RESISTIVITY METHODS IN PROSPECTING FOR GROUND WATER

by

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INTRODUCTION

Purpose of Investigation

A technique for groundwater exploration in alluvial sediments in the area near Manhattan, Kansas, was developed. The investigation was a part of the studies of groundwater recharge in river valleys sponsored by Kansas Agriculture Experiment Station, Manhattan, Kansas.

Use of direct current earth resistivity methods in other parts of Kansas has been reported. Successful application of these methods enables one to infer areas of maximum depth-to-bedrock and sediments of high permeability. Many previous investigations in other parts of the country have been successful, but no such investigation had been conducted in the Kansas and Blue River Valleys near Manhattan.

A sure way to find the best place to develop water wells is to drill a series of test holes in the area of interest. The test drilling may be minimized, however, when the drilling is planned in conjunction with an earth resistivity survey. A rapid preliminary resistivity survey can suggest the best places for the test holes. After the test holes are drilled and sample analysis has been performed, a more extensive resistivity survey can suggest the best location(s) for maximum yield. Costly test drilling is minimized and the total cost of well development may be decreased significantly.

Physiography

The area is just east of Manhattan, Kansas, in Riley and Pottawatomie Counties. The resistivity data were collected in the valley in Sec. 4, Sec. 5, Sec. 8, and Sec. 9, T. 10 S., R. 8 E. Some data were obtained from Sec. 32, T. 9 S., R. 8 E.

The area is in the northwest part of the Osage Plains section of the Central Lowlands Physiographic Province (Thornbury, 1965, p. 250). The Blue River Valley is approximately one-and-one-half to two miles wide and trends south-southeast downstream near Manhattan. Tuttle Creek Dam on the Blue River, one of the largest earth fill dams in the Midwest, is four miles upstream from the area.

The watershed for the reservoir is in northcentral Kansas and southcentral Nebraska where rocks of the Permian and Cretaceous Systems crop out. Average annual precipitation is between 30 and 32 inches per year, most of which normally comes as thundershowers between April and September.

Geology

The Blue River Valley is bordered on east and west by bluffs underlain by westward dipping limestones and shales of the Permian System with relief of 200 feet. The valley is filled with alluvium which ranges from less than 10 feet at the margin of the valley to as much as 114 feet as indicated by test hole 6A drilled by Layne-Western (Layne-Western, 1968).

The alluvium consists of sand bars, gravel, silt, and clay, deposited by the meandering of the Blue River since maximum downcutting occurred sometime during Early Wisconsin time (Nuzman, C. E., 1969, p. 4).

The deepest part of the bedrock channel is probably not very wide, because rarely does one find depth-to-bedrock exceeds 70 feet. Exploration during preliminary investigation for Tuttle Creek Dam revealed a channel approximately 200 yards wide beneath 100 feet of alluvium at the deepest point. This alluvium rests unconformably on Permian bedrock.

Extensive deposition occurred in both the Kansas and Blue River Valleys during the Wisconsin Stage of the Pleistocene Epoch. Subsequent entrenchment of these two rivers has produced an alluvial terrace a few feet above the modern-day flood plain. This surface has been named Newman Terrace by Davis and Carlson (1952), after the town of Newman, Kansas, where the terrace is conspicuously preserved (Gregory, 1967).

The flood plain is relatively free of relief except near rivers where cliff-like banks of up to 30 feet in height rise up from the rivers' edges. Surface relief introduces error into earth resistivity measurements because uniform current flow is disturbed, but the flood plains are flat enough to reduce this source of error to near zero.

Hydrology

The area for this investigation was chosen partly because much was known about its hydrologic characteristics. The City of Manhattan has pumped an average of 3.7 million gallons of water per day for several years from the seven wells in SW$\frac{1}{4}$, Sec. 8, T. 10 S., R. 8 E. Several irrigation wells operate in the summer, with yields probably ranging between 500 and 1000 gallons per minute.

Layne-Western Company, Inc., conducted a groundwater study for the City of Manhattan in 1968. Much of their study was in the same area as the resistivity survey of this investigation. Thirteen of the seventeen Layne Western test wells lie in or very near the area of the resistivity survey. Table 1 summarizes the well logs, and Figure 1 shows bedrock elevations at the locations of the thirteen holes.

The bedrock elevation at test hole 6A, Figure 1, is considerably lower than any of the other holes. Test hole 17 did not reach bedrock, so bedrock in that hole would have had the lowest elevation with the probable exception of test hole 6A.

Results of partial chemical analyses of water samples from the test holes are given in table 2. The chemical quality of the water from all the wells except test hole 6A is very similar. The sample from test hole 6A contained a significantly higher quantity of chloride ions, as well as

Table 1. Summarized Test Hole Logs

TEST HOLE 1.	**STATIC WATER LEVEL 17.8 FEET**	
0' to	15'	Soil and brown silt
15'	27'	Gray medium to coarse sand and gravel
27'	28'	Gray clay
28'	59'	Gray coarse sand and gravel
59'	61'	Gray shale
TEST HOLE 2.	**STATIC WATER LEVEL 13.8 FEET**	
0'	9'	Soil and brown silt
9'	20'	Tan medium to coarse sand and gravel
20'	22'	Gray clay
22'	55'	Gray coarse sand and gravel
55'	60'	Gray shale
TEST HOLE 3.	**STATIC WATER LEVEL 21 FEET**	
0'	29'	Soil and brown clay
28'	68'	Gray sand and gravel
68'	74'	Gray shale
TEST HOLE 4.	**STATIC WATER LEVEL 30.1 FEET**	
0'	20'	Soil and brown clay
20'	47'	Gray clay
47'	61'	Gray sand and gravel
61'	67'	Gray shale
TEST HOLE 5.	**STATIC WATER LEVEL 22.2 FEET**	
0'	13'	Soil and brown silt
13'	17'	Fine sand and brown silt
17'	48'	Gray sand and gravel
48'	54'	Gray shale
TEST HOLE 6A.	**STATIC WATER LEVEL 21.7 FEET**	
0'	10'	Soil and brown silt
10'	58'	Tan sand and gravel
58'	98'	Gray fine sand, sandy clay
98'	103'	Gray clay
103'	114'	Gray sand and gravel
114'	115'	Limestone, very hard
TEST HOLE 7.	**STATIC WATER LEVEL 33.2 FEET**	
0'	49'	Soil and gray clay
49'	63'	Gray sand and gravel
63'	66'	Gray shale
TEST HOLE 8.	**STATIC WATER LEVEL 22.4 FEET**	
0'	20'	Soil and brown silt
20'	29'	Gray sand and gravel
29'	31'	Gray clay

Table 1. (continued)

TEST HOLE 8.	STATIC WATER LEVEL	22.4 FEET (continued)
31'	66'	Gray sand and gravel
66'	70'	Gray shale
TEST HOLE 9.	STATIC WATER LEVEL	20.3 FEET
0'	16'	Soil and brown sandy silt
16'	47'	Gray sand, gravel, with silt
47'	53'	Gray shale
TEST HOLE 13.	STATIC WATER LEVEL	22.4 FEET
0'	15'	Soil and brown sandy silt
15'	26'	Brown sand and gravel
26'	72'	Gray sand and gravel
72'	73'	Green shale
TEST HOLE 14.	STATIC WATER LEVEL	22.2 FEET
0'	23'	Soil and brown silty clay
23'	49'	Gray sand and gravel, some fine
49'	50'	Gray limestone, hard
TEST HOLE 15.	STATIC WATER LEVEL	22.5 FEET
0'	16'	Soil and brown silt
16'	20'	Brown fine to medium sand
20'	32'	Gray sand and gravel
32'	38'	Gray silty clay
38'	44'	Gray sand and gravel
44'	46'	Gray limestone, hard
TEST HOLE 16.	STATIC WATER LEVEL	17.2 FEET
0'	16'	Soil and brown clay
16'	20'	Brown sand
20'	35'	Gray sand and gravel
35'	38'	Gray silty clay
38'	43'	Gray sand and gravel
43'	46'	Gray shale
TEST HOLE 17.	STATIC WATER LEVEL	20.6 FEET
0'	10'	Soil and brown silt
10'	16'	Brown fine sand
16'	18'	Brown clay
18'	22'	Tan sand
22'	70'	Gray sand and gravel

Data from Layne-Western Report (1968) pp. 7-9.

Table 2. Partial Chemical Analysis from Test Holes

Listed in milligrams per liter are the results of partial chemical analyses of twelve samples of water collected from test holes drilled for the City of Manhattan, Kansas, water supply development project.

	TH1	TH1A*	TH4	TH2	TH3	TH4A**
Total Hardness (as $CaCO_3$) =	405.	349.	326.	329.	164.	322.
Calcium (as Ca) =	126.	107.	104.	94.	54.	101.
Magnesium (as Mg) =	22.	20.	16.	23.	7.2	17.
Alkalinity (as $CaCO_3$) =	324.	316.	284.	212.	184.	308.
Chloride =	36.	63.	28.	156.	13.	24.
Sulfate =	107.	64.	67.	118.	33.	38.
Nitrate (as NO_3) =	0.66	1.5	0.89	1.7	1.7	1.7
Fluoride =	0.3	0.3	0.1	0.4	0.3	0.1
Iron =	2.8	5.0	3.6	1.7	2.3	2.2
Manganese =	0.17	1.0	0.31	0.92	1.2	0.84

	TH5	TH6	TH6A	TH8	TH9	TH11
Total Hardness (as $CaCO_3$) =	346.	203.	800.	334.	400.	374.
Calcium (as Ca) =	112.	65.	213.	109.	121.	107.
Magnesium (as Mg) =	16.	10.	65.	15.	24.	26.
Alkalinity (as $CaCO_3$) =	322.	212.	382.	262.	392.	296.
Chloride =	20.	15.	1260.	37.	23.	112.
Sulfate =	44.	35.	135.	94.	75.	64.
Nitrate (as NO_3) =	1.7	1.7	1.8	1.7	2.0	1.7
Fluoride =	0.1	0.3	0.1	0.2	0.3	0.3
Iron =	2.3	0.46	0.41	1.3	6.2	1.4
Manganese =	0.90	1.9	0.00	0.59	1.4	1.7

*TH1A - Represents the sample from existing well No. 5.
TH7 - Was not recorded because the sample bottle was broken in the testing laboratory.
**TH4A - Sample taken from house well in vicinity of test hole 4.

Data from Layne-Western Report (1968)

the highest quantities of sulfate, magnesium, and calcium ions, and calcium carbonate. It is probable these higher dissolved mineral contents would cause significant differences in resistivity as will be discussed later.

A pumping test was conducted on test hole 13 where an 18 inch diameter gravel-packed well was constructed by Layne-Western for collecting hydrologic information near a possible new well field for the City of Manhattan. An analog computer model was designed for the transmissivity of the alluvial aquifer using drill sample analyses and transmissibility information from the pumping test. Figure 2 shows the conditions predicted by the computer model for the area involved in the resistivity survey. The area of high predicted transmissivity will be compared with similar areas predicted by resistivity mapping.

METHODS OF INVESTIGATION

Direct Current Resistivity Method

The direct current resistivity method is one of the most widely used methods of geophysical explorations for shallow studies. The method used in this investigation involved inducing a small (100 milliamperes) direct current into the ground through two different electrodes C_1 and C_2, and simultaneously measuring the potential developed between two other electrodes P_1 and P_2. The electrodes are placed in a collinear arrangement about a central point with the

THIS BOOK CONTAINS NUMEROUS PAGES WITH DIAGRAMS THAT ARE CROOKED COMPARED TO THE REST OF THE INFORMATION ON THE PAGE.

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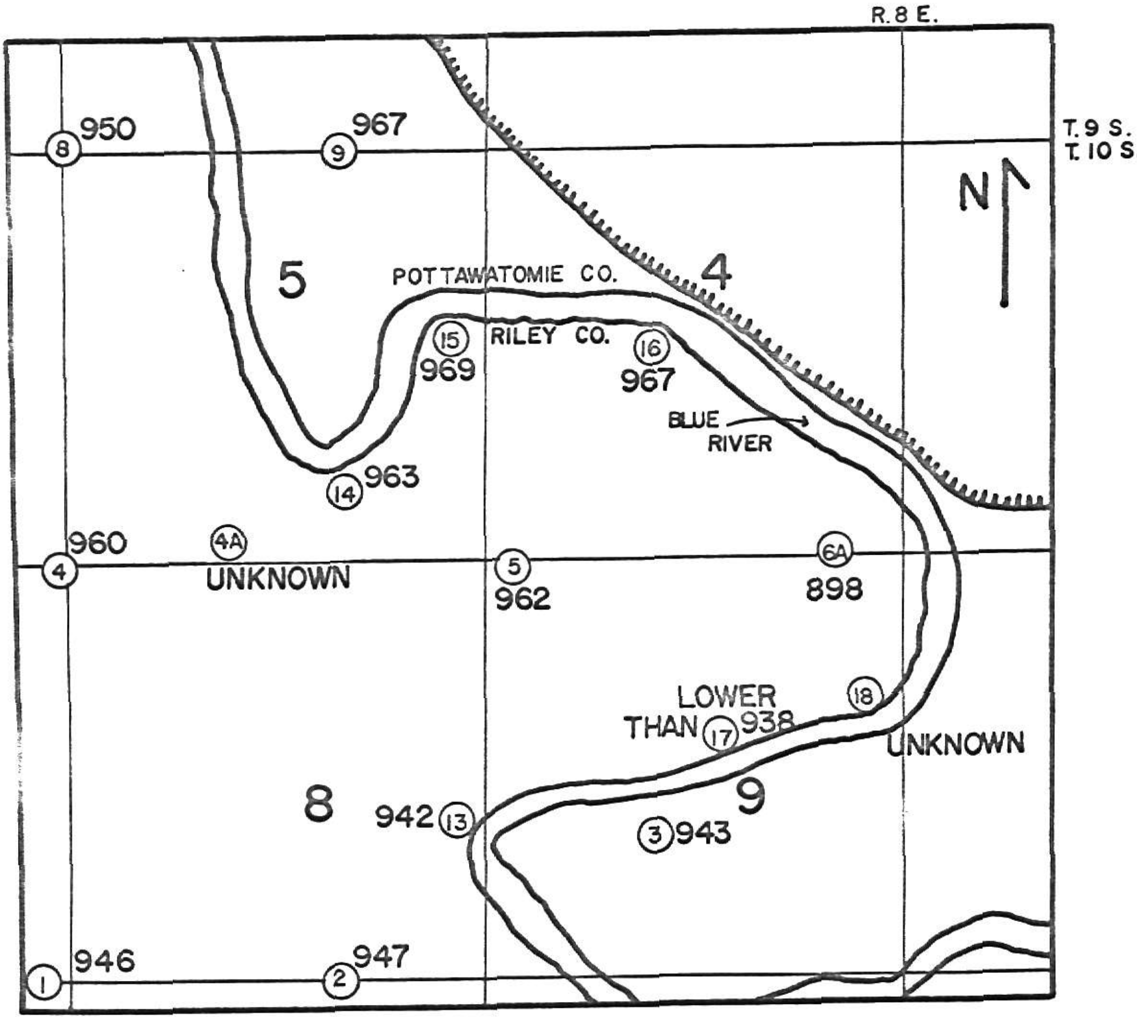
BEDROCK ELEVATION IN TEST HOLES EAST OF MANHATTAN, KANS.



LEGEND

AQUIFER BOUNDARY

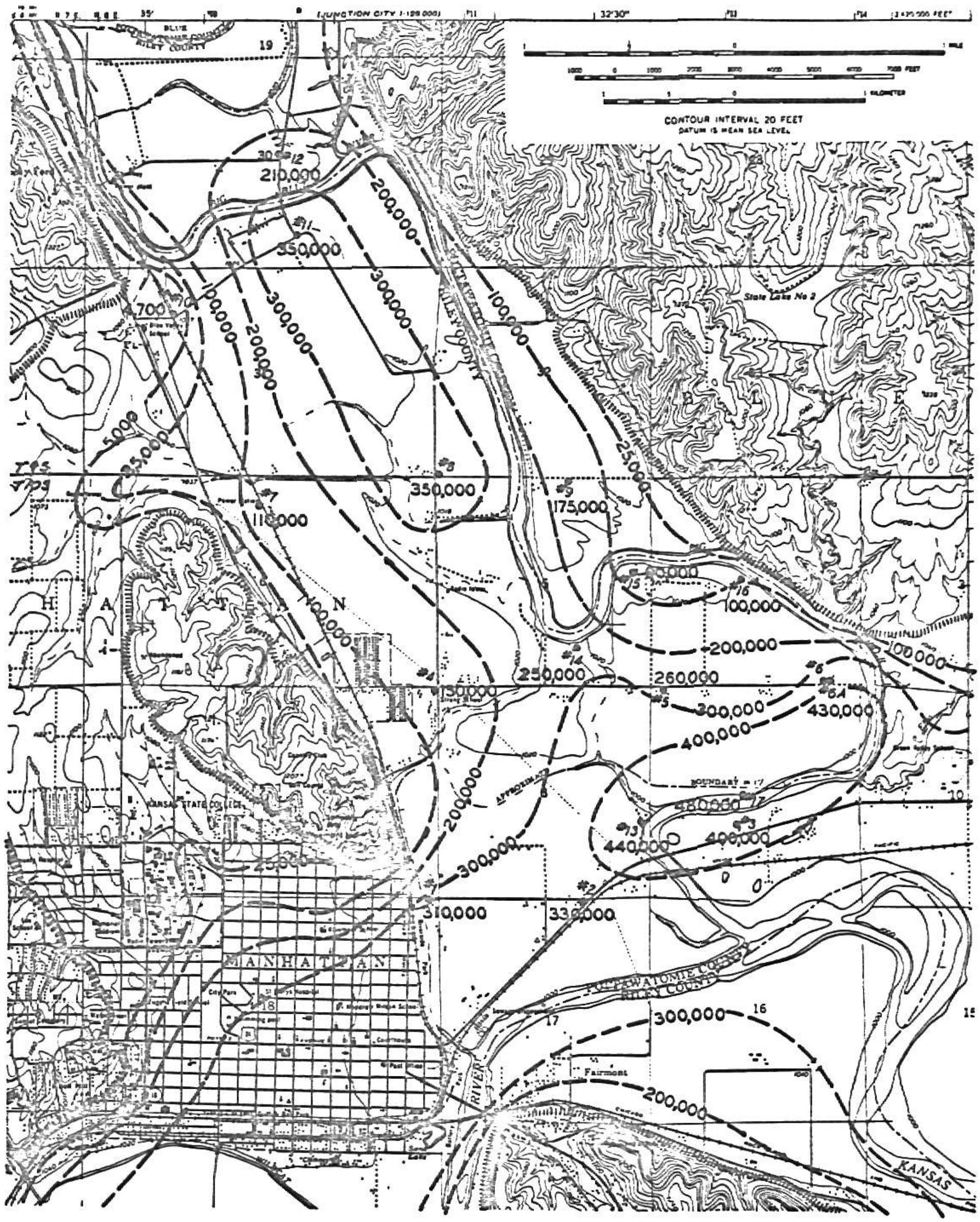
BEDROCK ELEVATIONS 947 etc.

TEST HOLE LOCATIONS ②

SCALE ←1/2 MILE→

DATA FROM LAYNE-WESTERN REPORT (1968)

Figure 1



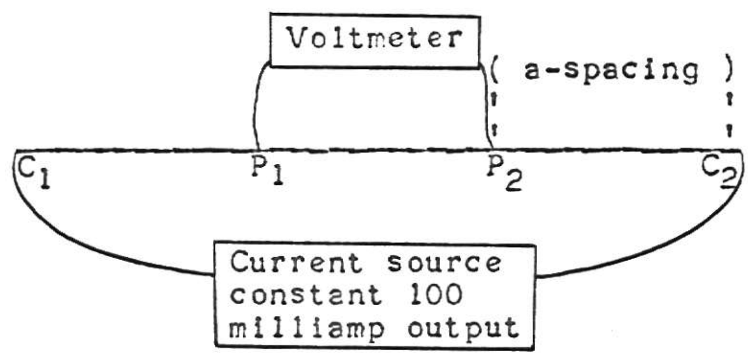
LEGEND

TRANSMISSIVITY (GPD/FT.)

AQUIFER BOUNDARY

FIGURE 2 GEOLOGIC CONDUCTIVITY MODIFIED FROM NUZMAN (1969) current electrodes at the extremities of the spread and adjacent electrodes equidistant from each other. This electrode configuration is known as the Wenner Spread. The distance between electrodes is the a-spacing. A diagram of the Wenner Spread is shown in Figure 3.

Fig. 3 Top view of Wenner Spread.



Two widely used survey methods using earth resistivity are profiling and geoelectric sounding. In profiling, the equipment is moved from station to station without changing the relative positions of the electrodes, i. e., the a-spacing remains constant. This type of survey is good for general reconnaisance work and for determining various near vertical or vertical boundaries which are indicated by contrasting resistivity values for some particular a-spacing at stations on opposite sides of the boundary.

The second type of survey is known as the depth sounding or geoelectric sounding method. Some early investigators were so overly optimistic as to call it the "electrical coring method" (Keller and Frischknecht, 1966, p. 90), assuming they could predict geologically significant depths with considerable accuracy.

Several different a-spacings at each station are used in the geoelectric sounding method to detect geologic boundaries by analyses of readings at that station. Under ideal conditions the depth sounding method will permit construction of a relative depth contour map when several stations in a suitable area are compared with each other. In this investigation the depth sounding method was used exclusively.

The use of direct current resistivity equipment in the field requires only a knowledge of high school physics, but analysis of data obtained ordinarily requires a basic understanding of both direct current circuitry and principles of electricity and magnetism combined with enough experience to give the investigator some knowledge of the problems encountered.

An understanding of the concepts of resistance and resistivity as they apply to earth materials is necessary to understand the concepts involved in an investigation of the type dealt with in this paper. The resistance of a substance is one ohm if a difference of potential of one volt is required to induce a current of one ampere. The resistivity of a substance is the resistance in ohms between opposite faces of a unit cube of the substance. Resistivity, therefore, is not dependent upon volume and is a fundamental electrical property of a particular material.

Because the vast majority of geologic formations are not homogeneous, the concept of apparent resistivity has been commonly used in geologic investigations.

> The apparent resistivity of a geologic formation is equal to the true resistivity of a fictitious homogeneous and isotropic medium in which, for a given electrode arrangement and current strength I, the measured potential difference V is equal to that for the given inhomogeneous medium. The apparent resistivity depends upon the geometry and resistivities of the elements constituting the given geologic medium. (Bhattacharya and Patra, 1968, p. 12)

The apparent resistivities of natural earth materials are, to a high degree, a function of the resistivities of the fluids contained in those materials. Dissolved minerals in water can cause significant decreases in apparent resistivity in materials which commonly have relatively high apparent resistivities. Table 3 shows resistivity values for several water samples with various amounts of dissolved solids. Table 4 shows some common lithologic materials and their ranges of apparent resistivity in the Kansas-Missouri area. The values determined in the Manhattan area are near the lower limits suggested in table 4. This is due to the fact the water table is very near the surface and much clay and silt are present. The bedrock is shale in most places, and dissolved solids in the water increase with depth.

This paper does not develop current flow and electric field theory mathematically. Such discussions are available in many standard books on geophysics such as Jakosky (1950), Dobrin (1960), or Keller and Frischknecht (1966).

The equation for calculating apparent resistivity using the Wenner Spread is: $R = \frac{(A)(2\pi)(V)}{(I)}$, where R is apparent resistivity, A is the a-spacing, V is the voltage difference measured between the two potential electrodes, I is the current (100 milliamperes throughout the project), and 2π is the numerical value 6.28. Computation of an R value for each reading was facilitated by use of tables printed by an IBM 360 series computer.

Since I was held constant throughout the course of the field work and 6.28 is a constant, R became a function of only two variables, A and V. Values for A were arranged in horizontal columns and values for V in vertical columns; then values of R could be read directly at the intersection of the proper columns. The time required to determine the apparent resistivity by use of the tables was about half that required using a desk calculator or a slide rule.

Field Procedures

A Soiltest R-50 Strata Meter D. C. Resistivity Instrument was used for the field work of this investigation. The instrument is battery powered and portable; the total

Table 3. Electrical Effect of Dissolved Solids in Water

Sample	Dissolved Solids	Resistance (ohms)
Snow from Greenland	5.4	100,000
Well, Yellowstone Park	309	6,100
Well, Gulfport, Mississippi	177	4,670
Well, Carlsbad, New Mexico	4400	170
Smith River, No. California	94	7,100
Mineral Spring Mt. Shasta, California	31200	28

Modified from Davis and DeWiest (1966) p. 97

Table 4. Apparent Resistivities of Common Earth Materials

Field Measurements[1]

Material Classification	Resistivity Range in Ohm-feet
Clays	10 to 300
Silts	75 to 400
Sands and Gravels (saturated)	300 to 900
Sandstones	500 to 1500
Shales	100 to 600
Limestones	800 to Infinity

Data from Wohler (1966) p. 5

Laboratory Measurements

Material Classification	Approximate Resistivities in Ohm-feet
Brine	1.5×10^{-1}
Shale	3.0
Freshwater	150
Gravel and Sand (saturated)	300
Limestone	3000

Modified from Davis and DeWiest (1966) p. 283

[1]This table is a general tabulation of some average resistivity values for some of the more common lithologic types in the Kansas-Missouri area. These ranges of values can only be called approximate, and may not be at all accurate for some specific areas.

weight including the wire and electrodes is about 75 pounds. The majority of the work was done by a two-man crew and the remainder by a three-man crew. The three-man crew could work about twice as fast as the two-man crew, under most conditions.

Several different electrode arrangements were tried with varying degrees of success. The Schlumberger spread is similar to the Wenner spread except the potential electrodes remain in the same place, and only the current electrodes are moved at any instrument station. The Schlumberger spread requires less labor in the field, but it requires better instrumentation, and data interpretation is more difficult.

The Schlumberger configuration met with very limited success, primarily because the resistivity instrument was not sensitive enough to yield useful data. Very low values of apparent resistivity were encountered for most of the stations, and the voltmeter would not register a value at some of the wider electrode spacings needed in this investigation.

The single moving probe configuration, also called potential drop ratio, yielded ambiguous information. It suggested three or more geologic boundaries, any of which may have been incorrect. The three suggested answers varied by as much as 25 feet in the depth to bedrock, at least 15 feet above the tolerable limit.

The tolerable limit of error must be low enough to enable one to show positively that the bedrock in the channel is farther below the surface than bedrock in adjacent areas. "The best depth determinations that can ordinarily be expected with the resistivity method for the three-layer case is to within an accuracy of only 10 percent" (Van Nostrand and Cook, 1966, p. 96). The maximum tolerable limit of error is 10 feet in this investigation if one is to accurately plot the course of the bedrock channel.

The Lee configuration was tested on two stations. It is a variation of the Wenner configuration which was used to obtain the information contained in this paper. The Lee variation is like the Wenner spread except that a fifth electrode is placed at the center of the spread where the instrument station is located. The purpose of the Lee variation is to emphasize the lateral variations in the geologic conditions, reducing the chances for misinterpretation of the data obtained at a particular station. The Lee configuration was not used to any great extent because the resistivity instrument was not wired for the fifth electrode, and each reading involved rearranging the wires at the terminals of the voltmeter. This method required approximately twice as much time as the standard Wenner method, and the magnitude of the lateral variations was not great enough to warrant its use.

The standard Wenner spread was used exclusively to procure the data used in preparation of the relative resistivity maps for several reasons. The equipment was designed primarily for use with the Wenner spread, the Wenner spread is easier to set up in the field, and many analytical techniques are available to treat the data obtained. The Wenner spread has been used for most of the geoelectric work done in the English speaking countries.

> Descriptions of the Wenner method of sounding, and the techniques for its interpretation, are available in a number of textbooks written in the English language. On the other hand, descriptions of the Schlumberger method of sounding, and the powerful techniques of interpretation which have developed chiefly outside the English speaking world (notably by French and Soviet geophysicists), are mentioned in only a few English textbooks. (Bhattacharya and Patra, 1968, p. 2)

Horizontal control was established by the use of aerial photographs of the area on which the locations of the instrument stations were marked to the nearest hundred feet.

The land in the area of interest was under cultivation and growing crops during the time when field work was done which limited access to some areas. In many places it was impossible to run two perpendicular traverses at the same station because of row crops, fences, pipelines, or steel cased wells. Metallic objects draw current flow toward them, causing lower apparent resistivity values. It is desirable to run perpendicular traverses in order that stations in areas of considerable lateral variation be recognized when the data are analyzed. This procedure was omitted because of physical, agricultural, and cultural features.

ANALYSES OF DATA

Several methods of analysis were used in an attempt to find a method which would yield results compatible with facts known from previous studies. Previous investigations include Nuzman (1969) and Gregory (1967).

The simplest but least reliable and least scientific method is to merely inspect apparent resistivity curves for maxima or minima points or points of inflection. It was obvious when comparing resistivity curves from stations near test holes with drillers logs that simple inspection could not be applied with any degree of accuracy to the problem. This method was first proposed by Gish and Rooney in 1925.

The Moore cumulative resistivity method was no more successful as it seemed to portray the water table at most stations at depths between 20 and 25 feet which is known to be correct from wells in the area. At some stations, however, the Moore cumulative values plotted in a straight line, indicating no resistivity boundaries whatsoever.

The curve-matching method using Roman's curves showed good results in the area around test hole 6-A where the known depth-to-bedrock is 114 feet. Curve-matching indicated bedrock at a depth of 105 feet which is less than 10 percent error with drill log. At the other extreme, near test hole 13 the depth-to-bedrock is 72 feet. Curve-matching indicated a depth-to-bedrock of 140 feet which is an error of nearly 100 percent. Another reason this method was rejected is that very large a-spacings are required to determine depths accurately. The resistivity instrument was incapable of providing accurate readings for a-spacings of greater than 300 feet where a-spacings of 500 feet were needed.

The method used in preparation of relative resistivity maps involved use of Keck's curves. The origin of these curves is rather obscure, and it is doubtful they have ever appeared in print. Elmer Wohler, a practicing engineering geologist, made them available for trial in this project. The curves are plotted on 3-cycle log-log graph paper, but the writer is not certain whether the curves were calculated according to some mathematical formula or if they were devised empirically by Keck after a considerable amount of experience in the use of resistivity methods.

The curves essentially give a value for the relative apparent resistivity between two a-spacing intervals, the smaller of which is one-half the length of the other. Apparent resistivity values for the two a-spacings are read along the abscissa and the curves to a point of intersection. The relative resistivity value is the ordinate value of the point of intersection. The intervals chosen for use in this study are the 20 to 40, the 70 to 140, and the 100 to 200 foot values. The instructions on the curves state that the smaller a-spacing interval used must be half the larger one.

The purpose of choosing three different sets of intervals is twofold; first, it enables one to compare relative resistivity values with increasing depth; secondly, the larger intervals decrease the relative contribution of near-surface material. The apparent resistivity of material at depth contributes much to the values obtained and near surface material is cancelled out, unmasking the true relative resistivity at depths approximately equal to the smaller of the two a-spacings.

The relative resistivity contour maps were prepared using the apparent resistivity values taken from a smoothed field curve and adjusted by Keck's curves, then placed on the map at the position of the instrument station.

RESULTS

Resistivity Mapping Versus Computer Model

The 20 to 40 foot interval map shows relative resistivities in the upper part of the alluvium, but for the most part below the water table. It is interesting to compare this map with the analog computer model shown on Plate 2.

The analog computer model shows contoured values for transmissivity expressed in gallons per day per foot. Davis and

De Wiest (1966, p. 162, 182) show transmissivity is equal to the coefficient of permeability multiplied by the saturated thickness of the aquifer. The coefficient of permeability is directly proportional to the square of the grain size. Hence, it may be inferred that high transmissivity values indicate coarse grained materials such as sands and gravels.

The high relative resistivity values, as shown in Table 4, are also due to coarser materials such as sand or gravel. The low relative resistivity values are due to clay, silt, shale bedrock, and possible higher dissolved solid content in the contained water. The high relative resistivity trends on the map are quite similar in area and orientation to the areas of high transmissivity inferred in the analog computer model.

The resistivity values, being a form of indirect measurement as opposed to the direct evidence from drill samples used for the computer model, are probably not as reliable. On the other hand, only 14 drill holes were used in the area, compared to about 80 resistivity stations. Hence, it may be inferred that the resistivity map is probably more accurate in detail than the computer model.

In particular, west of test hole 9, a set of rather high relative resistivity values was obtained. These high values suggest the analog computer model would have been altered significantly if test hole 9 had been drilled approximately 200 yards west of its actual location. In the south half of section 4 several very high values cause the resistivity map to differ markedly from the computer model. In this case the resistivity map is more nearly correct in predicting the presence of potential high-yield aquifer because many high resistivity indications are present in an area where no data was obtained for the computer model.

In the NE¼, sec. 8 and the NW¼, sec. 9 the contour lines of the computer model and the resistivity map are nearly parallel, indicating a high degree of agreement between the two methods, and a high degree of confidence is inferred about their correctness.

In contrast to the 20 to 40-foot spacing interval map, the 70 to 140 and 100 to 200-foot spacing interval maps show lesser degrees of similarity, respectively, to the computer model. As the electrode spacing is increased, the material at depth has more influence upon apparent resistivity values measured at the earth's surface. Consequently, the near surface material has less effect upon apparent resistivity measurements.

The 70 to 140-foot spacing interval map differs considerably from the 20 to 40-foot spacing interval map in the SE¼, NE¼, sec. 8. The material at depth must have a very low resistivity, or bedrock is relatively shallow in this region. Subtle differences are evident in the NW¼, sec. 5 as the 70 to 140-foot spacing interval map show considerably lower relative resistivity values than the 20 to 40-foot spacing interval map. This may also be attributed to shallow bedrock composed of low resistivity material at depth, such as shale or shale with interstitial mineralized water.

The 100 to 200-foot spacing interval map accentuates the differences between the 70 to 140 and 20 to 40-foot spacing interval maps. The values seem to be quite consistent throughout considerable areas of the map, even to the extent of adjacent values being identical in several instances. Much of the apparent resistivity at these wide spacings result from current flow penetrating bedrock. In this case, most of the effects of alluvium have been removed in all areas except near the deepest part of the bedrock channel.

High relative resistivity values indicate a channel trending east-west in the SW$\frac{1}{4}$ of sec. 8. While there is no direct drill evidence to support this idea, it is certainly possible for a narrow, relatively deep erosional channel to be present as suggested by this map.

The information inferred by these maps differs only in detail from the driller's logs of the test holes drilled for the hydrologic study for the City of Manhattan and with information supplied by farmers concerning depth to bedrock in their wells. Mr. L. A. Peterson (oral communication, July, 1969) stated his domestic well was 67 feet deep, and the driller had remarked it was unusual they had not hit bedrock at that depth. His well is near the northwest corner of the SW¼ of sec. 4, only 250 yards southeast of test hole 15 which hit bedrock at a depth of 44 feet. If Mr. Peterson's story is factual, it appears this information supports the conclusions drawn from the 100 to 200-foot spacing interval resistivity map, concerning a deep channel in bedrock.

CONCLUSIONS

The similarity between the analog computer model and the 20 to 40-foot spacing interval resistivity map is more than coincidental. Both methods of solution give generally factual results, though they may differ in detail. The resistivity method is probably more accurate in detail because more data stations were used. The resistivity method is less expensive than the analog computer method, because so many test holes must be drilled to construct a reliable computer model.

The deep erosional channel of the Blue River was not delineated with the desired degree of accuracy. Part of this difficulty occurs because of an increased amount of dissolved solids in the water at depth in the alluvium. This causes resistivity to decrease, much as the resistivity decreases in the bedrock beneath the alluvium, because the resistivity of a material is partly a function of contained fluids within the body of the material. The path of the buried channel suggested is a hypothesis which could be substantiated or rejected by further test drilling.

The direct current resistivity method used in this investigation is useful in predicting transmissibility in an area where alluvium covers bedrock. It can be recommended for use in similar geologic and hydrologic situations to select the most likely sites for water wells where high yield is important. Wells should not be constructed without test drilling however. The method is best used in conjunction with test drilling and is not a reliable method by itself.

RESISTIVITY STATION LOCATIONS

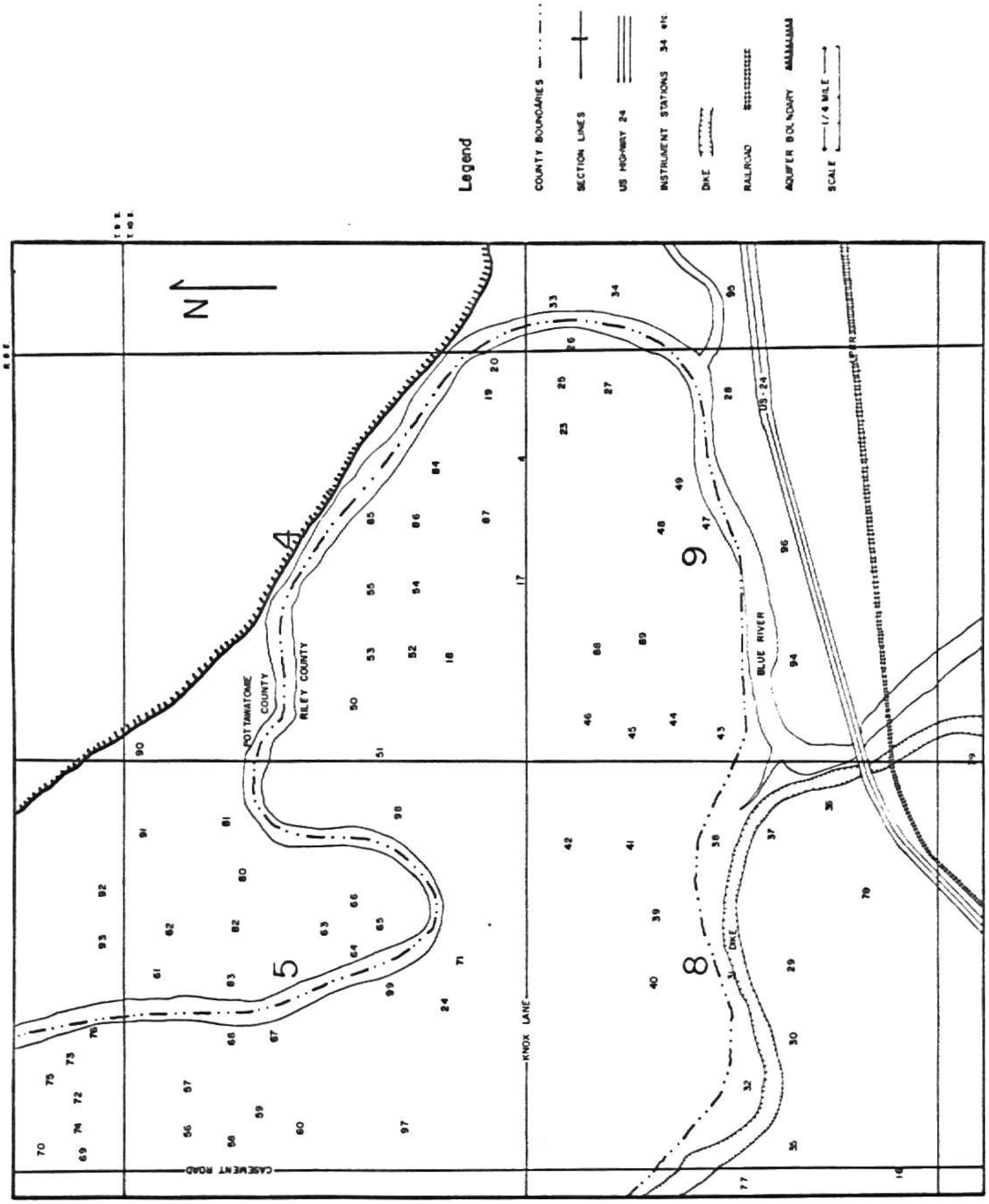


Figure 4

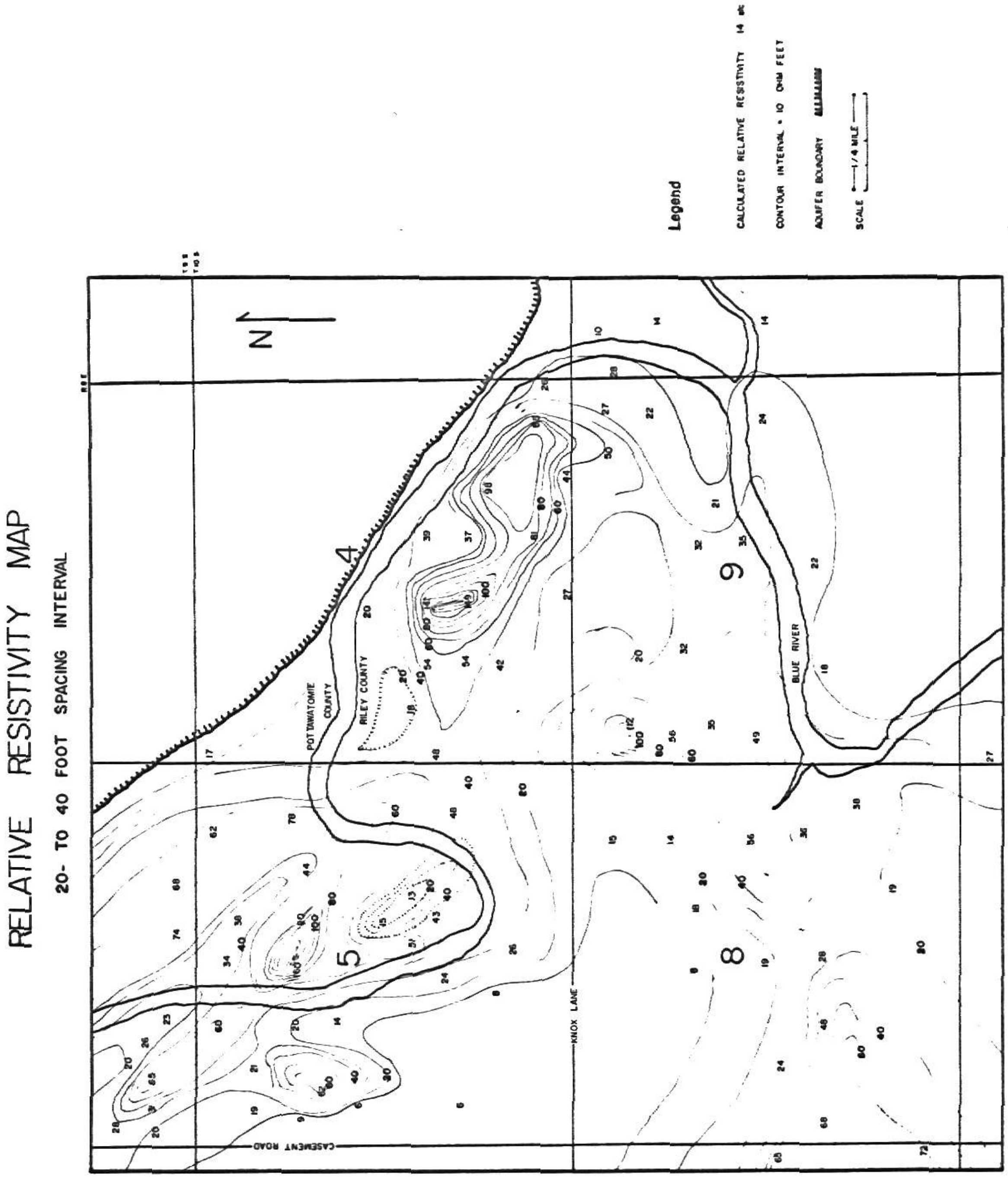

RELATIVE RESISTIVITY MAP
20- TO 40 FOOT SPACING INTERVAL
Legend
CALCULATED RELATIVE RESISTIVITY
CONTOUR INTERVAL = 10 OHM FEET
AQUIFER BOUNDARY
SCALE 1/4 MILE
N
POTTAWATOMIE COUNTY
RILEY COUNTY
BLUE RIVER
KNOX LANE
CASEMENT ROAD
4
5
8
9

Figure 5

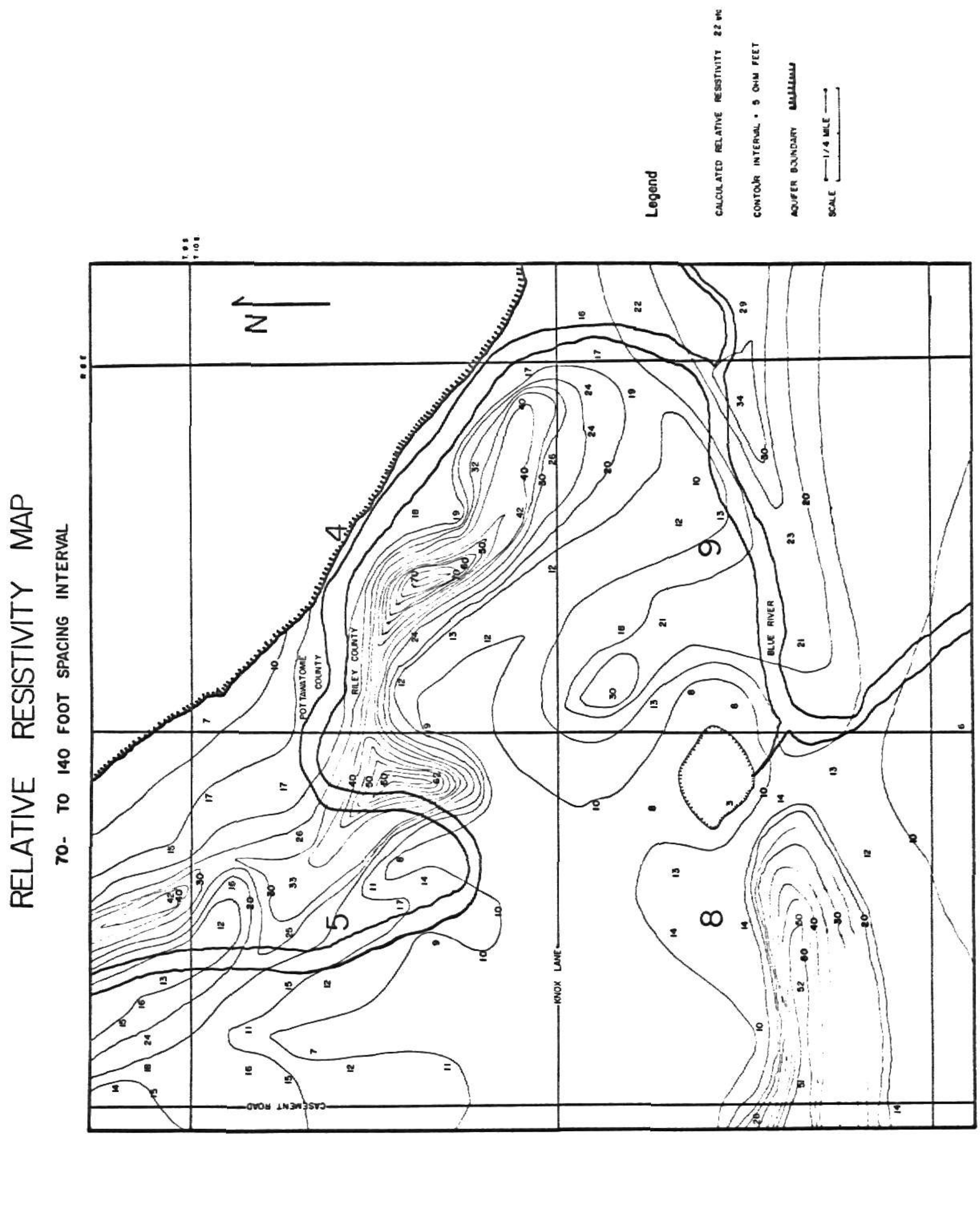

RELATIVE RESISTIVITY MAP
70- TO 140 FOOT SPACING INTERVAL
Legend
CALCULATED RELATIVE RESISTIVITY 22 ohm
CONTOUR INTERVAL = 5 OHM FEET
AQUIFER BOUNDARY
SCALE 1/4 MILE
N
POTTAWATOMIE COUNTY
RILEY COUNTY
KNOX LANE
BLUE RIVER
CASEMENT ROAD

Figure 6

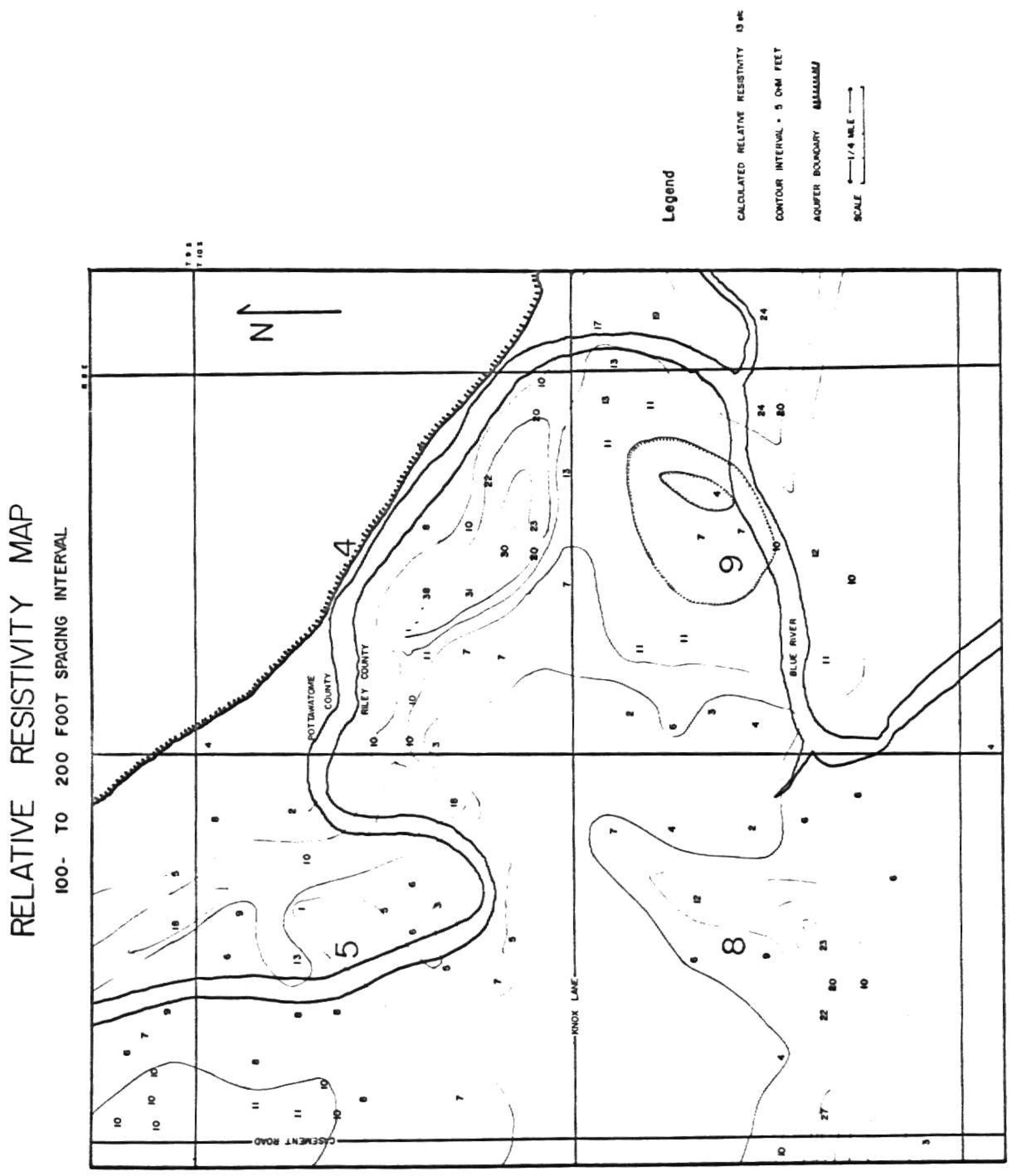

RELATIVE RESISTIVITY MAP
100- TO 200 FOOT SPACING INTERVAL
Legend
CALCULATED RELATIVE RESISTIVITY
CONTOUR INTERVAL • 5 OHM FEET
AQUIFER BOUNDARY
SCALE
1/4 MILE
N
POTTAWATOMIE COUNTY
RILEY COUNTY
BLUE RIVER
KNOX LANE
CASEMENT ROAD

Figure 7

ACKNOWLEDGMENTS

The advice and assistance of many individuals was essential to the completion of this investigation. Dr. Henry V. Beck, major professor and research director, offered initial inspiration for the project and provided ample guidance and assistance. Dr. Charles P. Walters offered valuable advice in several fruitful discussions.

No small amount of thanks is due the individuals who assisted in the field work. In particular, John K. Thomas, Jon A. Jeppesen, and Kenneth J. Macho deserve mention. The author's wife spent many hours calculating apparent resistivity values from field data and did most of the typing for the project, and her help was invaluable.

The cooperation of the residents of the Blue River Valley east of Manhattan was sincerely appreciated.

Mr. Elmer Wohler deserves a special 'thank you' for his advice, assistance, and the loan of much of his personal library including Keck's curves.

APPENDIX I

Field Data

The a-spacings are in feet and apparent resistivity values are expressed in ohm feet. The first 15 stations are not included because they were used to perfect and refine field technique and were not used in the preparation of this paper.

APPENDIX I

a-spacing	App. Res.	a-spacing	App. Res.	a-spacing	App. Res.
STATION # 16		STATION # 17		STATION # 18	
2	9.55	2	8.29	2	13.82
3	10.74	3	9.24	3	14.14
5	13.19	5	11.00	5	15.71
8	16.84	8	11.56	8	16.84
10	19.48	10	12.57	10	18.22
15	16.96	15	21.68	15	21.68
20	33.93	20	17.59	20	25.13
30	43.35	30	20.73	30	30.16
40	47.75	40	22.62	40	31.42
50	50.27	50	22.62	50	34.56
60	53.91	60	24.50	60	31.67
80	48.76	80	24.13	80	29.15
100	42.10	100	21.36	100	26.39
120	33.18	120	18.85	120	22.62
140	26.50	140	17.59	140	19.35
160	22.12	160	15.08	160	16.08
200	13.19	200	11.94	200	12.57
240	9.60	240	9.80	240	11.31
STATION # 19		STATION # 20		STATION # 21	
2	8.17	2	6.41	2	12.32
3	9.99	3	6.79	3	14.14
5	12.88	5	8.64	5	15.39
8	17.09	8	8.30	8	15.08
10	19.48	10	8.17	10	15.08
15	27.80	15	10.84	15	17.91
20	35.06	20	12.57	20	17.59
30	47.12	30	16.59	30	18.10
40	55.29	40	18.35	40	18.85
50	62.83	50	21.99	50	19.16
60	64.09	60	24.13	60	19.60
80	70.37	80	24.88	80	19.35
100	62.83	100	23.88	100	17.27
120	58.06	120	21.87	120	16.21
140	51.02	140	19.35	140	14.95
160	43.23	160	20.11	160	14.07
200	35.19	200	14.45	200	10.68
220	29.72	220	13.13	240	9.05

a-spacing	App. Res.	a-spacing	App. Res.	a-spacing	App. Res.

STATION # 22

a-spacing	App. Res.
2	14.45
3	15.83
5	15.39
8	15.58
10	16.65
15	16.96
20	15.08
30	14.51
40	13.57
50	13.51
60	13.95
80	13.57
100	14.45
120	13.57
140	12.75
160	12.06
200	10.00
240	9.05

STATION # 23

a-spacing	App. Res.
2	9.68
3	11.31
5	15.71
8	23.12
10	27.02
15	34.87
20	39.00
30	43.35
40	43.98
50	44.61
60	47.12
80	46.50
100	42.10
120	37.33
140	32.99
160	28.15
200	20.73
240	15.83

STATION # 24

a-spacing	App. Res.
2	5.34
3	4.71
5	5.03
8	4.60
10	4.90
15	5.56
20	5.84
30	6.79
40	7.54
50	8.32
60	8.29
80	9.30
100	10.75
120	9.80
140	9.24
160	9.05
200	7.54
240	7.54

STATION # 25

a-spacing	App. Res.
2	8.55
3	9.05
5	11.94
8	15.08
10	15.08
15	18.38
20	20.73
30	19.79
40	22.2
50	23.88
60	25.45
80	27.14
100	27.96
120	26.76
140	24.20
160	22.62
200	19.48
240	15.08

STATION # 26

a-spacing	App. Res.
2	12.57
3	16.87
5	23.88
8	30.16
10	32.04
15	32.50
20	32.68
30	32.04
40	30.16
50	29.53
60	28.65
80	26.89
100	24.81
120	23.51
140	21.56
160	20.60
200	17.60
240	14.32

STATION # 27

a-spacing	App. Res.
2	6.91
3	7.54
5	8.96
8	9.05
10	9.74
15	9.90
20	11.69
30	14.24
40	15.71
50	17.28
60	18.85
80	20.36
100	20.42
120	21.11
140	19.36
160	18.10
200	14.44
240	12.82

a-spacing	App. Res.	a-spacing	App. Res.	a-spacing	App. Res.
STATION # 28		STATION # 29		STATION # 30	
2	6.28	2	12.69	2	14.45
3	6.97	3	14.89	3	20.73
5	6.60	5	19.16	5	29.53
8	6.28	8	24.63	8	35.69
10	6.28	10	27.33	10	36.75
15	7.16	15	31.57	15	36.76
20	8.86	20	32.05	20	38.33
30	11.60	30	30.16	30	40.53
40	14.33	40	30.16	40	41.47
50	17.12	50	29.53	50	43.98
60	19.42	60	30.54	60	47.12
80	23.12	80	34.18	80	51.77
100	25.13	100	38.01	100	59.37
120	26.39	120	39.60	120	55.79
140	25.94	140	40.46	140	51.02
160	25.14	160	38.70	160	45.24
200	22.62	200	28.27	200	36.44
240	20.36	240	18.10	240	30.91
STATION # 31		STATION # 32		STATION # 33	
2	3.39	2	3.96	2	3.20
3	3.77	3	4.15	3	2.64
5	4.40	5	5.03	5	2.64
8	5.03	8	6.03	8	2.66
10	5.34	10	6.91	10	2.80
15	7.065	15	8.72	15	3.16
20	8.42	20	10.68	20	3.77
30	10.93	30	13.38	30	5.18
40	12.57	40	15.205	40	5.90
50	13.82	50	15.865	50	7.07
60	14.515	60	16.59	60	7.92
80	15.08	80	16.84	80	9.30
100	15.71	100	15.71	100	11.00
120	15.08	120	14.33	120	11.31
140	14.51	140	12.75	140	12.32
160	14.07	160	11.56	160	11.56
200	11.94	200	8.17	200	13.06
240	9.80	240	6.79	240	11.32

a-spacing	App. Res.	a-spacing	App. Res.	a-spacing	App. Res.
STATION # 34		STATION # 35		STATION # 36	
2	6.31	2	24.50	2	16.34
3	5.65	-	---	3	16.78
5	4.56	5	43.98	5	17.91
8	4.10	8	52.78	8	18.35
10	4.40	10	62.83	10	17.59
15	5.14	15	72.60	15	18.85
20	5.97	20	77.90	20	18.85
30	7.44	30	72.50	30	21.68
40	8.68	40	72.90	40	25.89
50	10.21	50	62.83	50	26.70
60	10.93	60	67.86	60	26.39
80	12.82	80	65.35	80	25.13
100	14.14	100	64.09	100	24.19
120	15.08	120	62.96	120	21.30
140	16.54	140	59.38	140	18.91
160	16.28	160	53.78	160	16.59
200	15.62	200	41.47	200	12.57
240	15.82	-	---	240	9.05
STATION # 37		STATION # 38		STATION # 39	
2	16.30	2	7.79	2	6.22
3	20.70	3	10.18	3	7.44
5	22.46	5	10.52	5	8.32
8	22.62	8	12.82	8	9.55
10	22.60	10	14.83	10	10.18
15	22.15	15	19.32	15	10.84
20	22.62	20	22.62	20	12.19
30	26.39	30	29.22	30	13.85
40	28.65	40	33.93	40	14.83
50	31.42	50	31.42	50	15.55
60	32.80	60	25.82	60	15.83
80	31.93	80	21.11	80	15.08
100	27.65	100	14.13	100	15.08
120	26.01	120	11.68	120	14.93
140	21.55	140	9.24	140	14.51
160	19.10	160	8.55	160	13.57
200	12.57	200	5.65	200	13.19
240	9.05	240	5.28	240	11.31

STATION # 40

a-spacing	App. Res.
2	8.42
3	9.70
5	10.21
8	9.05
10	8.48
15	8.245
20	8.105
30	8.11
40	8.60
50	8.95
60	9.42
80	11.06
100	11.31
120	12.06
140	11.44
160	10.05
200	7.54
240	6.03

STATION # 41

a-spacing	App. Res.
2	4.27
3	5.47
5	6.91
8	8.04
10	8.48
15	8.95
20	9.42
30	10.83
40	11.56
50	11.94
60	11.69
80	9.05
100	11.62
120	11.31
140	9.68
160	9.05
200	6.91
240	5.28

STATION # 42

a-spacing	App. Res.
2	8.04
3	8.29
5	9.42
8	10.30
10	10.05
15	9.90
20	10.05
30	11.69
40	12.44
50	13.03
60	13.00
80	14.07
100	13.82
120	13.19
140	11.00
160	10.56
200	8.80
240	6.03

STATION # 43

a-spacing	App. Res.
2	7.04
3	8.29
5	12.57
8	16.08
10	18.53
15	23.56
20	27.65
30	33.93
40	36.44
50	38.64
60	39.58
80	41.47
100	35.19
120	22.99
140	18.68
160	15.08
200	14.14
240	9.80

STATION # 44

a-spacing	App. Res.
2	9.42
3	12.06
5	14.77
8	18.10
10	20.11
15	23.09
20	25.89
30	29.22
40	30.16
50	32.36
60	31.29
80	25.13
100	20.11
120	18.10
140	14.52
160	13.06
200	7.80
240	5.73

STATION # 45

a-spacing	App. Res.
2	6.79
3	8.67
5	11.62
8	17.09
10	20.11
15	28.46
20	35.18
30	44.30
40	45.24
50	43.98
60	39.58
80	31.42
100	26.71
120	23.37
140	20.24
160	18.60
200	12.94
240	9.80

a-spacing	App. Res.	a-spacing	App. Res.	a-spacing	App. Res.
STATION # 46		STATION # 47		STATION # 48	
2	10.30	2	8.29	2	14.07
3	11.78	3	9.80	3	15.27
5	17.44	5	12.57	5	18.22
8	25.13	8	16.34	8	21.11
10	30.16	10	18.85	10	22.30
15	41.00	15	23.09	15	24.10
20	51.52	20	25.76	20	25.13
30	65.10	30	29.22	30	26.39
40	74.20	40	27.65	40	27.65
50	78.54	50	30.32	50	27.81
60	79.17	60	29.41	60	27.52
80	72.89	80	27.14	80	24.38
100	64.09	100	24.82	100	23.25
120	58.96	120	21.87	120	19.98
140	48.38	140	19.80	140	13.28
160	36.70	160	18.60	160	15.58
200	17.60	200	13.20	200	11.92
240	9.80	240	10.56	240	7.54
STATION # 49		STATION # 50		STATION # 51	
2	11.81	2	15.08	2	9.55
3	16.78	-	---	-	---
5	22.62	5	16.96	5	8.32
8	29.66	-	---	-	---
10	32.35	10	16.34	10	9.42
15	31.60	15	16.49	15	12.25
20	27.65	20	15.71	20	15.08
30	23.56	30	15.36	30	21.68
40	24.63	40	16.96	40	27.65
50	25.45	50	16.96	50	30.94
60	25.60	60	17.53	60	32.42
80	26.14	80	17.09	80	27.70
100	24.19	100	16.96	100	24.50
120	20.74	120	15.08	120	21.87
140	16.28	140	14.52	140	17.16
160	13.56	160	13.56	160	14.58
200	9.44	200	13.20	200	8.80
-	--	240	11.32	-	--

a-spacing	App. Res.	a-spacing	App. Res.	a-spacing	App. Res.
STATION # 52		STATION # 53		STATION # 54	
2	13.19	2	17.59	2	15.83
5	16.65	5	23.72	5	19.79
10	20.11	10	22.62	10	29.21
15	24.03	15	25.91	15	42.03
20	28.27	20	30.16	20	55.29
30	35.81	30	35.81	30	74.45
40	38.96	40	40.21	40	86.71
50	37.70	50	43.98	50	95.80
60	36.57	60	45.62	60	101.79
80	33.43	80	46.49	80	110.58
100	29.53	100	44.92	100	109.96
120	25.64	120	39.21	120	101.79
140	21.55	140	33.43	140	86.65
160	19.10	160	28.65	160	78.92
200	13.82	200	21.36	200	58.43
240	10.56	240	15.43	240	42.22
STATION # 55		STATION # 56		STATION # 57	
2	21.99	2	3.52	2	6.53
5	21.68	5	3.05	5	8.80
10	24.19	10	3.71	10	8.80
15	32.51	15	4.71	15	9.90
20	42.09	20	5.78	20	10.74
30	59.37	30	7.73	30	12.82
40	71.63	40	9.80	40	14.45
50	80.11	50	11.31	50	16.34
60	84.82	60	12.82	60	17.34
80	85.45	80	14.32	80	18.10
100	84.82	100	16.02	100	17.60
120	82.94	120	15.83	120	16.21
140	77.41	140	15.39	140	13.63
160	71.38	160	13.57	160	12.57
200	57.18	200	13.19	200	11.31
240	42.98	240	9.80	240	8.29

a-spacing	App. Res.	a-spacing	App. Res.	a-spacing	App. Res.
STATION # 58		STATION # 59		STATION # 60	
2	8.42	2	8.67	2	4.46
5	9.11	5	11.31	5	3.92
10	7.54	10	17.28	10	3.14
15	6.83	15	23.09	15	3.11
20	6.85	20	27.65	20	3.52
30	7.16	30	34.87	30	4.15
40	7.91	40	40.21	40	4.78
50	8.80	50	42.41	50	5.65
60	9.42	60	38.83	60	6.22
80	10.56	80	31.16	80	7.54
100	11.62	100	21.04	100	7.86
120	11.68	120	16.96	120	8.67
140	12.32	140	14.96	140	8.80
160	11.56	160	14.08	160	9.04
200	11.31	200	13.82	200	8.16
240	9.60	240	12.82	240	8.28
STATION # 61		STATION # 62		STATION # 63	
2	10.81	2	8.17	2	13.19
5	11.62	5	11.31	5	24.50
10	14.14	10	16.96	10	28.27
15	16.49	15	20.73	15	25.44
20	18.22	20	25.76	20	23.88
30	22.62	30	30.16	30	20.36
40	25.13	40	31.42	40	18.85
50	27.49	50	30.47	50	19.00
60	29.03	60	29178	60	19.23
80	28.15	80	26.39	80	18.10
100	25.76	100	24.82	100	17.28
120	22.62	120	23.37	120	15.83
140	17.60	140	21.56	140	13.64
160	15.08	160	18.10	160	11.56
200	10.06	200	14.44	200	8.80
240	10.86	240	11.32	240	6.03

a-spacing	App. Res.	a-spacing	App. Res.	a-spacing	App. Res.
STATION # 64		STATION # 65		STATION # 66	
2	9.80	2	9.80	2	7.41
5	9.42	5	12.88	5	10.37
10	12.25	10	19.16	10	12.25
15	16.02	15	23.56	15	11.59
20	19.48	20	26.39	20	10.87
30	25.45	30	32.42	30	11.31
40	30.16	40	35.19	40	11.56
50	31.10	50	36.76	50	11.31
60	32.23	60	37.51	60	12.06
80	31.42	80	35.94	80	12.06
100	28.58	100	33.62	100	11.94
120	25.64	120	27.52	120	10.94
140	22.44	140	20.68	140	9.28
160	18.60	160	15.08	160	8.54
200	13.82	-	---	200	7.52
240	9.80	-	---	240	6.03

a-spacing	App. Res.	a-spacing	App. Res.	a-spacing	App. Res.
STATION # 67		STATION # 68		STATION # 69	
2	6.03	2	6.28	2	10.30
5	5.65	5	6.75	5	13.19
10	5.28	10	7.23	10	18.85
15	5.47	15	8.29	15	23.56
20	6.03	20	9.30	20	25.13
30	7.35	30	11.60	30	24.50
40	9.05	40	13.57	40	22.62
50	10.21	50	15.08	50	20.73
60	11.50	60	16.21	60	19.415
80	12.06	80	16.84	80	18.60
100	12.88	100	17.90	100	18.535
120	12.06	120	16.59	120	16.59
140	11.00	140	16.48	140	16.27
160	10.56	160	13.56	160	15.08
200	10.06	200	11.92	200	12.57
240	8.28	240	11.32	240	9.80

a-spacing	App. Res.	a-spacing	App. Res.	a-spacing	App. Res.
STATION # 70		STATION # 71		STATION # 72	
2	9.93	2	8.80	2	13.82
5	11.155	5	6.28	5	16.34
10	11.62	10	5.59	10	18.22
15	13.19	-	----	15	21.02
20	15.08	20	9.17	20	24.88
30	18.565	30	13.03	30	33.93
40	21.11	40	14.58	40	38.96
50	22.15	-	----	50	42.41
60	23.37	60	15.65	60	43.35
80	24.63	80	17.09	80	40.97
100	24.50	100	17.59	100	38.33
120	22.995	120	15.46	120	33.93
140	21.286	140	13.19	140	31.23
160	19.10	160	12.57	160	27.65
200	15.08	200	9.42	200	18.85
240	12.06	240	9.50	240	13.57
STATION # 73		STATION # 74		STATION # 75	
2	26.39	2	13.45	2	12.44
5	37.70	5	13.51	5	15.39
10	47.75	10	15.08	10	16.02
15	49.80	15	17.15	15	17.44
20	45.24	20	19.48	20	18.22
30	37.70	30	22.24	30	18.10
40	35.69	40	24.25	40	19.10
50	34.56	50	25.76	50	19.79
60	32.04	60	25.64	60	21.11
80	29.86	80	24.88	80	22.12
100	27.02	100	23.56	100	21.99
120	23.67	120	22.24	120	20.36
140	20.67	140	20.23	140	18.47
160	18.10	160	18.60	160	15.08
200	13.19	200	15.08	200	11.31
240	9.80	240	11.31	240	8.29

a-spacing	App. Res.	a-spacing	App. Res.	a-spacing	App. Res.
STATION # 76		STATION # 77		STATION # 78	
2	8.67	2	17.59	2	17.59
5	15.55	5	22.62	5	19.48
10	19.79	10	32.35	10	21.24
15	21.21	15	40.53	15	25.91
20	19.48	20	50.27	20	18.85
30	19.79	30	54.66	30	17.81
40	20.61	40	57.81	40	18.60
50	21.99	50	56.55	50	19.48
60	22.24	60	56.55	60	19.41
80	23.12	80	55.29	80	20.61
100	20.42	100	52.46	100	17.27
120	19.60	120	45.24	120	16.96
140	17.15	140	38.26	140	14.51
160	16.59	160	34.18	160	12.06
-	---	200	23.88	200	10.05
-	---	240	14.33	240	6.79

a-spacing	App. Res.	a-spacing	App. Res.	a-spacing	App. Res.
STATION # 79		STATION # 80		STATION # 81	
2	7.54	-	---	-	---
5	12.88	-	---	-	---
10	22.62	10	14.45	10	35.19
15	28.75	-	---	-	---
20	30.79	20	18.85	20	53.41
30	32.99	30	23.56	30	51.83
40	28.90	40	28.90	40	60.32
50	23.25	-	---	-	---
60	20.73	60	32.42	60	68.99
80	17.59	80	33.68	80	75.40
-	---	100	33.30	100	60.32
120	12.06	120	30.16	120	42.22
-	---	160	25.13	160	28.65
200	6.91	200	18.22	200	18.22

a-spacing	App. Res.	a-spacing	App. Res.	a-spacing	App. Res.
STATION # 82		STATION # 83		STATION # 84	
10	27.02	10	69.12	10	28.27
20	57.12	20	103.67	20	41.47
30	58.43	30	122.45	30	54.66
40	72.89	40	130.70	40	65.35
60	82.94	60	116.87	60	67.86
80	80.42	80	80.42	80	62.83
100	78.54	100	62.83	100	57.81
120	63.33	120	58.81	120	45.99
160	39.21	160	42.22	160	41.22
200	16.96	200	30.16	200	35.19
STATION # 85		STATION # 86		STATION # 87	
10	47.12	10	46.50	10	35.19
20	41.47	20	55.29	20	45.24
30	39.58	30	49.95	30	54.66
40	40.21	40	45.24	40	60.32
60	42.60	60	40.72	60	67.86
80	40.72	80	37.55	80	75.40
100	37.07	100	33.93	100	72.26
120	31.67	120	30.16	120	64.09
160	24.13	160	23.12	160	49.76
200	17.59	200	17.59	200	40.84
STATION # 88		STATION # 89		STATION # 90	
10	7.54	10	25.13	10	9.42
20	10.05	20	25.13	20	13.19
30	12.44	30	26.39	30	14.70
40	14.07	40	28.90	40	15.49
60	15.83	60	32.80	60	14.33
80	17.09	80	29.15	80	13.07
100	17.59	100	27.65	100	12.57
120	17.34	120	26.39	120	11.68
160	16.08	160	21.11	160	9.05
200	13.82	200	17.59	200	6.91

a-spacing	App. Res.	a-spacing	App. Res.	a-spacing	App. Res.
STATION # 91		STATION # 92		STATION # 93	
10	30.16	10	16.34	10	21.99
20	37.70	20	28.27	20	30.79
30	45.24	30	36.76	30	38.64
40	49.01	40	41.47	40	46.50
60	48.25	60	49.01	60	52.78
80	40.21	80	46.24	80	55.29
100	33.93	100	40.21	100	54.66
120	29.41	120	31.67	120	53.53
160	22.12	160	21.11	160	41.72
200	15.71	200	15.08	200	30.16
STATION # 94		STATION # 95		STATION # 96	
10	13.82	10	5.03	10	13.82
20	13.82	20	5.28	20	11.44
30	14.70	30	6.97	30	13.38
40	16.59	40	8.80	40	16.08
60	18.85	60	12.06	60	22.24
80	20.11	80	14.85	80	25.64
100	20.73	100	16.96	100	26.07
120	21.11	120	18.10	120	26.39
160	19.10	160	20.11	160	20.11
200	15.08	200	20.11	200	17.59
STATION # 97		STATION # 98		STATION # 99	
10	3.52	10	15.71	10	10.68
20	3.90	20	28.90	20	9.80
30	4.52	30	30.16	30	12.06
40	5.03	40	37.70	40	14.83
60	5.65	60	47.12	60	18.47
80	6.53	80	57.81	80	20.61
100	7.22	100	62.83	100	20.73
120	7.54	120	64.09	120	17.34
160	8.04	160	48.25	160	11.06
200	7.54	200	32.67	200	10.05

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RESISTIVITY METHODS IN PROSPECTING FOR GROUND WATER

by

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AN ABSTRACT OF A MASTER'S THESIS

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Manhattan, Kansas

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ABSTRACT

As part of groundwater recharge studies sponsored by Kansas State Agricultural Experiment Station, a method of groundwater exploration was developed.

Direct current earth resistivity has been the subject of wide use and misuse all over the country during recent decades. Part of the difficulty is caused by attempts to use resistivity methods exclusively in the search for groundwater. Resistivity is better suited to application in conjunction with a limited but well-planned test-drilling program.

The resistivity survey in this investigation was performed with portable direct current equipment in a four-square-mile area just east of Manhattan, Kansas. The Wenner, Lee, Schlumberger, and single-moving-probe electrode configurations were initially used. The Wenner configuration ultimately became the basis for the field work used in the investigation.

Interpretation methods included curve inspection, Moore cumulative resistivity method, Roman's curve-matching method, and relative resistivity mapping using Keck's curves to adjust the values obtained in the field. These curves do not enable one to make quantitative depth estimates. They do make it possible to map relative resistivity for specified electrode spacing intervals.

The relative resistivity maps were compared with an analog computer model of transmissivity in the same four-square-mile area. The comparison showed similar trends for high resistivity and high transmissivity values. It was inferred that high resistivity and high transmissivity have a substantial degree of correlation.

Wider electrode spacing intervals showed probable trends for the direction of erosional channels in bedrock in a river valley. The channels are known to exist from test-hole drill evidence.

The method developed in this investigation can be recommended for use in areas where alluvium covers bedrock. The method should not be used by itself without test drilling or some other independent method of exploration.