

Several different groups of Highway Commission geologists, have attempted to use this instrument to obtain accurate subsurface information for use in foundation studies. These investigations did not produce acceptable results when interpretations were by the Moore Cumulative Method (Soiltest, 1968, p. 33) or the Barnes Layer Method (Soiltest, 1968, p. 36).

Geoelectric soundings were conducted by Paul C. Clark, geologist, State Highway Commission of Kansas, in the Kansas River Valley south of Ogden, Kansas. When depth-to-bedrock determinations were made by use of partial curve-matching interpretive techniques (Wohler, 1970,

Table 1. Water Quality in Area of Investigation

Well Location																Hardness as $CaCO_3$	
¼	¼	Sec.	T S	R E	Dis. solids[A]	SiO_2	Fe^{++}	Ca^{++}	Mg^{++}	$Na^{+}+K^{+}$	HCO_3^{-}	SO_4^{++}	Cl^{-}	F^{-}	NO_3^{-}	Total[C]	Carbonate	Noncarbonate
NE	SW	33	9	11	457	23	0.005	124[B]	16	21	433	33	15	0.1	12	376	355	21
NE	NE	2	10	11	481	20	0.94[B]	130[B]	20	15	412	78	13	0.3	1.5	406	338	68
SE	SE	5	10	11	496	21	7.4[B]	138[B]	24	14	522[B]	32	8.0	0.2	1.3	443	428	15
SW	NE	15	10	11	489	3.2	0.06	105[B]	21	51	429	48	27	0.1	23	348	348	0
NE	NE	7	10	12	766[B]	23	0.65[B]	196[B]	25	34	544[B]	77	41	0.2	102[B]	592	446	146
NW	SE	16	10	12	469	20	1.2[B]	116[B]	17	32	410	47	24	0.3	11	360	336	24
SW	SW	28	10	12	552[B]	11	12.0[B]	107[B]	22	73	471	0	86	0.1	18	358	358	0
NW	NW	31	10	13	445	19	4.9[B]	124[B]	15	19	418	49	12	0.2	0.97	371	343	28

From Beck (1959)

All values are in parts-per-million

A indicates total dissolved solids

B indicates value is in excess of U. S. Department of Public Health drinking water standards (U. S. Dept. of H. E. & W., 1962)

C all waters can be described as very hard (Durfor & Becker, 1968)

pp. 3-16), the results were within 5 per cent of the depth determined by drilling.

Table 2. Comparison of Water Qualities in Kansas River Valley System

		Iron[1]	Total Hardness[2] as $CaCO_3$
Near Topeka (Davis & Carlson, 1952, p. 245)	Kansas River Alluvium	12	442
Near Junction City (Latta, 1949, p. 74)	Smoky Hill River Valley	2.44	517
	Republican River Valley	1.32	344
Near Manhattan (Nuzman, 1969, p. 6)	Big Blue River Valley	5	800

All values are in parts-per-million

1 indicates value is in excess of U. S. Department of Public Health drinking water standards (U. S. Department of H. E. & W., 1962)

2 all waters can be described as very hard (Durfor & Becker, 1968)

METHODS OF INVESTIGATION

Direct Current Earth Resistivity

Most subsurface data were obtained by direct current earth-resistivity methods with a Master Geo-Electric Explorer using a Schlumberger electrode array. The instrument was built and is owned by Elmer J. Wohler, consulting geologist, St. Marys, Kansas. This instrument was chosen for this study because of greater power output, high sensitivity, light weight (approximately 30 pounds including wire and electrodes)

and its capacity to use the Schlumberger electrode array. The other instrument available, manufactured by Soiltest, is limited to 100 milliamperes output, is heavier and designed for use only with the Wenner array. The Schlumberger array was chosen over the Wenner array because of greater availability of modern interpretive methods and more rapid movement of the array in the field (Steeples, 1970, p. 17).

Both arrays (fig. 4) use four electrodes implanted in a straight line. The outer two electrodes are used for input of electrical current into the earth while the two inner electrodes measure the potential difference caused by this current. Apparent resistivity of the material and effective depth beneath the electrode spread are calculated by Ohm's Law from the amount of input current, the voltage measured between the potential electrodes and the distance between the electrodes.

The following formulas are used for the calculation of apparent resistivity for each of the two electrode arrays:

Schlumberger Electrode Array

$$\rho_a = 0.785 \frac{(L + 1)(L - 1)}{1} \times \left(\frac{V}{I}\right)$$

Wenner Electrode Array

$$\rho_a = 6.28\ a \times \left(\frac{V}{I}\right)$$

where ρ_a is the apparent resistivity

V is the potential difference

I is the input current

L is the electrode spacing

a is the distance between electrodes

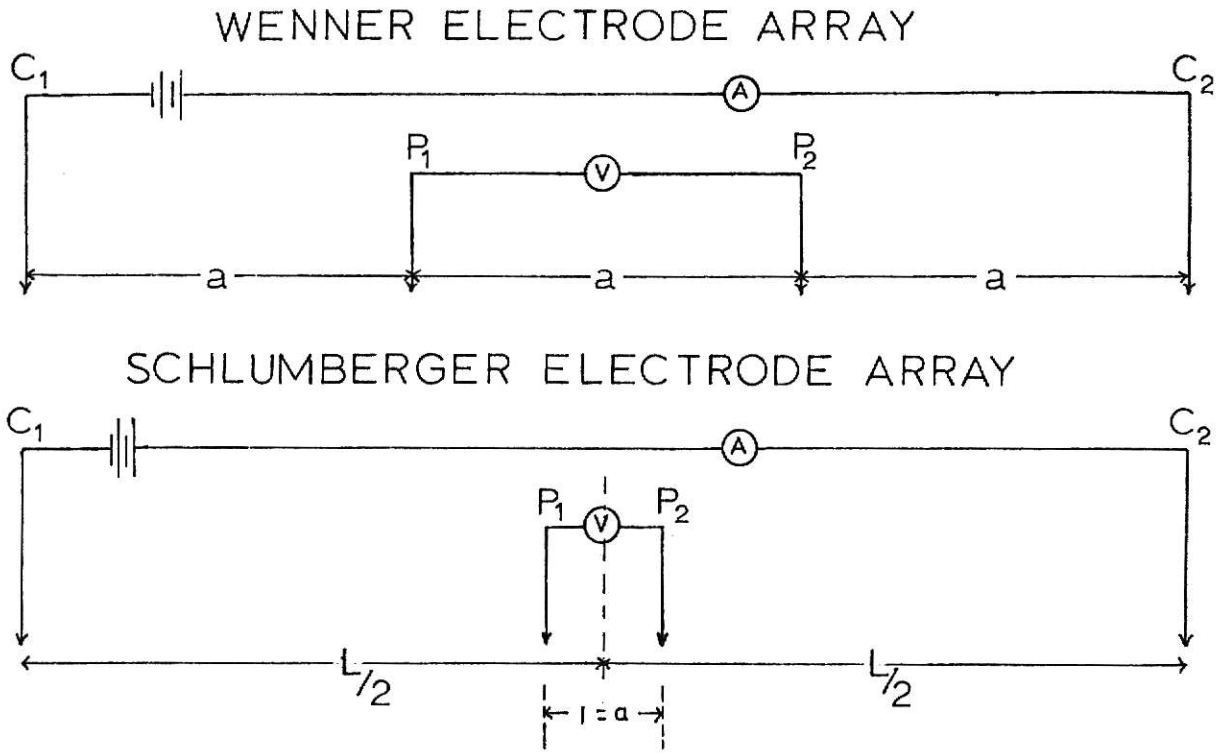


Figure 4

For a discussion of apparent resistivity, see Wohler (1970, pp. 1-3), Bhattacharya and Patra (1968, p. 12) or Steeples (1970, p. 13).

Two methods of field investigation using earth resistivity are geoelectric sounding and geoelectric profiling. In geoelectric sounding the array is established about a central point and the electrodes are moved outward with each reading. This results in the current flow penetrating a greater depth of alluvium beneath the central point and providing data about the change of apparent resistivity with depth. By interpretive methods (Keller and Frischknecht, 1966), these values can

be used to find the change of actual resistivity and depth of the underlying electrical stratigraphic units. Geoelectric profiling is accomplished by occupying a series of stations with an electrode array of a fixed spacing. This permits comparison of lateral changes in apparent resitivity within a volume of alluvium affected by the spacing used.

A modified form of geoelectric profiling called double-depth sounding was used for a reconnaissance study of the entire area. At each double-depth station readings were taken at two electrode spacings. These two spacings were selected on the basis that the narrow spacing would measure the apparent resistivity within the river-valley alluvium and the wide spacing would be influenced by the resistivity of the bedrock underlying the majority of the valley floor. The wide spacing was expected to measure only the apparent resistivity of the alluvium over the area occupied by the deep bedrock channel.

The use of the double-depth soundings allowed observation of both lateral and vertical changes of apparent resistivity. The data derived were interpreted by several methods and the information plotted and contoured on base maps for comparison studies (fig. 6-12).

Table 3 lists resistivity values determined for many geologic materials in the mid-continent area. Table 4 gives resistivity values determined for various materials by Elmer J. Wohler while working with earth resistivity in Kansas and Missouri.

Table 3. Resistivity Values of Geologic Material in the Mid-continent

Area and age of rocks	Formations	Lithology	Average resistivity (ohm-meter)	95% range in resistivity (ohm-meter)
Quaternary alluvium Mississippi Valley		Alluvium	182	105-308
Miocene and Pliocene Sedimentary rocks Great Plains	Ogallala Fm. Arikaree Fm. Alum Bluff Gp. Choctawhatchee Fm. Hattiesbrug Clay	Fresh water marls, sand, silt and gravel		
	Oakville Fm.		480	263-830
Upper Cretaceous Sedimentary rocks Great Plains	Montana Gp. Pierre Sh. Foxhills Ss. Laramie Fm. Niobrara Fm. Benton Sh.	Shale and sandstone, lignite, chalk and calcareous shale		
	Dakota Ss.		49	33-71
Permian Sedimentary rocks Mid-continent	Cloud Chief Fm. Duncan Fm. Woodward Gp. Enid Fm. Wichita Fm.	Dolomite, limestone gypsum, salt, shale, anhydrite and sandstone		
	Cottonwood Ls.		48	29-88
Pennsylvanian Sedimentary rocks Mid-continent	Pontotoc Gp. Nelagoney Fm. Ochelata Fm. Seminole Cong. Holdenville Sh. Wetumka Sh.	Sandstone and shale		
	Calvin Ss.		70	46-105

(From Keller and Frischknecht, 1966, pp. 44-47)

Table 4. Apparent Resistivities of Geologic Materials

Material	Apparent Resistivity (ohm-meters)
Clays	3.0- 90
Silts	20 -120
Shales	30 -180
Sands and Gravels (saturated)	90 -275
Sandstone	150 -450
Limestones	250 - ∞

Drill Soundings

Three test holes were drilled to support the results of interpretation of the earth resistivity data. Elmer Wohler provided a truck-mounted drill and drilled these holes; the logs for these test holes are in Appendix VI. All available information collected on the bedrock altitudes is tabulated in Appendix V and plotted as figure 12.

Water-Quality Study

Finally water from household wells was sampled to determine if quality of near surface ground water affected the values obtained during the double-depth reconnaissance study. Samples of deep ground water were not available because none of the irrigation wells were operating during the winter months. The values and locations of samples are in Appendix IV and plotted on figure 11.

FIELD INVESTIGATION

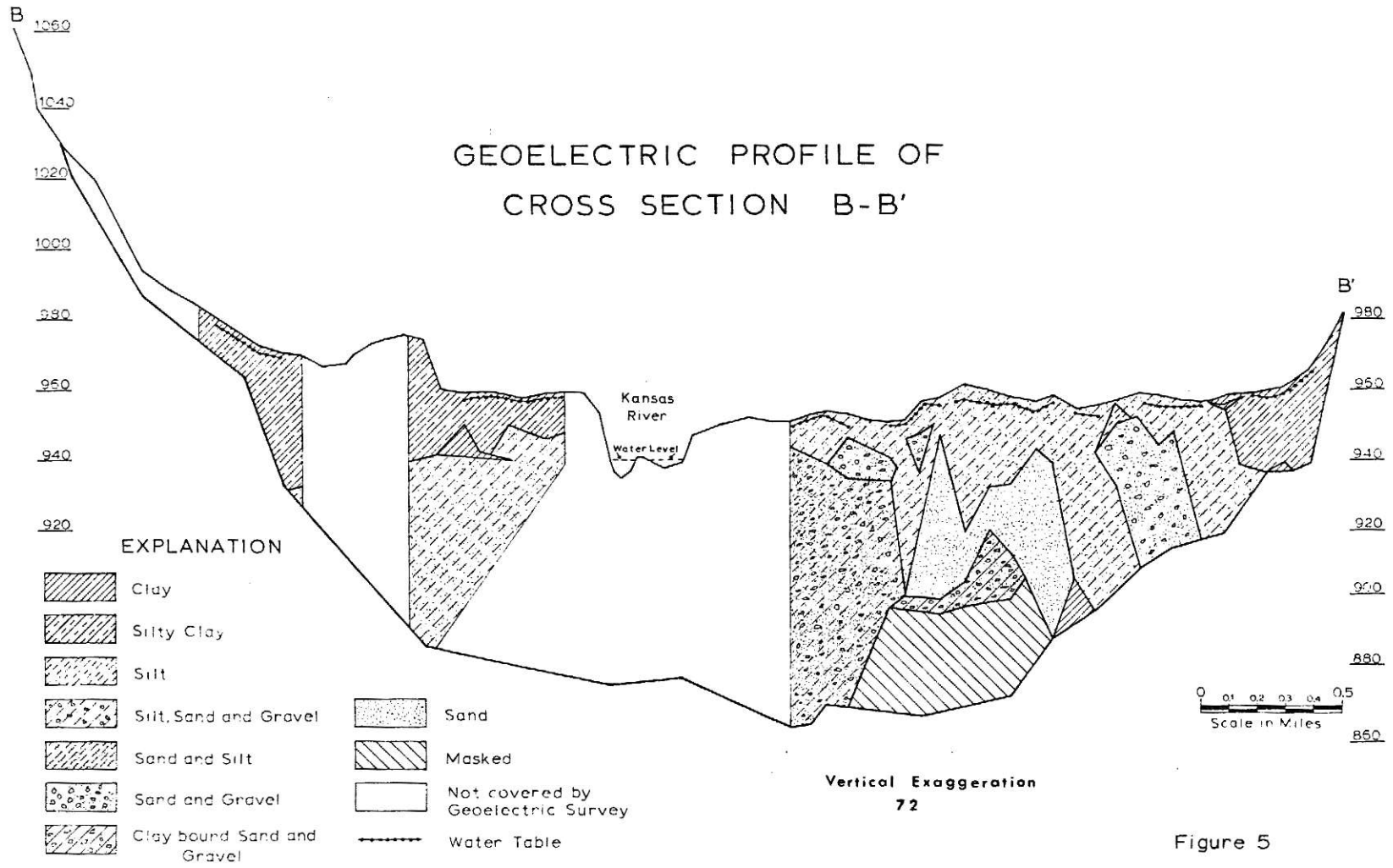
Preliminary Survey

Once the area was selected and distances from the Belvue-St. Marys locality were determined, a detailed survey was conducted along the county road 1 $\frac{1}{2}$ miles east of Belvue which is the only road that crosses the Kansas River in the area. The distance across the valley was measured and 53 stations were marked by nails set in power and telephone poles. Altitudes of these stations were established by levelling from the U. S. Coast and Geodetic Survey benchmark P 262 (1942) in SW$\frac{1}{4}$, SW$\frac{1}{4}$, SW$\frac{1}{4}$, Sec. 36, T. 11 E., R. 9 S. All cultural features along the line were evaluated for possible influence on resistivity measurements.

Geoelectric Sounding Survey

The geoelectric sounding survey was conducted by occupying 40 of the 53 stations as the mid-point of the electrode spread. At three other stations the mid-point of the spread was offset from established stations to provide a more level surface. Each station was used for only one spread because of the proximity of roads which carried heavy traffic.

A detailed profile of the earth resistivity across most of the valley was developed from the survey data (fig. 5). The survey also provided some indication of resistivity values that might be expected in the valley during the double-depth survey.



See Table 4 for resistivity values of geologic materials.

Figure 5

Double-Depth Reconnaissance Survey

The reconnaissance study using double-depth stations was done to see how effective the method would be for preliminary ground-water surveying. Of the 84 stations, all but two were along highways and/or county-township roads. If this method were to be successful in mapping the bedrock contact or the changes within the alluvium, when compared with test-hole information, it could reduce the number of test holes required, improve the selection of test-hole locations for maximum results and decrease the need to enter onto private property. The 84 stations do not cover the study area as well as desired but, in most areas, they yield the necessary information.

Conductivity

Water samples were obtained from wells and returned to the K.S.U. Geology Department, where they were allowed to stabilize to room temperature. The conductivity of the samples was measured with a Lab-Line Lectro Mho-Meter within 24 hours of sampling. The values were corrected for the cell constant and converted to resistivity values in ohm-meters. The locations of the samples and the values obtained are in Appendix IV. The resistivity values are plotted and contoured on figure 11.

ANALYSIS OF DATA

Interpretation of Geoelectric Soundings

Data obtained from the geoelectric soundings must be treated by one of several interpretive techniques discussed in Bhattacharya and Patra (1968, pp. 41-120), Keller and Frischknecht (1966, pp. 92-196)

or Van Nostrand and Cook (1966, pp. 27-110). Many of these techniques can be used to convert the apparent resistivity and effective depth of the field data into the actual resistivity and depth of the electrical-stratigraphic units beneath the spread.

The method chosen for use is partial-curve matching. This technique with mathematical analysis is described in Keller and Frischknecht (1966, pp. 144-147). Each step of the technique is discussed by Wohler (1970, pp. 3-16). The interpretive charts required for this method are in Bhattacharya and Patra (1968, in pocket), Wohler (1970, pp. 5, 12-14) and in numerical tables for plotting the interpretive charts in Keller and Frischknecht (1966, pp. 490-497).

The curve-matching technique, in common with many others for use with vertical soundings, is based upon the assumption that the material beneath the spread is laterally uniform and any change is vertical only. This assumption is not normally valid in the field use of earth resistivity because geologic materials are not normally deposited with a completely uniform distribution of particle size. If it is assumed that lateral changes are electrically insignificant, published techniques can be used in the field with fair results.

Interpretation of Double-Depth Reconnaissance Study

The data from the double-depth survey were interpreted by three different procedures to determine if any one of the three yielded superior results. The first interpretation used the difference between the two apparent resistivity values obtained at each station. Values were plotted on a base map (fig. 8) and contoured for comparison with

other interpretive techniques.

The second interpretation used Keck's Curves. The full history of these curves is not known. They have not appeared in commercial print (Wohler, 1970, p. 37) and according to Fritz (1973) they appear to have been derived empirically. By the curves an average apparent resistivity value is determined from the apparent resistivity of two electrode spacings, the smaller of which must be one-half the spacing of the larger spread. Of the values from the double-depth survey, 68 per cent fell below the range of values that could be plotted on Keck's Curves. An additional set of curves was developed which extrapolated the curves into a lower range of values. Even with these additional curves only 55 per cent of the stations could be solved. The values that could be found were plotted (fig. 9) and contoured resulting in a lower density of points on which to contour as compared with the previous interpretive method.

The final procedure for double-depth interpretation was the use of Keck's Formula (Wohler, 1970, pp. 37-39). Again, it was found that some stations could not be used when they yielded a meaningless negative apparent average resistivity. Of the double-depth stations, 76 per cent yielded positive values and were used to contour the base map (fig. 10). Most values by Keck's Formula were close to those derived from Keck's Curves.

RESULTS

Geoelectric Sounding

Information on the vertical variation of resistivity derived by

partial-curve matching, was plotted on a cross-section of the valley (fig. 5) and the areas of near equal resistance were connected. The profile shows both vertical and horizontal variations of electrical stratigraphic units. From this profile interpretations were made of the depth to bedrock and the composition of each unit. A drilling program was conducted to evaluate the accuracy of the interpretation. The bedrock high which had been indicated beneath stations 17 to 23 in the interpretation (fig. 5), did not exist. A lense of sand and gravel bound by clay 20 feet thick at station 18, had electrical characteristics similar to that of clay shale. The misinterpretation emphasizes the need to correlate earth resistivity information with some other form of subsurface information. That several different geologic materials may have similar resistivities must be considered at all times.

Test holes drilled at other sites were within 10 per cent of the predicted bedrock depth. The water table was not traced with any degree of success on the profile. The high moisture content of the entire soil profile may have affected the results. Also, the sharp lateral differences in alluvium may mask the expected drop of resistance at the water table. Mr. Wohler stated (personal communication, March, 1973) that he has not had good results in delineating the water table in the Kansas River Valley. In a study of resistivity using the Wenner electrode array in the Kansas River Valley, Merriam (1954, pp. 107-108) indicated he could locate the water table within 2 feet in the 10 to 20 foot depth range and bedrock within 5 feet in the 40 to 80-foot depth range. This study did not attain the accuracy stated by Merriam.

A negative thickness was indicated by 22.7 per cent of the

geoelectric soundings at some point in the interpretive procedure. A study was made of the stations at which this occurred and the area covered by the electrode spreads. It was found that in each case the electrode spread crossed some sort of vertical boundary. In most cases, it was an old meander scar, the edge of a terrace, or the edge of a backswamp area. A problem of this type can be detected in the field by running a second spread perpendicular to the first at each station. Such a procedure was not done in this investigation because of the traffic on the roads which were used.

Double-Depth Reconnaissance Study

The double-depth reconnaissance study was conducted to map the bedrock channel through the area. This was accomplished by comparing the lateral variation of the average apparent resistivity.

The three methods used for interpretation indicate an area of high apparent resistivity in sections 12 and 13, T. 10 S., R. 11 E. and sections 7 and 18, T. 10 S., R. 12 E. Figure 8 (Double-Depth Difference Map) shows an area irregular in outline and of higher value than shown by the other two methods. Figures 9 and 10 show the high apparent resistance as an irregular oblong area running northwest-southeast through the corner common to the four sections. The two Keck interpretive methods indicate a high apparent resistance area in sections 32 and 33, T. 9 S., R. 11 E. which does not show on the double-depth difference map. These apparent resistivity highs are interpreted as a fill of clean gravel in the deep bedrock channel.

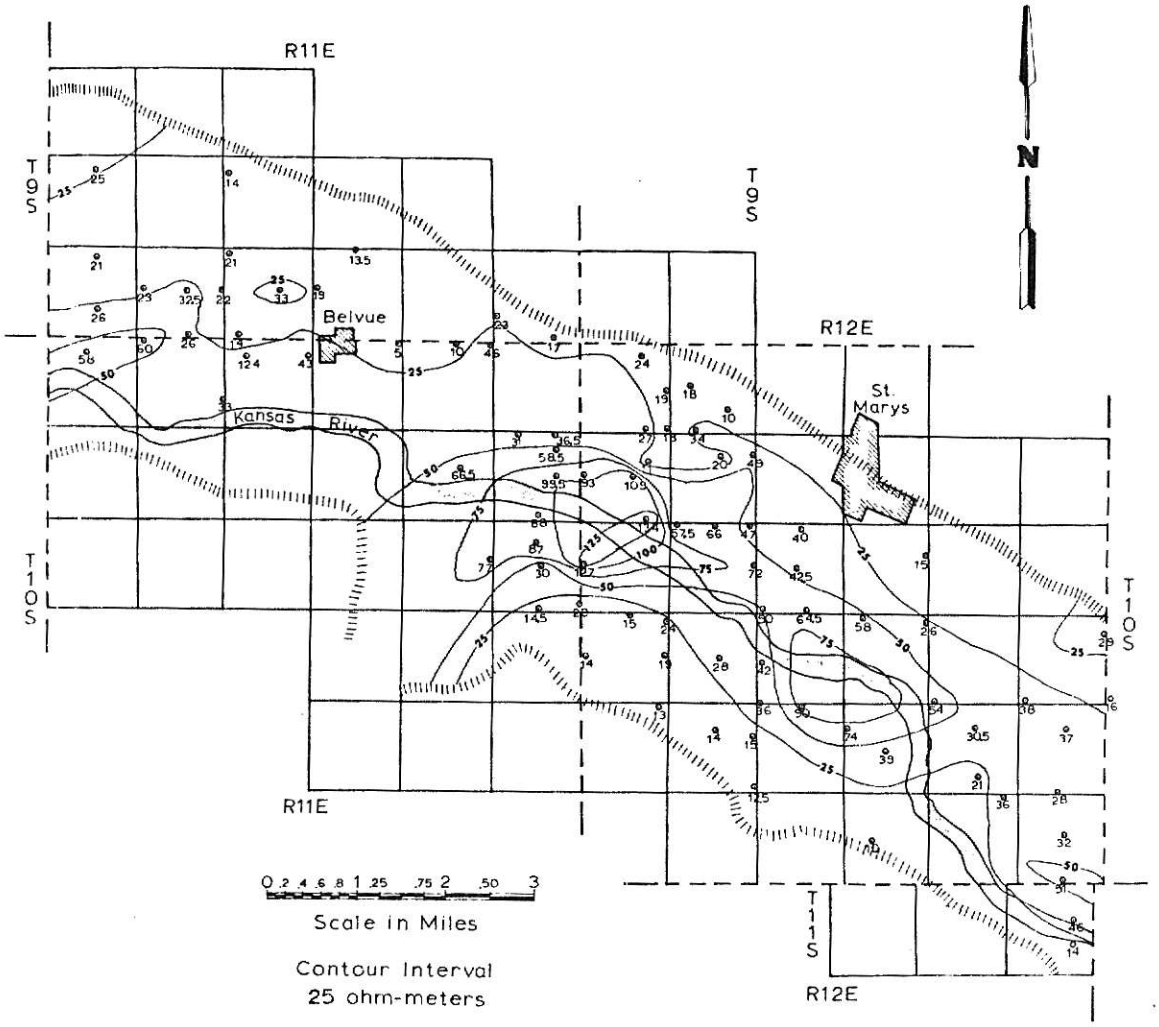
The double-depth difference map indicates many small scattered

areas of high and low apparent resistance over most of the map which are not considered to be significant because they are small. An area of high apparent resistance occurs in sections 21, 27 and 28, T. 10 S., R. 12 E. (fig. 8) but it is indicated as an area of low apparent resistance on both of the Keck interpretive maps (fig. 9 and 10) which coincides with the trend of the bedrock channel. The channel fill through this location may contain large quantities of finer sediment causing lower apparent resistivities than the channel fill upstream.

The Keck interpretive methods (fig. 9 and 10) indicate a crescent-shaped area of high apparent resistance in sections 9, 15, 16, 21 and 22, T. 10 S., R. 12 E. No pattern of significance in this area is evident on figure 8. This pattern does not appear to indicate a bedrock feature, but does coincide with an old meander channel in the surface through these sections. The apparent resistivity pattern may reflect near surface deposits of coarser sand in the old channel.

Patterns of high apparent resistivity project into the river valley from the mouths of tributary stream valleys in sections 13 and 14, T. 10 S., R. 11 E. and sections 6 and 24, T. 10 S., R. 12 E. These apparent resistivity highs may indicate coarse alluvium deposited by the tributaries in their own channels which interfingered with finer alluvium of the river.

In sections 8, 9, 16 and 20, T. 10 S., R. 12 E.; bedrock information from water wells indicates buried ridges projecting into the river valley from both valley walls (fig. 12). None of the double-depth interpretive maps (fig. 8, 9 and 10) show patterns which correlate with these features.

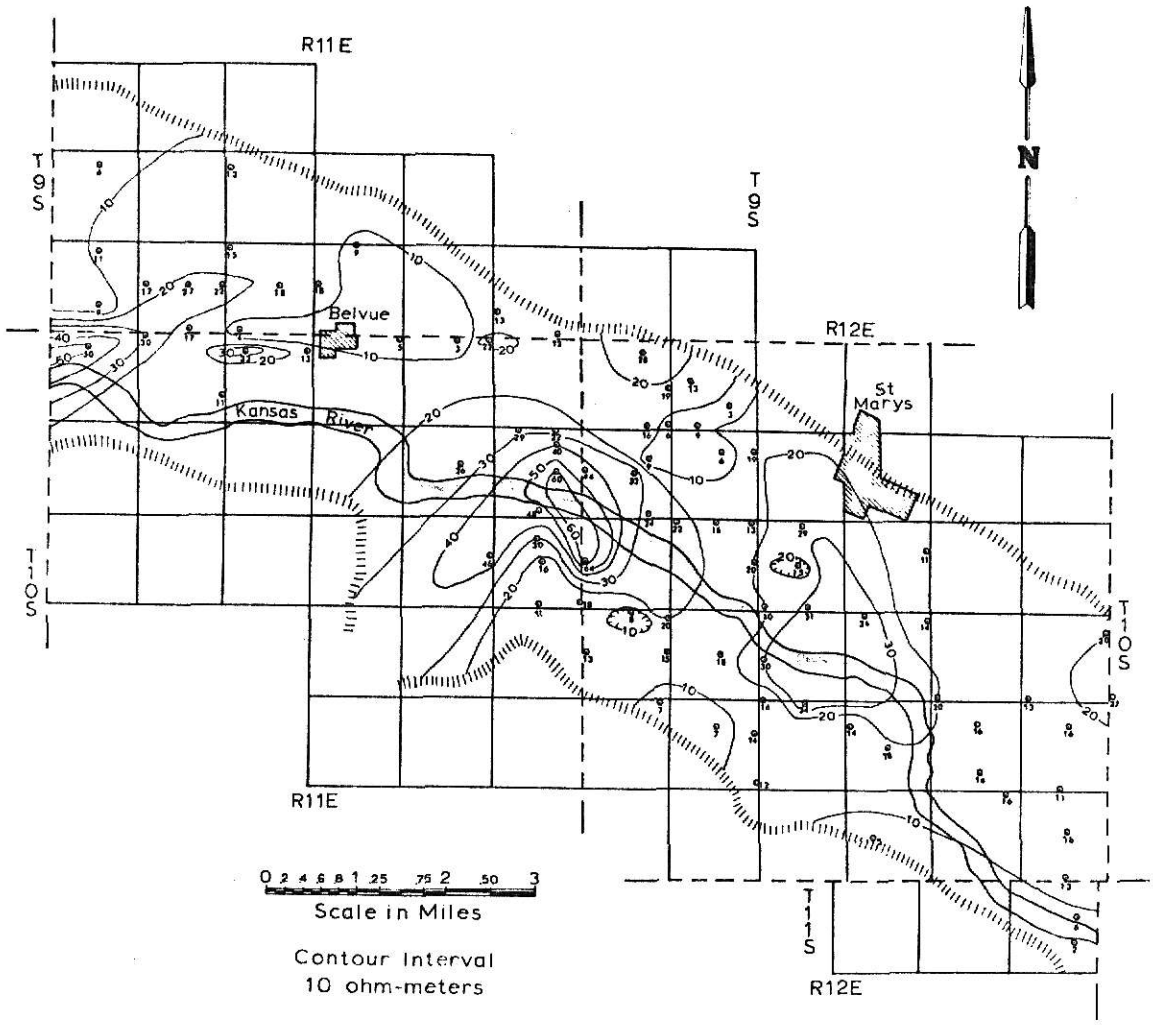


LATERAL VARIATION OF APPARENT RESISTIVITY 40-METER SPACING

Figure 6

EXPLANATION

- Township line
- Section line
- Valley wall
- Towns
- Station

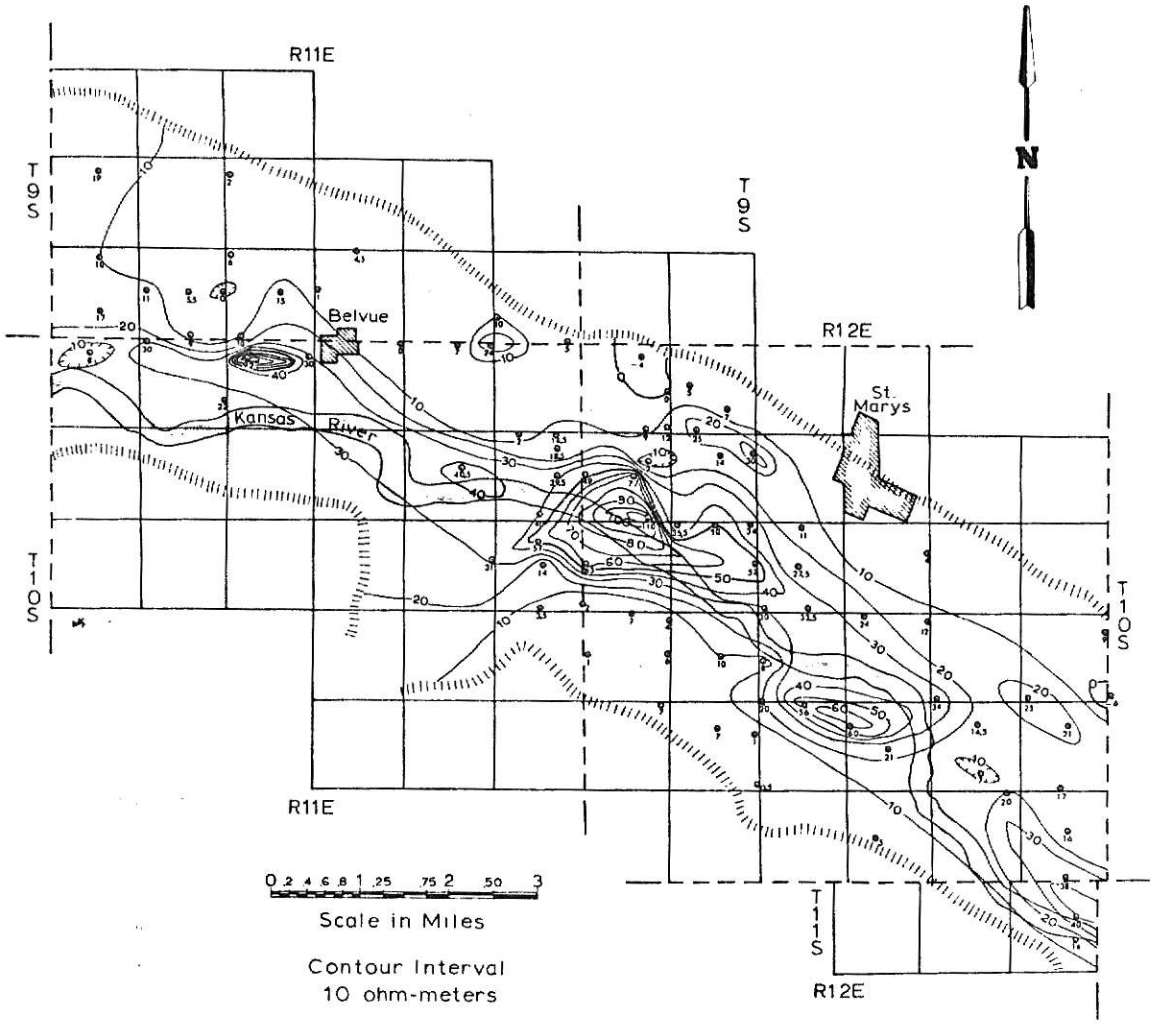


LATERAL VARIATION OF APPARENT RESISTIVITY 80-METER SPACING

Figure 7

EXPLANATION

- Township line
- Section line
- Valley wall
- Towns
- Station



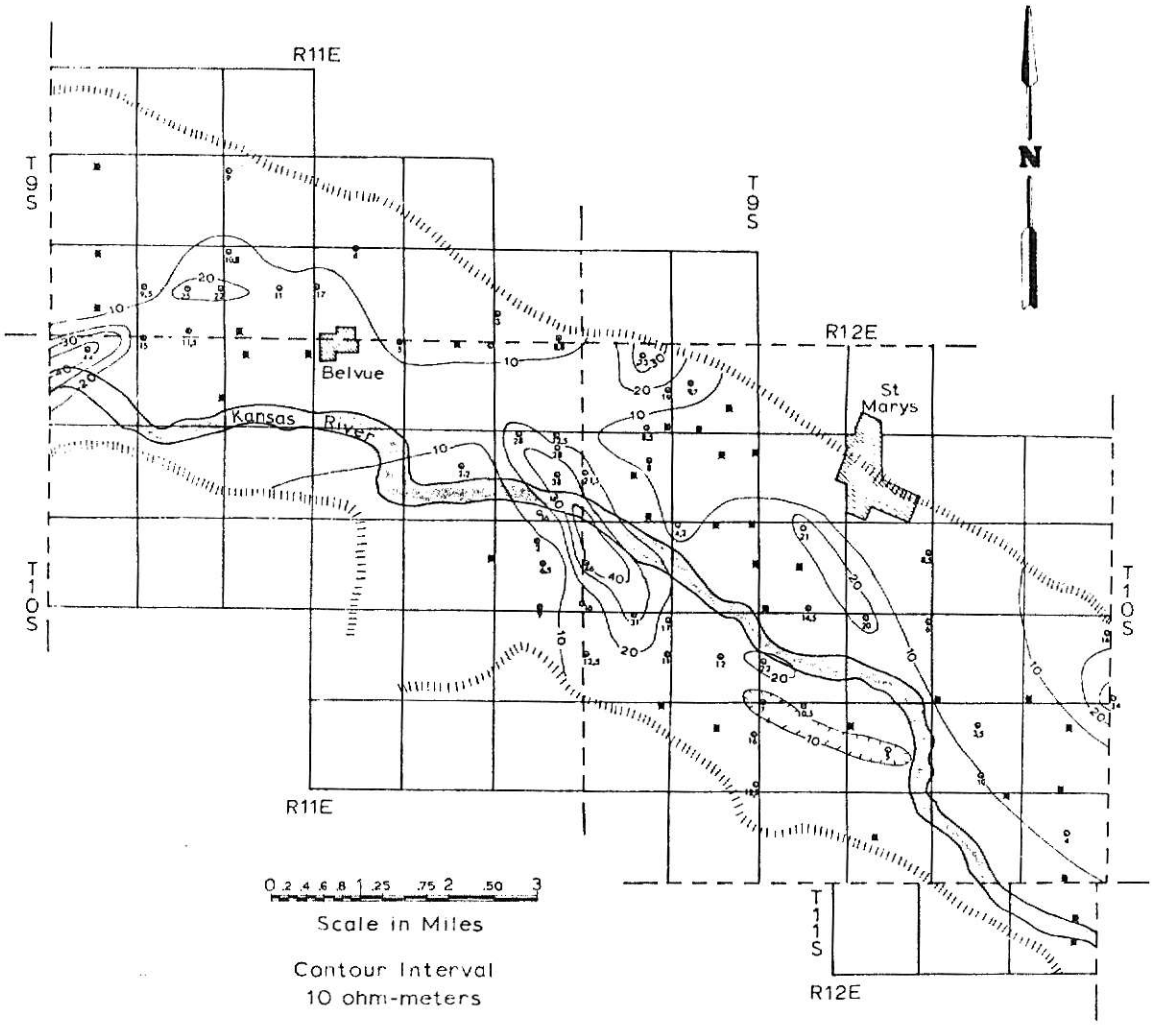
DOUBLE-DEPTH DIFFERENCE MAP

Figure 8

(Apparent Resistivity, 40-Meter Spacing)–
(Apparent Resistivity, 80-Meter Spacing)

EXPLANATION

- Township line
- Section line
- Valley wall
- Towns
- Station

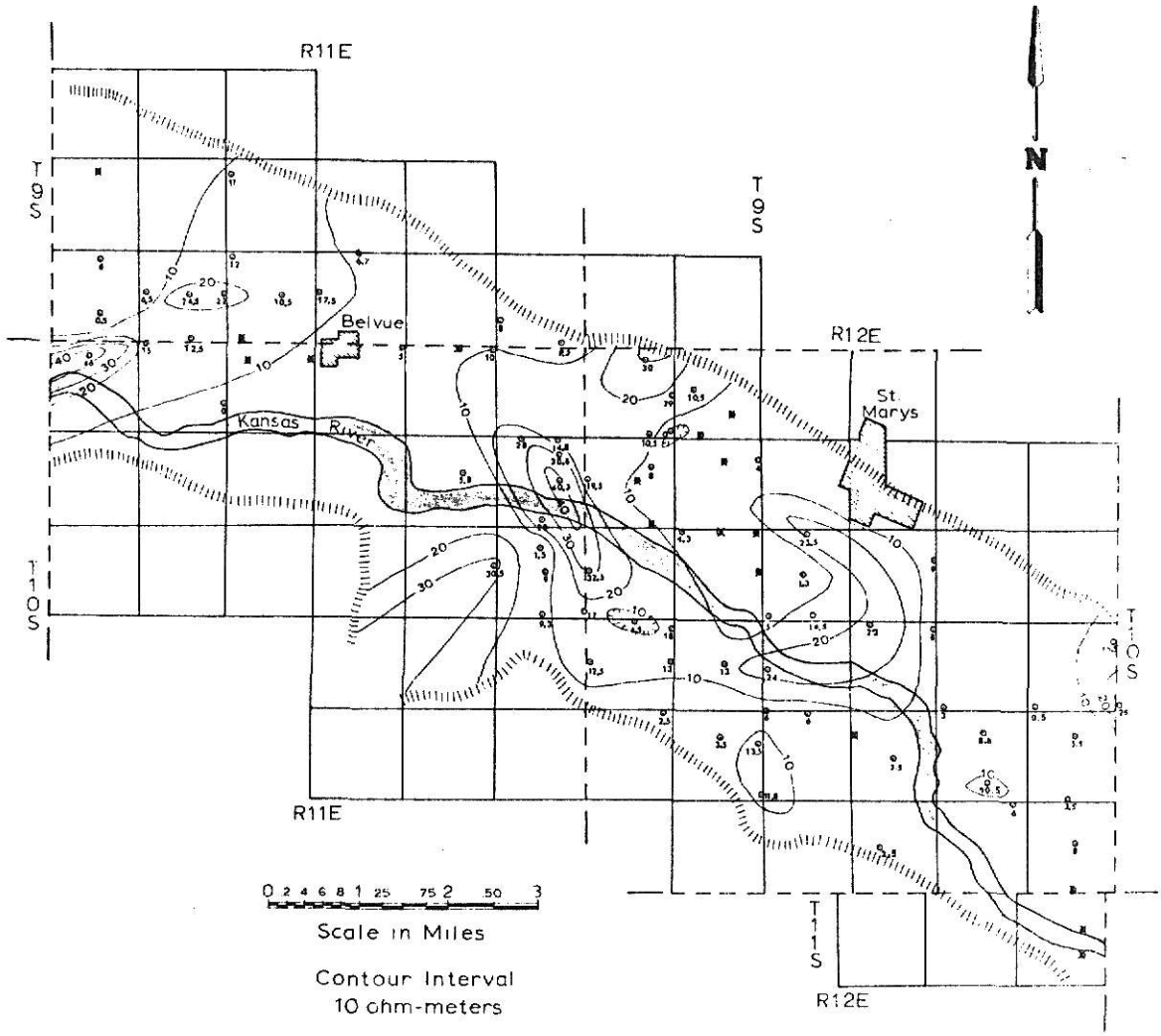


RELATIVE RESISTIVITY MAP
KECK'S CURVES

Figure 9

EXPLANATION

- Township line
- Section line
- Valley wall
- Towns
- Station(usable value)
- Station(value not usable)



RELATIVE RESISTIVITY MAP Figure 10
KECK'S FORMULA

EXPLANATION

- Township line
- Section line
- Valley wall
- Towns
- Station(usable value)
- Station(value not usable)

40-Meter Spacing

The apparent resistivity patterns of the map of the 40-meter spacing (fig. 6) show little resemblance to the contour patterns of the bedrock surface map (fig. 12). The rock units underlying the alluvium do not influence the apparent resistivity readings obtained with the 40-meter spacing. The readings should be influenced by the quality of deeper ground water or variations in the size of sediments within the alluvium.

An area of high apparent resistance occurs in sections 12, 13 and 14, T. 10 S., R. 11 E. and sections 7, 17 and 18, T. 10 S., R. 12 E., which coincides with, but does not have the same orientation as the high apparent resistance area on the double-depth interpretive maps (fig. 8, 9 and 10). A branch from this high trends southwest into the valley of Roberts Creek. This branch may indicate coarse sand and gravel brought into the river valley by Roberts Creek or the movement of less mineralized water from the alluvium of Roberts Creek into the alluvium of the river valley. Water samples with high resistance from sections 13, 14 and 24, T. 10 S., R. 11 E. (fig. 11) may support the hypothesis that water moving into the river valley is less mineralized. No other discernible relationship between the patterns of the contours of the 40-meter spacing and those of the water sample resistivity map (fig. 11) are evident. The quality of the near surface ground water does not have a significantly high effect on the apparent resistance of the alluvium measured by the 40-meter spacing according to Dr. Whittemore (1973, personal communication).

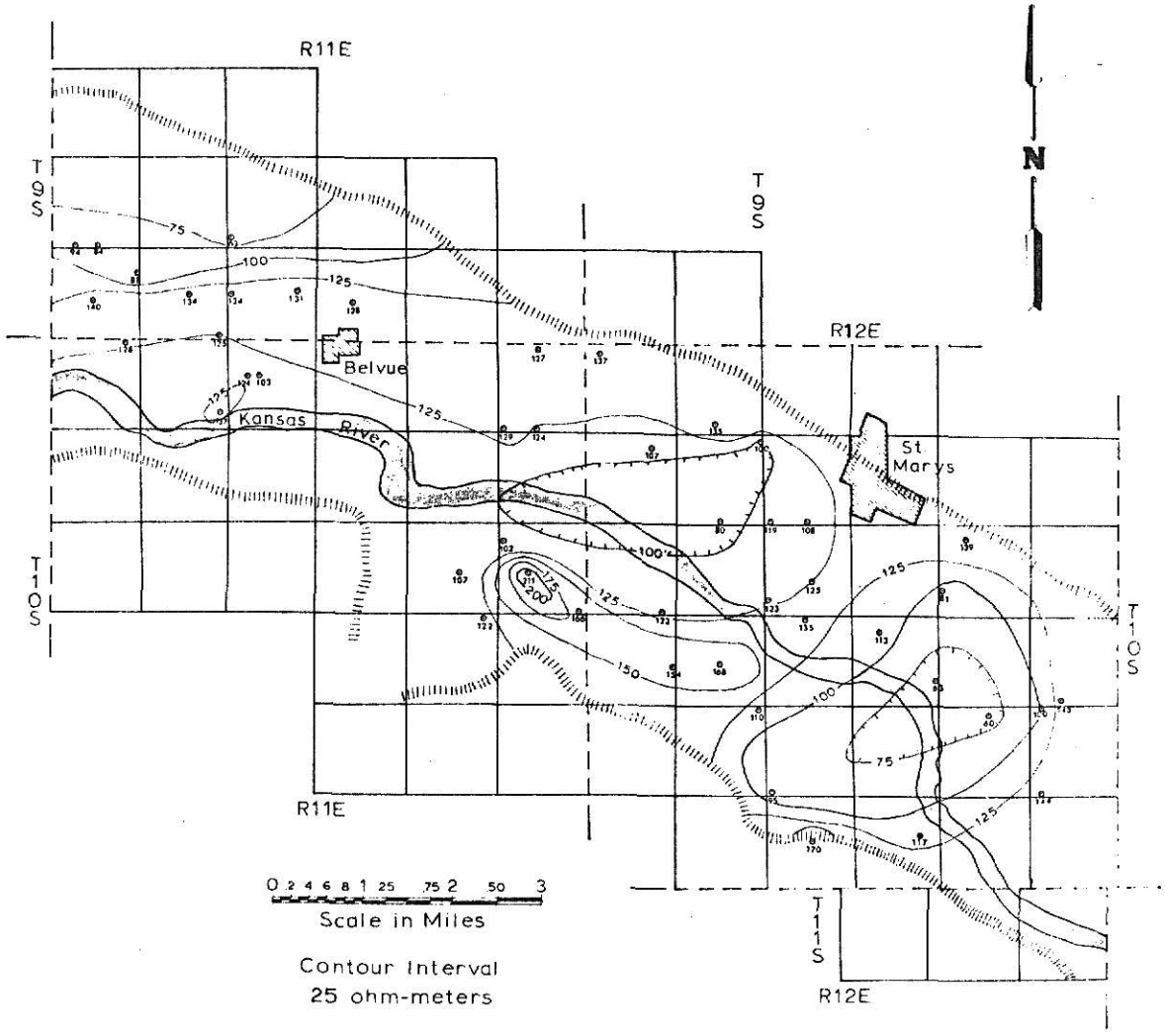
80-Meter Spacing

The 80-meter spacing map (fig. 7) indicates an area of high apparent resistance is sections 12, 13 and 14, T. 10 S., R. 11 E. and sections 7 and 8, T. 10 S., R. 12 E. The pattern of this high is elongated more north-south than the patterns on the double-depth interpretive maps (fig. 8, 9 and 10). A branch of this high extends southwest into section 14, T. 10 S., R. 11 E. and may indicate a deep gravel-filled channel of Roberts Creek entering that of the Kansas River. Other areas of high apparent resistance projecting into the river valley coincide with those on the double-depth interpretive maps (fig. 8, 9 and 10) at the mouths of the tributary-stream valleys.

An area of low apparent resistance overlying the buried bedrock ridge in sections 17, 20, 29 and 30, T. 10 S., R. 12 E., which projects into the river valley from the south valley wall (fig. 11), may indicate bedrock of low resistance such as a clay shale. An area of high apparent resistance south of St. Marys may indicate a gravel deposit in the wide portion of the bedrock channel.

Ground-Water Quality Study

Conductivity values of water samples from farm wells were converted to resistivity values (Appendix IV), plotted on a base map and contoured (fig. 11). This map was compared with the double-depth interpretive maps (fig. 8, 9 and 10) and the map of the apparent resistivity of the 40-meter spacing (fig. 6). There was very little correlation among the maps. The lack of correlation between the 40-meter spacing and the water-sample resistivity maps may indicate most of the water



RESISTIVITY MAP OF WATER-WELL SAMPLES

Figure 11

EXPLANATION

- Township line
- Section line
- Valley wall
- Towns
- Sample location

samples had been obtained from a depth shallower than was represented by the 40-meter spacing. If the patterns of the map were similar, it would indicate near surface ground water strongly affects the double-depth interpretation. Therefore the lack of correlation indicates quality of the near surface ground water has no effect on resistivity measurements at these spacings and the concept of double-depth sounding is valid.

The brief study of water quality indicates further studies are needed concerning the distribution of water quality in the Kansas River Valley, the source of the high concentrations of dissolved minerals in the ground water and the rate of movement of the ground water. These questions were considered to be beyond the scope of the present investigation. Dr. Whittemore (1973, oral communication) has indicated that these questions will be investigated in future studies.

Table 5. Comparison of Conductivity of Wells over 20 Years

Location	Beck (1953)	Gilliland (1973)
	micromhos/cm.	
SE¼, SE¼, Sec. 5, T. 10 S., R. 11 E.	950	731
NW¼, SE¼, Sec. 16, T. 10 S., R. 12 E.	860	798
SW¼, SE¼, Sec. 28, T. 10 S., R. 12 E.	1030	1050

The two wells in sections 16 and 28 of Table 5 are known to be the same wells from which Beck obtained water samples. The values indicate that little change in the quality of the ground water has occurred in the last 20 years. The well in section 5 is not the same

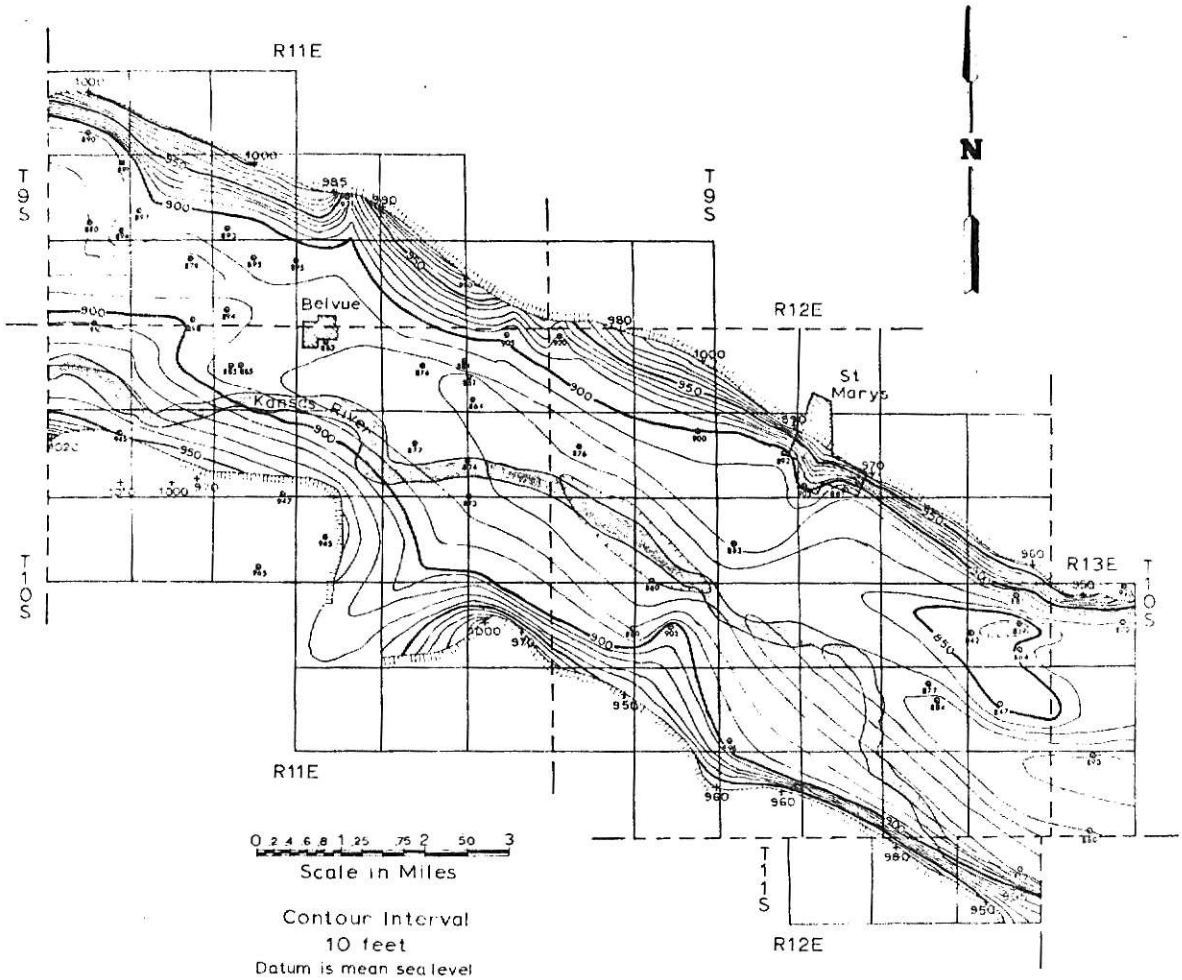
well as sampled by Beck. According to the present land owner, his father had too much trouble with the old well producing iron water. Some time in the early 1960's he had the well drilled deeper, cased and gravel packed. This may explain the change in conductivity.

Bedrock-Interpretation Map

The bedrock-interpretation map (fig. 12) is contoured on the contact between the alluvium and the undifferentiated bedrock units using sea-level datum. Bedrock information was obtained from water wells, test holes and bedrock outcrops plotted on topographic maps. The earth-resistivity information influenced several subsurface features contoured.

A deep bedrock channel of Early or Middle Wisconsinan age cuts through the middle of the river valley in the west and middle portions of the study area. West of Belvue and southwest of St. Marys restrictions in the width of the channel indicate the river has cut through more resistant strata at these areas. The channel widens and splits downstream from the restriction, sec. 15, 16, 21 and 22, T. 10 S., R. 12 E., with one low area swinging to the north side of the river valley and the lowest channel cutting close to the south valley wall. The low channel to the north is apparently the deep bedrock channel of Bourbonais Creek entering the Kansas River deep channel.

Vertical contact between bedrock and the alluvium appears very steep in many places. In sec. 19, T. 9 S., R. 11 E. the valley wall drops 110 feet in one-quarter of a mile.



BEDROCK MAP Figure 12

EXPLANATION

- Township line
- Section line
- Valley wall
- Towns
- Bedrock elevations from drill holes or wells
- Outcrop elevations

CONCLUSIONS

The direct current earth-resistivity surveys yielded bedrock contact information useful in the location of sites for test drilling for irrigation wells. The hypothetical bedrock map must be supplemented by more drill-hole information that substantiates trends. More information is also needed to map postulated bedrock channels of the tributary systems which may also be potential sites for high yield wells. Before extensive development of the water from a bedrock channel, an investigation should be made into the quality of that water and its suitability for farm or industrial use.

The values of earth resistivity in this investigation are considerably lower than values reported for similar alluvium in other parts of the nation. The high concentration of dissolved minerals in the ground water of the Kansas River alluvium is responsible for these low values. Difficulty was encountered in using Keck's interpretive techniques because of low resistivity values obtained in the field.

The apparent success of the double-depth reconnaissance study has shown that this method can be used in early stages of ground-water surveys. The short time it takes to investigate each station makes this method of value when covering a large area. Additional spacings at each double-depth station may result in more information concerning the horizontal changes within the alluvium at little added expense (Steeples, 1970, pp. 22-26). Also closer spacing of stations will provide better control for subsequent interpretations.

The lack of success in locating the water table by geoelectric

sounding should be investigated. It may be that the Wenner array would produce better results in locating the water table than does the Schlumberger array (Merriam, 1954, p. 104).

There has been a report of buried glacial till overlying alluvial gravels (Wohler, 1971, personal communication) east of St. Marys in the bedrock channel area in sec. 24, T. 10 S., R. 12 E. (fig. 12). Glacial till at this altitude indicates that there was 110 to 200 feet of scour below the base level of the Kansan-age Kansas River (Beck, 1959, p. 40). A report of glacial till occupying deep bedrock scour channels as much as 250 feet below the Kansan-age river base level at Kansas City was reported by O'Connor and Fowler (1963). The author believes that additional information should be gathered concerning the buried tills before any hypotheses are formulated concerning their emplacement.

Early in the study this investigator was confused by the great variety of earth-resistivity interpretation methods appearing in the literature. After working for some time with resistivity, the conclusion was reached that most investigators who have written about resistivity interpretive methods only reported their success with the method used and did not report their failures. Most interpretative studies were not validated by drill-hole information.

ACKNOWLEDGEMENTS

This investigation would not have been possible without the aid and advice of many people. Dr. Henry V. Beck, as major professor, provided guidance and assistance enabling the investigation to be completed. Dr. Charles P. Walters asked many questions in personal discussion which helped the author recognize problems which had not been considered. Dr. Donald O. Whittemore provided assistance in the study of ground-water conditions.

John Miesse, Gale Yarrow, Ron Pearce and Martin Leftoff assisted in fieldwork for this investigation and cannot be given enough thanks. Thanks also go to several members of the Geology Section of the State Highway Commission of Kansas who gave freely of their ideas and knowledge at the request of the investigator.

Elmer J. Wohler, Consulting Geologist, cannot be given enough credit for his help. He suggested the idea for this investigation and provided equipment, his personal library and professional experience.

Last to be acknowledged yet highly appreciated is my wife who endured the pressures of graduate school, let me talk out my problems and helped with the drafting.

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APPENDICES

APPENDICES

The following appendices present the data gathered in the field and the information derived from it.

Appendix		Page
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II.	Geoelectric Soundings, Field Readings	43
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APPENDIX I

Profile Stations, Locations and Altitudes

Station	Distance[1]	Station Altitude[2]	Spread Mid-point Altitude[2]
1	0	981.8	981.8
1A	0.065	972.4	967.8
2 *	0.122	965.4	963.4
2A	0.174	962.1	961.2
3	0.219	960.4	959.1
4	0.267	959.6	958.0
5 *	0.313	959.1	959.1
6 *	0.363	958.7	956.0
7	0.410	958.4	955.7
8	0.458	957.1	955.4
9	0.506	956.2	955.2
10 (Offset 267 feet west)	0.599	957.3	959.5
11 *	0.651	958.1	956.3
12	0.720	958.9	956.4
13 *	0.794	956.7	955.3

1 Station 1 is located at the centerline intersection of two township roads, SW¼, SW¼, NW¼, Sec. 36, T. 11 E., R. 9 T. (point B' on fig. 1). All station locations are given in miles and fraction of a mile south from Station 1.

2 Altitudes are in feet above mean sea level.

* Indicates that a negative thickness occurred during interpretation.

Station	Distance	Station Altitude	Spread Mid-point Altitude
14	0.866	955.7	954.4
15	0.944	954.6	953.8
16	1.022	958.1	955.1
17 *	1.087	957.1	954.8
18	1.174	957.9	955.3
19	1.263	959.6	957.3
20	1.342	961.5	958.8
21	1.427	957.7	955.8
22	1.490	956.2	954.7
23	1.558	951.2	949.7
24 *	1.619	950.5	949.8
25	1.686	951.7	950.9
26	1.753	953.4	952.6
27	1.819	953.8	953.1
28	1.886	952.6	951.3
29	1.955	950.8	949.6
30	2.021	950.7	
North end Bridge	2.354	969.33	
South end Bridge	2.596	969.17	
31	2.774	959.6	953.7
32 *	2.827	959.3	956.0
33	2.902	957.9	955.5
34	2.959	958.5	957.4
35	3.014	959.3	956.9

Station	Distance	Station Altitude	Spread Mid-point Altitude
35+ 245' *	(Offset 382' east)		955.6
36	3.065	959.4	
37	3.120	959.3	958.2
38	3.192	960.8	
39-55'	3.263 (Offset 200' east)	974.3	970.9
40	3.321	875.8	
41	3.381	974.6	
42	3.437	973.4	
43	3.495	970.1	
44	3.528	967.7	
45	3.569	967.0	
46	3.608	966.7	
47	3.690	970.0	
48	3.757	870.5	968.0
49	3.831	872.4	970.7
50 *	3.897	975.6	974.5
51	3.963	979.7	978.6
52	4.064	984.7	

APPENDIX II

Geoelectric Soundings
Field Readings

Station	L=a[1]	Spread[2] 1	2	3	4	5	6	8	10	15	20	30	40	50	60	80	100
1	1		28.4	15.3	15.7	21	20	22	23		23						
1A	2		13.1	11.1	10.4	11	8.5	10	12	13	16	14					
	5									6.5	12	11	10.8	6	8		
	2		8.9	8.2	7.8	7.4	6.5	7.5	8								
2	1		17	11.8	11.4	12	11	12	13	14	16.5						
	2									16.5	13	14	13	16	6.8		
	5													14	15	8	4
2A	1		4.1	4.1													
	2		6.8	3.7	3.5	3.7	3	4	5.5	7	4.5						
	5									6	4						
3	1		15.4	7.4	7.1	7	7.4	8	8	9	6						
	2										5	8	8.5				
4	1	45.4	14.8	10.2	8.7	8	9	10	14	18	18	12					
	5									17	17	17	12	19	13		
5	1	57.2	17.3	15.6	15.4	15.5	23	17.5	24	24	20	40					
	5									23	23	19.5	16	12	9		
	20												23	20	17	13	8

Table values are apparent resistance in ohm-meters

1 Potential electrode separation in meters
2 Current electrode separation from mid-point of spread in meters

Station	L=a	1	2	3	4	5	6	8	10	15	20	30	40	50	60	80	100
6	1	29	20.2	19.6	21.4	21.4	21	23.5	26	20	19	11					
	5									32	24	20	17	20	8		
	20												28	19	16	6	2
7	1	25.4	31.7	36.4	41	44.6	50	46	44	41	30	20					
	5									45.5	43	30	24	25	28		
	10												33	26	26	24	14
8	1	23.1	12.7	11.3	12.2	13.7	16	17	20.5	25.5	31	28					
	5									31	35	37	38	28	20		
9	1	17.4	16	19.3	22.6	22.9	29	33	35.5	51	36	20					
	5									37	45	48.5	20	31	26		
10	1	99.9	52.6	42.7	38.8	41.4	45	44	50	52							
Offset	5							39	42.9	48	46	44	38	34			
	20											25	46	42	33.5	22	
11	1	61.7	46.1	54.9	61.5	64	78	82	85	97	104	80					
	5									114	114	95	84	80	68		
	10												91	87	70	30	
12	1	79.2	61.5	61	66.7	71.8	84	83.5	88.5	90	90	84					
	10									88.3	98	80	106	54	38	28	4
13	1	66.3	70.5	80.2	85.6	88.5	100	96	87								
	5						93.9	91.2	90.1	92	81	58.5	60	57	50		
	10												56	54	40	35	26
14	1	21.9	21.7	24.4	27.6	30.7	41	44	52	72	75	88					
	5									88	94	114	112	98	80		
	10												119	95	65	64	0
15	1	19.6	17.3	18.7	21	19.9	23	32	24	30	27	20					
	5									40	41	46	36	28	12		

44

Station	I=a	1	2	3	4	5	6	8	10	15	20	30	40	50	60	80	100
16	1	27.4	23.8	24.7	28	28.2	28	29	32	48.5	54	68					
	5									74.5	83	82	60	82	92		
	10												74	70	56	19	0
17	1	41.8	34.7	29	31.1	29.3	44	47	47.5	44	36	72					
	5									58	60	70	60	32	16		
	10											72	50	47	51	2	
18	1	60.9	49	48.1	49.9	51.4	68	69.5	75.5	92.5	87	86					
	5									101	104	99	90	75	72		
	10											97	90	70	66	56	36
19	1	64.4	49.7	42	36.9	31.9	30	34	37	43	56	44					
	5									50	59	61	60	52	40		
	10												58	54	47	23	17
20	1	100	82	71.4	60.3	52.3	35.5	36	48	44							
	5							55.8	58.1	64	71	72.5	62	52	44		
	10												61	51	20	5	7
21	1	39.5	38.4	38.8	37.6	37.7	43.5	39	49	56	62	92					
	5									63	71	84	84	70	56		
	10												87	74	62	42	22
22	1	38.1	25.9	31.1	37	44.1	52	74	77	100	110	84					
	5									128	135	99	79	67	52		
	10												71	62	52	24	10
23	1	15.5	11.9	12.4	14.7	16.6	14	21	23	24	14.5	8					
	5									27	35	29	17	12			
24	1	10.7	6.8	6.7	7.4	8	8.5	12	12	15.5	13						
25	1	15.6	10	9.7	11.8	12.7	9	13	21	28	14	20					
	5									29	25	30	46	44	50		
	10												36	28.5	13	52	10

Station	L=a	1	2	3	4	5	6	8	10	15	20	30	40	50	60	80	100
26	1	46.7	48.2	58.7	100												
	2			59.5	65.5	74	79.2	104	96	100	98	93	82				
	10									95.7	85.5	86.5	96	105	90	36	1
27	1	49.6	41.3	44.3	47.2	46.5	49	58	69	77	94	80					
	5									65	77	90	100	90	72		
	10												97	89	80	60	28
28	1	58.5	42.5	43.2	48.8	53.2	58.5	68.5	78.5	92	97	92					
	5									92	93	88	82	73	62		
	10												87	85	78	54	
29	1	49.5	19.8	23	24.1	33	39	49	47	-	64	72					
	5										86	78	59	38	6		
31	1	12.2	7.6	9.2	10.2	10.2	10	10	11	14	28	36					
32	1	17.5	9.1	10	11.5	12.4	16	21	20	20	24						
	10								14.2	14.8	22	17	38	26	30	26	61
33	1	17.1	9.5	8.2	8.6	9	2	16	15	12.5	13	2					
	5									8	21	17	12				
34	1	22.1	15.1	17.4	18.6	19.5	21	21	24	26	41	22					
	10									20.3	35.5	39	26	35	44	28	
35	1	35	12.5	11.7	10	8.9	7	3	4	1							
	5							12.1	11	8	16	21.5	26	15	68		
	10												25	19	20	20	2
37	1	56.6	20.9	16.4	13.1	12	11	11	11	11							

Station	L=a	1	2	3	4	5	6	8	10	15	20	30	40	50	60	80	100
35+245'	1	42	20	17	16	16	15	16									
Offset	2						15	16	11	15	13	13	14				
	5										18	16	20	21	24		
	10													22	20	12	16
	20														19	12	12
39	1	80.3	21.8	18.8	17.7	16.7	20	18.5	19.5	22.5	25						
Offset	5									31	25	25	23	20	14		
48	1	21.3	9.3	7.1	6.9	6.8	8	6	5.5	11	6	10					
	5									10	16.5	16	20	12	24		
49	1	16.6	9.3	7.8	7.7	7.7	7	7	7								
50	1	16.9	9.2	9.9	10.3	9.9	8	8	11	12	17	18					
	5									17	18	17.5	20	20	20		
51	1	14.3	10.3	9.3	9	8.4	6	8	8	10	13	14					
	5									13.5	13	13	14	14			

APPENDIX III

Double-Depth Stations

No.	Location ¼ ¼ ¼	Sec.[1]	T.[2]	R.[3]	40m.[4]	80m.[5]	Diff.[6]	Keck's Curves[7]	Keck's Formula[8]
N 1	NE NE SE	6	10	12	19	19	0	19	19
N 2	SE SE SE	6	10	12	18	6	12	-	0
N 3	NE NW NE	7	10	12	27	16	9	8.5*	10.5
N 4	NE SW NE	7	10	12	11	9	2	8 *	8
N 5	SW SW NE	7	10	12	109	32	77	-	- 6.5
N 6	NE NE SE	12	10	11	93	44	49	21.5	19.5
N 7	SW SE NE	12	10	11	99.5	60	39.5	38	40.25
N 8	NE NE NW	12	10	11	31	29	2	28	28
N 9	NE NE NE	12	10	11	36.5	22	14.5	12.5	14.75
N 10	SE NW NE	12	10	11	58.5	40	18.5	28	30.75
N 11	NW NE NE	18	10	12	134	24	110	-	-31
N 12	NW NW NW	17	10	12	57.5	22	35.5	4.2*	4.25
N 13	NW NW NW	17	10	12	66	16	50	-	- 9

1 Section
2 Township south
3 Range east
4 40-meter spread in ohm-meters
5 80-meter spread in ohm-meters
6 Double-depth difference apparent resistivity in ohm-meters
7 Keck's curves average apparent resistivity in ohm-meters
8 Keck's formula average apparent resistivity in ohm-meters
negative values are not usable
- Indicates value not found on Keck's curves
* Indicates value is from extended Keck's curves

No.	Location ¼ ¼ ¼	Sec.	T.	R.	40m.	80m.	Diff.	Keck's Curves	Keck's Formula
N 14	NE NE NE	17	10	12	47	13	34	-	- 4
N 15	NE NE SE	17	10	12	72	20	52	-	- 6
N 16	SW SW SW	16	10	12	50	20	30	-	5
N 17	SW SW SE	16	10	12	64.5	31	33.5	14.5	14.25
N 18	NE NW NW	22	10	12	58	34	24	20	22
N 19	SW SW NE	16	10	12	42.5	15	27.5	-	1.25
N 20	NW NW NE	16	10	12	40	29	11	21	23.5
N 21	SE NE NE	8	10	12	49	19	30	-	4
N 22	SW NW NE	8	10	12	20	6	14	-	- 1
N 23	NE NW NE	2	10	11	10	3	7	-	- 0.5
N 24	NE NE NE	3	10	11	5	5	0	5 *	5
N 25	NE NW NW	4	10	11	14	4	10	-	- 1
N 26	SW SW SE	32	9	11	26	17	9	11.5*	12.5
N 27	NW NW NW	5	10	11	60	30	30	15	15
N 28	SE NE NW	6	10	11	58	50	8	44	46
N 29	SW SW NW	32	9	11	23	12	11	9.5*	6.5
N 30	SW SW NE	32	9	11	32.5	27	5.5	25	24.25
N 31	SE SE NE	32	9	11	22	22	0	22	22
N 32	SW SW NE	33	9	11	33	18	15	11	10.5
N 33	SE SE NE	33	9	11	19	18	1	17	17.5
N 34	NW NW SE	5	10	12	10	3	7	-	- 0.5
N 35	NW NW SW	5	10	12	18	13	5	9.5*	10.5
N 36	SE NW NE	6	10	12	24	28	- 4	33	30
N 37	SW SE SW	5	10	12	34	9	25	-	- 3.5
N 38	SW SE SE	36	9	11	17	12	5	8.8*	9.5

No.	Location ¼ ¼ ¼	Sec.	T.	R.	40m.	80m.	Diff.	Keck's Curves	Keck's Formula
N 39	SW SE NE	11	10	11	66.5	26	40.5	2.2*	5.75
N 40	NE SE NE	15	10	12	15	11	4	8.5*	9
N 41	NE NE NE	22	10	12	26	14	12	6 *	8
N 42	SW SW SW	23	10	12	54	20	34	-	3
N 43	SE NE NW	26	10	12	30.5	16	14.5	5.5*	8.75
N 44	NW SW SE	26	10	12	21	14	7	10	10.5
N 45	NW NE NE	35	10	12	36	16	20	-	6
N 46	SE SE SW	25	10	12	28	11	17	-	2.5
N 47	SW SW NE	36	10	12	32	16	16	4 *	8
N 48	NE NW NE	1	11	12	51	13	38	-	- 6
N 49	NW NE SW	1	11	12	46	6	40	-	-14
N 50	SW NW NE	25	10	12	37	16	21	-	5.5
N 51	SW SW SW	24	10	12	38	13	25	-	0.5
N 52	SW SW SW	19	10	13	16	22	- 6	34	25
N 53	SE NE NE	24	10	12	29	20	9	14	15.5
N 54	SE NE NE	4	10	11	43	13	30	-	- 2
N 55	SE NW NW	4	10	11	124	32	92	-	-14
N 56	SE NE SE	5	10	11	33	11	22	-	0
N 57	SW NW SE	31	9	11	26	9	17	-	0.5
N 58	SW NW NE	31	9	11	21	11	10	-	6
N 59	SW NW NE	30	9	11	25	6	19	-	- 3.5
N 60	SW NW NW	28	9	11	14	12	2	9 *	11
N 61	NW NW NW	33	9	11	21	15	6	10.75	12
N 62	NE NE NW	34	9	11	13.5	9	4.5	6 *	6.75

No.	Location ¼	¼	¼	Sec.	T.	R.	40m.	80m.	Diff.	Keck's Curves	Keck's Formula
S 1	SW	SW	NE	13	10	11	30	16	14	6.5*	9
S 2	SE	SE	SW	12	10	11	88	48	40	16	28
S 3	SE	NE	NW	13	10	11	87	30	57	2 *	1.5
S 4	SE	SE	NE	13	10	11	127	64	63	46	32.5
S 5	SE	SE	SE	13	10	11	20	18	2	16	17
S 6	SW	SW	SE	13	10	11	14.5	11	3.5	9 *	9.25
S 7	SW	SW	NW	19	10	12	14	13	1	12.5*	12.5
S 8	NW	NW	NE	19	10	12	15	8	7	31 *	4.5
S 9	NE	NE	NE	19	10	12	24	20	6	17	18
S 10	SE	SE	NE	19	10	12	19	15	4	11	13
S 11	SW	SW	NE	20	10	12	28	18	10	12	13
S 12	NW	NW	NW	21	10	12	42	30	8	22	24
S 13	NW	NW	NW	28	10	12	36	16	20	7 *	6
S 14	NE	NE	NW	28	10	12	90	34	56	10.5	6
S 15	SW	NW	NW	27	10	12	74	14	60	-	-16
S 16	NE	NE	SW	27	10	12	39	18	21	5 *	7.5
S 17	SW	SW	NE	29	10	12	15	14	1	16 *	13.5
S 18	SE	SE	SE	29	10	12	12.5	12	0.5	12.5	11.75
S 19	NW	SE	SE	1	11	12	16	2	14	-	- 5
S 20	SW	SE	NW	34	10	12	10	5	5	-	2.5
S 21	NE	SE	NW	29	10	12	14	7	7	-	3.5
S 22	NW	NE	NE	30	10	12	13	6	7	-	2.5

Double-depth from profile stations

No.	Location ¼ ¼ ¼	Sec.	T.	R.	40m.	80m.	Diff.	Keck's Curves	Keck's Formula
Station 5	SW NW SW	36	9	11	23	13	10	3 *	8
Station 6	NW SW SW	36	9	11	28	6	22	-	- 5
Station 10	NE NE NE	2	10	11	46	22	24	10.5	10
Station 34	SE SE SE	14	10	11	77	46	31	29	30.5

APPENDIX IV

Conductivity Stations

No.	Location ¼ ¼ ¼	Sec.[1]	T.[2]	R.[3]	Average value[4] micromhos/cm.[6]	Corrected for cell constant[5] micromhos/cm.[6]	Resistance ohm-meters
F 1	SE SE SE	32	9	11	800	823.3	125
F 2	NW NE NE	6	10	11	759	781.1	128
F 3	NE NE SW	31	9	11	692	712.1	140
F 4	SE SW SW	30	9	11	1030	1060.0	94
F 5	SW SW SE	30	9	11	1152	1185.5	84
F 6	NE SE NE	31	9	11	1098	1130.0	88
F 7	SW SE NE	33	9	11	744	765.7	131
F 8	NE NE SW	34	9	11	760	782.1	128
F 9	SW SW SW	1	10	11	755	777.0	129
F 10	SE SE SW	1	10	11	782	804.8	124
F 11	SE NW NE	7	10	12	907	933.4	107
A 15D	NE NE NW	4	10	11	1185	1219.5	82
A 15S	NE NE NW	4	10	11	945	972.5	103
A 1D	NE NE NW	4	10	11	768	790.4	127
A 1S	NE NE NW	4	10	11	786	808.9	124
F 12	NE NE NW	1	10	11	764	786.2	127

1 Section
2 Township south
3 Range east
4 Average of three readings corrected for temperature to 25 degrees C
5 Cell constant = 1.029
6 The new and preferred term for conductivity is siemens.

No.	Location ¼ ¼ ¼	Sec.	T.	R.	Average value micromhos/cm.	Corrected for cell constant micromhos/cm.	Resistance ohm-meters
F 13	NE NE NE	8	10	12	970	998.2	100
F 14	SE SE SW	5	10	12	718	738.9	135
F 15	SW SW SW	28	9	11	1545	1590.0	63
F 16	SW SW NE	32	10	12	726	747.1	134
F 17	SE SE SW	9	10	12	874	899.4	111
F 18	SW SW SW	9	10	12	790	813.0	123
F 19	SE SE SW	8	10	12	1205	1240.1	81
F 20	NW SW SW	16	10	12	790	813.0	123
F 21	NE NE NW	21	10	12	720	741.0	135
F 22	SW NE NW	22	10	12	860	885.0	113
F 23	NW NW NW	6	10	12	710	730.7	137
F 24	SW SW NW	33	9	11	727	748.2	134
F 25	NW NW SE	14	10	11	908	934.4	107
F 26	NW NE SW	13	10	11	460	473.4	211
F 27	NW NE NE	23	10	11	830	854.2	117
F 28	SE SE SE	13	10	11	584	601.0	166
F 29	SW SE SE	18	10	11	787	809.9	123
F 30	NE NE SE	19	10	12	632	650.4	154
F 31	NE NE SW	20	10	12	580	596.9	168
F 32	SW SW SW	28	10	12	1020	1049.7	95
F 33	NW NE NE	29	10	12	880	905.6	110
F 34	SW NW NW	13	10	11	953	980.7	102
F 35	SW NW SE	16	10	12	775	797.6	125

No.	Location ¼ ¼ ¼	Sec.	T.	R.	Average value micromhos/cm.	Corrected for cell constant micromhos/cm.	Resistance ohm-meters
F 36	SW NW SW	14	10	12	1200	1234.9	81
F 37	SE NE SE	22	10	12	1552	1597.2	63
F 38	NW NW NE	26	10	12	1610	1656.9	60
F 39	SE SW SE	25	10	12	680	699.8	143
F 40	SW SE SW	24	10	12	675	694.7	144
F 41	NE NW NW	25	10	12	970	998.2	100
F 42	SW NE NW	14	10	12	700	720.4	139
F 43	SW SE NE	34	10	12	832	856.2	117
F 44	SW SE NE	33	10	12	570	586.6	170
F 45	NE NW NW	35	10	12	1137	1170.1	85
F 46	NE SE SE	5	10	11	710	730.7	137

APPENDIX V

Bedrock-Depth Locations From Water Wells and Test Holes

Location number	Location ¼ ¼ ¼	Section	Township south	Range east	Bedrock Altitude Feet
B 1	SE SW	9	9	11	890
B 2	SW SW	28	9	11	893
B 3	NW SW	29	9	11	897
B 4	NE NE	30	9	11	891
B 5	SW SE	30	9	11	880
B 6	SE SE	30	9	11	894
B 7	SW SE	31	9	11	910
B 8	SW SW	33	9	11	894
B 9	NE SW	2	10	11	874
B 10	NE NW	3	10	11	883
B 11	SW SE	7	10	11	945
B 12	SE NW	11	10	11	877
B 13	SW SE	16	10	11	965
B 14	SE NW	7	10	12	876
B 15	NE SE	9	10	12	892
B 16	SW SW	10	10	12	903
B 17	SW SE	10	10	12	881

B designated wells are from Beck (1959).
E designated wells are from Wohler (1972).
F & I designated wells are from area farmers (1972-73).
A designated wells are from Agronomy research plot, Fulmer's farm.

Location number	Location ¼ ¼ ¼	Section	Township south	Range east	Bedrock Altitude Feet
B 18	NW SW	16	10	12	883
B 19	NE SW	20	10	12	905
B 20	SE NE	24	10	12	881
B 21	SW SE	24	10	12	864
B 22	SW NE	26	10	12	884
B 23	SW SW	28	10	12	898
B 24	NE NE	19	10	13	925
B 25	NE SE	19	10	13	870
B 26	NE NW	31	10	13	890
B 27	SE SW	31	10	13	880
A 1D	NW NE NW	4	10	11	885
A 15D	NE NE NW	4	10	11	885
E 1	SW SE NW	15	10	11	945
E 2	SW SE SE	9	10	11	947
E 3	NW NW SE	27	9	11	921
F 9	SW SW SW	1	10	11	867
F 36	SW NW SW	14	10	12	898
I 1	SE SW SE	32	9	11	898
I 2	center NE	32	9	11	879
I 3	center N½	33	9	11	895
I 4	center E line, NE	33	9	11	895
I 6	SE NE NE	8	10	12	900
I 7	SW NW NE	26	10	12	877
I 8	SE SE NW	25	10	12	847

Location number	Location ¼ ¼ ¼	Section	Township south	Range east	Bedrock Altitude Feet
I 9	NW NW SW	24	10	12	842
I 10	NE NW SE	24	10	12	839

Test Hole 1 Station 1
SW¼, SW¼, NW¼, Sec. 36, T. 9S., R. 11 E.
bedrock altitude 978.1 feet

Test Hole 2 135' north Station 17
SE¼, SE¼, NE¼, Sec. 1, T. 10 S., R. 11 E.
bedrock altitude 892.2 feet

Test Hole 3 45' east Station 18
NW¼, NW¼, SW¼, Sec. 1, T. 10 S., R. 11 E.
bedrock altitude 875.1 feet

Bridge Soundings
State Highway Commission of Kansas
Bridge No. 99ER115

BR#1 NW¼, SW¼, SW¼, Sec. 12, T. 10 S., R. 11 E.
bedrock altitude 877.6 feet

BR#4 SE¼, NE¼, SE¼, Sec. 11, T. 10 S., R. 11 E.
bedrock altitude 875.1 feet

BR#6 NE¼, NE¼, SE¼, Sec. 11, T. 10 S., R. 11 E.
bedrock altitude 878.4 feet

Test hole on dike north end Maple Hill Bridge

NW¼, NE¼, SW¼, Sec. 1, T. 11 S., R. 12 E.
bedrock altitude 857.0 feet (Stuart, 1973, oral communication)

APPENDIX VI

Test-Hole Logs

Test Hole 1 — Station 1

SW¼, SW¼, NW¼, Sec. 36, T. 11 E., R. 9 S.

Top hole altitude 981.8 feet

Feet	
0.0- 2.0	Silty clay, brown, dry
2.0- 3.9	Silty clay, light brown
3.9- 6.0	Weathered shale, tan to gray, limestone fragments
6.0-10.0	Weathered shale, gray to brown, silty
10.0-12.2	Weathered shale, tan brown, clayey with silt, damp
12.2-14.0	Sandstone, tan, fine grained, hard
14.0-14.3	Shale, tan brown
14.3-16.4	Sandstone, tan,fine grained, hard
16.4-17.0	Shale, gray
17.0-17.5	Sandstone, tan
17.5-18.9	Shale, black, fissile
18.9-19.6	Limestone, gray, sugarey, hard
19.6-21.8	Shale, gray-green
21.8-23.0	Shale, dark gray, clay
23.0	Total depth

Test Hole 2 — 135 feet north Station 17

SE¼, SE¼, NE¼, Sec. 1, T. 11 E., R. 10 S.

Top hole altitude 957.6 feet

Feet	
0.0- 0.5	Road metal
0.5- 1.5	Silt, dark, organic
1.5- 2.6	Silt, brown
2.6- 9.2	Silt, tan
9.2-23.1	Silt, tan to gray, wet, increasing clay with depth
23.1-31.1	Medium silty sand
31.1-45.0	Gravel, some coarse with sand, dirty
45.0-54.4	Sand and gravel, clean
54.4-65.4	Fine to medium gravel, gray, with some coarse gravel
65.4-68.0	Shale, gray, weathered
68.0	Total depth

Test Hole 3 — 45 feet east Station 18

NW¼, NW¼, SW¼, Sec. 1, T. 11 E., R. 10 S.

Top hole altitude 955.3 feet

Feet	
0.0- 1.5	Silty clay, dark brown
1.5- 4.9	Silty clay, brown
4.9- 9.8	Silt with very fine sand, tan
9.8-16.2	Fine sand, tan brown, damp
16.2-19.4	Very fine sand, tan, "blow sand"
19.4-23.6	Sand, fine to medium, very damp
23.6	Gravel chatter
23.6-34.4	Sand, fine to medium, wet, increasing silt and gravel with depth
34.4-39.5	Sand, gray, increasing dirty
39.5-45.4	Sand, bound with silt and clay
45.4-52.3	Gravel and sand, bound with clay
52.3-52.8	Thin clay lenses
52.8-55.0	Gravel, clay bound
55.0-80.2	Coarse gravel and sand, less clay with depth, increasing feldspar content with depth
80.2	Shale, weathered, very thin
80.2-82.0	Shale, gray
82.0	Total depth

Bridge Soundings from the State Highway Commission of Kansas

BR#1 — South Abutment

NW¼, SW¼, SW¼, Sec. 12, T. 11 E., R. 10 S.

Top hole altitude 953.1 feet

Feet	
0.0-75.5	Fine grained sand to silt, sand becomes coarser below altitude, 868.2 feet
75.5-82.7	Shale, rusty, maroon colored, silty clay
76.2	0.1 secondary limestone
82.7-94.2	Shale, gray and gray-green, inclined to be slightly sandy in the upper part, firm for the most part, mostly clay some silt
94.2-96.1	Limestone, light gray to gray, hard
96.1-98.5	Shale, dark gray to green, calcareous, clayey

Hole was deeper but there was no more log in the files.

BR#4 Just north of Pier #3 from south end of bridge

SE¼, NE¼, SE¼, Sec. 11, T. 11 E., R. 10 S.

Top hole altitude 932.9 feet

Feet	
0.0-57.8	Sand
57.8-58.6	Shale, red and gray, altitude 875.1 feet
58.6-59.7	Limestone, light gray, thin shale brake
59.7-62.0	Shale, rust-red, clay
62.0-75.4	Shale, gray, clay, slightly arenaceous near top, firm
75.4-75.7	Limestone, light gray, medium hard
Total depth	altitude 857.2 feet

BR#6 North Approach

NE¼, NE¼, SE¼, Sec. 11, T. 11 E., R. 10 S.

Top hole altitude 936.7 feet

Feet	
0.0-58.3	Sand
58.3-78.0	Shale, green and gray, clay, firm, altitude 878.4 feet
59.6	0.5 secondary limestone
78.0-78.4	Limestone, hard
Total depth	altitude 858.3 feet

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A GROUND-WATER STUDY USING EARTH RESISTIVITY METHODS

by

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An investigation was conducted to evaluate the usefulness of direct current earth-resistivity methods for gathering subsurface information in ground-water studies. This investigation was carried out in the Kansas River Valley near Belvue and St. Marys, Kansas.

It was found that geoelectric sounding could be used to determine the composition of alluvium beneath the electrode spread, if the derived information was used in conjunction with other methods of gathering subsurface information. The Schlumberger electrode array did not consistantly yield information from which the water table could be determined. A modification of geoelectric profiling called double-depth profiling was found useful in mapping both lateral changes within the alluvium and the contact between alluvium and bedrock. This technique is useful in rapid reconnaissance of large areas. The low resistivity values encountered in this investigation were the result of high concentrations of dissolved minerals in the ground water within the alluvium.

A deep bedrock channel was mapped through the area and noted as a possible source of water for irrigation wells. Changes in the sand and gravel filling the channel were also noted in several areas.