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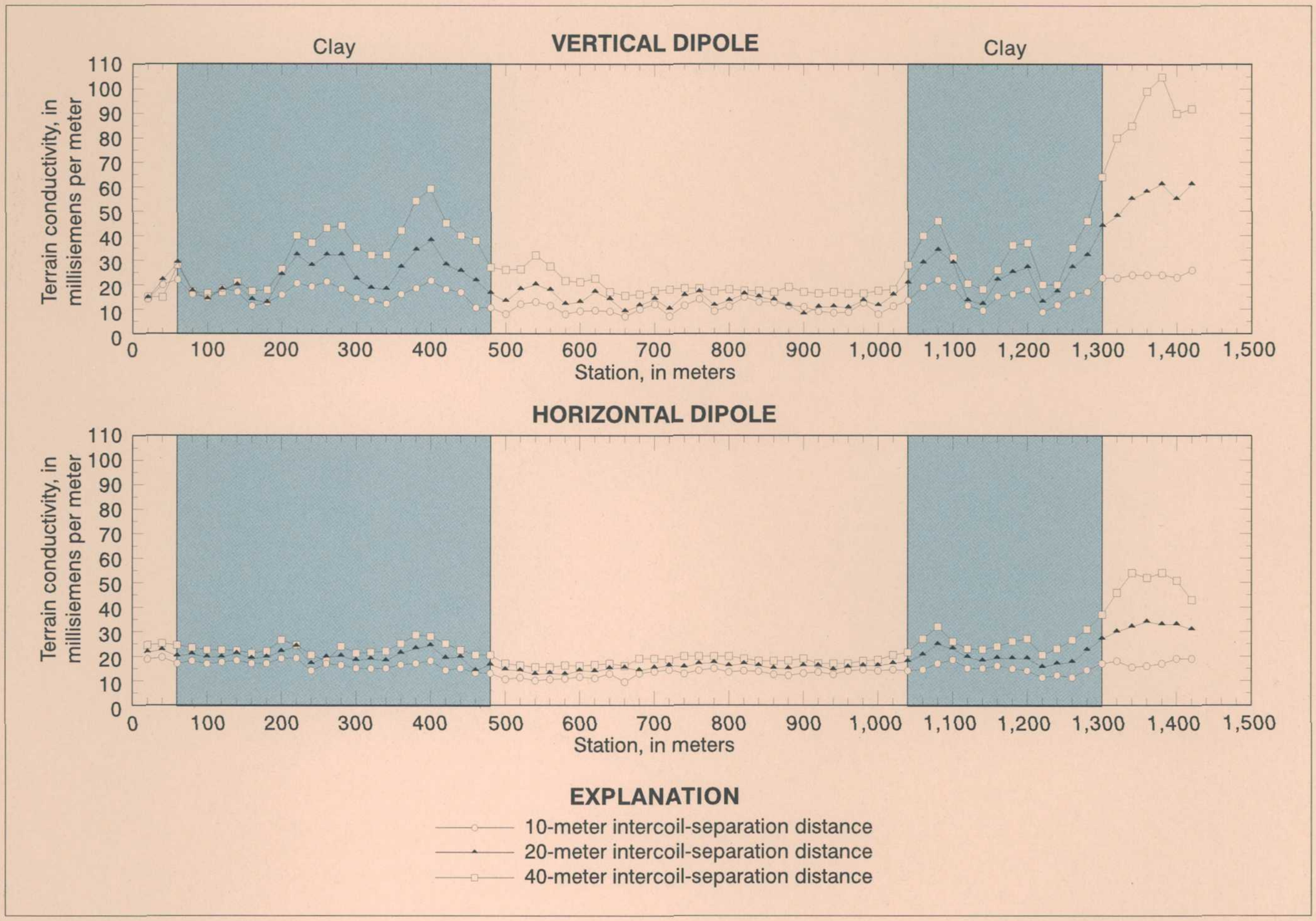
Electromagnetic Surveys to Detect Clay-Rich Sediment in the Rio Grande Inner Valley, Albuquerque Area, New Mexico

Water-Resources Investigations Report 00-4003
A contribution to the Ground-Water Resources Program



Terrain conductivity along the PDNN composite section.

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ELECTROMAGNETIC SURVEYS TO DETECT CLAY-RICH SEDIMENT IN THE RIO GRANDE INNER VALLEY, ALBUQUERQUE AREA, NEW MEXICO

By James R. Bartolino and Joseph M. Sterling

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 00-4003

Albuquerque, New Mexico
2000

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CONVERSION FACTORS

Multiply	By	To obtain
kilometer	0.622	mile
meter	3.281	foot
centimeter	0.3937	inch
meter per day	3.281	foot per day
millisiemen per meter	0.305	millisiemen per foot
microsiemen per centimeter	10.0	millisiemen per meter

Temperature in degrees Celsius (°C) can be converted to degrees Fahrenheit (°F) as follows:

$$°F = 1.8\ (°C) + 32$$

Electrical conductivity units are given in siemens (S), which is the preferred unit name under the International System of Units. It is numerically equivalent to the older term mhos.

Electrical resistivity (ohm-meters) can be converted to electrical conductivity (siemens per meter) by taking its inverse.

ELECTROMAGNETIC SURVEYS TO DETECT CLAY-RICH SEDIMENT IN THE RIO GRANDE INNER VALLEY, ALBUQUERQUE AREA, NEW MEXICO

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ABSTRACT

Information on the presence of clay-rich layers in the inner-valley alluvium is essential for quantifying the amount of water transmitted between the Rio Grande and the Santa Fe Group aquifer system. This report describes a study that used electromagnetic surveys to provide this information. In the first phase of the study, electromagnetic soundings were made using time-domain and frequency-domain electromagnetic methods. On the basis of these initial results, the time-domain method was judged ineffective because of cultural noise in the study area, so subsequent surveys were made using the frequency-domain method. For the second phase of the study, 31 frequency-domain electromagnetic surveys were conducted along the inner valley and parallel to the Rio Grande in the Albuquerque area in the spring and summer of 1997 to determine the presence of hydrologically significant clay-rich layers buried in the inner-valley alluvium. For this report, the 31 survey sections were combined into 10 composite sections for ease of interpretation.

Terrain-conductivity data from the surveys were modeled using interpretation software to produce geoelectric cross sections along the survey lines. This modeling used lithologic logs from two wells installed near the survey lines: the Bosque South and Rio Bravo 5 wells. Because of cultural interference, location of the wells and soundings, complex stratigraphy, and difficulty interpreting lithology, such interpretation was inconclusive. Instead, a decision process based on modeling results was developed using vertical and horizontal dipole 40-meter intercoil spacing terrain-conductivity values. Values larger than or equal to 20 millisiemens per meter were interpreted to contain a hydrologically significant thickness of clay-rich sediment. Thus, clay-rich sediment was interpreted to underlie seven segments of the 10 composited survey lines, totaling at least 2,660 meters of the Rio Grande inner valley. The longest of these clay-rich segments is a 940-meter reach between Bridge and Rio Bravo Boulevards.

INTRODUCTION

Quantifying the hydraulic linkage of the Rio Grande to the Santa Fe Group aquifer system is of prime importance in managing the water resources in the Middle Rio Grande Basin. The river and aquifer are linked through the approximately 25-meter (m)-thick sequence of inner-valley alluvium underlying the Rio Grande inner valley. These alluvial deposits, which contain sediments ranging from cobbles to clay, are a major factor controlling the volume of water that can move between the Rio Grande and the aquifer system. In the ground-water-flow model of Kernodle, McAda, and Thorn (1995) vertical hydraulic-conductivity values for the inner-valley alluvium were assumed to range from 12.2 meters per day (m/day) for most of the inner-valley alluvium to 0.15 m/day for an area of silty clay. Clay-rich layers exist within much of the inner-valley alluvium; although many of these layers are discontinuous, they are as thick as 4 to 6 m locally. Information on the distribution and geometry of clay-rich layers in the inner-valley alluvium is essential for quantifying the amount of water transmitted between the Rio Grande and the Santa Fe Group aquifer system. A study supported by the Ground-Water Resources

Program of the U.S. Geological Survey (USGS) as part of the Middle Rio Grande Basin Study was conducted using ground-based electromagnetic surveys during 1996-97 to provide qualitative information on the presence of clay-rich layers in the alluvium of the inner valley of the Rio Grande in the Albuquerque area between Alameda and Rio Bravo Boulevards (fig. 1).

This report describes the results of the study. The application of both time- and frequency-domain electromagnetic methods is described as well as interpreted results of 10 composited frequency-domain surveys.

Description of Study Area

The study area is the Rio Grande inner valley in the Albuquerque area between Alameda and Rio Bravo Boulevards (fig. 1). By common definition, the inner valley is the area adjacent to the Rio Grande underlain by alluvium of Quaternary age of the most recent cut-and-fill episode of the river. In the study area, the inner valley is approximately 6 kilometers (km) wide and incised into older Santa Fe Group sediments.

The inner valley is the traditional location of irrigated agriculture, which is supported by extensive irrigation works; however, urbanization and industrialization are replacing farmland. Flood-control projects since 1925 have stabilized the channel of the Rio Grande and contributed to the growth of the bosque—a dense riverside forest—between the levees on either side of the river. The bosque is highly prized for recreation and is protected as a State park through much of the Albuquerque area.

Hydrogeologic Setting

The Santa Fe Group aquifer system is the principal source of ground water in the Middle Rio Grande Basin. As defined by Thorn, McAda, and Kernodle (1993), the Santa Fe Group aquifer system is composed of Santa Fe Group (late Oligocene to middle Pleistocene) sediments as well as hydraulically connected overlying valley and basin-fill deposits (Pleistocene to Holocene). In the inner valley, these younger sediments consist of an approximately 25-m-thick sequence of interbedded gravel, sand, silt, and clay of flood-plain and river-channel deposits of the Rio Grande. The Rio Grande and Santa Fe Group aquifer system are linked through this inner-valley alluvium, and the amount of fine-grained sediment with low hydraulic conductivity is a major factor controlling the volume of water that can move between the Rio Grande and the aquifer system.

During the irrigation season, water within the inner valley is diverted from the Rio Grande at Angostura (approximately 25 river km upstream from the Alameda Boulevard bridge north of Albuquerque) and run through the Albuquerque area in a series of irrigation canals and smaller ditches for application to fields. This water either recharges to ground water, is lost through evapotranspiration, or is intercepted by interior drains and returned to the river. The other main component of the inner-valley surface-water system is the system of riverside drains, which are deep canals that parallel the river immediately outside the levees. They are designed to intercept lateral ground-water flow from the river, thus preventing waterlogged conditions in the inner valley. The main sources of recharge to ground water in the inner valley are infiltration from irrigation canals, from segments of interior drains that are now above the water table, and from applied irrigation. Other sources of recharge are infiltration of sewage effluent and of precipitation. The main sources of discharge from the ground-water system are seepage into the riverside drains, withdrawal from wells, and evapotranspiration (Kernodle, McAda, and Thorn, 1995; Anderholm, 1997).

Detailed descriptions of the hydrogeology of the Middle Rio Grande Basin can be found in Hawley and Haase (1992) and Thorn, McAda, and Kernodle (1993). Descriptions of the hydrogeology of the inner valley can be found in Peter (1987) and Anderholm (1997).

Previous Investigations

Many publications are available about the hydrogeology of the Middle Rio Grande Basin. A 1993 summary of the hydrogeologic framework and hydrologic conditions of the basin (including a summary of previous investigations) was presented by Thorn, McAda, and Kernodle (1993). A subsequent ground-water-flow model by Kernodle, McAda, and Thorn (1995) was based on this framework. A major revision of this ground-water-flow model provided the main impetus for the current study.

Several techniques have been used to determine recharge from the Rio Grande into the Santa Fe Group aquifer system. Gould (1994) installed permeameters at five sites along the Rio Grande in the Albuquerque

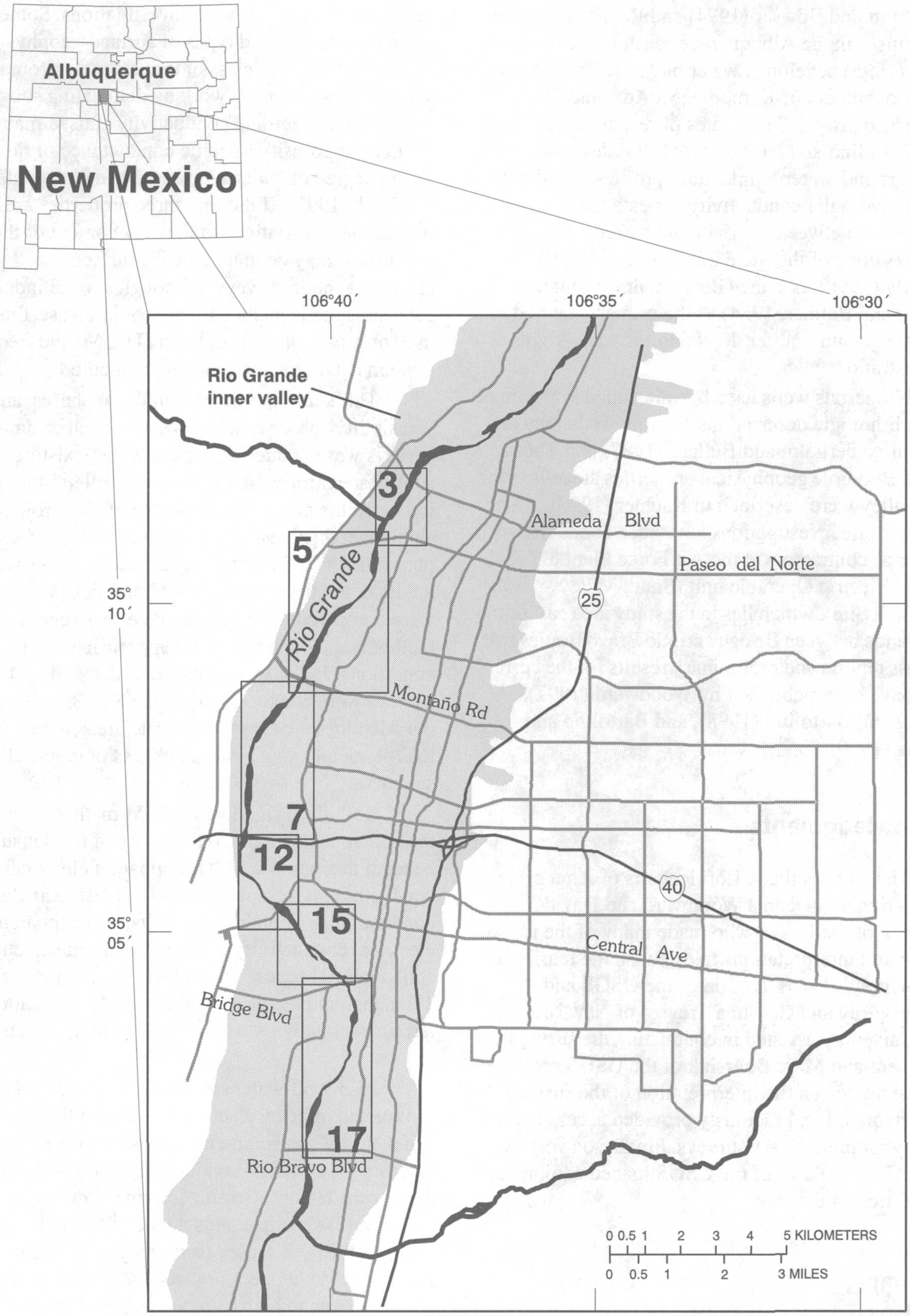


Figure 1. Albuquerque and locations of terrain-conductivity survey lines. The numbered boxes show the area and figure number of detailed maps of the survey lines.

area. Pruitt and Bowser (1994) and Roark (1998) used flood pulses in the Albuquerque reach of the river, and Gould (1995) developed water budgets. The ground-water-flow model of Kernodle, McAda, and Thorn (1995) also provided estimates of recharge from the river. Bartolino and Niswonger (1999) described the use of ground-water temperature profiles to estimate vertical hydraulic conductivity beneath the river and vertical flux between the river and aquifer. The New Mexico Office of the State Engineer (NMOSE) currently (1999) uses the Glover-Balmer equation (Glover and Balmer, 1954) as the primary method to calculate stream-aquifer depletion for water-rights administration.

Numerous wells have been installed in the inner valley; lithologic descriptions at some wells may be found in Anderholm and Bullard (1987) and Thorn (1998). Borehole geophysical properties at wells in the inner valley were described in Kaehler (1990). Extensive site investigations have been conducted by a number of contractors at the Air Force Plant 83/ General Electric Operable unit (South Valley Superfund Site), which lies in the study area east of the Rio Grande between Bridge and Rio Bravo Boulevards. Progress reports and preliminary results for the current study have been published by Woodward (1997), Sterling and Bartolino (1998), and Bartolino and Sterling (1999).

Acknowledgments

The authors thank Lori Roberts of Amtec Engineering and Dennis Woodward and David Fitterman of the USGS who made many of the initial surveys and interpretations to establish the feasibility of the surveys. Louis Trujillo of the USGS and Kimberly Ray and Carolina Trevizo of New Mexico State University assisted in conducting the surveys. Pete Haeni and Marc Buursink of the USGS provided valuable advice on the interpretation of the surveys. Schwartzman, Inc. graciously provided access to their property for preliminary surveys. Finally, on very short notice, Charles Perry of the USGS loaned equipment for a portion of the study.

METHODS

The application of surface-geophysical methods has become a common means to study the shallow subsurface in ground-water investigations. Some of the more commonly used types of surface-geophysical surveys fall into the class of inductive electromagnetic survey. These methods work by delineating subsurface variations in electrical conductivity caused mainly by changes in porosity, specific conductance of the soil water, degree of water saturation, and clay content (McNeill, 1991). If the first three properties are taken into account, variations in the clay content of the subsurface may be mapped with surface electromagnetic surveys. Although several inductive electromagnetic methods are in common use, this study used only two: the time domain (TDEM) and frequency domain (FDEM) electromagnetic methods.

This study was divided into two phases: an initial "feasibility" phase in which a series of electromagnetic surveys was conducted in areas where existing subsurface information (generally drillers' logs) indicated the presence or absence of a hydrologically significant thickness of clay-rich deposits and a second phase in which the actual production surveys were made. In the first phase, TDEM and FDEM methods were compared to determine the effectiveness of each method and which was more appropriate for local conditions. In the second phase of the study, FDEM surveys were conducted along the Rio Grande through the Albuquerque area to delineate areas with a buried, hydrologically significant thickness of clay-rich sediment.

Both the TDEM and FDEM methods measure the apparent electrical conductivity of the subsurface beneath the instrument. This apparent electrical conductivity is a combination of the different electrical conductivities of underlying units; thus, apparent electrical conductivity does not equal true electrical conductivity because the Earth is not homogeneous. The apparent electrical conductivity is also called terrain conductivity, which is the term used in this report.

In ground-water studies the soil and rock matrix is assumed to be an electrical insulator; thus, terrain-conductivity measurements are assumed to actually measure the electrical conductivity of the soil moisture. Among the factors affecting terrain conductivity are (1) porosity, (2) specific conductance of the soil water, (3) shape of the pore spaces (tortuosity), (4) degree of saturation, (5) temperature, and (6) presence of clays with moderate to high cation exchange capacity (CEC) (McNeill, 1991). Of these six factors, porosity, tortuosity, and CEC can be expected to vary in the presence of clay-rich sediments. The degree of saturation and soil temperature were assumed to be approximately the same for all sites because of their similar proximity to the river and because all surveys were conducted during the summer months. The sole remaining unaccounted factor in the terrain-conductivity measurements is the specific conductance of the ground or soil water, which is discussed in the "Ground-water effects on terrain conductivity" section.

Time-Domain Electromagnetic Surveys

The time-domain (or transient) electromagnetic induction method uses a transmitter loop on the surface to generate a static magnetic field in the subsurface. The transmitting unit then abruptly terminates the signal and a separate receiver coil records the resulting electromagnetic fields as they decay over a few milliseconds. The depth of investigation is a function of the size of the transmitter loop, amount of current used in the transmitter loop, the terrain conductivity of the profile being investigated, and background electromagnetic noise levels. This method is an effective tool for examining lateral and vertical changes in terrain conductivity in depths ranging from 5 to 2,500 m (McNeill, 1991; Hoekstra and others, 1992).

A TDEM survey instrument consists of a square transmitter loop of insulated wire with a small receiver coil in the center of the square. The penetration depth may be varied by changing the size of the transmitter loop, which is commonly between 5 and 160 m on a side. Usually the depth of investigation is approximately equal to two or more loop diameters, depending on site conditions (Fitterman, 1986).

Advantages of the TDEM method include greater resolution for a given depth of investigation compared with other inductive electrical methods. Among the disadvantages of the TDEM method is that it cannot measure the terrain conductivity of the first few meters of the subsurface, it is especially sensitive to metallic objects, and it is more difficult and takes longer to move the equipment between measurement points on a survey line compared with other methods (Hoekstra and others, 1992; Jansen and others, 1992).

As part of the first phase of the study, four TDEM surveys were conducted at two sites using Geonics EM-47 equipment. A 5-m loop configuration was used to examine the shallow subsurface as well as limit lateral interference from conductive cultural objects.

TDEM measurements produce a curve of the decaying magnetic signal at the receiver coil as a function of time. This decay curve may then be converted into a geoelectric section using computer software, such as the TEMIX-G program (Interpex Limited, 1988) used for this study. Because such models do not produce unique solutions, however, subsurface lithologic and petrophysical logs from wells and borings made near the sections are useful in interpreting results.

After evaluation of the results and comparison with FDEM results, it became apparent that the TDEM method was significantly affected by cultural noise (such as power lines, fences, and buried electrically conductive material) and was not appropriate for use in this study.

Frequency-Domain Electromagnetic Surveys

With the frequency-domain electromagnetic induction method, a coil on the surface generates an alternating magnetic field by causing induced electrical currents to flow in the subsurface. A separate receiver coil measures the resulting magnetic field, allowing the terrain conductivity of the subsurface to be determined directly. The depth of investigation is a function of coil orientation and spacing as well as transmitter frequency and soil electrical conductivity. For the equipment and intercoil spacing (10, 20, and 40 m) used in this study, the maximum depth of investigation was approximately 60 m (McNeill, 1991; Jansen and others, 1992).

One of the most common FDEM survey instruments consists of a transmitter, transmitting coil, receiver, receiver coil, and connector cable. An operator carries the receiver unit and receiver coil and records the measurements while an assistant carries the transmitter coil and transmitter unit. Measurements are made with two different coil orientations: horizontal dipole, in which the coils are oriented vertically, and vertical dipole, in which the coils are oriented horizontally. The investigation depth with the horizontal-dipole orientation is approximately 0.75 times the intercoil separation distance, and with the vertical-dipole orientation is approximately 1.5 times the intercoil separation distance. For this study, the maximum depth of investigation was approximately

60 m because a 40-m intercoil spacing was used. By making measurements at different combinations of dipole orientations and intercoil spacings, a terrain-conductivity profile with depth can be calculated.

The relative contribution to the terrain-conductivity reading from different depths varies with differing intercoil separation and orientation. For vertical-dipole measurements, material at a depth between 0.1 and 1.5 times the intercoil separation distance contributes most to the terrain-conductivity reading, which is most sensitive to material at a depth 0.4 times the intercoil spacing (Haeni, 1995). For horizontal-dipole measurements, McNeill (1980b) stated, "the relative contribution of material near-surface is large and falls off monotonically with depth." FDEM response with depth is discussed in more detail in McNeill (1980b).

Advantages of the FDEM method include fast survey times, simple use and interpretation, and relatively inexpensive equipment. Disadvantages include relatively shallow survey depths and the inability to define complicated stratigraphy (McNeill, 1991; Hoekstra and others, 1992; Jansen and others, 1992).

For the feasibility phase of this study, stations were spaced 20 m apart in each section, and horizontal- and vertical-dipole measurements were collected at intercoil separation distances of 10, 20, and 40 m. During this phase, FDEM surveys were conducted at the same two sites as the TDEM surveys, using a Geonics EM-34-3XL instrument (hereinafter referred to as the EM-34). After the reliability of the method for application in the inner valley was established, 31 FDEM sections, ranging from 80 to 1,600 m long, were located in the Rio Grande inner valley between Alameda and Rio Bravo Boulevards (fig. 1). For ease of interpretation, contiguous survey sections were combined into 10 composite sections for this report. These composite sections were given a four-digit alphanumeric designation based on the nearest road and direction from that road. Thus, the PDNN section was north of Paseo del Norte, the MNS5 section was the fifth survey line south of Montaño Road, and the I40S section was south of Interstate 40.

The changing terrain-conductivity readings with different dipole orientation and intercoil spacing can be used to provide input to computer programs to produce an interpreted depth section that shows thickness and terrain conductivity of the interpreted layers. As with TDEM modeling, such models do not produce unique solutions, and subsurface lithologic and petrophysical logs from wells and borings made near the sections can help eliminate implausible solutions. For this study, preliminary modeling was done with the EM34.FOR (Grantham, Ellefsen, and Haeni, 1987) and EMIX 34 Plus computer programs (Interpex Limited, 1994). Using forward modeling, the EM34.FOR program predicts the terrain-conductivity measurements for a given geoelectric Earth model. The EMIX 34 Plus computer program uses the Inman-style ridge regression approach of nonlinear least squares curve fitting to adjust the parameters starting with terrain-conductivity measurements and a specified number of plane layers (though it also contains a forward-modeling feature). This inverse modeling provides a geoelectric Earth model that best fits the data in a least squares sense. Modeling results are discussed in the following sections.

EVALUATION OF TERRAIN CONDUCTIVITY

A series of 31 FDEM survey lines were made in the inner valley of the Rio Grande between Alameda and Rio Bravo Boulevards using the methods described previously; for ease of interpretation, however, contiguous survey lines were composited into a total of 10 composite sections (table 1). Terrain-conductivity measurements for the composite sections are shown in tables 7-16 in the "Supplemental information" section at the end of this report. Gaps in coverage between Alameda and Rio Bravo Boulevards are due to the presence of observable, conductive cultural objects such as bridges, culverts, or Kellner jetties or electromagnetic interference from power-transmission lines. (Kellner jetties are three pieces of approximately 4-m-long steel angles bolted together in the center at right angles and laced with heavy wire. These jetties "protect the levees by retarding flood flows, trapping sediment, and promoting establishment of vegetation" (Bullard and Wells, 1992).) With one exception, all survey lines were on the east side of the Rio Grande and paralleled the riverside drain; the CENS survey line paralleled the riverside drain on the west side of the river. For ease of interpretation, the generally south-trending survey lines have been numbered so that station numbers increase from the north to south ends of the line regardless of original survey direction.

Table 1. Length and location of 10 composited electromagnetic survey sections

[m, meters]

Survey section	Length (m)	Location of start
PDNN	1,440	100 m south of Alameda Boulevard
PDNS	4,560	300 m south of Paseo del Norte
MNS1	1,680	200 m south of Montaño Road
MNS5	80	100 m south of the south end of MNS1
MNS6	640	70 m south of the south end of MNS5
CAMS	720	80 m south of the south end of MNS6
I40S	880	200 m south of Interstate Highway 40
CENN	640	200 m south of the south end of I40S
CENS	2,000	650 m south of Central Avenue
RBRN	2,080	2,700 m south of Bridge Boulevard

Modeling and Verification of Terrain Conductivity

The ultimate goal of any geophysical study is to convert the values of the physical property measured by the geophysical equipment into an interpretation of the subsurface at the site. To do this the measured values and the geology at the site need to be compared. For this study, such a comparison was attempted through inverse and forward modeling. As discussed earlier, the EM-34 equipment measures the terrain conductivity of the underlying earth with a combination of intercoil spacing and dipole orientation. However, the resulting measurements integrate the terrain conductivity of the geoelectric section in different proportions, thus complicating the direct comparison of a terrain-conductivity measurement to the depth of a given layer in a multilayer system. Computer programs are available that calculate terrain-conductivity instrument readings given the thickness and electrical conductivity of subsurface units (forward modeling). Other programs calculate the electrical conductivity and thickness of geologic units on the basis of the terrain-conductivity measurements made by the instrument (inverse modeling). Both kinds of programs require some knowledge of the subsurface lithology because a large number of non-unique solutions exist for a given set of terrain-conductivity measurements. For this study, values of electrical conductivity of various materials comparable to typical lithologies found in the Rio Grande inner valley were taken from the literature and are shown in table 2. Though some of the electrical-conductivity values are for stratified drift in New England (stratified drift is transported by glaciers and deposited by streams emanating from the glacier), drift may be considered to be similar to the fluvial deposits of the Rio Grande. The specific conductance of ground water also contributes to the terrain conductivity and is discussed in more detail in the "Ground-water effects on terrain conductivity" section. However, the values of specific conductance listed in table 2 are comparable with values measured in the inner valley.

Lithologic logs from two observation wells, Bosque South and Rio Bravo 5, which are at least 45 m in depth along the survey reach (tables 17-18 in the "Supplemental information" section), were used to construct simplified, one-dimensional, three-layer lithologic models that were in turn used to calculate idealized geoelectric Earth models (table 3). The values of electrical conductivity used for the geoelectric Earth models were those for similar materials listed in table 2.

The USGS drilled the Bosque South well in 1997 for the NMOSE. It is located approximately 125 m west-northwest of the north end of the I40S section (see fig. 12). The lithologic log for the Bosque South well is shown in table 17 (tables 17 and 18 are in the "Supplemental information" section); a less detailed version was published in Thorn (1998). The shallowest depth at which silty clay is noted on the lithologic log for the Bosque South well is about 19 m.

Table 2. Electrical conductivities of various materials comparable to common lithologies in the Rio Grande inner valley

[μS/cm, microsiemens per centimeter at 25 °C (degrees Celsius); mS/m, millisiemens per meter; --, unknown value]

Material	Specific conductance of ground water (μS/cm)	Electrical conductivity (mS/m)	Source
Gravel	--	0.17-10	Milsom, 1989
Loose sand	--	0.2-2	Milsom, 1989
Clay	--	10-1,000	Milsom, 1989
Sandstone	--	200-8,000	Milsom, 1989
Unsaturated, coarse-grained stratified drift	--	0.5	Haeni, 1995
Unsaturated, fine-grained stratified drift	--	3.3	Haeni, 1995
Saturated, coarse-grained stratified drift	--	1.2	Haeni, 1995
Saturated, fine-grained stratified drift	--	20	Haeni, 1995
Gravel, well sorted (Smyrna, N.Y.)	710	1.8	Haeni, 1995
Sand and gravel, some silt (Preble, N.Y.)	550	4	Haeni, 1995
Sand, fine, and some silt (Preble, N.Y.)	550	17	Haeni, 1995

The USGS drilled the Rio Bravo 5 well in 1992 approximately 300 m southwest of the south end of the RBRN survey section (see fig. 17). The lithologic log shown in table 18 was compiled by the authors from field notes provided by C.R. Thorn (U.S. Geological Survey, written commun., 1998). The lithologic log for the Rio Bravo 5 well first notes the presence of clay at a depth of about 21 m. This well was drilled using the mud-rotary method, which tends to cause an underestimation of the amount of fine sediment.

The values of layer thickness and electrical conductivity from the geoelectric Earth models were modeled using the EM34.FOR computer program of Grantham, Elefsen, and Haeni (1987) to generate predicted terrain conductivities. These predicted terrain conductivities were compared with those measured with the EM-34 at the station nearest the respective well to test the validity of the initial geoelectric models (table 4). There is broad agreement between the modeled and measured terrain conductivities, although the forward modeling uniformly predicts a lower value of terrain conductivity than measured. This is probably because of low values of electrical conductivity chosen for the observed units in the initial geoelectric Earth models. Electrical conductivity of these lithologic units may be greater than originally assigned because of the difference in locations between the well and geophysical survey line; subjectiveness in interpreting the geologic logs; localized, elevated levels of specific conductance of ground water; or concentration of conductive minerals in the unsaturated zone by evaporation and transpiration, to name several possibilities. A geophysical electrical-conductivity log for the Bosque South well (Thorn, 1998) indicates generally larger electrical-conductivity values than measured or predicted by the models in that it shows electrical-conductivity values for unit 2 to vary between approximately 10 and 40 millisiemens per meter (mS/m) and those for unit 3 to vary between approximately 18 and 50 mS/m.

Finally, the EMIX 34 Plus computer program (Interpex Limited, 1994) was used to find the best geoelectric Earth model for the measured terrain conductivities. For inverse modeling of terrain-conductivity measurements, the EMIX 34 Plus program requires an initial geoelectric Earth model for a starting condition. The three-layer initial geoelectric Earth models for each site (table 3) in addition to the terrain conductivities measured nearest each well (table 4) were provided as starting values to the program. The resulting inverse-model solution showing unit thickness and electrical conductivity is shown in table 3.

Table 3. Simplified lithologic logs, idealized initial geoelectric Earth models, and inverse model solutions

[m, meters; mS/m, millisiemens per meter; --, not applicable; ∞, infinite]

		Lithologic logs		Initial geoelectric Earth model			Inverse model solution using measured terrain conductivity		
Well	Unit	Lithology	Thickness (m)	Lithology	Thickness (m)	Conductivity (mS/m)	Thickness (m)	Conductivity (mS/m)	Error (percent)
Bosque South	1	Unsaturated sand	3	Unsaturated, coarse-grained stratified drift	3	0.5	0.2	0.3	10.6
	2	Saturated sand and gravel	19	Sand and gravel, some silt (Preble, N.Y.)	19	4	12	19	--
	3	Saturated silty clay	6	Sand, fine, and some silt (Preble, N.Y.)	∞	17	∞	16	--
Rio Bravo 5	1	Unsaturated fine sand	3	Unsaturated, coarse-grained stratified drift	3	0.5	1.1	0.6	13.5
	2	Saturated sand and gravel	24	Sand and gravel, some silt (Preble, N.Y.)	24	4	16	16	--
	3	Saturated silty to gravelly clay	34	Sand, fine, and some silt (Preble, N.Y.)	∞	17	∞	63	--
Hypothetical 3-layer section with clay	1	Unsaturated sand	3	Unsaturated sand	3	2	--	--	--
	2	Saturated sand and gravel	20	Sand and gravel, some silt (Preble, N.Y.)	20	4	--	--	--
	3	Saturated clay	∞	Saturated clay	∞	100	--	--	--
Hypothetical 2-layer section with clay	1	Unsaturated sand	3	Unsaturated, coarse-grained stratified drift	3	0.5	--	--	--
	2	Saturated clay	∞	Saturated clay	∞	100	--	--	--

Table 4. Comparison of measured to forward-modeled terrain conductivities based on generalized geoelectric sections of the Bosque South and Rio Bravo 5 wells

[m, meters; mS/m, millisiemens per meter]

		Terrain conductivity (mS/m)					
		Vertical dipole			Horizontal dipole		
Well	**Description**	**10 m**	**20 m**	**40 m**	**10 m**	**20 m**	**40 m**
Bosque South	Forward-modeled geoelectric section	2.7	4.4	6.8	4.0	6.2	9.3
	Measured at station 60, I40S section	15.2	12.8	15	16.2	15.2	13
Rio Bravo 5	Forward-modeled geoelectric section	2.5	4.0	6.1	3.6	5.5	8.4
	Measured at station 2,080, RBRN section	14	22.2	34	12.5	15	21
Hypothetical 3-layer section with clay	Forward-modeled geoelectric section	4.1	9.3	21	5.5	14.1	30.4
Hypothetical 2-layer section with clay	Forward-modeled geoelectric section	35.4	51	61.5	43.7	49.8	50.7

A comparison of the initial geoelectric Earth models with those predicted by inverse modeling indicates several broad trends (table 3). First, the inverse modeling changed the electrical conductivity of the unsaturated unit for both well sites very little, although it decreased the unit thickness from 3 to 0.2 m and from 3 to 1.1 m for the Bosque South and Rio Bravo 5 sites, respectively. Second, for both sites, the inverse modeling markedly decreased the thickness of the saturated coarse unit and increased the electrical conductivity. The thickness of the saturated coarse unit was reduced from 19 to 12 m for the Bosque South well site and from 24 to 16 m for the Rio Bravo 5 well site. The electrical conductivity of the saturated coarse unit was increased from 4 to 19 mS/m and from 4 to 16 mS/m for the Bosque South and Rio Bravo 5 sites, respectively. Finally, the inverse modeling increased the electrical conductivity of the lowermost, saturated fine-grained unit for the Rio Bravo 5 site from 17 to 63 mS/m. The regression error value for the Bosque South site was slightly less than that for the Rio Bravo 5 site.

In summary, lithologic logs show that the Bosque South and Rio Bravo 5 sites are largely composed of coarse-grained deposits in the uppermost 20 m. Forward modeling of a geoelectric Earth model based on the lithologic logs indicates that terrain-conductivity measurements made near the sites were greater than modeled values. Inverse modeling of the same terrain-conductivity measurements indicates that initial geoelectric Earth models overestimated the depth and underestimated the electrical conductivity of fine-grained (clay-rich) units.

If an increase in terrain conductivity is assumed to correlate to an increase in clay-rich material, the inverse modeling generally overestimates the thickness and quantity of such clayey units. For this reason, in addition to the number of stations potentially affected by cultural noise and the lack of well control, inverse modeling was not used to interpret the survey results.

To test the effect of clay-rich sediments on terrain-conductivity measurements, two geoelectric Earth models were constructed: one a hypothetical three-layer section with clay, the other a hypothetical two-layer section with clay. The three-layer model consists of a 3-m-deep, unsaturated, coarse-grained unit underlain by 20 m of saturated sand and gravel that is in turn underlain by clay. The two-layer model consists of a 3-m-thick, unsaturated, coarse-grained unit underlain by clay (table 3). The electrical-conductivity value used for the clay in both sections was 100 mS/m, which is a mid-magnitude value chosen from the range in table 2. The resulting forward-modeled terrain-conductivity measurements are shown in table 4. The terrain-conductivity values predicted from the hypothetical three-layer section better match the values measured near either well than the forward-modeled values, except for the horizontal-dipole measurements for the 40-m intercoil spacing. For the hypothetical two-layer section all readings are larger than 35 mS/m and generally do not match the measured terrain conductivity as well as the original or hypothetical three-layer geoelectric sections. Thus, the modeling suggests that the non-unique solutions presented by the models tend to underestimate the thickness of sand and gravel and that clay is present at depth and can be detected by the EM-34. Based on these results, a process was devised for the qualitative interpretation of terrain-conductivity measurements collected for this study.

Interpretation of Terrain-Conductivity Measurements

As discussed previously, the inverse modeling of terrain-conductivity measurements did not match the known lithology at two wells, the Bosque South and Rio Bravo 5 wells. Though several factors may have contributed to this, the most significant are probably that (1) the wells and soundings were not collocated, (2) the alluvial stratigraphy along the Rio Grande is complex and lithologic logs from the wells are difficult to interpret, and (3) the EM-34 is a qualitative tool and provides a non-unique solution. Because of this, a procedure was developed using forward modeling of terrain conductivity to qualitatively interpret the survey results. The resulting process used three steps to determine whether a survey station was underlain by a hydrologically significant thickness and area of clay-rich sediment within the survey depth of 60 m. These three steps are in the form of a flowchart and are shown in figure 2. These decisions are:

(1) Are both the vertical- and horizontal-dipole 40-m intercoil spacing terrain-conductivity measurements for the station greater than or equal to 20 mS/m? If not, there is probably no hydrologically significant presence of clay-rich sediment underlying the station. If so, proceed to decision number 2.

(2) Are any terrain-conductivity values for the station greater than or equal to 80 mS/m? If so, cultural interference probably is affecting the measurements. If not, proceed to decision number 3.

(3) Do three or fewer stations separate the station from another station underlain by clay? If not, the areal extent of the clay-rich sediment is too small to be of hydrologic significance. If so, the station is underlain by a significant area and thickness of clay-rich sediment within the upper 60 m of the subsurface.

By using the criteria in the flowchart, seven segments within 4 of the 10 composited survey lines probably are underlain by hydrologically significant clay-rich sediments. The seven segments of the survey lines that have been interpreted as underlain by a hydrologically significant area and thickness of clay-rich sediment are shown in table 5. The maps in figures 3-18 show the locations of the survey lines, the terrain-conductivity measurements for the survey lines, and hydrologically significant clay-rich segments. The terrain-conductivity measurements for each of the 10 composite sections are shown in tables 7-16.

Table 5. Summary of terrain-conductivity survey line segments underlain by the hydrologically significant presence of clay-rich sediment

[m, meters; mS/m, millisiemens per meter]

Survey section	Stations (m)	Range of terrain-conductivity values for 40-m intercoil spacing (mS/m)	
		Vertical dipole	Horizontal dipole
PDNN	60-480	16.5-59	18-28.5
	1,040-1,300	18-64	20.5-37
PDNS	1,600-1,620	27-35	20-20
CENS	620-680	15.2-30	21-23
	1,320-2,000	21-35	16.5-29
RBRN	640-920	35-42	19.8-23.5
	1,140-2,080	27-54	18.5-33

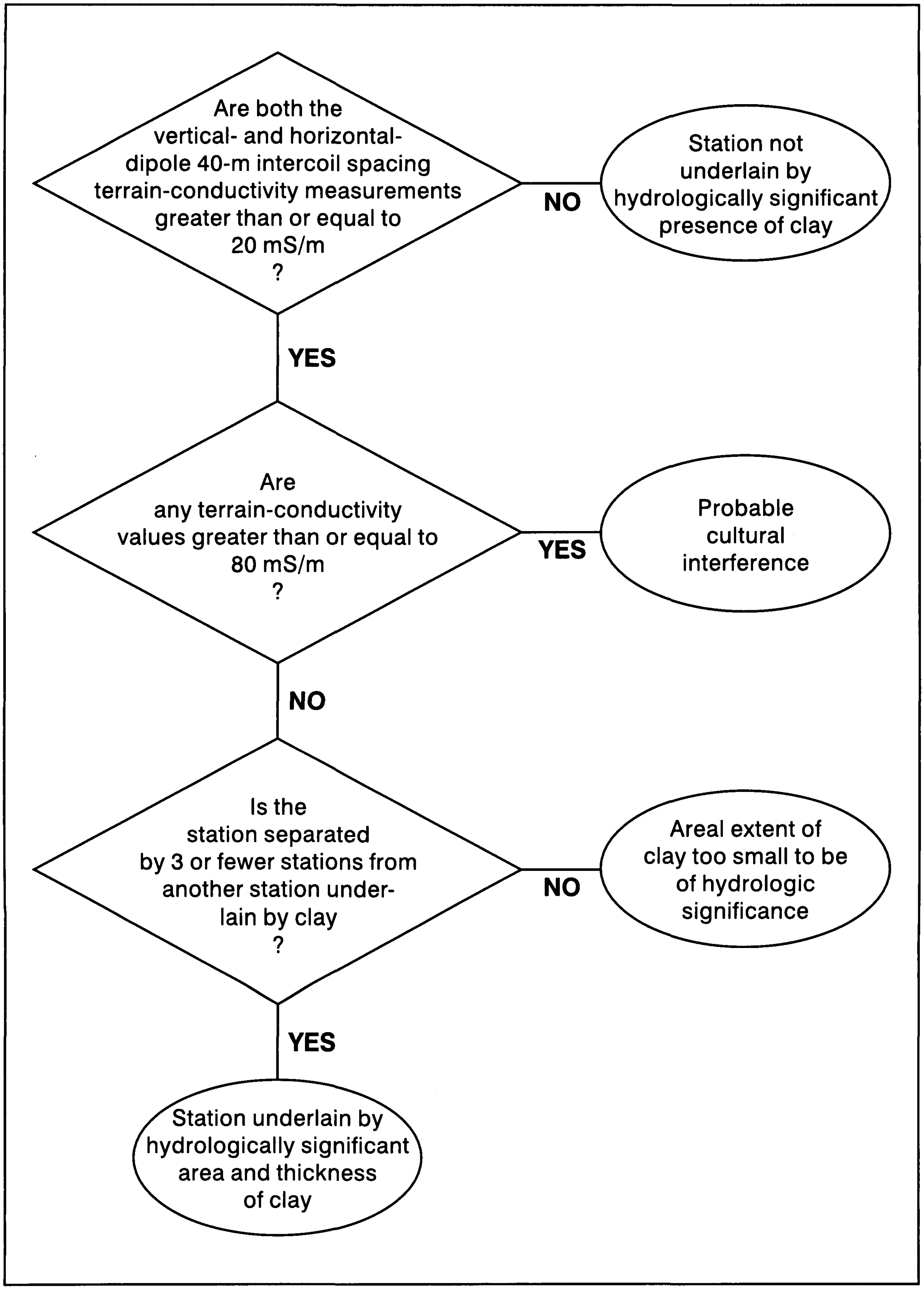


Figure 2. Decision process used in interpreting terrain-conductivity measurements made for this study (m, meters; mS/m, millisiemens per meter).

This correlation of greater terrain-conductivity measurements with increased clay content is consistent with another study along the Rio Grande. In examining soil salinity at the Bosque del Apache National Wildlife Refuge (approximately 130 km downstream from Albuquerque), Steven (1997) found the highest terrain-conductivity values to be within or at the top of the clay layers and the lowest values to be in profiles that contained only sand.

The PDNN survey line began approximately 100 m south of Alameda Boulevard and was 1,440 m long (fig. 3). Terrain-conductivity measurements for the section are shown in figure 4 and table 7. Two segments of the survey line were interpreted as underlain by hydrologically significant clay-rich sediment (table 5). The first of these segments (stations 60 to 480) partly coincides with a Kellner jetty field 15 m west of the survey line. Because the elevated terrain-conductivity readings begin 200 m before the field and end 180 m before the end of the field, terrain-conductivity measurements for this segment do not appear to have been affected by the jetties. The second segment interpreted as underlain by clay extends from stations 1,040 to 1,300. The segment from stations 1,320 to 1,400 was interpreted as affected by cultural interference, possibly associated with the power lines south of the section. For the entire survey reach, terrain-conductivity values for the different intercoil separations for both the vertical- and horizontal-dipole plots are somewhat parallel (but with generally increasing terrain conductivity with depth), suggesting fairly laterally uniform and continuous layering throughout the length of the survey line.

The location of the PDNS survey line that began approximately 300 m south of Paseo del Norte and was 4,560 m long is shown in figure 5. Terrain-conductivity values for the section are shown in figure 6. Interpretation of the survey line suggests that one short, discontinuous segment (stations 1,600 to 1,620) was underlain by clay (table 5). A number of 30-cm galvanized culverts crossed the survey line at right angles at a 2- to 3-m depth (table 8). These culverts were not associated with elevated terrain-conductivity readings and were thus assumed to have little or no effect on the surveys. The spiking terrain-conductivity values at stations 120 and 1,180 and the chaotic, "noisy" vertical-dipole measurements at stations greater than approximately 2,800 m were interpreted as affected by cultural interference. This noise was not due to any readily apparent source.

The MNS1 survey line began approximately 200 m south of Montaño Road and was 1,680 m long (fig. 7). Terrain-conductivity values for the section, shown in figure 8, indicate that the section was not underlain by any segments of hydrologically significant clay-rich sediment. The segment from stations 940 to 1,080 was apparently affected by cultural noise because of the large values of terrain conductivity. Again, the presence of culverts perpendicular to the survey line did not appear to have any effect on the terrain-conductivity measurements (table 9).

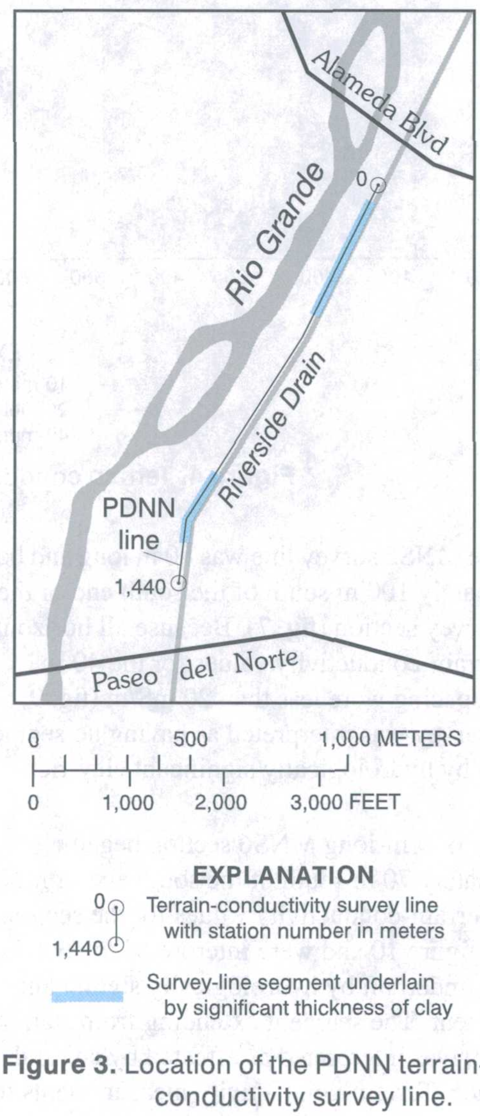


Figure 3. Location of the PDNN terrain-conductivity survey line.

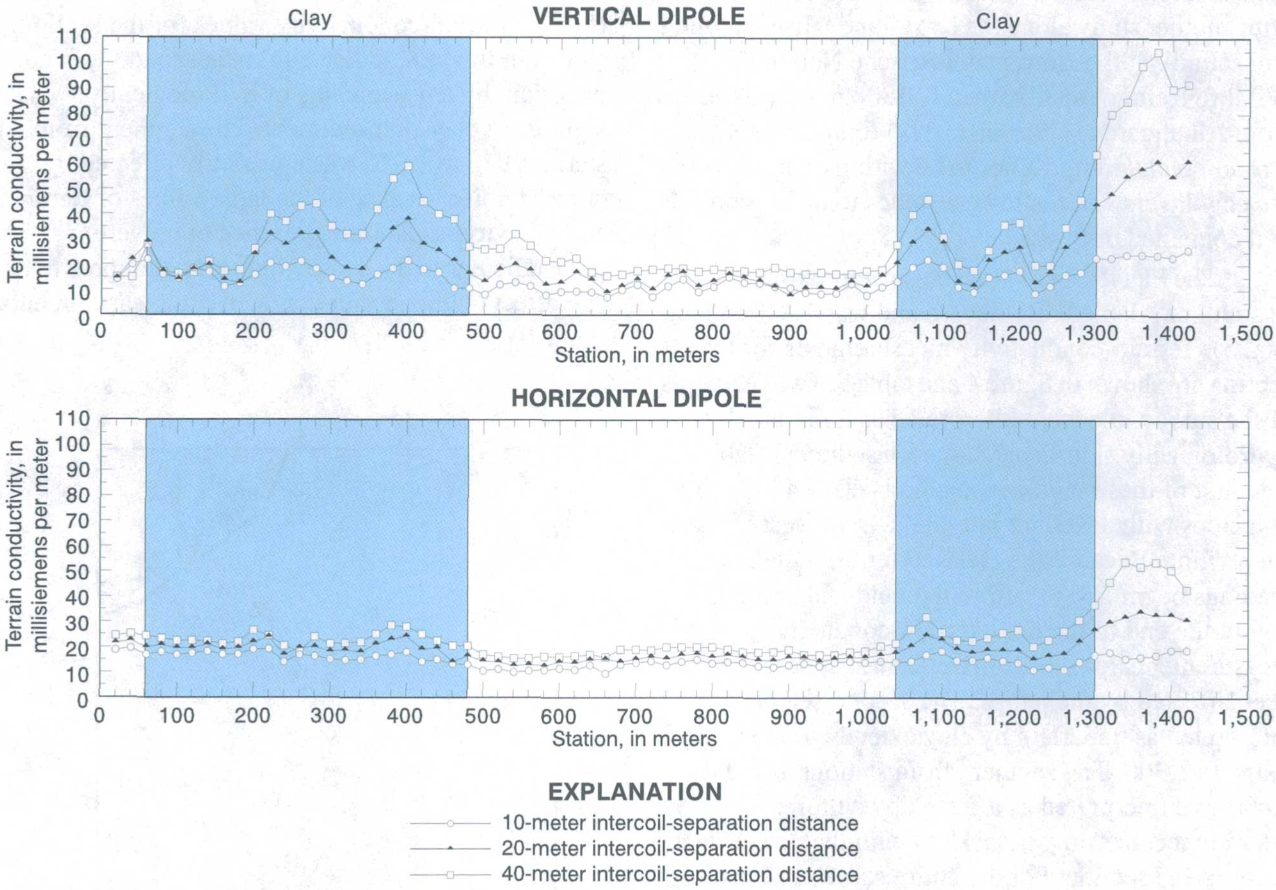


Figure 4. Terrain conductivity along the PDNN survey line.

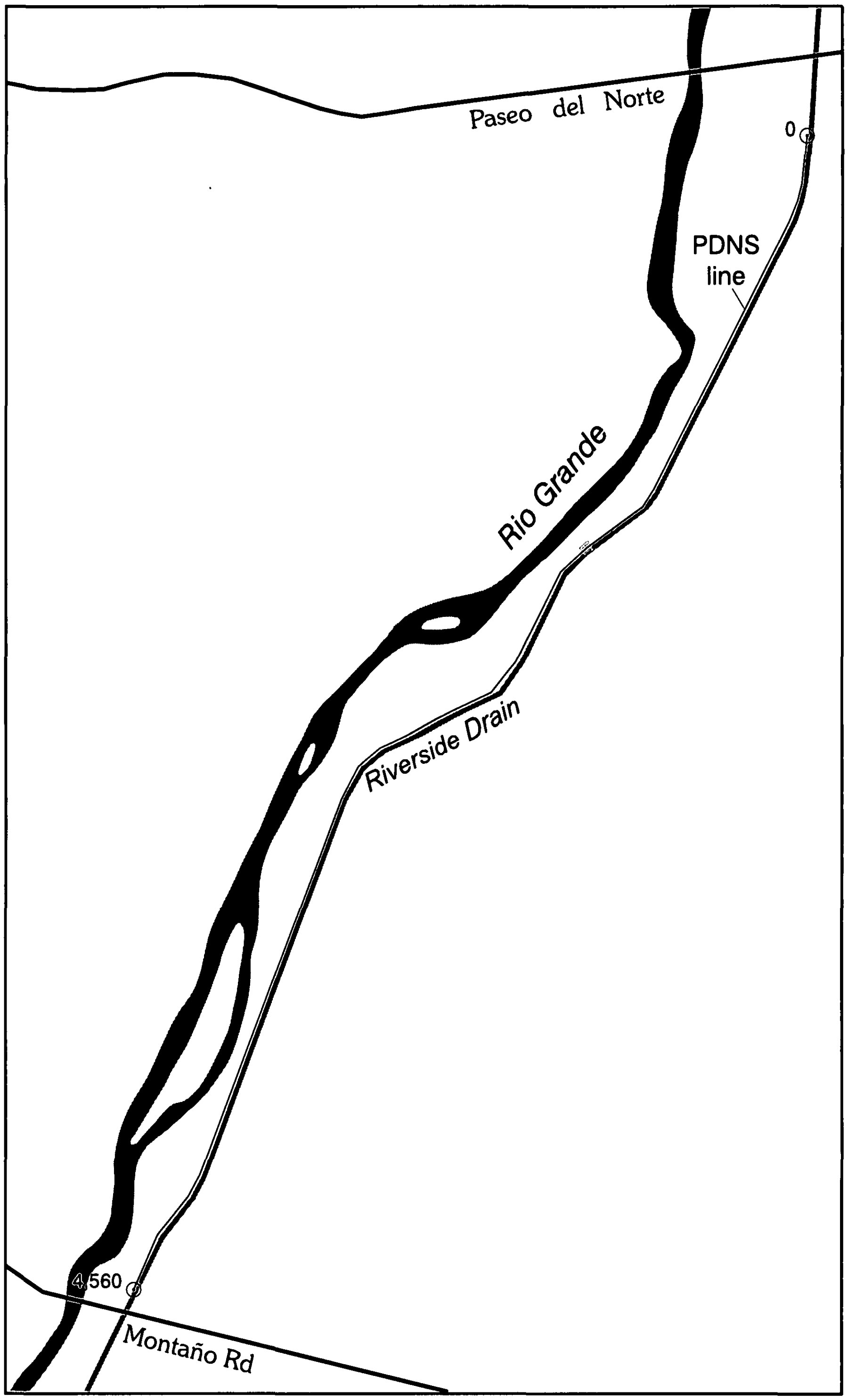
The MNS5 survey line was 80 m long and began approximately 100 m south of the south end of the MNS1 survey section (fig. 7). Because all horizontal-dipole terrain-conductivity values for the 40-m intercoil spacing were less than 20 mS/m (fig. 9; table 10), the survey was interpreted as having no segments underlain by hydrologically significant clay-rich sediment.

The 640-m-long MNS6 section began approximately 70 m south of the south end of MNS5 (fig. 7). Terrain-conductivity values for the section are shown in figure 10 and were interpreted to contain no segments underlain by hydrologically significant clay-rich sediment. The segment extending from stations 320 to 380 was interpreted as affected by cultural interference. Terrain-conductivity measurements for the section are shown in table 11.

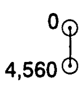
The 720-m-long CAMS survey line began approximately 80 m south of the south end of MNS6 (fig. 7). Terrain-conductivity values for the survey line are shown in figure 11 and table 12. Because all 40-m intercoil spacing terrain-conductivity measurements were less than 20 mS/m, hydrologically significant amounts of sediment were not interpreted to underlie the survey line. The segments between stations 260 to 280 and 560 to 620 appear to have been affected by cultural interference.

The I40S survey line began approximately 200 m south of Interstate Highway 40 and was 880 m long (fig. 12). Terrain-conductivity values for the section are shown in figure 13 and table 13. In this survey line all horizontal-dipole terrain-conductivity measurements for the 40-m intercoil spacing were less than 20 mS/m and were thus interpreted as indicating the absence of significant clay-rich sediment in the alluvium beneath this section.

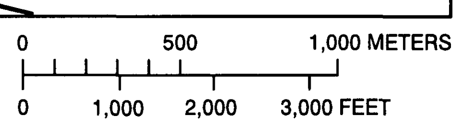
The 640-m-long CENN survey line began approximately 200 m south of the south end of I40S (fig. 12). The terrain-conductivity values for the different intercoil separations for both the vertical- and horizontal-dipole plots shown in figure 14 are somewhat parallel, suggesting laterally uniform layering throughout the length of the survey line.



EXPLANATION



Terrain-conductivity survey line with station number in meters



Survey-line segment underlain by significant thickness of clay

Figure 5. Location of the PDNS terrain-conductivity survey line.

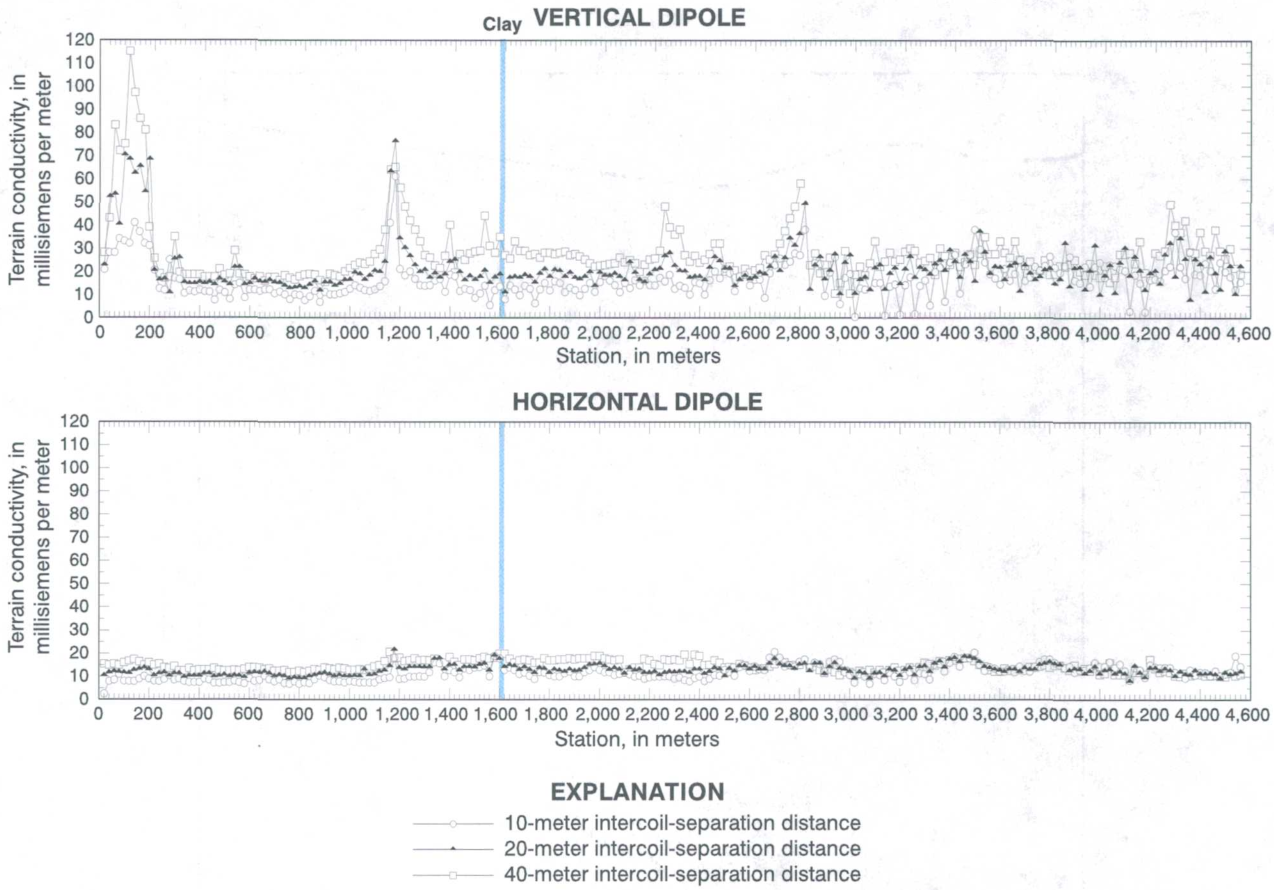


Figure 6. Terrain conductivity along the PDNS survey line.

Because all horizontal-dipole terrain-conductivity measurements for the 40-m intercoil spacing were less than 20 mS/m, hydrologically significant clay-rich sediment was not interpreted to underlie the survey line. The general increase in the 40-m intercoil spacing measurements along the survey line may indicate a slight increase in clay-rich sediments. Again, 30-centimeter (cm)-diameter galvanized culvert is present at a 2- to 3-m depth perpendicular to the survey line but does not seem to influence the terrain-conductivity measurements (table 14).

The CENS survey line began approximately 650 m south of Central Avenue and was 2,000 m long (fig. 15). Terrain-conductivity values for the section are shown in figure 16. Based on the interpretation criteria discussed above, two segments (stations 620-680 and 1,320-2,000) were interpreted as underlain by the presence of significant amounts of clay (table 5). This survey line was on the west side of the Rio Grande and encountered a great deal of potential cultural interference (table 15). The two segments interpreted as underlain by hydrologically significant clay-rich sediment do not appear to be substantially influenced by cultural interference, though the chaotic character of the 10-m dipole measurements may indicate some shallow interference.

The 2,080-m-long RBRN survey line began approximately 2,700 m south of Bridge Boulevard (fig. 17). Terrain-conductivity values for the section are shown in figure 18 and were interpreted to indicate two segments underlain by hydrologically significant clay-rich sediment (table 5). The first segment, stations 640 to 920, has generally smaller values of terrain conductivity than portions of the second segment, stations 1,140 to 2,080, suggesting a shallower depth or greater thickness of clay-rich sediment near the center of the second segment. In addition, the terrain-conductivity values for the different intercoil separations for both the vertical- and horizontal-dipole plots are fairly parallel, suggesting laterally uniform layering throughout the length of the survey line. The continued presence of culverts perpendicular to the survey line did not appear to have any effect on the terrain-conductivity measurements (table 16).

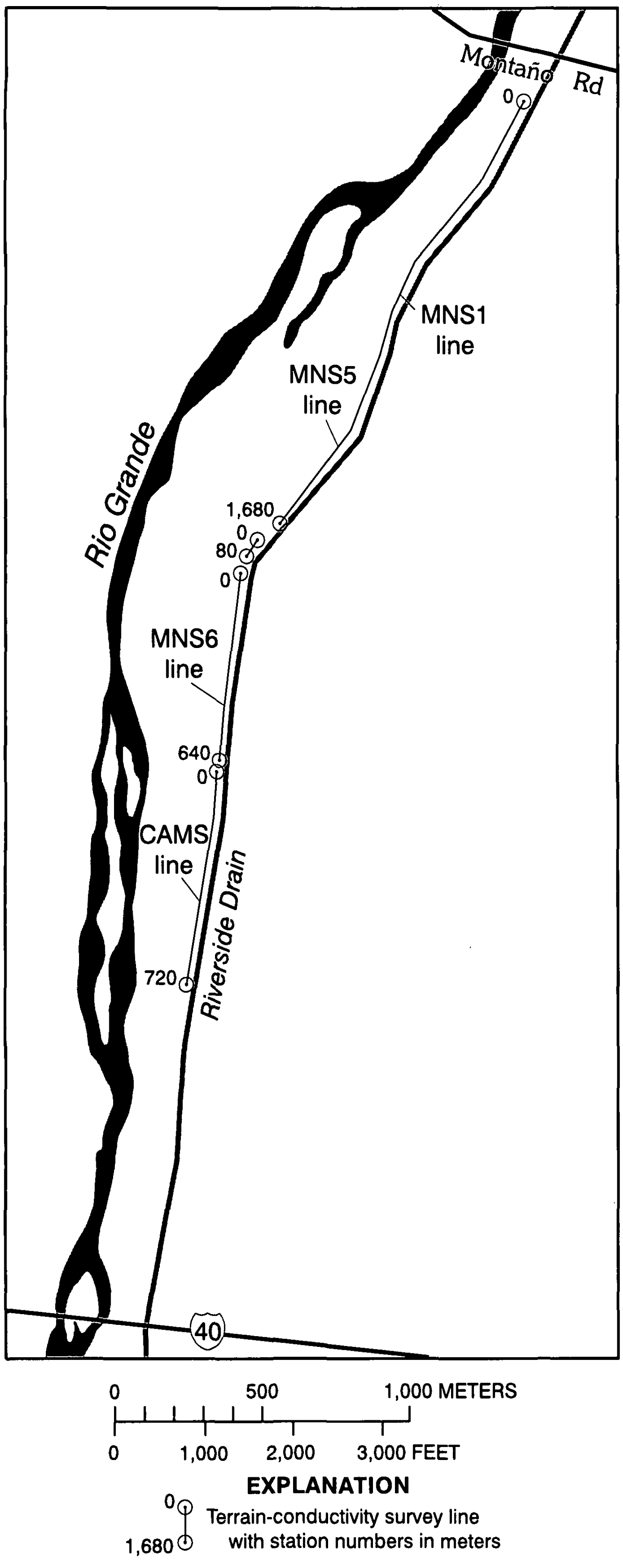


Figure 7. Locations of the MNS1, MNS5, MNS6, and CAMS terrain-conductivity survey lines.

Ground-Water Effects on Terrain Conductivity

An unaccounted factor in the terrain-conductivity measurements is the specific conductance of the ground or soil water. The degree to which terrain conductivity may be affected by changes in the specific conductance of ground water can be calculated using Archie's Law, an empirically based relation that is sufficiently accurate for fully saturated consolidated and unconsolidated materials. From McNeill (1991):

$$\sigma_a = \sigma_w \Phi^m \qquad (1)$$

where σ_a = the bulk electrical conductivity of the soil;
σ_w = the specific conductance of the soil water;
Φ = the soil porosity; and
m = a cementation exponent whose value varies with grain size, grain-size distribution, and tortuosity.

McNeill (1980a) gave a range of 1.2-1.85 for *m*, whereas Asquith and Gibson (1982) gave an *m* value of 2.15 as part of the Humble formula for unconsolidated sands.

By assuming a soil porosity of 30 percent (uniform sand) and selected cementation exponents, the variation in terrain conductivity caused strictly by soil water may be calculated for conditions in the study area. Bexfield and Anderholm (1997) measured specific conductance ranging from 280 to 1,771 microsiemens per centimeter at 25 degrees Celsius in water from 14 wells in the Rio Grande inner valley in the Middle Rio Grande Basin. The maximum, minimum, and mean specific conductance of water from the 14 wells and their calculated terrain-conductivity values for selected values of *m* are shown in table 6.

For larger values of ground-water specific conductance and smaller values of *m*, the calculated terrain conductivity is large enough to falsely indicate the presence of clay. For most combinations of ground-water specific conductance and cementation exponent shown in table 6, however, potential bias is probably not significant.

Steven (1997) noted that the introduced pheatophyte tamarisk or salt cedar (*Tamarix chinensis*) may be concentrating salinity within ground water and the unsaturated zone at the Bosque del Apache National Wildlife Refuge. Although tamarisk is common along the survey lines for the current study, no relation was apparent between increased terrain-conductivity measurements and stands of tamarisk.

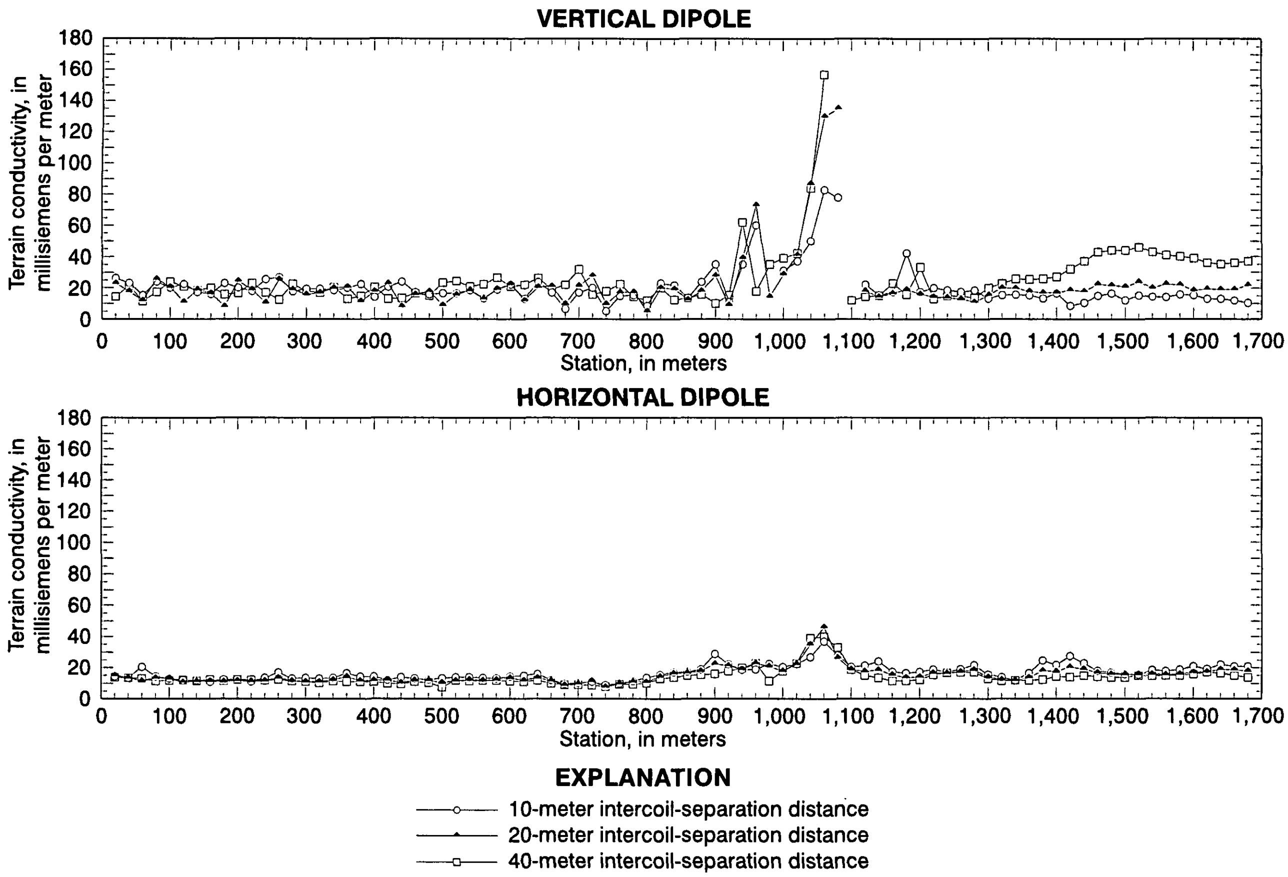


Figure 8. Terrain conductivity along the MNS1 survey line.

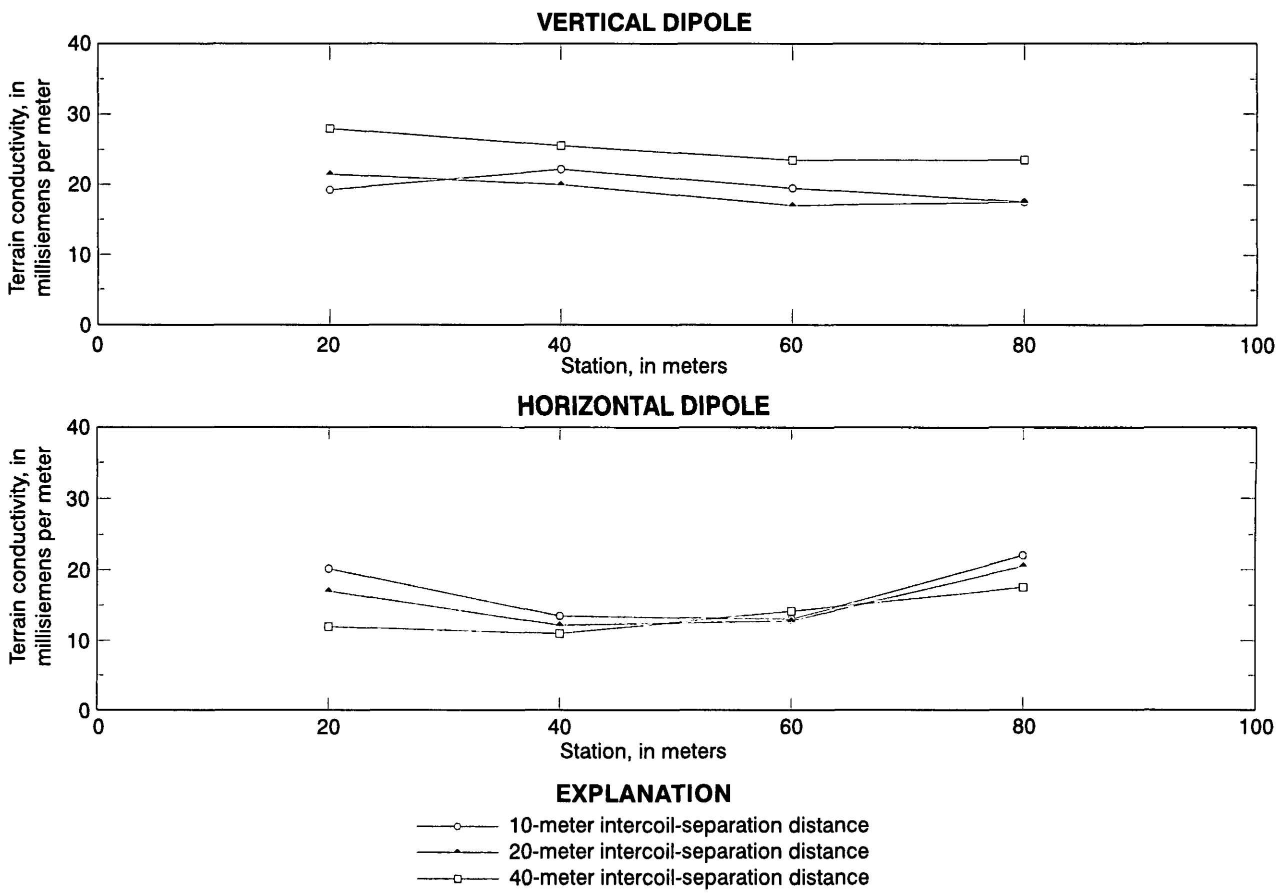


Figure 9. Terrain conductivity along the MNS5 survey line.

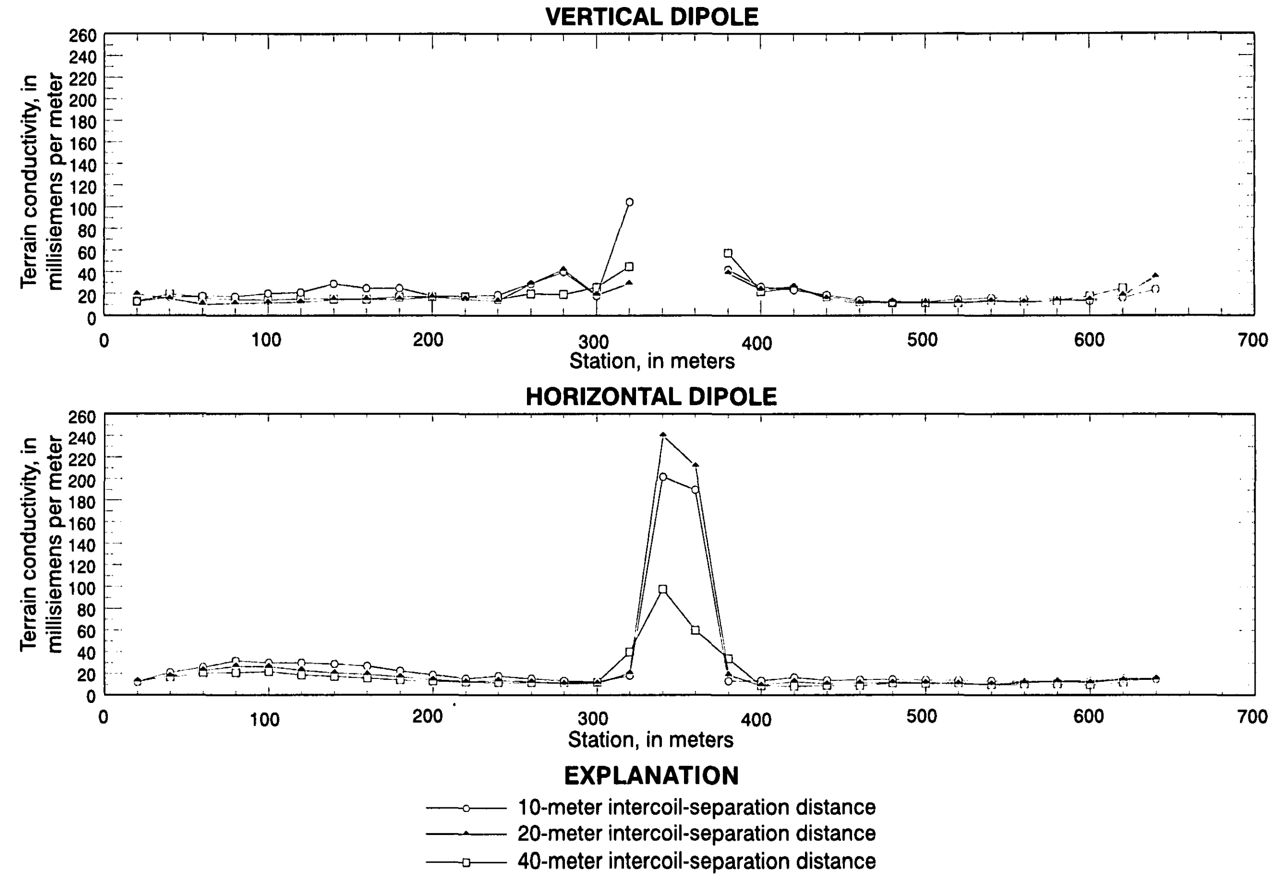


Figure 10. Terrain conductivity along the MNS6 survey line.

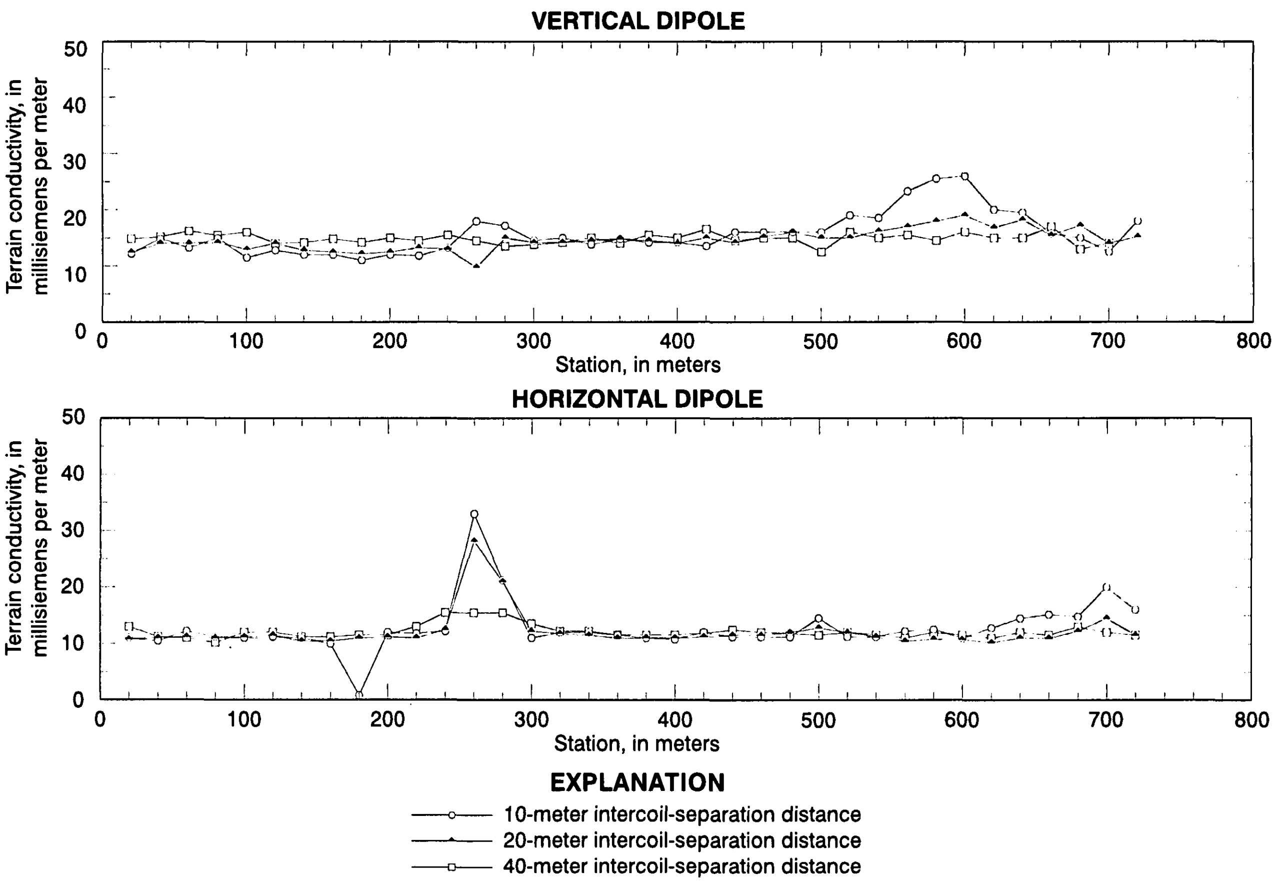


Figure 11. Terrain conductivity along the CAMS survey line.

Table 6. Calculated terrain-conductivity values for selected specific conductances of ground water from 14 wells in the Middle Rio Grande Basin

[Soil porosity is assumed to be 30 percent. µS/cm, microsiemens per centimeter at 25 degrees Celsius; mS/m, millisiemens per meter]

Cementation exponent	Maximum specific conductance (1,771 µS/cm)	Minimum specific conductance (280 µS/cm)	Mean specific conductance (652 µS/cm)
	Calculated terrain conductivity (mS/m)		
1.2	42	6.6	15
1.85	19	3.0	7.0
2.15	13	2.1	4.9

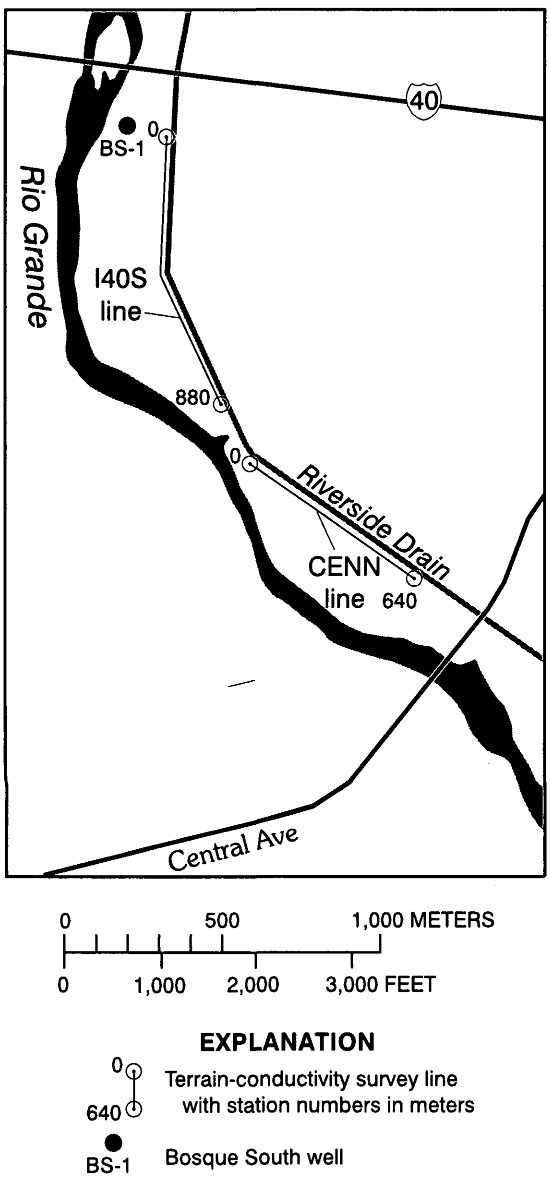


Figure 12. Locations of the I40S and CENN terrain-conductivity survey lines.

SUMMARY AND CONCLUSIONS

A study was conducted to use electromagnetic surveys to provide information on the presence of hydrologically significant clay-rich layers in the alluvium of the inner valley of the Rio Grande in the Albuquerque area. This information is essential for quantifying the amount of water transmitted between the Rio Grande and the Santa Fe Group aquifer system. In the first phase of the study, test electromagnetic soundings were made at sites where existing subsurface information (generally drillers' logs) indicated the presence or absence of hydrologically significant clay-rich sediment. In this first phase of the study, the time domain and frequency domain electromagnetic methods were used to determine which method was more appropriate for local conditions. On the basis of these initial results, the TDEM method was judged as too susceptible to cultural noise in the study area, so subsequent surveys were made using the FDEM method.

For the second phase of the study, frequency-domain electromagnetic surveys were conducted along the inner valley and parallel to the Rio Grande in the Albuquerque area in the spring and summer of 1997 to determine the distribution of hydrologically significant clay-rich sediment in the inner-valley alluvium. Surveys were conducted using an EM-34 terrain-conductivity meter. During the second phase, 31 terrain-conductivity sections ranging from 80 to 1,600 m long were located in the Rio Grande inner valley between Alameda and Rio Bravo Boulevards. Stations were spaced 20 m apart in each section, and horizontal- and vertical-dipole measurements were collected at three intercoil separation distances (10, 20, and 40 m). The 31 survey sections were combined into 10 composite sections for ease of interpretation.

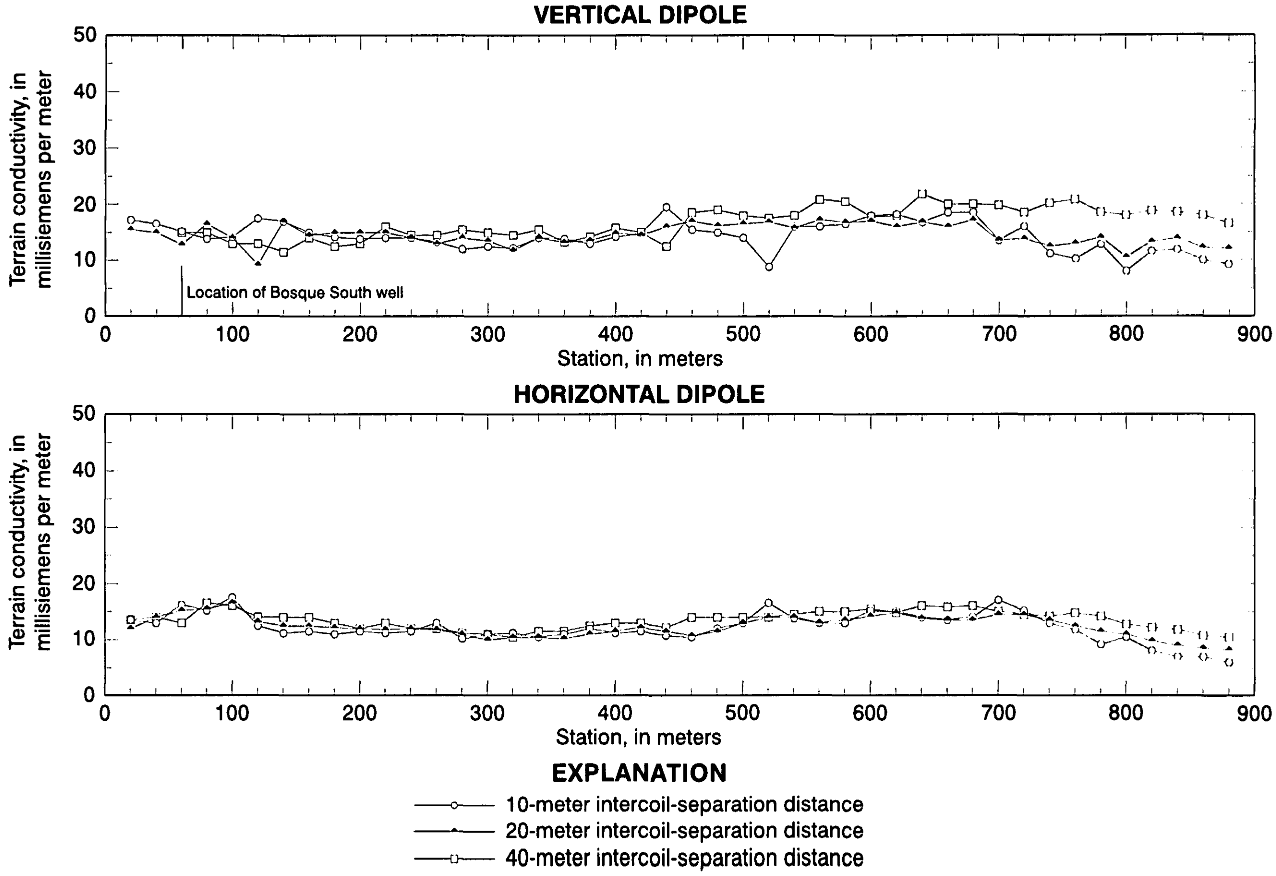


Figure 13. Terrain conductivity along the I40S survey line.

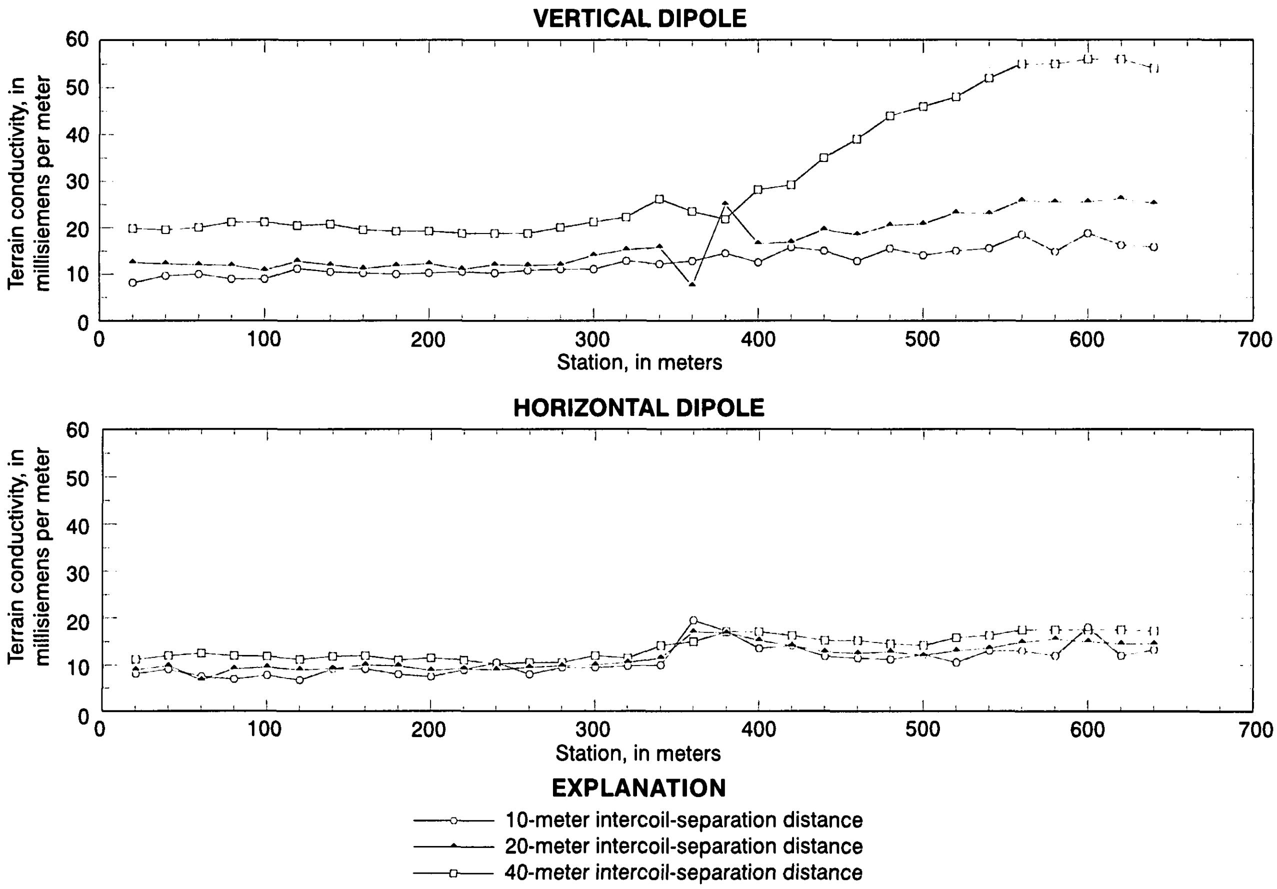


Figure 14. Terrain conductivity along the CENN survey line.

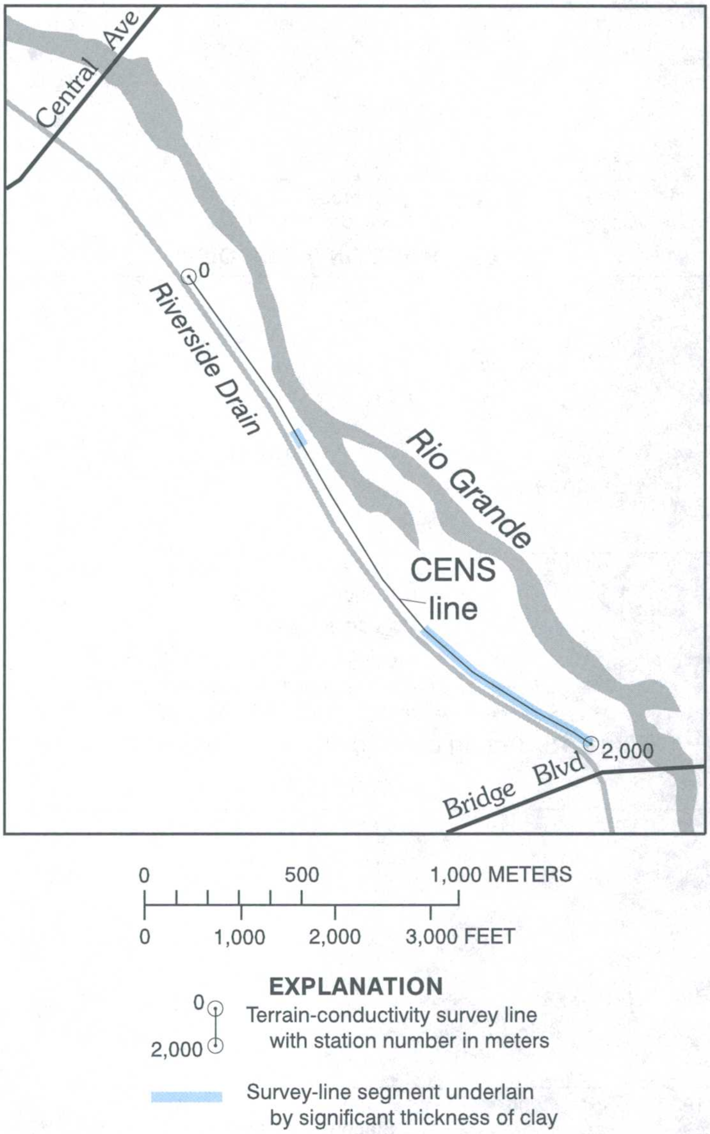


Figure 15. Location of the CENS terrain-conductivity survey line.

Terrain-conductivity data from the surveys were modeled using interpretation software to produce geoelectric cross sections along the survey lines. This modeling used lithologic logs from two wells installed near the survey lines: the Bosque South and Rio Bravo 5 wells. Due to cultural interference, location of the wells and soundings, complex stratigraphy, and difficulty interpreting lithology, such interpretation was inconclusive. Instead, a decision process based on modeling results was developed using vertical- and horizontal-dipole 40-m intercoil spacing terrain-conductivity values. Values larger than or equal to 20 mS/m were interpreted to contain a hydrologically significant thickness of clay-rich sediment (with some qualifiers). Thus, clay-rich sediments were interpreted to underlie seven segments in 4 of the 10 composited survey lines, totaling at least 2,660 m of the Rio Grande inner valley. The longest of these clay-rich segments is a 940-m reach between Bridge and Rio Bravo Boulevards.

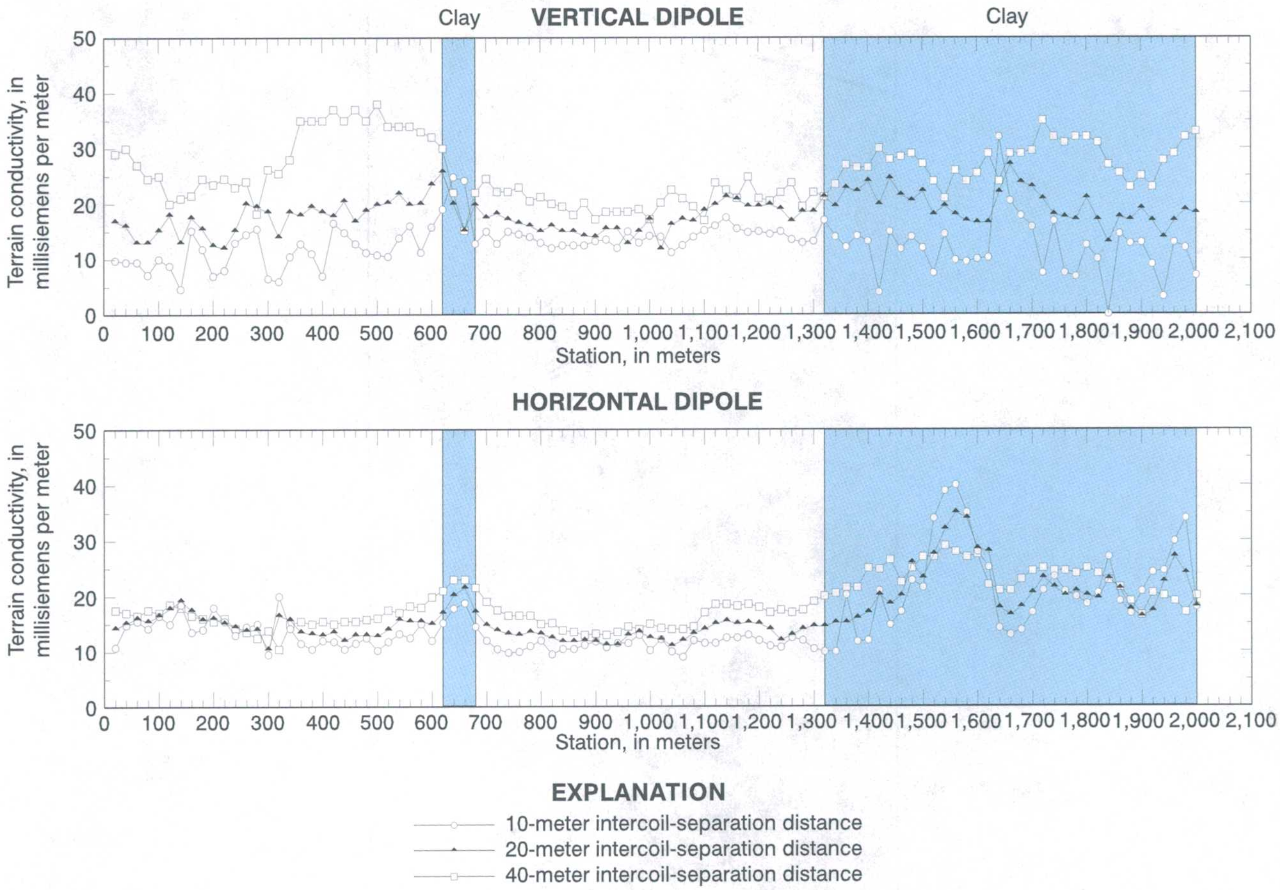


Figure 16. Terrain conductivity along the CENS survey line.

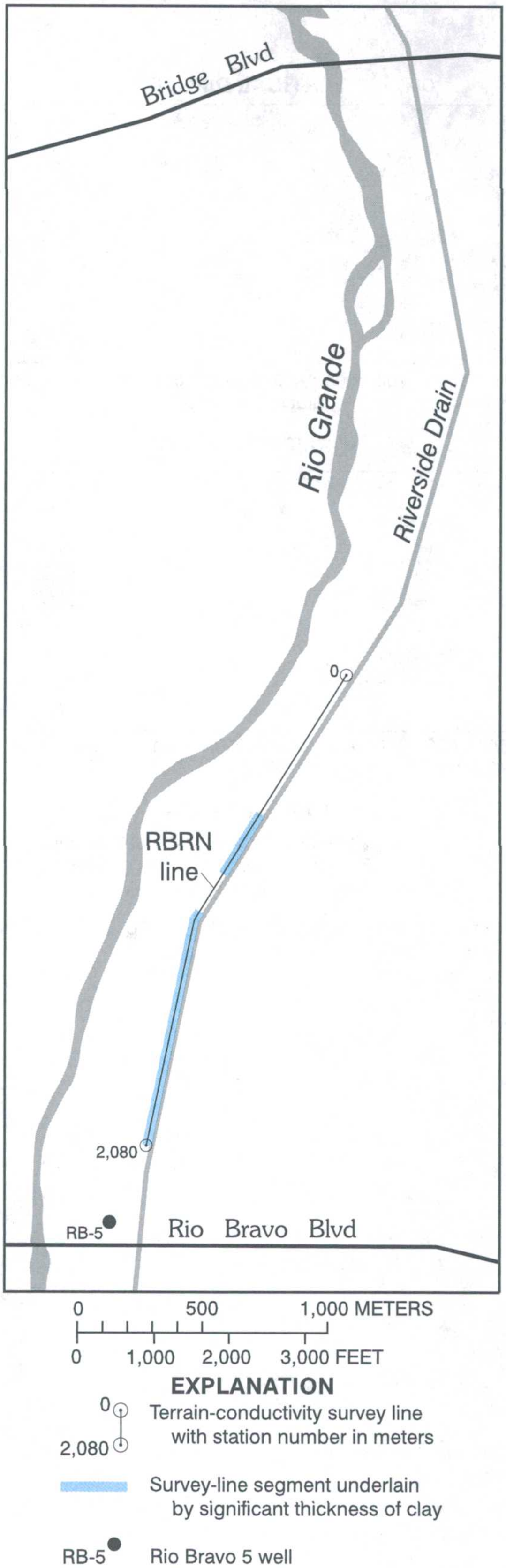


Figure 17. Location of the RBRN terrain-conductivity survey line.

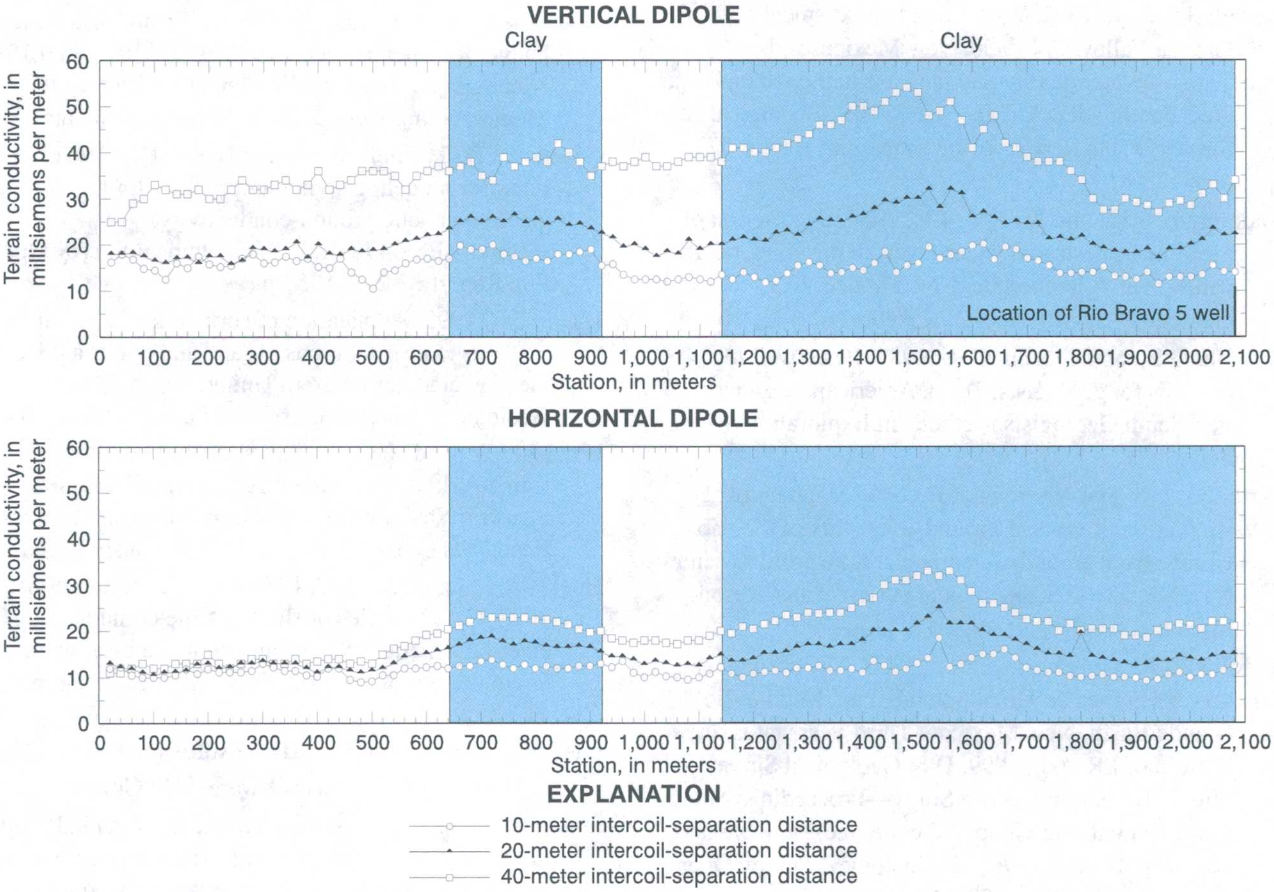


Figure 18. Terrain conductivity along the RBRN survey line.

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SUPPLEMENTAL INFORMATION

Terrain-Conductivity Measurements

Table 7. Terrain-conductivity measurements for the PDNN survey section

[m, meters; mS/m, millisiemens per meter; --, missing value]

Station (m)	Terrain conductivity (mS/m)						Notes
	Vertical dipole			Horizontal dipole			
	10 m	20 m	40 m	10 m	20 m	40 m	
20	14	14.5	15	18.8	21.5	24.5	
40	20	21.8	14.8	19.5	22.5	25.2	
60	22	29	28	17	20	24.5	
80	16	17.2	17	18	20.8	23.5	
100	14.5	14	16.5	16.8	19.5	22.5	
120	18.5	18	16.8	17.5	19.5	22.5	
140	17	19.8	21	18.2	21	22.2	
160	11.2	13.8	17.2	17	19	21.2	
180	12.5	12.5	17.8	17	19.5	22	
200	15.8	24	26.2	19	21.8	26.5	
220	20.5	32	40	19.2	24	24.5	
240	19.2	27.8	37	14	16.8	20.5	
260	21.2	32	43	16.8	19.5	18	Kellner jetties 15 m west of survey line
280	18.2	32	44	16.3	20	24	
300	14.5	22.2	35	15	18.2	21.2	
320	13.5	18.5	32	14.8	18.8	21.5	
340	12.2	18	32	15	18	22	
360	16	27	42	16.5	21.2	25	
380	18.5	34	54	17	23	28.5	
400	21.5	38	59	18	24.2	28	
420	18	28	45	14.2	19.2	25	
440	16.8	25.5	40	15	19.5	22.5	
460	10.5	21.5	38	13.2	14	20.5	
480	10.5	16.5	27	13	16.5	20.5	
500	8	13.2	26	10.5	14.5	17	
520	12	18	26.2	11.2	14	16.2	
540	13	20	32	10	12.5	15.5	
560	11.5	17.8	27.5	10.5	13	15.5	
580	8	12	21.5	10.8	12.5	16.2	
600	9.2	12.8	21	11.5	14	16	
620	9.5	17	22.5	11	13.8	16.5	
640	9	14	17	12.8	15	17	
660	7	9	15.5	9.5	15.2	16	Kellner jetties 15 m west of survey line end
680	10	11.5	16	13	14.2	19	
700	12	14.2	17.5	13.8	15.2	19	
720	7.2	10.2	18	14.5	16.2	18.8	
740	11.5	15.5	18.5	12.8	15.5	20	
760	14.2	17	18.5	14.2	16.8	20	
780	9.2	11.5	17.2	15	17.2	20	
800	11.2	13.5	18	13.5	16	20	
820	15	16.2	17.5	14	16.8	19	
840	13	15	17.5	13.8	16	18	
860	12.8	13.8	17	12.5	15	18	
880	11.5	11.5	19	12.1	14.8	18.2	
900	11	8	17	13	16	19	
920	9	10.8	16.5	13.5	16	17	
940	8.5	11	17	12.5	14.5	17	
960	8.8	10.5	16.5	14	15.5	17	
980	12.5	13.5	16.5	14.5	16	18	
1,000	8	11.5	17.5	14	16	18.5	
1,020	11.2	15.8	18	14.5	17	20.5	

	Terrain conductivity (mS/m)						
	Vertical dipole			Horizontal dipole			
Station (m)	10 m	20 m	40 m	10 m	20 m	40 m	Notes
1,040	13.5	20.81	28	14	17.8	21.5	
1,060	19	29	40	14.5	20.5	27	
1,080	22	34	46	17	24.8	32	
1,100	19.2	29	31	18.5	23	26	
1,120	11.5	13.5	20.5	15	19.5	23	
1,140	9.5	12	18	15	18	22.8	
1,160	15.2	22	26	16	19.2	24	
1,180	16.2	25	36	14.8	19	26	
1,200	17.8	27	37	14	19	27	
1,220	8.8	13	20	11.2	15.5	20.5	
1,240	11.8	17.1	20	12.2	16.8	23	
1,260	16.2	27	35	11.2	17.5	26.5	
1,280	17.1	32	46	14.3	22.5	31	
1,300	22.8	44	64	17	27	37	
1,320	22.8	48	80	18	30	46	
1,340	24	55	85	15.5	32	54	
1,360	24	58	99	16	34	52	
1,380	24	61	105	17	33	54	
1,400	23	55	90	19	33	51	
1,420	26	61	92	19	31	43	
1,440	--	--	--	--	--	--	Power lines 20 m south

Table 8. Terrain-conductivity measurements for the PDNS survey section

[m, meters; mS/m, millisiemens per meter; cm, centimeter; --, missing value]

	Terrain conductivity (mS/m)						
	Vertical dipole			Horizontal dipole			
Station (m)	10 m	20 m	40 m	10 m	20 m	40 m	Notes
20	20.8	22.5	28	2.6	10.2	15.5	Power lines 20 m north
40	28	52	43	8	11.5	15	
60	28	53	83	8.5	12	15.5	
80	34	40	72	11	11.8	15	
100	33	70	75	8.2	11.5	16	
120	32	68	115	8	11.2	16.8	
140	41	62	97	8	12.5	17.5	
160	37	65	86	9	13	16.5	
180	32	54	81	10.2	13.5	15	
200	31	68	39	9	12.8	16	
220	20.5	20.2	25.5	8.2	10.2	15	
240	12.5	16	19	8	11	15.5	
260	11.8	16.5	17	8.8	11.5	14	
280	25	10.5	17.5	10.5	10	13.5	
300	17	25	35	8.5	11	14.5	
320	16.5	25.5	19.5	9	11	12.5	
340	10.5	14.8	18.5	8	9.5	12.5	
360	11.5	14.5	18.5	7.5	10	13.5	
380	11	14.5	18.5	7.5	10	12.5	30-cm galvanized culvert crosses line—2-m depth
400	12	15	18.5	7.5	10	13	
420	11.2	14.5	17.5	9	11	13	
440	11	15	17.5	8.5	11	13	
460	7.5	14	17.5	7.2	9.8	13.5	
480	11.8	16.5	21	7.2	10	12.8	
500	10.8	15.2	18.2	7.5	10.5	12.5	
520	8	14	18.8	7.5	9.8	12.5	
540	14.2	21.5	29	8.2	10.2	12.8	
560	14.8	21.5	18.8	7.5	10	12.5	
580	8.5	14	18.5	7	9.5	13.2	
600	12	14.5	17.5	9.2	11.2	14	
620	12	16.5	16.8	8	11.5	13.8	
640	11.5	15.5	17.8	8.5	11.5	13.8	30-cm galvanized culvert crosses line—2-m depth
660	12.2	15.2	16	10.5	12	13.2	
680	12.2	16	17.5	8.8	11.2	13.5	
700	10.5	15	17.5	8	10	12.5	
720	11.2	14.8	16.2	8.8	10.5	12.5	
740	10	13.5	18.2	7.2	10	12.8	30-cm galvanized culvert crosses line—2-m depth
760	8	12.5	17.2	7	9	12	
780	10	12.8	16.5	8	9.5	12	
800	9.8	13.2	18	7	9.2	12.5	
820	7.5	12.5	18.5	7.5	9.2	12	30-cm galvanized culvert crosses line—2-m depth
840	9.2	14	18.8	7.2	10	12.5	
860	11.5	15.5	18.5	8.8	10.5	13.2	
880	6.8	11.5	16.2	10.5	11	13	
900	11	15	15.5	9.8	11.5	14	
920	10	15	19	8.5	10.8	13.5	
940	10	13.5	18.2	8	10	13.2	30-cm galvanized culvert crosses line—2-m depth
960	10.5	14.5	17.8	8	10.5	13.8	
980	11	16	20	7.5	10	13.5	
1,000	12.5	16.2	21.5	8.2	10	13	30-cm galvanized culvert crosses line—2-m depth
1,020	14	19.2	22.8	7.8	10.2	13	
1,040	13	18.5	23.8	7.5	10	13.2	
1,060	12	16.2	23.2	7.5	13	13	30-cm galvanized culvert crosses line—2-m depth
1,080	11.5	18	24.2	7.5	10.5	13.5	
1,100	12.2	20	27.5	7.5	10.8	14.5	30-cm galvanized culvert crosses line—2-m depth
1,120	13.5	19.5	29.5	8.8	12	15	
1,140	15.8	24	38	9.5	12.5	16.8	30-cm galvanized culvert crosses line—2-m depth
1,160	41	63	64	9.8	14.5	20.8	

	Terrain conductivity (mS/m)						
	Vertical dipole			Horizontal dipole			
Station (m)	10 m	20 m	40 m	10 m	20 m	40 m	Notes
1,180	61	76	65	18.2	21.5	18	30-cm galvanized culvert crosses line—2-m depth
1,200	21	34	56	9	13.5	18.2	
1,220	18.2	30	48	9.2	13	16.8	
1,240	20	26.5	42	10	14	17	30-cm galvanized culvert crosses line—2-m depth
1,260	16.8	22.5	38	10	14	18	
1,280	14	19.5	33	10.2	14	17	
1,300	13.8	20.5	27	10	13.8	17.2	
1,320	14	17	26	12	14	17	
1,340	16	19	22.5	16.2	17.5	17.8	
1,360	16.8	17	21.5	15.8	17.8	16.5	
1,380	11.2	18.5	26.8	10.2	13	16	
1,400	18.5	24	40	12.8	14.8	18.5	30-cm galvanized culvert crosses line—2-m depth
1,420	18	24.8	19.5	12	15	16.5	
1,440	11.5	19.5	27.5	9.8	12.5	15	
1,460	12.5	16	25	13.5	14	17.5	
1,480	12	17.8	27.8	13	14	17.5	
1,500	8.5	16.2	28.5	14	13.8	17	
1,520	10.5	17.5	29	14.2	15	18	
1,540	13.8	20.2	44	14.8	15.5	18.5	30-cm galvanized culvert crosses line—2-m depth
1,560	5.5	14.8	31	10.2	12.5	18	
1,580	12	17.2	28	19	19	18.2	
1,600	13.5	18.5	35	18	17.5	20	
1,620	8	10.8	27	13	14	20	
1,640	14	17	25.5	14	14.8	17.8	
1,660	12.2	17.5	33	13	14.5	16	30-cm galvanized culvert crosses line—2-m depth
1,680	9.8	17	29	11.2	12.8	17	
1,700	13.8	18.2	28.8	11.8	14	17.5	
1,720	12.5	17.5	27	10.5	12.8	17	30-cm galvanized culvert crosses line—2-m depth
1,740	6.2	15	27.5	9	11.5	16	
1,760	12.2	18.8	26	12	13.5	16.2	
1,780	15	20.8	28	11.8	13.2	18	
1,800	11.8	17.5	28	10.8	11.5	17	30-cm galvanized culvert crosses line—2-m depth
1,820	15.8	20.5	27.5	10.2	13	17	
1,840	15	20	28	10.2	12.5	17.5	
1,860	11	17.5	28.5	11.5	12	17.5	30-cm galvanized culvert crosses line—2-m depth
1,880	13	19.2	27	12.2	13	18	
1,900	12	17	27.5	10.2	12.2	17.5	
1,920	9.8	16.5	26.5	10.2	12.5	18	
1,940	12.5	17.5	25.2	12	13.5	18	
1,960	15	19.5	23.5	12.8	15	18	
1,980	11.2	13.5	22	14.2	15.2	19	30-cm galvanized culvert crosses line—2-m depth
2,000	15.5	19.2	22.5	13	15.5	19	
2,020	18	18	22.8	12	14.5	18	Small pile of scrap—galvanized culvert next to line
2,040	16	18	23.2	12	12.8	17.5	30-cm galvanized culvert crosses line—2-m depth
2,060	14.2	18.8	23.5	10.8	13.5	17	
2,080	11	17.5	26	11.2	13	17.5	
2,100	15	16	24	12	11.2	11.8	
2,120	12.8	23.8	24.8	11	13.5	13.2	
2,140	16.2	19.2	23.5	10	12.5	14	
2,160	14	16.2	19.8	10.5	13	14	
2,180	16	15.2	23	9.2	11.5	17.8	
2,200	14.2	18.5	25.2	9.8	11.5	17	
2,220	14	20.5	25.5	10	12	15.5	
2,240	17.2	21	29	10	10.5	15	
2,260	15.8	26.5	48	10.2	11.5	17.5	
2,280	18.5	27.8	39	10.2	12	17	
2,300	12.5	22.2	36	9.2	11.8	17.5	
2,320	13.8	20	38	9.8	12	17	
2,340	13	19.8	27	8.5	12	19.5	
2,360	10	17	24.2	8	11.5	15.5	
2,380	15.5	17.5	26.8	9.5	13	19.5	
2,400	14.8	17.5	23.8	10	13	19	
2,420	10	16	25	8.2	11	15	

Station (m)	Terrain conductivity (mS/m) Vertical dipole 10 m	Vertical dipole 20 m	Vertical dipole 40 m	Horizontal dipole 10 m	Horizontal dipole 20 m	Horizontal dipole 40 m	Notes
2,440	16.2	21.5	27.5	9.2	12	15.2	
2,460	20	26	32	10.8	13.5	17	
2,480	17	24.2	32	10.5	13	16	30-cm galvanized culvert crosses line—2-m depth
2,500	21.2	21	20	13	10	14	
2,520	19.2	21	22	12	13.2	14.2	
2,540	11.5	13.5	20.5	10.5	12.1	14	
2,560	18	16.2	17.5	14.2	14.5	15.5	
2,580	18.5	18	21.2	15	14.5	14.8	
2,600	14	16.5	19.5	12.5	13	14	30-cm galvanized culvert crosses line—3-m depth
2,620	16.5	17.2	20.5	14.5	14.2	13	
2,640	16.5	19.2	21.5	13.2	13	13.5	
2,660	8.5	18.5	27	13	13	13.5	
2,680	19.2	21.8	25.2	18.2	15.5	14.5	
2,700	22.8	26.2	27.2	20.8	17.5	15.5	
2,720	25.5	20	32	18.2	15.2	17	
2,740	23	25.5	37.5	14.5	14.5	16.2	
2,760	24.2	34	43	15	14.5	15	
2,780	27.8	31	48	14.5	13.2	15	
2,800	27	36	58	16.5	15.2	15.2	
2,820	38	49	--	17.5	15.5	--	
2,840	--	12	22.8	14	12.2	14	
2,860	23.5	22.5	27.8	16	15.5	14.5	
2,880	23.2	26	19.2	15.5	15.5	13	30-cm galvanized culvert crosses line—3-m depth
2,900	9.5	16.5	23	12.2	11	11.8	
2,920	19.5	20.2	26	16.5	14	13.2	
2,940	26.2	27.2	10.5	17.5	15.8	12	
2,960	5.9	10	15	16.5	13.2	10.8	
2,980	17.2	23.5	28.8	12	13	12.5	
3,000	19	26.8	10.5	10.8	12	12	
3,020	0.3	10.2	18.5	7.5	9	11.2	
3,040	12.8	16.2	22	11	11.8	12.5	
3,060	12.2	17.2	18.2	10	11.2	12	
3,080	--	11.8	23.5	7	9	13	
3,100	15	21.2	33	11.2	11.2	11.8	
3,120	15	22.5	22	10.8	11.5	13	
3,140	0.9	12	24.2	8.5	10	11.8	
3,160	13.5	18.8	28	11.8	13	13	
3,180	14.5	21.2	24.2	10.2	12.5	14	
3,200	1.4	14.5	25.2	7.8	10.2	12.5	
3,220	14.2	20.8	28.5	10.5	12.8	13	
3,240	17.5	26.2	30	12	13.5	14	
3,260	1.5	17	29	8.5	10.5	13	
3,280	13.8	21.5	23.8	11.5	14	14.2	
3,300	16.2	20.5	24.5	11.2	14.5	16	
3,320	5.3	18.5	25.8	8.8	12	15.5	30-cm galvanized culvert crosses line—3-m depth
3,340	19.8	23	18.5	15.2	15.5	14.8	
3,360	21.8	24.5	30	15.5	16.5	16.8	
3,380	7	20.2	26.8	12.2	13.8	16.5	
3,400	24	29	23	16	17.2	17	
3,420	27.2	24	28	18.5	18	17	
3,440	10.5	17.2	22	14.5	16.2	17.8	
3,460	23.2	27	24	18	18.5	18	
3,480	27.2	24	27.5	18	18.2	18.2	
3,500	38	15.5	23	20.5	17.5	16.8	
3,520	29.5	37	27.8	15.2	16.2	15.2	
3,540	24	28	35	12.5	14.2	14.5	
3,560	18.8	18.8	27.5	14.2	13.5	13	
3,580	17	21.8	27.5	13.5	13	12.2	
3,600	14.5	21.5	33	12.2	12.5	12.2	
3,620	21.2	16.2	28	12.2	12	13.5	
3,640	16	22	26	12.5	13	13	
3,660	19	23.2	33	12	13	13.2	

Station (m)	Terrain conductivity (mS/m) Vertical dipole 10 m	20 m	40 m	Horizontal dipole 10 m	20 m	40 m	Notes
3,680	25	11.2	25.2	14.5	12	13	
3,700	16	22.5	22.5	12.5	13.5	13	
3,720	17.5	19	24.2	12.2	12.8	14.2	
3,740	22	16.2	21	14.5	13	14	
3,760	20.5	17.5	20.5	16.5	15	14.5	
3,780	22.5	20.5	24.8	17.5	15.5	15	
3,800	26.5	21	18.5	17.5	16.2	14	
3,820	21.8	14.5	19	16.2	15.5	15	
3,840	19.5	16.5	22.5	15.2	15	15	
3,860	22.5	32	22	13.8	--	14	30-cm galvanized culvert crosses line—3-m depth
3,880	26.5	13.2	23.2	14.5	12.5	13	
3,900	16.2	21.2	25	12	13.2	15	
3,920	15.2	21.5	20	13	13	12.5	30-cm galvanized culvert crosses line—2-m depth
3,940	22	12	18.5	13	11	13.5	
3,960	13.5	20	23.5	13.8	12.2	12.5	
3,980	22	31	18.5	16	14.2	15	
4,000	24	9.8	17.5	14.5	11	11	
4,020	17.5	18	22.5	14.5	12.5	11.5	
4,040	23	22.5	15.5	16.5	13	16	30-cm galvanized culvert crosses line—2-m depth
4,060	22.5	10.5	17.5	14	11	11	
4,080	21	23.5	27.5	15.5	12	11	
4,100	20.5	30	27.5	12.5	11	11	
4,120	2.9	18	28	8.5	8	9	
4,140	18.5	26.2	23.5	14	14.5	12	
4,160	15	20.2	33	13	11.5	12	
4,180	2.6	11.8	19.5	9.8	9.5	11	30-cm galvanized culvert crosses line—3-m depth
4,200	16.5	19	17.5	15.2	13.5	17.5	
4,220	16.8	20	28	14.2	13.5	13.5	
4,240	16	14.5	27	14	12.2	12	
4,260	20.5	27	29	14	13.2	12.5	
4,280	22.2	32	49	14	12.5	12	
4,300	37	17.5	40	12	10	10.5	30-cm galvanized culvert crosses line—3-m depth
4,320	22	34	37	11.5	12	10.2	
4,340	17	25.2	42	9.5	10.8	11.5	
4,360	28.5	7.5	28.5	13	10.5	10.5	
4,380	19	25	28	10.8	12.5	11	
4,400	18.5	23	37	12	11	11	
4,420	23.5	11	28.8	11.8	11	10.5	30-cm galvanized culvert crosses line—3-m depth
4,440	20.5	26	27	10.5	11.2	10.5	
4,460	12.5	19	38	12.5	10.8	10.8	
4,480	24	12	29	10.5	9	10.2	30-cm galvanized culvert crosses line—3-m depth
4,500	20	28.5	25.5	11.2	11.5	10	
4,520	17.8	22	30	12	10.8	11.5	
4,540	12.2	10	21.5	19	11	10.5	
4,560	15.5	22	19	14.5	12	11	

Table 9. Terrain-conductivity measurements for the MNS1 survey section

[m, meters; mS/m, millisiemens per meter; cm, centimeter; --, missing value]

Station (m)	Terrain conductivity (mS/m)						Notes
	Vertical dipole			Horizontal dipole			
	10 m	20 m	40 m	10 m	20 m	40 m	
20	26.2	23	14.5	14.5	15	14	
40	23.2	17.8	21.5	13.5	13.5	13.5	
60	15.2	12	11.5	20.5	11.5	13	
80	24	25.8	17.5	14.5	13.5	11.5	
100	20.2	20.5	24	13	13	12	
120	22.5	11	21	12	10.8	12.2	
140	17.5	19	18.5	12	11.5	11.8	
160	16.2	16.5	20.2	11.2	11.5	12.5	
180	23	8	16	12.5	11	11.5	30-cm galvanized culvert crosses line—3-m depth
200	20.2	24.5	16.5	12.5	11.8	12.5	
220	18	18.8	23	11.2	11	12.2	
240	25.5	10.5	17	13.5	11.5	12	
260	27	25.5	12.5	17	13.5	12.5	
280	17.8	19	22.5	13	11.5	11.5	
300	19.5	15.8	18	13.5	11	11.2	30-cm galvanized culvert crosses line—3-m depth
320	19.5	17	17	13	11.2	10.5	
340	18.5	20	20.5	13.5	12.5	11.5	
360	20.2	20.8	13	16.5	14.5	11	
380	22.5	11.5	14.8	14.5	11.8	11	
400	14.2	18	20.5	14.5	12	11	
420	20.8	23	13	12.2	12.2	10	
440	24	8	13.5	14	10.2	9.5	
460	17.2	16	16.5	13	12	11	
480	16	18	15	12.5	12	10.5	30-cm galvanized culvert crosses line—3-m depth
500	16.5	9	23.5	13.2	10.5	7.5	
520	16.5	15.8	24.5	14	11.8	12	
540	18.5	18.5	21	14	12.5	11.5	
560	13.5	13	22.5	13.5	12	12	
580	19	19.5	27	13.2	12.5	12	
600	22.2	22.5	21	14.5	13.5	11.5	
620	13	12	22	15	12	11	
640	23.8	20.5	26.5	16	13.5	12	
660	17	21.2	19	12.2	11.8	10	
680	6.5	9.5	22	9.5	9	9.2	
700	17	21.5	32	10.2	9.8	9.2	
720	20	28	16	11	11.5	9	
740	5.2	9.5	18	9	7.8	8	
760	14.8	17.2	22.5	10	10	9.5	
780	15.5	17.5	14.5	11.5	11.2	9.5	
800	8.5	5	12	13.8	10.8	10.2	
820	23.2	20	20	15.5	14.5	13	
840	21.8	19.5	12.5	17.2	16.5	14	
860	13.5	12.5	13.5	17.5	16.8	15	30-cm galvanized culvert crosses line—3-m depth
880	24	18.2	16	19	18	15.5	
900	35	28	10	29	22.5	16.2	
920	11.2	8.8	15.5	22.2	21.5	18	30-cm galvanized culvert crosses line—3-m depth
940	35	39	62	18.8	19	19.8	
960	60	73	18	19	23	23	
980	--	14.5	35	22.5	21	11.5	
1,000	31	29	39	20.5	18	18	
1,020	37	41	42	22.5	22.5	23	
1,040	50	87	84	27	35	39	
1,060	83	130	157	37	46	40	
1,080	78	135	--	28	26.5	33	
1,100	--	--	12	20.5	19	19	
1,120	22.2	18.2	14.5	21.5	17.8	15	
1,140	15.2	14.5	15	24	18.5	13.5	

Station (m)	Terrain conductivity (mS/m) Vertical dipole 10 m	20 m	40 m	Horizontal dipole 10 m	20 m	40 m	Notes
1,160	17.2	16.5	23	17.5	15.5	11.5	
1,180	42	19	15.8	16.5	13.8	11.8	Foot bridge
1,200	17.5	16.2	33	17.5	14.2	12.5	
1,220	20	14.5	13	19	16.8	15.8	
1,240	18.8	14	15	17.5	16.8	17	
1,260	17.8	13	14.8	19.2	17.8	17.2	
1,280	18.5	11	14	21.8	18.8	17.2	
1,300	13.2	15.5	20	15.8	14.2	13	
1,320	15.5	20	23	14	12.5	11.8	
1,340	15.8	19.8	25.8	12	12	12	
1,360	15.2	18	25.5	16.5	13.8	12	
1,380	13.2	17	26	24.8	18.2	12.5	
1,400	16.5	17	27.2	21.8	17.8	14.5	
1,420	8.5	18.5	32	27.5	20.5	14.2	
1,440	10.5	18	37	23	19.2	15	
1,460	15	22.5	43	18.2	17	14.5	
1,480	16.5	21.8	44	17	16.2	14	
1,500	12.2	21	44	16	15.8	14	
1,520	15.2	24	46	15.8	16	15.2	
1,540	14.5	20	43	18.5	16	14.8	
1,560	14.2	22.5	41	18	15.5	15	
1,580	16	22	40	18.8	16	15	
1,600	15.5	18.5	39	21	17	16	
1,620	13	19.5	36	19.2	17.5	17.2	
1,640	13	19.2	35	22	19	16.5	
1,660	12	19.2	36	21	18.8	15	
1,680	10.5	21.8	37	21	18	14	Bridge 40 m south

Table 10. Terrain-conductivity measurements for the MNS5 survey section

[m, meters; mS/m, millisiemens per meter]

Station (m)	Terrain conductivity (mS/m) Vertical dipole 10 m	20 m	40 m	Horizontal dipole 10 m	20 m	40 m	Notes
20	19.2	21.5	28	20.2	17	12	Bridge 40 m north
40	22.2	20	25.5	13.5	12.2	11	
60	19.5	17	23.5	13	12.8	14.2	
80	17.5	17.5	23.5	22	20.5	17.5	Power lines 50 m south

Table 11. Terrain-conductivity measurements for the MNS6 survey section

[m, meters; mS/m, millisiemens per meter; --, missing value]

	Terrain conductivity (mS/m)						
	Vertical dipole			Horizontal dipole			
Station (m)	10 m	20 m	40 m	10 m	20 m	40 m	Notes
20	13	19.2	13	12.2	13.2	--	Power lines 70 m north
40	17	15.5	19.5	21.2	18	17	
60	17.5	10.2	16.8	26	23	21	
80	17.2	11	14.8	32	26.8	21	
100	20	12	14.2	30	26.5	22	
120	21	12.5	15	30	23.2	19	
140	29	14.8	15	29	20.8	17.5	
160	25	15	15	27	19.5	16	
180	24.8	15	17	22.8	17	14.5	
200	18	17	17.2	19	14.5	13.2	
220	17.2	15.5	17.5	15.5	12.5	12.5	
240	19	13.5	15.5	18	13.8	12	
260	29.2	29	20	15.5	12.5	12	
280	40	42	19.5	13.5	11	12	
300	18.2	18.8	26	12.5	11.2	12.2	
320	105	29.2	45	18.5	20.5	40	
340	--	--	--	202	240	98	
360	--	--	--	190	212	60	
380	42	39	58	13.5	19	34	
400	26.2	24	22	13.8	9.5	9	
420	23.5	26.5	25.5	16.8	13	8.5	
440	19	16	17.5	14	10.5	9.5	
460	14	11.5	12.8	14.5	11.2	9	
480	12	13.2	11.5	14.8	11.8	11.5	
500	12.5	11.8	11.5	14	11.5	11	
520	14.8	12.2	11.5	13.8	11	11.5	
540	16.2	13.5	14	13.5	10.5	10	
560	15.5	12.5	13	12.5	12	10.5	
580	15.2	14	13.8	13.2	13	10.5	
600	13.5	14.8	17.8	13.2	11.8	10	
620	16.2	18.5	25.2	15.8	14.5	12	
640	24	35	--	15.5	15	--	Campbell Street bridge 20 m south

Table 12. Terrain-conductivity measurements for the CAMS survey section

[m, meters; mS/m, millisiemens per meter; --, missing value]

Station (m)	Terrain conductivity (mS/m)						Notes
	Vertical dipole			Horizontal dipole			
	10 m	20 m	40 m	10 m	20 m	40 m	
20	12.2	12.5	14.8	11	10.8	13	Campbell Street bridge 10 m north
40	14.8	14	15.2	10.5	11	11.2	
60	13.2	14	16.2	12.2	11.2	11	
80	15	14.2	15.5	11.2	11	10.2	
100	11.5	13	16	11	11.2	12	
120	12.8	14	14	11.2	11.5	12	
140	12	12.8	14.2	11	10.5	11.2	
160	12	12.5	14.8	10	10.5	11.2	
180	11	12.2	14.2	0.8	11	11.5	
200	12	12.5	15	12	11.2	11.5	
220	11.8	13.2	14.5	11.8	11	13	
240	13.2	13	15.5	12.2	12.5	15.5	
260	18	9.8	14.5	33	28.2	15.5	
280	17.2	15	13.5	21.2	21	15.5	
300	14.5	14.2	13.8	11	12.2	13.5	
320	15	14.2	14.2	12	11.8	12.2	
340	13.8	14.5	15	12	11.5	12.2	
360	14.8	14.8	14	11.5	11	11.5	
380	14.2	14.5	15.5	11	11	11.5	
400	14.2	14	15	10.8	11	11.5	
420	13.5	15	16.5	12	11.2	11.8	
440	16	14.2	14.5	11.2	11.5	12.5	
460	16	15.2	15	11.2	11.5	12	
480	16	16	15	11.2	12	11.8	
500	16	15	12.5	14.5	12.8	11.5	
520	19	15	16	11.2	12	12	
540	18.5	16.2	15	11.2	11.2	11.5	
560	23.2	17	15.5	12.2	10.5	11	
580	25.5	18	14.5	12.5	10.8	12	Power lines 250 m south
600	26	19	16	11	10.8	11.5	
620	20	16.8	15	12.8	10.2	11	
640	19.5	18.2	15	14.5	11	12	
660	15.8	15.5	17	15.2	11	11.5	
680	15	17.2	13	14.8	12.2	13	
700	12.5	14	14	20	14.5	12	
720	18	15.2	--	16	11.5	11.5	

Table 13. Terrain-conductivity measurements for the I40S survey section

[m, meters; mS/m, millisiemens per meter; --, missing value]

Station (m)	Terrain conductivity (mS/m)						Notes
	Vertical dipole			Horizontal dipole			
	10 m	20 m	40 m	10 m	20 m	40 m	
20	17.2	15.5	--	13.5	12	13.5	Power lines 120 m north
40	16.5	15	--	13	14	14	
60	15.2	12.8	15	16.2	15.2	13	
80	13.8	16.5	15	15.2	15.5	16.5	
100	14.2	14	13	17.5	16.5	16	
120	17.5	9.2	13	12.5	13.2	14	Foot bridge
140	17	17	11.5	11.2	12.5	14	
160	15	14.5	14	11.5	12.5	14	
180	14.2	15	12.5	11	12.2	13	
200	13.8	15	13	11.5	12	12	
220	14	15	16	11.2	11.8	13	
240	14	14	14.5	11.5	12	12	
260	13.2	13	14.5	13	11.8	12	
280	12	14	15.5	10.2	11	11.2	
300	12.5	13.5	15	11	10	11	
320	12.2	11.8	14.5	11.2	10.5	10.5	
340	14	14	15.5	10.5	10.5	11.5	
360	13.8	13.2	13.2	11	10.2	11.5	
380	13	13.5	14.2	12	11	12.5	
400	14.2	14.8	15.8	11.2	11.5	13	
420	14.8	14.5	15	11.5	12.2	13	Flood fence begins 15 m east of and parallel to survey line
440	19.5	16	12.5	10.8	11.5	12.2	
460	15.5	17	18.5	10.5	10.8	14	
480	15	16.2	19	12	11.5	14	
500	14	16.5	18	13	13	14	
520	8.8	16.8	17.5	16.5	14	14	
540	16	15.8	18	13.8	14	14.5	Flood fence ends 15 m east of and parallel to survey line
560	16	17.2	20.8	13	13	15	
580	16.5	16.8	20.5	13	13.5	15	
600	18	17	17.8	15.2	14.2	15.5	
620	18.2	16	18	15	14.8	14.8	
640	16.8	16.8	21.8	14	13.8	16	
660	18.5	16	20	13.5	13.5	15.8	
680	18.5	17.2	20	14	13.5	16	
700	13.5	13.5	19.8	17	14.5	15	
720	16	13.8	18.5	15.2	14.5	14.5	
740	11.2	12.5	20.2	13	13.5	14.2	
760	10.2	13	20.8	11.8	12.5	14.8	
780	12.8	14	18.5	9.2	11.5	14.2	
800	8	10.5	18	10.5	11	12.8	
820	11.5	13.2	18.8	8	9.8	12.2	
840	11.8	13.8	18.5	7	9	11.8	
860	10	12.2	18	7	8.5	10.8	
880	9.2	12	16.5	6	8.2	10.5	

Table 14. Terrain-conductivity measurements for the CENN survey section

[m, meters; mS/m, millisiemens per meter; cm, centimeter]

Station (m)	Terrain conductivity (mS/m)						Notes
	Vertical dipole			Horizontal dipole			
	10 m	20 m	40 m	10 m	20 m	40 m	
20	8.2	12.5	19.8	8.2	9	11.2	Begin power line 30 m to east
40	9.6	12.2	19.5	9.1	9.8	12	
60	10	12	20	7.5	6.8	12.5	
80	9	11.8	21.2	7	9.2	12	
100	9	10.8	21.2	7.8	9.5	11.8	
120	11.2	12.8	20.5	6.8	9	11.2	
140	10.5	12	20.8	9.2	9.2	11.8	
160	10.2	11.2	19.5	9.2	10	12	
180	10	11.8	19.2	8	9.8	11	
200	10.2	12.2	19.2	7.5	8.8	11.5	
220	10.5	11	18.8	9	9.2	11	30-cm galvanized culvert crosses line—2-m depth
240	10.2	12	18.8	10.5	9	10.2	
260	10.8	11.8	18.8	8	9.5	10.5	
280	11	12	20	9.5	9.8	10.5	30-cm galvanized culvert crosses line—2-m depth
300	11	14	21.2	9.5	10	12	
320	12.8	15.2	22.2	9.8	10.5	11.5	
340	12.2	15.8	26.2	10	11.5	14.2	
360	12.8	7.5	23.5	19.5	17	15	
380	14.5	25	21.8	17.2	16.8	17	
400	12.5	16.5	28.2	13.5	15.2	17	
420	15.8	16.8	29.2	14.2	14	16.2	
440	15	19.5	35	11.8	12.8	15.2	
460	12.8	18.5	39	11.5	12.5	15.2	
480	15.5	20.5	44	11.2	12.8	14.5	
500	14	20.8	46	12.2	12	14.2	
520	15	23.2	48	10.5	13	15.8	30-cm galvanized culvert crosses line—3-m depth
540	15.5	23	52	13	13.5	16.2	
560	18.5	25.8	55	13	14.8	17.5	
580	14.8	25.5	55	12	15.5	17.5	
600	18.8	25.5	56	18	15	17.5	
620	16.2	26.2	56	12	14.5	17.5	
640	15.8	25.2	54	13.2	14.5	17.2	Central Avenue bridge 60 m south

Table 15. Terrain-conductivity measurements for the CENS survey section

[m, meters; mS/m, millisiemens per meter; cm, centimeter]

	Terrain conductivity (mS/m)						
	Vertical dipole			Horizontal dipole			
Station (m)	10 m	20 m	40 m	10 m	20 m	40 m	Notes
20	9.8	16.8	29	10.8	14.2	17.5	Survey shifts to west side of Rio Grande
40	9.5	16	30	14.8	15.2	17	
60	9.5	13	27	15.5	16	16.5	
80	7.2	13	24.5	14.2	15.5	17.5	
100	10	15.2	25	16.5	16.5	17	
120	8.8	18	20	15	17.8	18.5	
140	4.6	13	21	18.5	19.2	18	
160	15.2	17.5	21.5	13.5	17.5	16.5	
180	11.8	15.5	24.5	14	15.8	16	
200	7	12.5	23.5	18	16	15.5	
220	8	12	24.5	15.5	15.2	16	
240	13	15.2	23	13	14.5	14.2	
260	14.5	20	24	14.5	13.8	13.5	
280	15.5	19.5	18.2	15	14	12.5	Two 1-m culverts 15 m west of survey line
300	6.5	18.5	26.2	9.5	10.5	13.8	Do.
320	6	14	25.5	20	16.5	10.5	Do.
340	10.5	18.5	28	14.2	15.8	15	
360	12.8	18	35	11.5	13.5	15.5	
380	11	19.5	35	10.5	13.2	15	
400	7	18.5	35	12	13	15.5	30-cm galvanized culvert crosses line—3-m depth
420	16.5	17.8	37	11.8	13.5	15	Chain link fence begins 20 m west of and parallel to line
440	14.8	20.5	35	10.5	12	15.5	
460	12.8	16.8	37	11.5	13	15.5	
480	11.2	18.8	35	12.5	13	15.8	
500	10.8	19.8	38	10.2	12.8	16	
520	10.5	20.2	34	11.8	14	17.5	
540	13.8	21.8	34	13.2	15.8	17	
560	16	19.8	34	12.5	15.5	18.2	
580	11.2	20	33	15	15.5	18	
600	15.8	23.5	32	12	15	19.8	
620	19	25.8	30	15.2	17	21	
640	24.8	20	22	17.8	20.2	23	Chain link fence ends 20 m west of and parallel to line
660	24.2	15.2	15.2	18.8	21.5	23	Barbed wire fence begins 20 m west of and parallel to line
680	12.8	19.8	22	14.5	17.2	21.5	
700	15	17.5	24.5	12	14.8	19	Barbed wire fence ends 20 m west of and parallel to line
720	12.8	18.2	22.2	10.5	13.8	17.5	Sheet metal fence begins 20 m west of and parallel to line
740	15	17.2	22.2	9.8	13.2	16.5	
760	14.5	16.5	23	10	13	16.5	
780	14	16	20.5	11	13.5	16.5	
800	13	15	21.2	12	13.2	15	
820	12	16	20	9.5	12.5	15.2	
840	12.5	15	19.5	10.5	11.8	13.8	Sheet metal fence ends 20 m west of and parallel to line
860	12.5	15	18	10.5	11.8	13.5	Barbed wire fence begins 20 m west of and parallel to line
880	12.5	14.2	20.2	11.2	12	13	
900	13.2	14	17.2	11.8	11.8	13.2	
920	13.5	15.5	18.5	10.8	11.2	13	
940	12	15.5	18.5	11.5	11.2	13.5	
960	15	12.8	18.5	11.5	13	14.5	
980	13	15	19	13	13.5	14	Barbed wire fence ends 20 m west of and parallel to line
1,000	14.2	17.2	17.2	10.2	12.5	15	
1,020	14	11.8	20.2	12.2	12.2	14.2	
1,040	11.2	16.2	22.5	10	11	14	
1,060	12.5	17.2	21	9	12	14	

	Terrain conductivity (mS/m)						
	Vertical dipole			Horizontal dipole			
Station (m)	10 m	20 m	40 m	10 m	20 m	40 m	Notes
1,080	14	16.8	19.5	12	13.2	14.5	
1,100	15.2	18.8	17	11.5	14	17	
1,120	16	19.8	23.8	11.5	15	18.5	
1,140	17.5	21.2	22.5	12.5	15.5	18.5	
1,160	15.5	20.8	21	12.5	15	18.2	
1,180	14.8	19.5	24.8	13	15.2	18.5	
1,200	15	19.5	21	12	15	18	
1,220	14.5	19.8	20.5	11	14	17	
1,240	15	19	22	10.8	12	17.5	
1,260	13.5	16.8	23.8	12.5	13	17	
1,280	13	18.5	19.5	12	14	17.5	
1,300	13.2	18.5	22	10.5	14.5	19	
1,320	17	21.2	21.2	10	14.5	20	
1,340	14	19.5	23.5	10	15.2	20.5	
1,360	12.2	22.8	27	20.2	15.2	21.5	
1,380	14.2	22.2	26.5	11.8	16	21.5	
1,400	13.2	24	26.5	12	17	25	
1,420	4	19.8	30	21	20.2	24.8	
1,440	15	24.5	28	14.8	18.5	26.5	
1,460	11.8	21.5	28.5	17.2	20	22.5	Power line begins 20 m west of and parallel to line
1,480	14	20.5	29	22.8	26	25	
1,500	12	22.2	27.2	21.5	23.2	27	
1,520	7.5	18	24	34	27.5	27	
1,540	14.5	19.5	21	39	32	29	Power line ends 30 m west of and parallel to line
1,560	9.8	18	26	40	35	28	Sheet metal fence begins 25 m west of and parallel to line
1,580	9.5	16.8	24	35	34	27	
1,600	10	16.5	25.5	28	28.5	27.5	Sheet metal fence ends 25 m west of and parallel to line
1,620	10.2	16.5	29	25.2	28	22	Mobile home park begins 25 m west of and parallel to line
1,640	32	22	24	14.2	17.8	21	
1,660	20.5	27	29	13	16.5	21	
1,680	17.8	23.8	29	13.8	18	23	
1,700	15.8	23	29.5	17	20.5	24.5	
1,720	7.5	20.8	35	21	23.2	25	
1,740	16.8	18	32	23.5	21.5	24.5	
1,760	7.5	17.5	31	20.8	20	24.5	Sheet metal fence begins 20 m west of and parallel to line
1,780	6.8	17	32	19.8	20.8	24	Sheet metal fence ends 20 m west of and parallel to line
1,800	12.5	21	32	18.5	20	25	Chain link fence begins 20 m west of and parallel to line
1,820	10	17	31	20.5	19.5	24	
1,840	0	13	27	27	23	22.8	Pile of scrap sheet metal west of line
1,860	14.5	17.5	25.5	19	21.2	21.5	Mobile home park ends 25 m west of and parallel to line; chain link fence ends 20 m west of and parallel to line
1,880	12.8	17	23	16.8	17.5	19	Houses begin 30 m west of and parallel to line
1,900	13	19	25	20.8	16.2	16.5	
1,920	9	16.8	23	24.2	17.2	20.5	
1,940	3.2	13.8	27.8	24.5	22.5	20	
1,960	13	16.8	29	29.8	27	19	
1,980	12	18.8	32	34	24	17	Power line begins 25 m west of and parallel to line
2,000	7	18.2	33	18	18	20	Power line ends 20 m west of and parallel to line

Table 16. Terrain-conductivity measurements for the RBRN survey section

[m, meters; mS/m, millisiemens per meter; cm, centimeter]

	Terrain conductivity (mS/m)						
	Vertical dipole			Horizontal dipole			
Station (m)	10 m	20 m	40 m	10 m	20 m	40 m	Notes
20	16.2	18	25	12	13	11	Survey shifts to east side of Rio Grande
40	18	18	25	12.2	12.2	11	
60	16.8	18.2	29	10.5	11.8	12	
80	14.8	17.5	30	10	11	13	
100	14.5	16.5	33	10	10.5	12	
120	12.5	16	32	10	11	12	
140	16	17	31	10.5	11.2	13	
160	15	17.2	31	11.8	11.5	13	
180	17.5	16	32	10.8	12.8	13	
200	15.8	17.5	30	11.8	13	15	
220	15.2	17.5	30	11.2	12	13	
240	15.5	15.8	32	11.2	12.2	12	
260	17	16.5	34	11.2	13	13	
280	18	19.2	32	11.5	13	14	
300	16	19	32	13	13.5	14	
320	16.2	18.5	33	12.2	13	13	30-cm galvanized culvert crosses line—2-m depth
340	17.5	19	34	11.5	13	13	
360	16.5	20.5	32	11.5	13	14	
380	17	17.2	33	10.5	12	13	30-cm galvanized culvert crosses line—2-m depth
400	15.2	20	36	10.2	11	13.5	
420	15	18	32	12	12.2	14	
440	17	17.8	33	12	12.2	14	30-cm galvanized culvert crosses line—2-m depth
460	14	19	34	9.5	11.5	13	
480	12.5	18.5	36	9	11	13.5	
500	10.5	18.8	36	9.2	11.5	13	
520	14	19	36	10.5	12	15	
540	14.5	20	35	10.5	13	16.2	
560	16	20.8	32	12	14.5	16.8	30-cm galvanized culvert crosses line—2-m depth
580	16.8	21.2	35	12	15	18	
600	17	22	36	12.2	15.2	19.2	
620	16.5	22.2	37	12.5	15.8	19.5	
640	17	23.5	36	12	16.2	20.5	
660	19.8	25	37	12.5	17	21.2	
680	19	26	38	12.5	18	22	30-cm galvanized culvert crosses line—2-m depth
700	19	25	35	13.5	18.5	23.5	
720	20	26	34	13.8	18.8	23	
740	18	25	39	12.8	17.8	23	30-cm galvanized culvert crosses line—2-m depth
760	17.5	26.5	37	12	17	23	
780	16.5	24.8	38	12.8	17.8	23	
800	17	25.5	39	12	17.5	22.5	
820	16.5	24.5	38	12.5	16.8	22.5	
840	18	25.5	42	12	16.5	22	
860	18	24.2	40	12	16.5	21.5	30-cm galvanized culvert crosses line—2-m depth
880	18.5	24.5	38	12.5	16.8	20.5	
900	19	23.5	35	12.5	16.5	19.8	
920	15.5	22.5	37	13	15.5	20	
940	15.8	21.5	38	12.2	14.5	18.5	30-cm galvanized culvert crosses line—2-m depth
960	13.5	19.5	37	13.5	14.5	18	
980	12.5	20	38	11	13.8	17.5	
1,000	12.5	19	39	10	12.8	18	
1,020	12.5	17.5	37	11.2	13.5	18	
1,040	12	18.5	37	10.2	13	17.5	
1,060	12.5	18	38	10	12.5	17.2	
1,080	13	21	39	9.5	12.8	18	
1,100	12.5	19	39	10	12.5	18	30-cm galvanized culvert crosses line—2-m depth
1,120	12	20	39	10.8	14	19	
1,140	13.5	20	38	12.2	14.8	20	
1,160	12.5	21	41	10.8	13.5	19.5	

Station (m)	Terrain conductivity (mS/m)						Notes
	Vertical dipole			Horizontal dipole			
	10 m	20 m	40 m	10 m	20 m	40 m	
1,180	14	21.5	41	10	13.5	21	
1,200	13	21	40	10.8	14	20.5	
1,220	11.8	20.8	40	11.2	15.2	21.5	
1,240	12.2	22.5	41	11.5	15.2	22.2	
1,260	13.8	23	42	11	15.5	23.5	
1,280	15.5	22	43	12	16.5	23	
1,300	16.2	24.2	44	12	17	24	
1,320	15.5	25.5	46	12.5	17	23.8	
1,340	13.8	25.2	46	11.5	16.5	24	
1,360	14	25	47	11.5	17	24	
1,380	15	26	50	11.8	17	25	
1,400	14.5	26.5	50	11	18	26.2	
1,420	16	27.8	49	13.5	20	27.2	
1,440	18.5	29.5	51	12.5	20	30	
1,460	14	29	53	11.2	20	31	
1,480	15.5	30	54	11.8	20	31	
1,500	16	30	53	13	21.5	32	
1,520	19.5	32	48	14.2	23	33	
1,540	17	28	49	18.5	25	32	
1,560	17.8	32	51	12.2	21.5	33	
1,580	18.5	31	47	12.8	21.5	31	
1,600	19.8	26	41	14.2	21.5	28.5	
1,620	20.2	27	45	15	20	26	
1,640	16.8	25.8	48	15	19	26	
1,660	19.5	24.5	42	16	19	25	
1,680	19	25	41	14.2	18	24	
1,700	17	24.5	39	12	17	22.5	
1,720	16.5	24.5	38	11.5	16	22	
1,740	15.5	21.2	38	11	15	22	
1,760	13.8	21.5	38	11	15	20	
1,780	13.8	21	36	10.2	14.5	21.5	
1,800	14	21.8	34	10	19.5	20	
1,820	14	20	30	10.2	14.5	20.5	
1,840	15.2	19.2	27.5	10.5	14	20.5	
1,860	13.2	18.5	27.5	10	13.5	20.5	
1,880	13	18.2	30	10	13	19	
1,900	12.5	18.2	29.2	9.8	12.5	19	
1,920	14	19	28.5	9.2	12.8	18.5	
1,940	11.5	17	27	9.5	13.5	20	
1,960	13	19	29	10.5	13.5	21	
1,980	13	19	29.5	11	14.5	21.5	
2,000	13	20	28.5	10	14	21.2	
2,020	13.5	21	31	10.5	13.5	20.5	
2,040	15.5	23.5	33	10.5	14.5	22	
2,060	14.2	22	30	11.5	15	22	
2,080	14	22.2	34	12.5	15	21	Power lines 100 m south

Table 17. Lithologic log for the Bosque South well

[Linda Logan, New Mexico Office of the State Engineer, written commun., 1998.
m, meters; ft, feet; <, less than; %, percent]

Bosque South — Installation date: 01/18/1997

Logged by: J.W. Hawley
Location: Approximately 300 ft east of Rio Grande and 500 ft south of I-40 bridge
Drilling method: Hollow-stem auger

Depth		Lithologic description
m	ft	
0-0.3	0-1	Disturbed surface material.
0.3-3.0	1-10	Very fine to medium sand, clean. Dark brown to brown. Moderately graded, angular to rounded. Quartzose-feldspathic, with common dark lithics.
3.0-5.6	10-18.5	Medium to very coarse sand, with <15% pebble gravel. Brown. Poorly to moderately graded, subangular to well-rounded pebble gravel. Brown. Poorly to moderately graded, subangular to well-rounded pebble gravel. General sand mineralogy as above to bottom of hole; gravel: mixed silicic to intermediate metamorphic, plutonic, and volcanic lithics and minerals, with chert, basalt, siliceous sandstone, and siltstone. Driller: water table about 10 ft.
5.6-11.7	18.5-38.5	Gravelly, medium to very coarse sand, with <35% pebble to small cobble gravel. Sand color and grading, roundness, and composition of gravel as above (10 to 18.5 ft) to at least 63 ft.
11.7-15.4	38.5-50.5	Medium to very coarse sand, with <15% pebble gravel. Driller: drills like 10- to 18.5-ft interval.
15.4-19.2	50.5-63	Very gravelly sand, with 30-50% pebbles to small cobbles (see 10-38.5 ft). Driller: drills like 18.5- to 38.5-ft interval, with increase in coarse gravel (very coarse pebbles to fine cobbles?). Probable contact of upper Quaternary valley fill with Santa Fe Group at 63 ft.
19.2-19.5	63-64	Silty clay. Remarks: Presence of silt/clay layers between 63 and 92.5 ft based on interpretation of borehole geophysical and driller's logs. Probable upper Santa Fe Group.
19.5-22.4	64-73.5	Gravelly sand, with <25% pebbles to small cobbles (driller interpretation). Remarks: geophysical log indicates presence of thin silt/clay bed between 69 and 70 ft. Possible base of valley fill at 73.5 ft.
22.4-24.8	73.5-81.5	Silty clay with sandy interbeds. Driller: harder, denser zones noted at 73.5-74.5 ft and 81.5-91 ft. Remarks: presence of silt/clay layers based on interpretation of borehole geophysical and driller's logs. Definitely in upper Santa Fe Group below 73.5 ft.
24.8-28.3	81.5-93	Sand, with silty clay interbeds. Driller: harder, denser layer noted at 85.5-86 ft. Remarks: presence of silty clay bed(s) based on interpretation of borehole geophysical and driller's logs.
28.3-30.0	93-98.5	Sand with sandstone(?) layer from 93 to 94.5 ft. Remarks: geophysical logs (to 94.6 ft) combined with driller's observations suggest cemented sand zone (rather than silty clay) above 94.5 ft.
	Remarks:	Correlation with the nearby New Mexico State Highway and Transportation Department geotechnical test holes that extend below 60 ft suggests that the best pick of the valley-fill/basin-fill (upper Santa Fe Group) contact is 63 ft.

Table 18. Lithologic log for the Rio Bravo 5 well

[C.R. Thorn, U.S. Geological Survey, written commun., 1998. Log was compiled by the authors from field notes. m, meters; ft, feet; --, missing interval; %, percent]

Rio Bravo 5 Installation date: 09/23/1992

Logged by: C.R. Thorn and F.E. Gebhardt
Location: Left bank of Rio Grande, upstream from Rio Bravo bridge
Drilling method: Mud rotary

Depth		Lithologic description
m	ft	
0-6.1	0-20	Very fine sand.
6.1-7.6	20-25	Poorly sorted rounded pebbles.
7.6-10.7	25-35	Moderately sorted rounded pebbles.
10.7-12.2	35-40	Rounded pebbles with broken cobbles.
12.2-15.2	40-50	Rounded coarse sand and broken cobbles. Lithology quartz and igneous rocks.
15.2-16.8	50-55	--
16.8-18.3	55-60	Subrounded pebbles and broken cobbles.
18.3-21.3	60-70	Well-rounded pebbles. Lithology quartz and igneous rocks.
21.3-24.4	70-80	Rounded pebbles with broken cobbles and some tan-brown clay.
24.4-25.9	80-85	Coarse sand and rounded pebbles.
25.9-27.4	85-90	Mostly coarse sand with a few broken cobbles.
27.4-35.0	90-115	As above with some tan to brown clay.
35.0-36.6	115-120	Mostly tan clay, few rounded pebbles.
36.6-38.1	120-125	Mostly clay and broken cobbles with coarse sand.
38.1-39.6	125-130	Pebbles, coarse sand, and clay.
39.6-41.1	130-135	Mostly tan clay, some coarse sand.
41.1-42.7	135-140	Coarse sand, rock fragments, and clay.
42.7-44.2	140-145	Coarse sand and rock fragments.
44.2-45.7	145-150	50% coarse sand-sized rock fragments and clay.
45.7-47.2	150-155	Fine to coarse sand, medium pebbles, and smaller gravel, 5-10% sample is light-brown silt.
47.2-48.8	155-160	Fine to coarse sand, fine pebbles, and smaller gravel, 30% sample is light-brown silt.
48.8-50.3	160-165	70% light-brown silt and clay. Sand and gravel decreased in size and quantity.
50.3-51.8	165-170	90% clay and silt, remainder fine to coarse sand with few small gravel clasts.
51.8-56.4	170-185	Same as above with gravel clasts to medium pebble size.
56.4-61.0	185-200	30-40% coarse sand and small gravel, increasing amount of light-brown silt, decreasing amount of clay.
61.0-183	200-600	Log continues to 600 ft.

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