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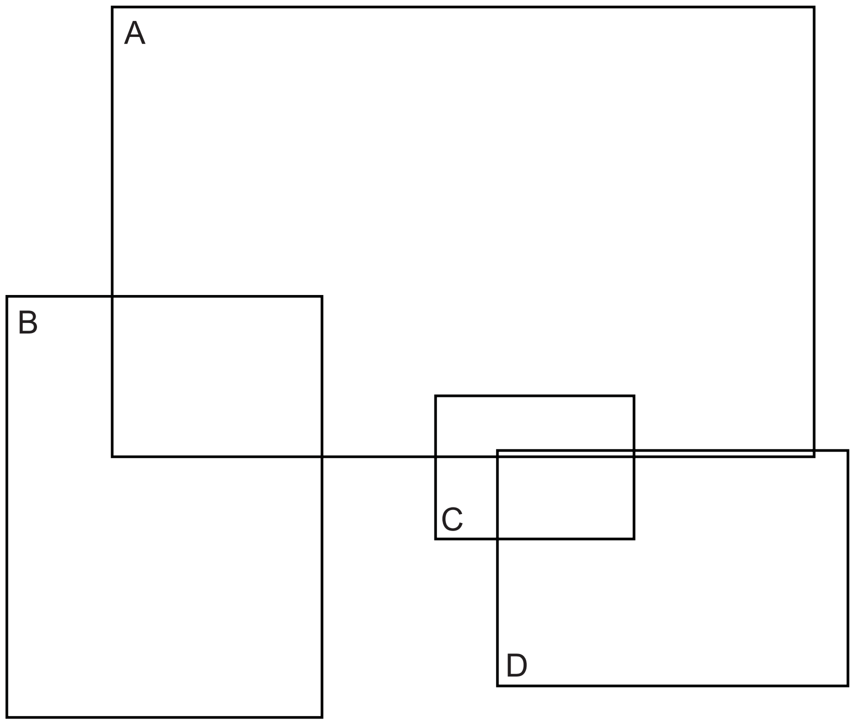
POSSIBLE EXTENT AND DEPTH OF SALT CONTAMINATION IN GROUND WATER USING GEOPHYSICAL TECHNIQUES, RED RIVER ALUMINUM SITE, STAMPS, ARKANSAS, APRIL 2003

Water-Resources Investigations Report 03-4292

U.S. Department of the Interior
U.S. Geological Survey



Cover:

A. Looking east from 125 meters along resistivity line 1 at the Red River Aluminum site; B. Looking southwest from 50 meters along resistivity line 3 at the Red River Aluminum site; C. Resistivity switching unit; D. Electrode and cable in use during a two-dimensional, direct-current resistivity survey.

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Little Rock, Arkansas
2003

U.S. DEPARTMENT OF THE INTERIOR

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CONTENTS

ILLUSTRATIONS

TABLES

CONVERSION FACTORS, ABBREVIATIONS, AND VERTICAL DATUM

Multiply	By	To obtain
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)

In this report, vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD of 1929). Horizontal coordinate information is referenced to North American Datum of 1927 (NAD 27).

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ABSTRACT

A surface-geophysical investigation of the Red River Aluminum site at Stamps, Arkansas, was conducted in cooperation with the Arkansas Department of Environmental Quality to determine the possible extent and depth of saltwater contamination. Water-level measurements indicate the distance to water level below land surface ranges from about 1.2 to 3.9 feet (0.37 to 1.19 meters) in shallow monitor wells and about 10.5 to 17.1 feet (3.20 to 5.21 meters) in deeper monitoring wells. The two-dimensional, direct-current resistivity method identified resistivities less than 5 ohm-meters which indicated possible areas of salt contamination occurring in near-surface or deep subsurface ground water along four resistivity lines within the site. One line located east of the site yielded data that demonstrated no effect of salt contamination. Sections from two of the five data sets were modeled. The input model grids were created on the basis of the known geology and the results and interpretations of borehole geophysical data. The clay-rich Cook Mountain Formation is modeled as 25 ohm-meters and extends from 21 meters (68.9 feet) below land surface to the bottom of the model (about 52 meters (170.6 feet)). The models were used to refine interpretation of the resistivity data and to determine extent of saltwater contamination and depth to the Cook Mountain Formation.

Data from the resistivity lines indicate both near-surface and subsurface saltwater contamination. The near-surface contamination appears as low resistivity (less than 5 ohm-meters) on four of the five resistivity lines, extending up to 775 meters (2,542.8 feet) horizontally in a line that traverses the entire site south to north. Model resistivity data indicate that the total depth of saltwater contamination is about 18 meters (59 feet) below land surface. Data from four resistivity lines identified areas containing low resistivity anomalies interpreted as possible salt contamination. A fifth line located just east of the site showed no saltwater contamination.

INTRODUCTION

The Red River Aluminum site located at Stamps, Arkansas (fig. 1), once contained exposed waste piles of salt and metal byproducts (referred to as salt cake) from the smelting of aluminum. The salt cake was subjected to rainfall, resulting in dissolution of the salts and metals (RMT, Inc., 2000). Surface-water brines from the piles flowed into canals and ponds (fig. 2). Surface-water runoff (from the over 50 inches (128.2 centimeters) of precipitation per year (Freiwald, 1985) occurs radially from a topographic high occurring onsite until it is intercepted by man-made or natural drainages.

Red River Aluminum was identified for removal action under the Comprehensive Environmental Response and Liability Act (CERCLA) and Superfund Amendments and Reauthorization Act (SARA) of 1986. On November 6, 2000, the U.S. Environmental Protection Agency (USEPA) Region 6 Response and Prevention Branch tasked the Superfund Technical Assessment Team (START) contractors to provide oversight, sampling, and managerial tasks during removal activities at Red River Aluminum under the direction of USEPA. Several thousand cubic yards of waste were leveled and shaped into a cell that is about

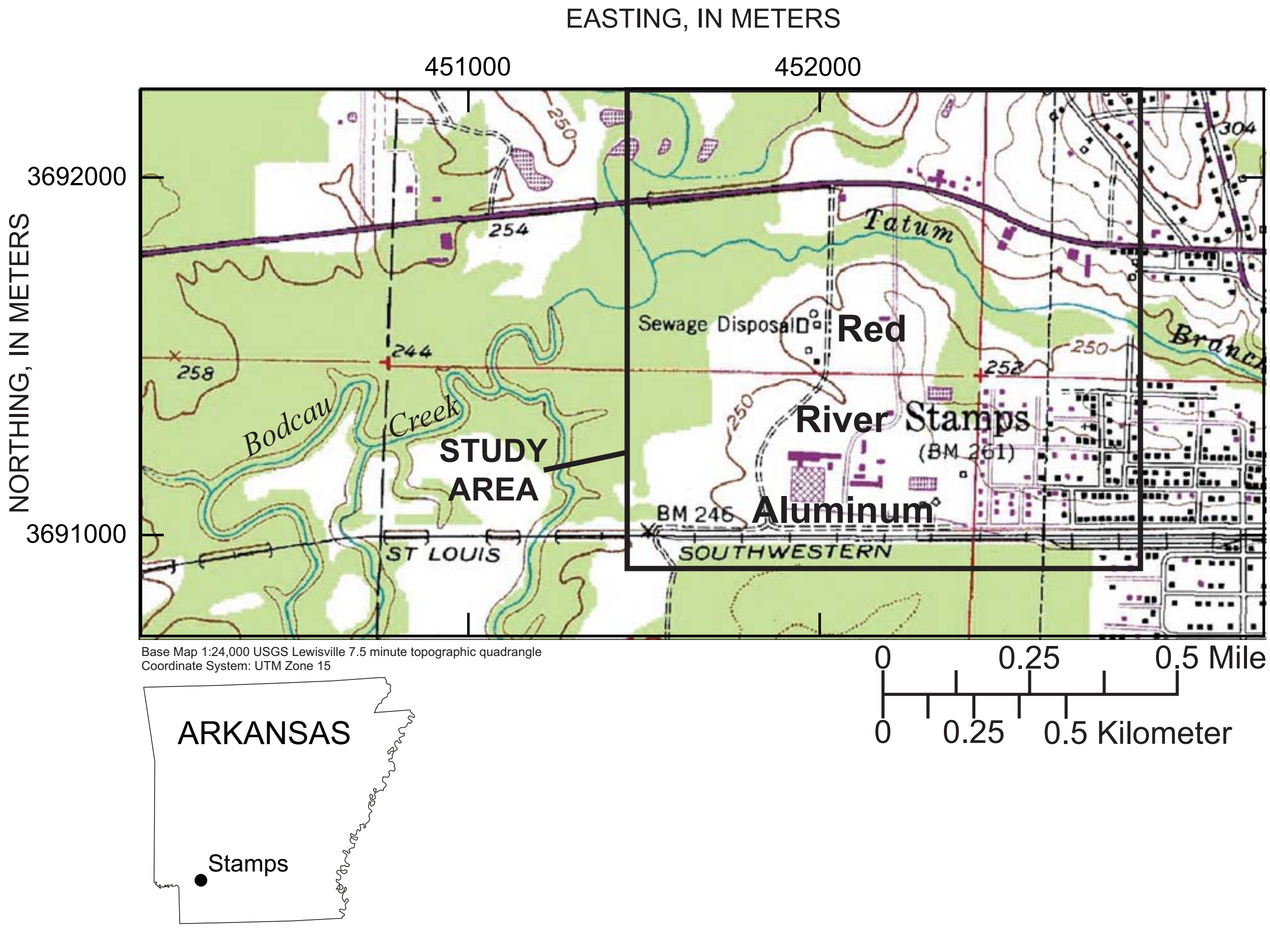
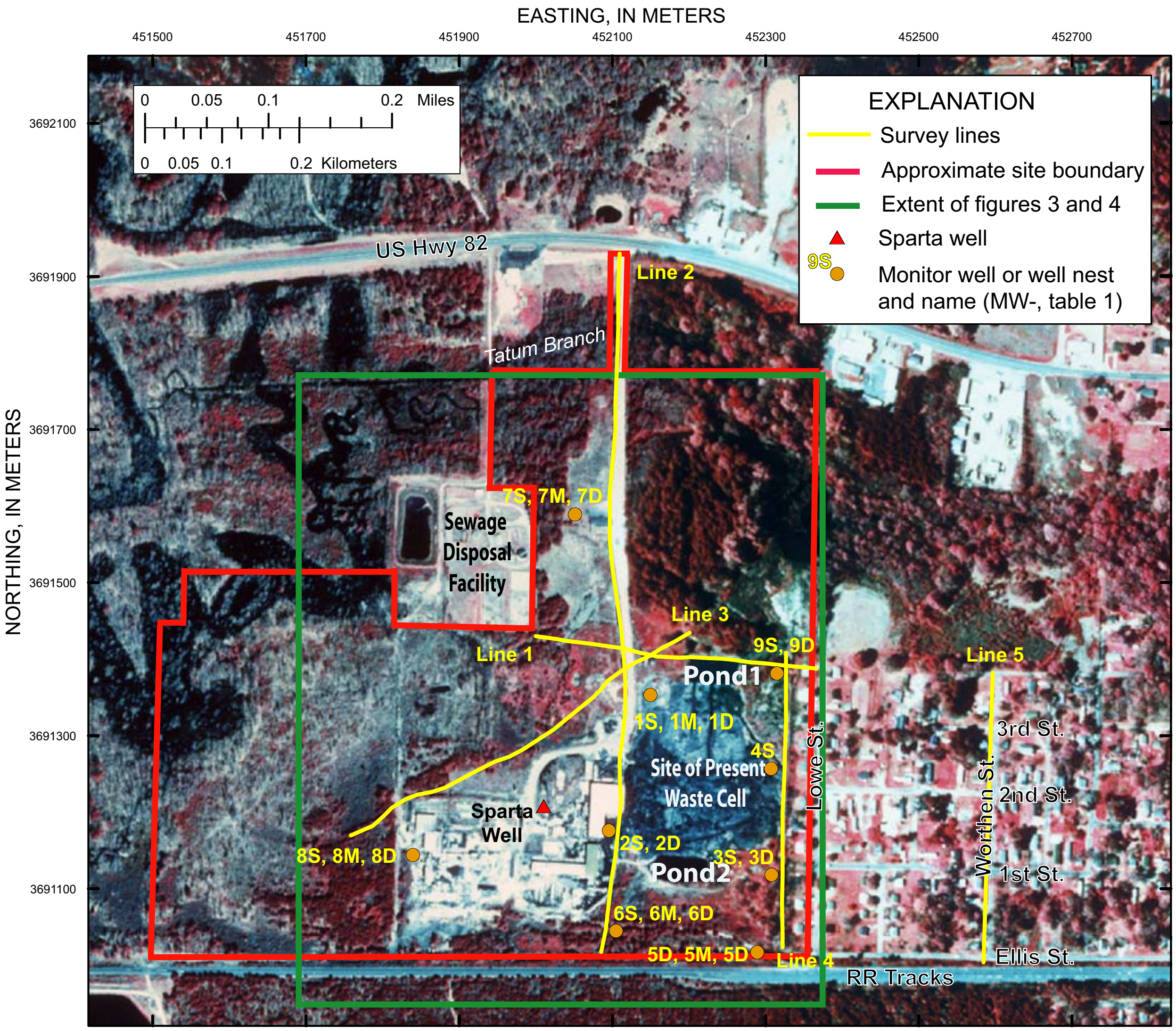


Figure 1. Location of study area.

677 feet (206 meters) long by 349 feet (106 meters) wide. The waste cell was capped with about 63,000 cubic yards (82,341 cubic meters) of clay. USEPA completed site work on October 10, 2001 (Weston, 2001).

The site formerly was used as a sawmill until its sale to Red River Aluminum in March 1987 (Weston, 2001). Most of the sawmill water was obtained from water mains connected to the city of Stamps water system. One onsite well completed within the Sparta aquifer also supplied water for the sawmill. Two ponds (ponds 1 and 2, fig. 2) constructed onsite were used to collect and reuse runoff that occurred as water was sprinkled on logs stacked on concrete pads located between the two ponds.

In 1987, Red River Aluminum Company occupied the site and began extracting and recovering aluminum as a primary aluminum smelter. The site entered into bankruptcy and ceased operations as a primary aluminum smelter in 1988. After reorganization, the facility reopened as a secondary-tertiary smelter utilizing dross (the material that forms on the surface of molten aluminum during the primary smelting process) as its primary feedstock (Weston, 2001). Aluminum was separated from these drosses using natural-gas rotary kilns. Halite (NaCl) and sylvite (KCl) salts were added to each batch of dross as flux agents. Molten aluminum was separated from the overlying flux agents by gravity. The remaining salt cake was gathered into piles between the two ponds (Woodward-Clyde Consultants, 1992). Several thousand cubic yards of saltcake was stored onsite during plant operation. The two ponds subsequently have been drained, and filled with local clay (Weston, 2001) as a part of waste cell construction.



Base map USGS Digital Orthophoto Quarter Quadrangle in color infrared - 2000
Coordinate system: UTM Zone 15, NAD 1927

Figure 2. Two-dimensional direct-resistivity lines, terrace-deposit monitor wells, and the Sparta well in the study area of the Red River Aluminum site. Color infrared image recorded in 2000 does not show waste cell constructed in 2001.

A 3,164 feet (964.3 meters) deep injection well was constructed onsite in 1992. A permit was issued from Arkansas Department of Environmental Quality (ADEQ) for disposal of soluble salts from the salt cake, but it is unknown to what extent the well was used for that purpose. Red River Aluminum Company abandoned the site in 1998 and site remediation was begun by the USEPA in 2000.

Czarnecki and others (2001) documented the presence of brine within the shallow ground-water system based on specific conductance of ground water as high as 196,200 microsiemens per centimeter at 25 degrees centigrade (µS/cm). Specific conductance and hydraulic head decrease with distance from the salt-cake piles indicating the potential for dissolved salts to move radially outward from the source. Primary transport of saline water occurs horizontally within the shallow flow system based on specific-conductance data from water samples and from borehole geophysical logging data. However, some vertical transport of saline water has occurred based on elevated specific conductance in water from wells 38 to 64 feet (11.58 to 19.51 meters) deep. From November 2001 until December 2002, specific conductance of samples from each monitoring well was measured on site (John Czarnecki, U.S. Geological Survey, written commun. 2003). These data indicate that very little change has occurred in specific conductance of the ground water sampled at the Red River Aluminum site since the study by Czarnecki and others (2001) but information is needed on the extent and depth of salt contamination. Ground-water contamination is particularly a concern with regard to the regionally important Sparta aquifer, part of whose recharge is derived from the site. This situation is of great concern to the local citizens and the city of Stamps, Arkansas, as well as State and Federal agencies. The Cook Mountain Formation is a confining unit that overlies Sparta aquifer at the site, and information about the depth to the top of the Cook Mountain Formation is relevant for assessments of possible contamination. To address these needs, the U.S. Geological Survey (USGS) in cooperation with the ADEQ, conducted a two-dimensional, direct-current (2D-DC) resistivity survey of the Red River Aluminum site.

Purpose and Scope

This report describes the results of a surface geophysical investigation of near-surface and deep ground water in the vicinity of the Red River Aluminum site conducted in April, 2003 to determine the possible extent and depth of salt contamination in ground water. Five 2D-DC resistivity lines were surveyed. The purpose of this report is to document 1) 2D-DC resistivity data collected in the vicinity of the Red River Aluminum site, and 2) modeled interpretations of two lines of the 2D-DC resistivity data using local known geology and results and interpretations of borehole geophysical data. The depth of the Cook Mountain Formation was determined from the modeled interpretations of driller's and borehole geophysical logs. Geophysical logs from Czarnecki and others (2001) necessary for interpretations of the surface geophysical data also are included.

The study area (which includes the property previously owned by the Red River Aluminum Company, referred to as the Red River Aluminum site, and a portion of a residential area) is east of Bodcau Creek, mostly south of Tatum Branch of Bodcau Creek, north of the former St. Louis-Southwestern Railroad (now owned by Union Pacific Railroad), and west of the city of Stamps (fig.1). The areas adjacent to the Red River Aluminum site are mostly forested with the exception of the area east of the site, which is residential. An inactive wastewater treatment (sewage disposal) facility is located directly northwest of the site. The topographic relief of the study area is about 20 feet (6.1 meters). Part of the study area lies at a local topographic high point, and the waste cell is located at this topographic high.

Previous Investigations

Four reports describe the regional setting and hydrogeologic characteristics of the study area. Ludwig (1972) described the regional hydrogeologic setting in his reconnaissance of the water resources of the area. Woodward-Clyde Consultants (1992) characterized the lithology and hydrology of five shallow (15 feet (4.6 meters) deep) borings on the site, and provided slug-test data for two monitor wells. RMT Inc. (2000) analyzed water samples from surface and ground water, and added an additional monitor well (3D) to a depth of 45 feet (13.7 meters) below land surface. The RMT investigation showed that the shallow wells drilled by Woodward-Clyde Consultants terminated in a shallow perched-water body, and that the deeper monitor well, 3D, was completed in the first saturated sand zone. The results from this investigation showed elevated salt concentrations in ground- and surface-water samples. Czarnecki and others (2001) documented (1) ground-water flow direction in the vicinity of the Red River Aluminum site and (2) measured values of pH, temperature, and specific conductance in water samples taken from monitor wells, ponds, and Tatum Branch. Czarnecki and others (2001) concluded that no evidence of perched water was observed onsite. All wells constructed onsite yielded water with time, even the moderate-depth wells constructed in clay units; albeit, some wells yielded very little water. Water levels in two of the moderate-depth wells were still recovering weeks after construction.

HYDROGEOLOGY

Based on a driller's log for a 351-foot (106.0-meter) deep well (Sparta Well, fig. 2) drilled onsite for the sawmill operator and logs for numerous shallower wells drilled subsequently, the upper 190 feet of sediments beneath the site consist of interbedded sands, silts, clays, and gravels associated with stream terrace deposits of Quaternary age. Based on the stratigraphic section of Ludwig (1972), the Sparta Sand of Tertiary age is interpreted from the log of the 351-foot (106.0 meter) deep well to occur at depths between 190 to 288 feet (57.9 to 87.8 meters) below land surface, and is overlain by a clay unit 68 to 190 feet (21.0 to 57.9 meters) below land surface. Water-quality samples from this well indicate no saltwater contamination was present in the Sparta aquifer at this location (C. McWilliams, Arkansas Department of Environmental Quality, written comun., 2001).

A detailed investigation of the driller's log from onsite monitor wells revealed that from land surface to a depth of about 10 to 20 feet (3.0 to 6.1 meters), sediments consist of sandy clays, gravels, and minor silts (Czarnecki and others, 2001). This is underlain by a dense, sometimes brittle clay unit between 20 to 30 feet (6.1 to 9.1 meters) thick, which is underlain by unconsolidated fine sand with a thickness of at least 20 feet (6.1 meters). These shallow units exhibit very little contrast in conductivity/resistivity (except in areas affected by brine) and are depicted in the 2D-DC resistivity models for this report as a generalized, homogeneous layer for simplification purposes of modeling.

Water levels were measured in all available monitor wells onsite and are listed in table 1. Well names include "MW-" followed by a number and letter designating the relative depth of the well - D, deep; M, moderate; and S, shallow. Well locations and names are shown in figure 2. Water-level measurements collected in April 2003 indicate the depth to water level below land surface ranges from about 1.2 to 3.9 feet (0.37 to 1.19 meters) in shallow monitor wells and about 10.5 to 17.1 feet (3.2 to 5.21 meters) in deeper monitoring wells. Water-level data indicate that flow occurs radially away from the waste cell in the shallow ground-water system (fig. 3) and to the soutwest in the deep ground-water system (fig. 4).

METHODOLOGY AND APPROACH

Surface-geophysical methods offer quick, inexpensive, and non-invasive means that help to characterize subsurface geology (Powers and others, 1999). Surface geophysics provides information on the subsurface features, such as sediment thickness, depth to bedrock, and presence of conductive fluids (Powers and others, 1999). The 2D-DC resistivity method was used to identify the areal extent and depth of the saltwater contamination and determine the depths of subsurface strata. Five 2D-DC resistivity lines were collected in April 2003 (fig. 2). Borehole geophysical induction-conductivity logs collected in 2001 (Czarnecki and others, 2001) and other nearby logs were used to correlate lithologies with 2D-DC resistivity data collected in this investigation. Three layer, finite-difference models of two resistivity lines were created to aid the interpretation of the 2D-DC resistivity lines. The models were constructed using borehole geophysical data collected onsite and from nearby wells and known local geology.

Two-Dimensional Direct-Current Resistivity

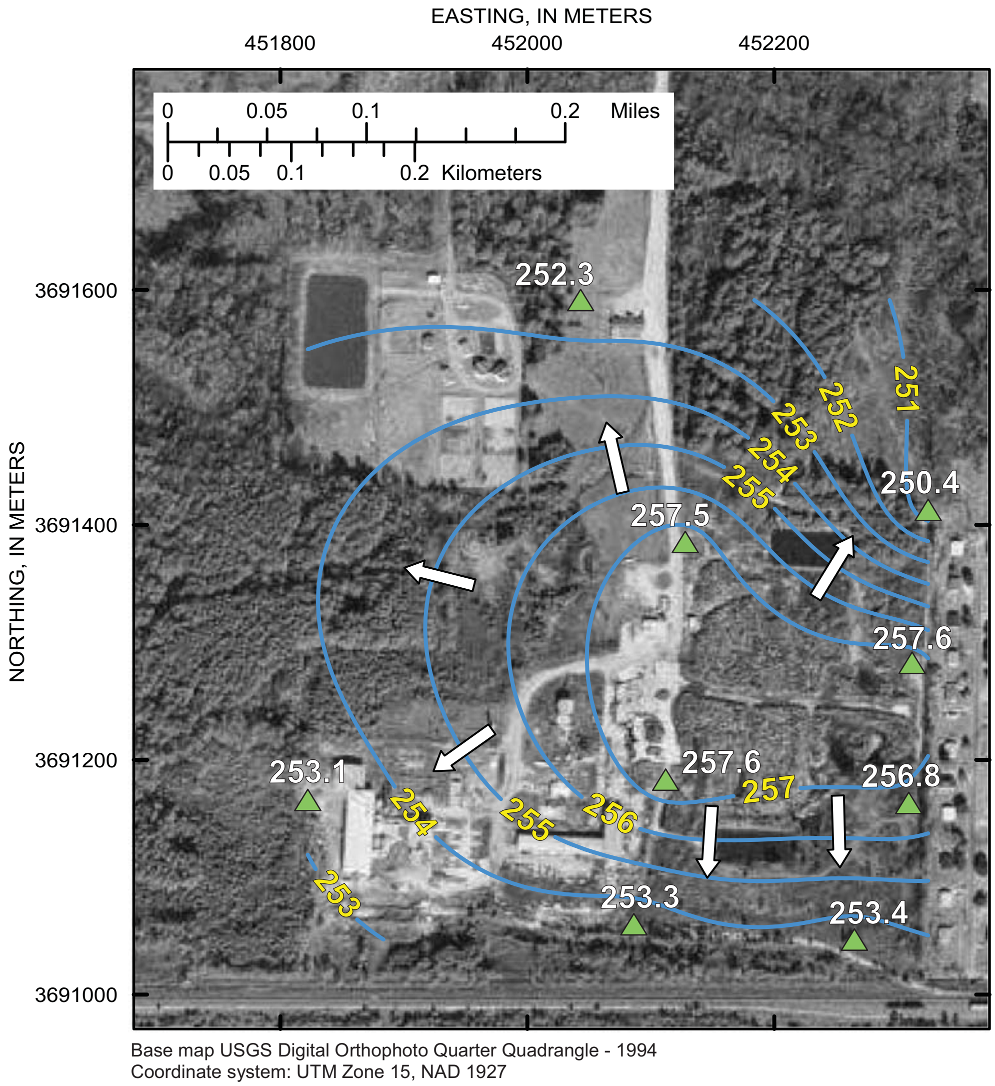
Two-dimensional direct-current (2D-DC) resistivity measures the electrical resistivity of the subsurface. Electrical resistivity is determined by the resistivity of the sediment, which is related to the quantity and quality of the contained water (Haeni and others, 1993). In general, coarse-grained sediments are more resistive compared to fine-grained sediments. The presence of dissolved solids such as halite (NaCl) and sylvite (KCl) can reduce the resistivity of ground water (Loke, 2002).

2D-DC resistivity uses two electrodes to induce current into the ground and the voltage difference is measured between two potential electrodes. An apparent resistivity is obtained after dividing the measured voltage by the induced current and applying a geometric correction. Field data and model data were inverted using RES2DINV version 3.51 (Loke, 2003) to create

Table 1. Water-level measuring point locations, well-construction data, and water levels

[UTM, Universal Transverse Mercator, North American Datum 1927; NGVD, National Vertical Datum of 1929; MW, monitoring well; D, deep; M, moderate; S, shallow; N/A, not applicable]

Well or site name	UTM easting (meters)	UTM northing (meters)	Well depth (feet)	Midpoint altitude of screen (feet above NGVD of 1929)	Measuring point altitude (feet above NGVD of 1929)	Borehole diameters (inches)	Casing diameter (inches)	Screen length (feet)	Depth to water below measuring point on 4/25/03 (feet)	Depth to water below land surface (feet)	Water-level altitude (feet above NGVD of 1929)
MW-1D	452152.53	3691363.30	59	207	262.90	7.50	2	5.0	18.65	17.05	244.50
MW-1M	452150.68	3691365.72	26	239	263.15	7.50	2	2.5	9.61	7.91	253.54
MW-1S	452151.24	3691370.91	13	256	263.05	10.25	4	10.0	5.54	3.04	257.51
MW-2D	452115.58	3691186.21	54	209	259.85	7.50	2	5.0	16.91	15.72	242.94
MW-2S	452135.27	3691166.60	14	252	260.45	10.25	4	10.0	2.81	1.21	257.64
MW-3D	452310.25	3691128.40	45	224	264.50	6.00	2	10.0	17.59	14.19	246.91
MW-3S	452333.23	3691146.61	13	255	262.95	10.25	4	10.0	6.15	3.95	256.80
MW-4S	452336.00	3691266.99	8	256	261.40	10.25	4	5.0	3.80	1.70	257.60
MW-5D	452291.74	3691027.67	43	218	258.40	8.25	2	5.0	11.74	10.53	246.66
MW-5M	452290.51	3691028.57	21	238	258.45	7.50	2	2.5	5.32	4.01	253.13
MW-5S	452288.98	3691029.16	11	249	258.70	7.50	2	2.5	5.32	3.66	253.38
MW-6D	452105.12	3691042.28	49	212	257.65	7.50	2	5.0	14.38	13.13	243.27
MW-6M	452106.95	3691042.00	22	237	257.35	7.50	2	2.5	4.28	3.38	253.07
MW-6S	452109.38	3691042.32	11	248	258.10	7.50	2	2.5	4.83	3.41	253.27
MW-7D	452064.52	3691575.12	60	202	259.35	7.50	2	5.0	13.61	12.11	245.74
MW-7M	452061.12	3691579.35	22	238	258.55	7.50	2	2.5	7.92	6.84	250.63
MW-7S	452066.01	3691578.79	11	249	258.85	7.50	2	2.5	6.51	5.44	252.34
MW-8D	451842.88	3691154.57	64	196	257.95	7.50	2	5.0	17.03	16.00	240.92
MW-8M	451843.21	3691151.83	20	242	259.95	8.25	2	2.5	4.88	1.88	255.07
MW-8S	451843.84	3691149.10	11	248	257.95	7.50	2	2.5	4.85	3.75	253.1
MW-9D	452349.04	3691396.62	38	225	260.50	7.50	2	5.0	14.68	13.48	245.82
MW-9S	452349.03	3691398.45	12	249	259.20	7.50	2	2.5	8.75	8.25	250.44
Sparta Well	452029.03	3691218.57	286	-16	259.35	N/A	6	20.0	31.88	30.44	227.47



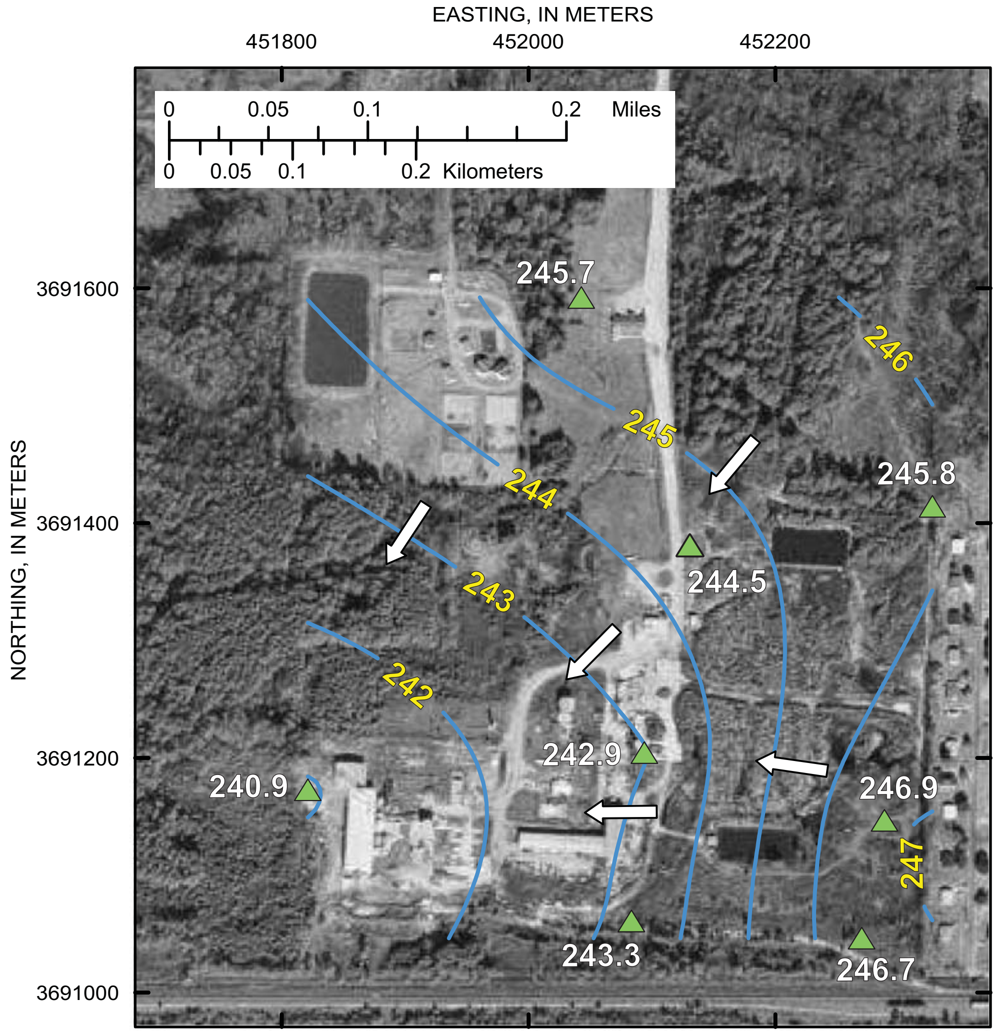
EXPLANATION

253 — WATER TABLE CONTOUR -- Shows altitude of water table, April 25, 2003. Contour interval, 1 foot. Datum is National Geodetic Vertical Datum of 1929

253.1 — WELL LOCATION -- Number is water-level altitude, in feet above National Geodetic Vertical Datum of 1929

DIRECTION OF GROUND-WATER FLOW

Figure 3. Water-level altitudes within the shallow ground-water system. Base aerial photograph was taken January 19, 1994, and does not depict actual site conditions today.



Base map USGS Digital Orthophoto Quarter Quadrangle - 1994
Coordinate system: UTM Zone 15, NAD 1927

EXPLANATION

242 — WATER TABLE CONTOUR -- Shows altitude of water table, April 25, 2003. Contour interval, 1 foot. Datum is National Geodetic Vertical Datum of 1929

240.9 — WELL LOCATION -- Number is water-level altitude, in feet above National Geodetic Vertical Datum of 1929

DIRECTION OF GROUND-WATER FLOW

Figure 4. Water-level altitudes within the deep ground-water system. Base aerial photograph was taken January 19, 1994, and does not depict actual site conditions today.

inverted datasets. Inverted datasets provide a much closer approximation of the true resistivity of the subsurface (Loke, 2002).

2D-DC resistivity data collection was once a repetitive process of setting up electrodes at the appropriate spacing, measuring the resistivity at that point, and moving the electrodes to the next spacing to measure the next data point and so on. Recent advances in microcomputers and resistivity equipment allow the user to set up numerous electrodes in succession along a multi-conductor cable, enter the desired array into the microcomputer/switching unit, and allow the switching unit to collect data facilitating more rapid data collection. The data at the Red River Aluminum site were collected using an IRIS Syscal R1 Plus Resistivity Meter. The switching unit used 72 electrodes at a 5-meter spacing to achieve the desired depth of investigation. Resistivity lines were lengthened using the roll-along technique. After collecting an initial resistivity section of data, 18 electrodes were moved and switched on ahead of the resistivity line. A partial resistivity section of data then is collected using the 18 electrodes that were moved. This process is continued until all data along the desired line length are collected. A Wenner-Schlumberger array (Loke, 2002 and 2003) was used in the data collection, inversion, and modeling of the resistivity data. Advantages of the Wenner-Schlumberger array over other arrays are better horizontal coverage in areas of limited open space and greater depth of penetration.

Borehole Geophysical Log Evaluation

Geophysical logs of the boreholes are presented in the Supplemental Data section at the end of this report. Natural gamma logs indicate the presence or absence of clays. Low electrical resistivity is an excellent indicator of the presence of brines resulting from leaching of the salt cake. Increased dissolved solids in saltwater decrease the resistivity (increase the conductivity) response on the induction logs. The logs presented in the Supplemental Data section also include a general lithologic description based on cuttings collected during auger drilling from Czarnecki and others (2001). Locations of the wells are included in figure 2. The cuttings were sometimes collected at sporadic intervals and could not be correlated with precise well depths because of field conditions and limitations of the auger drilling technique; therefore lithologic descriptions from Czarnecki and others (2001) in the supplemental data section data section may not correlate with the more detailed log responses.

Two-Dimensional Finite-Difference Modeling of Resistivity Data

The 2D-DC field datasets were inverted to provide a closer approximation of the true resistivity of the subsurface (Loke, 2002) and interpretations were made; however, those interpretations can be tested with a two-dimensional (2D) finite-difference model of the resistivity line which comprises a rectangular grid representing the subsurface. A separate model was developed for each resistivity line using RES2DMOD (Loke, 2003), which divided the subsurface into rectangular blocks according to the resistivity array represented. For the Wenner-Schumberger arrays used in data collection, the thickness of the first row of blocks was set to 0.25 times the electrode spacing (5 meters (16.4 feet)). The thickness of each deeper subsequent row of blocks was increased by 10 percent. Each rectangular block was assigned a resistivity value as model input.

The 2D model inputs are based on known geology, interpretations from the inverted 2D-DC field datasets, borehole geophysical logs from wells onsite and near the site, and the driller’s logs from the onsite Sparta well. The model grid length is equal to the resistivity line it represents. Each model consisted of three layers of local geology, which are: dry terrace deposits and saturated terrace deposits in the two uppermost layers, and the clay-rich Cook Mountain Formation in the lower layer. The top of the Cook Mountain Formation as determined from driller’s logs and borehole geophysical logs is about 21 meters (68.9 feet) below land surface. The bottom of the model equals the depth of investigation for the Wenner-Schlumberger array at the 5-meter spacing which is about 52 meters (170 feet) below land surface (Loke, 2003). The bottom of the Cook Mountain Formation (as determined from logs), which is the top of the underlying Sparta Sand, is about 58 meters (190 feet) below surface and is consequently below the bottom of the model grid. The inverted field datasets indicated areas of low resistivity that were anomalous to the local geology and interpreted as areas of saltwater contamination. These areas of low resistivity were input to the model as needed to represent the saltwater contamination. Several iterations of model simulations were produced, each after adjustments were made to the resistivity values in the model to represent non-homogeneity in the local geology and areas of contamination. A model solution was reached when the resistivity section from the field data approximately matched the inverted modeled resistivity section. The resulting model grid serves as a non-unique interpretation of the subsurface geology and saltwater contamination (if present) along the resistivity line.

ANALYSIS AND RESULTS OF SURFACE GEOPHYSICAL INVESTIGATIONS

The apparent resistivity values collected in the field were inverted. Results from data collected along the five 2D-DC resistivity lines are presented as inversion resistivity sections along the lines. The resistivity sections (figs. 5 - 11) show the inverted resistivity data as contoured resistivity in gradational colors. Low resistivity areas in blue, darkening with lower resistivity, denote possible areas of salt contamination. The clay layer of the Cook Mountain Formation is difficult to distinguish from shallow silty clay terrace deposits on the inverted resistivity section of two-dimensional, direct-current resistivity field data because of the low contrast in the resistivity of the upper 21 meters (68.9 feet). Each line is described in detail with analysis of the resistivity sections in the following report sections. Lines that intersect each other are annotated as such on the resistivity sections. In this situation, the resistivity values on the corresponding sections may not correlate at the point of intersection because of the different orientations of the individual resistivity lines and thus the different locations of electrodes.

The purpose of the modeling process is to determine the resistivity of the rectangular blocks that will produce an apparent resistivity section that agrees with the actual field measurements (Loke, 2003). A model solution is reached after numerous iterations, each with a modified model, when the resistivity section from the field data and the inverted synthetic resistivity section from the model data approximately match (Degnan and others, 2001). The model solutions are non-unique; however, with inclusion of known information to the model, the solutions represent a likely generalized interpretation of the subsurface. The modeled interpretation of resistivity lines 2 and 5 can be applied to those that were not modeled. Model cross sections of the subsurface resistivity distribution were created for lines 2 and 5 only and were simulated using RES2DMOD (Loke, 2003). The input model grids (figs. 7b and 11b) were created on the basis of the known geology and the results and interpretations of the inverted field data and the borehole geophysical data. Modeled lines (2 and 5) are described in more detail based on finite-difference model input.

For this investigation, 2D-DC resistivity lines and resistivity modeling were used as a reconnaissance method, to detect anomalies within the subsurface of the Red River Aluminum site. Possible salt contamination and depths of subsurface strata can be substantiated by drilling methods and ground-water quality data collection.

All wells showed decreased resistivity (increased conductivity) response that indicated some level of saltwater contamination (see Supplemental Data section). Wells 1D, 2D, 3D, and 9D show decreased resistivity in a shallow zone indicating saltwater contamination less than 5 meters (16.4 feet) below land surface. Wells 2D, 5D, 6D, 7D, and 8D show a deeper zone of decreased resistivity indicating saltwater contamination greater than 5 meters (16.4 feet) below land surface.

Resistivity Line 1

Resistivity line 1, which traverses the central portion of the Red River Aluminum site in a west-east trend, passing just north of the waste cell near wells 1D and 9D (figs. 2 and 5), indicates low resistivity fluid near the surface and in the deep subsurface adjacent to the waste cell. A zone of low resistivity less than 5 ohm-meters is evident near the surface from 25 to 275 meters (82.0 to 902.3 feet) along resistivity line 1 (fig. 5), which indicates a shallow lens of high conductivity fluid just below the surface. This zone of low resistivity underlies a zone of greater resistivity (50 to 200 ohm-meters) at 25 to 75 meters (82.0 to 246.1 feet) along the line, which corresponds to a grassy field with gravelly topsoil. The zone of low resistivity appearing on the inverted resistivity section at an altitude of about 50 to 60 meters (164.1 to 196.9 feet) at a distance of about 210 to 250 meters (689 to 820.3 feet) along the line appears to be related to the area of the waste cell that was pond 1 (fig. 2). This zone of contamination is possibly associated with leakage through a zone of large hydraulic conductivity such as a gravel layer.

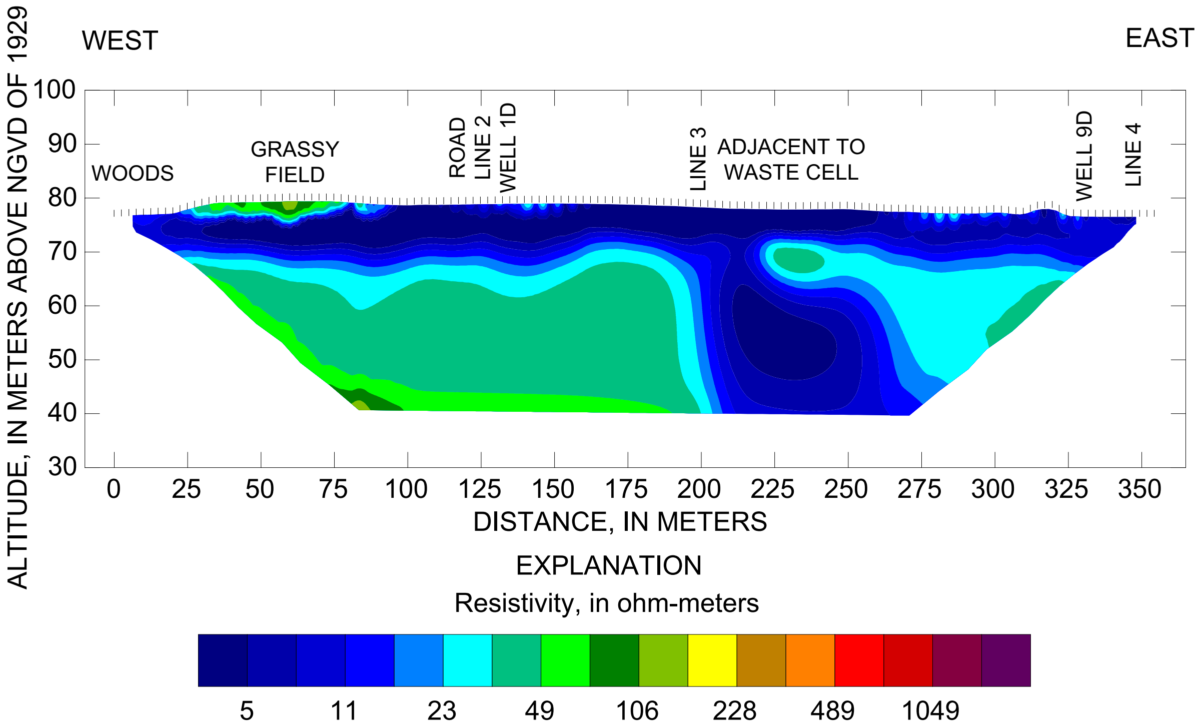


Figure 5. Inverted resistivity section of two-dimensional, direct-current resistivity line 1 field data.

Resistivity Line 2

Resistivity line 2 traverses the Red River Aluminum site in a south-north trend, beginning at the railroad tracks, between a building and the waste cell and follows a main gravel road passing just west of wells 6D, 2D and 1D and east of well 7D (figs. 2 and 6). This line was modeled with a finite-difference grid model to aid in interpretation of the inverted field data. The input model cross section (fig. 7a) was created on the basis of the known geology and the results and interpretations of borehole geophysical data. The clay-rich layer of the Cook Mountain Formation is difficult to distinguish from shallow silty clay terrace deposits on the inverted resistivity section of 2D-DC resistivity line 2 field data because of the low contrast in resistivity (fig. 6). The depths to the top of the Cook Mountain Formation and Sparta Sand were determined only by examining borehole geophysical logs of nearby deep wells and confirmed through the 2D modeling process. Terrace deposits were modeled as the uppermost layer with a resistivity of 50 ohm-meters in uncontaminated sediments and extend to about 21 meters (68.9 feet) below land surface. The clay-rich Cook Mountain Formation is modeled as 25 ohm-meters and extends from 21 meters (68.9 feet) below land surface to the bottom of the model. Model data were inverted to represent the field-data inversion resistivity section in figure 6. A low resistivity zone extends from 0 to 775 meters (0 to 2,542.8 feet) on the resistivity section and is explained in detail below in the model discussion.

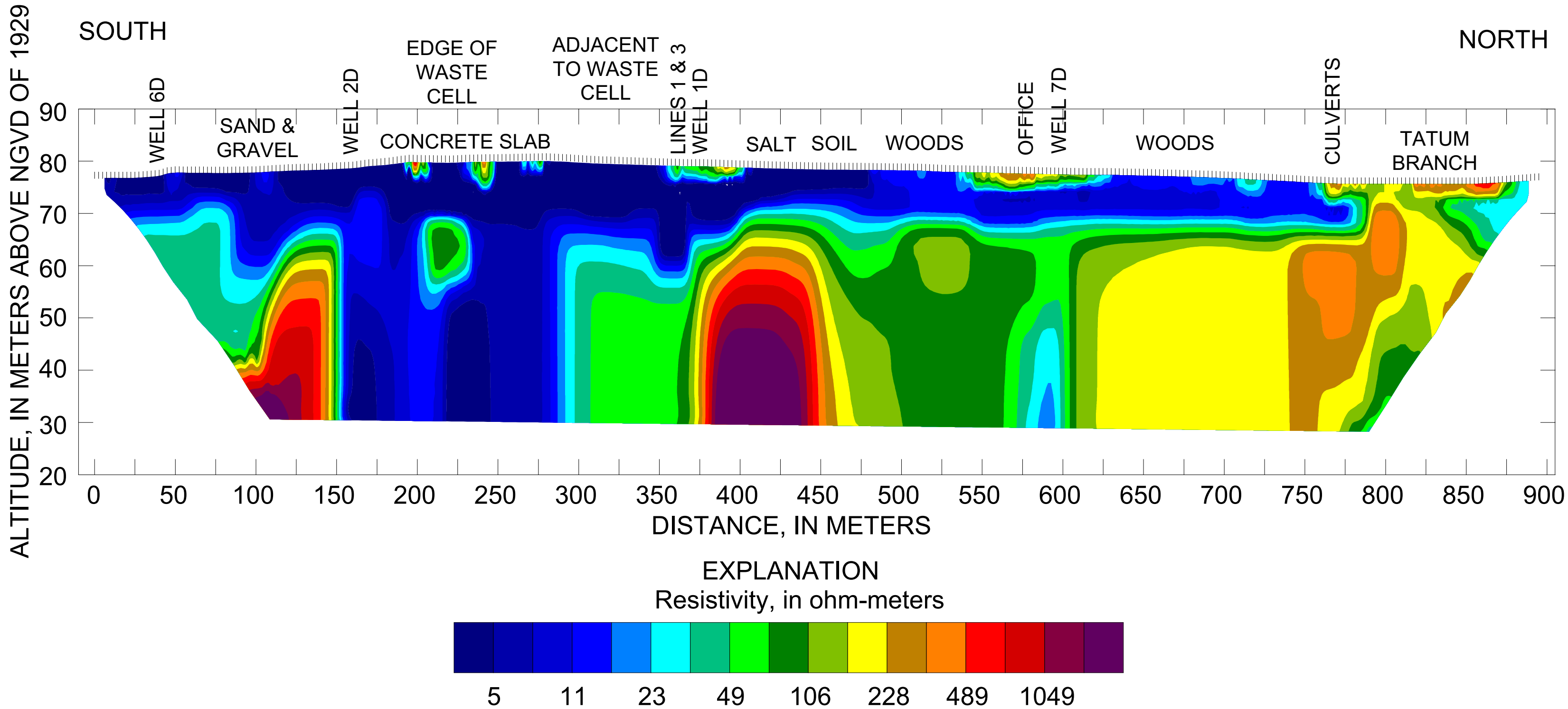


Figure 6. Inverted resistivity section of two-dimensional, direct-current resistivity line 2 field data.

Modeled inversion results (fig. 7a) indicate near-surface saltwater contamination on the resistivity section from 0 to 775 meters (0 to 2,542.8 feet) and extensive deep subsurface saltwater contamination from about 140 to 410 meters (459.3 to 1,345.2 feet). The extensive deep subsurface contamination was modeled to a depth of about 18 meters (59.1 feet) below land surface (fig. 7b), which is above the top of the Cook Mountain Formation, the overlying confining unit of the Sparta aquifer. The inverted resistivity section of field data (fig. 6) shows a large deep zone of low resistivity from about 150 to 275 meters (492.2 to 902.3 feet). This deep zone of low resistivity on the inverted resistivity section was emulated on the modeled inversion resistivity section even though saltwater contamination was modeled to only 18 meters (59.1 feet) below land surface in the model grid (figs. 7a and 7b). This indicated a non-unique model solution of saltwater contained in the terrace deposits that did not extend into the Cook Mountain Formation or Sparta Sand. Anomalies appearing as high resistivity zones near the surface at about 200 and 250 meters (656.2 to 820.1 feet) on the inverted resistivity section (fig. 6) correspond with the edges of a concrete slab and could be caused by runoff of low conductance precipitation from the concrete slab. The shallow, high resistivity anomaly at 550 to 600 meters (1,805 to 1,969 feet) could be caused by fill dirt used during construction of the office building and truck scale in this area. The high resistivity anomaly from 775 to 880 meters (2,542.8 to 2,887.3 feet) probably is associated with the infiltration of relatively high resistivity water from Tatum Branch and associated uncontaminated water in stream sediment deposits.

Resistivity Line 3

Resistivity line 3 trends southwest to northeast from the bottom woodlands of Bodcau Creek near well 8D to northeast of well 1D as shown in figure 2. The line 3 inverted resistivity section (fig. 8) indicates several near-surface zones of salt contamination. Areas underlying woods and grassy fields with high soil-moisture content appear as near-surface zones of reduced resistivity from 0 to 300 meters (0 to 984.3 feet) in the resistivity section. A possible small zone of salt contamination appears as a low resistivity zone (less than 5 ohm-meters) at an altitude of about 70 meters (229.7 feet) and about 70 meters (229.7 feet) on the resistivity section, which underlies a concrete tank on the surface. A more extensive zone of salt contamination appears near the surface from about 300 to 500 meters (984.3 to 1,641 feet) on the resistivity section as less than 5 ohm-meters resistivity. This near-surface zone of contamination is possibly associated with leakage through a zone of large hydraulic conductivity such as a gravel layer. The low resistivity zone appearing at depth near 400 meters (1,312.4 feet) on the resistivity section and at an altitude of about 30 to 60 meters (98.4 to 196.9 feet) is probably an artifact of the inversion process as a result of low resistivity shadowing from near surface. It is uncertain what the depth of contamination is in this specific area, although the modeled resistivity data from line 2 indicates it is probably less than 18 meters (59.1 feet) below land surface.

Resistivity Line 4

Resistivity line 4 extends along the east boundary of the Red River Aluminum site directly west of concrete slabs that were formerly occupied by houses on Lowe Street in the city of Stamps, Arkansas (fig. 2), and indicates a shallow zone of salt contamination adjacent to the Red River Aluminum site on the east boundary in the area of the former salt cake pile (fig. 9). The houses were removed in 2002 and the associated properties became part of the Red River Aluminum site. Monitor wells 3D and 9D are west of the line at about 90 meters (295.3 feet) and 350 meters (1,148.4 feet), respectively, on the inverted resistivity section (fig. 9). A low resistivity zone (less than 5 ohm-meters) appears between about 100 and 315 meters (328.1 to 1,034 feet) on the resistivity section (fig. 9) at an altitude of 70 to 78 meters (229.7 to 255.9 feet), 0 to 8 meters (0 to 26.2 feet) from land surface. This low resistivity zone is probably associated with infiltration of precipitation through the salt cake material, which was once stored adjacent to the line 4 location, but was moved to the waste cell further west of line 4 (fig. 2) in 2001. A near-surface high resistivity anomaly appears from about 115 to 210 meters (377.3 to 689 feet) on the resistivity section and is probably caused by a thin layer of organic material in the grassy areas that were once backyards of the former house locations on Lowe Street.

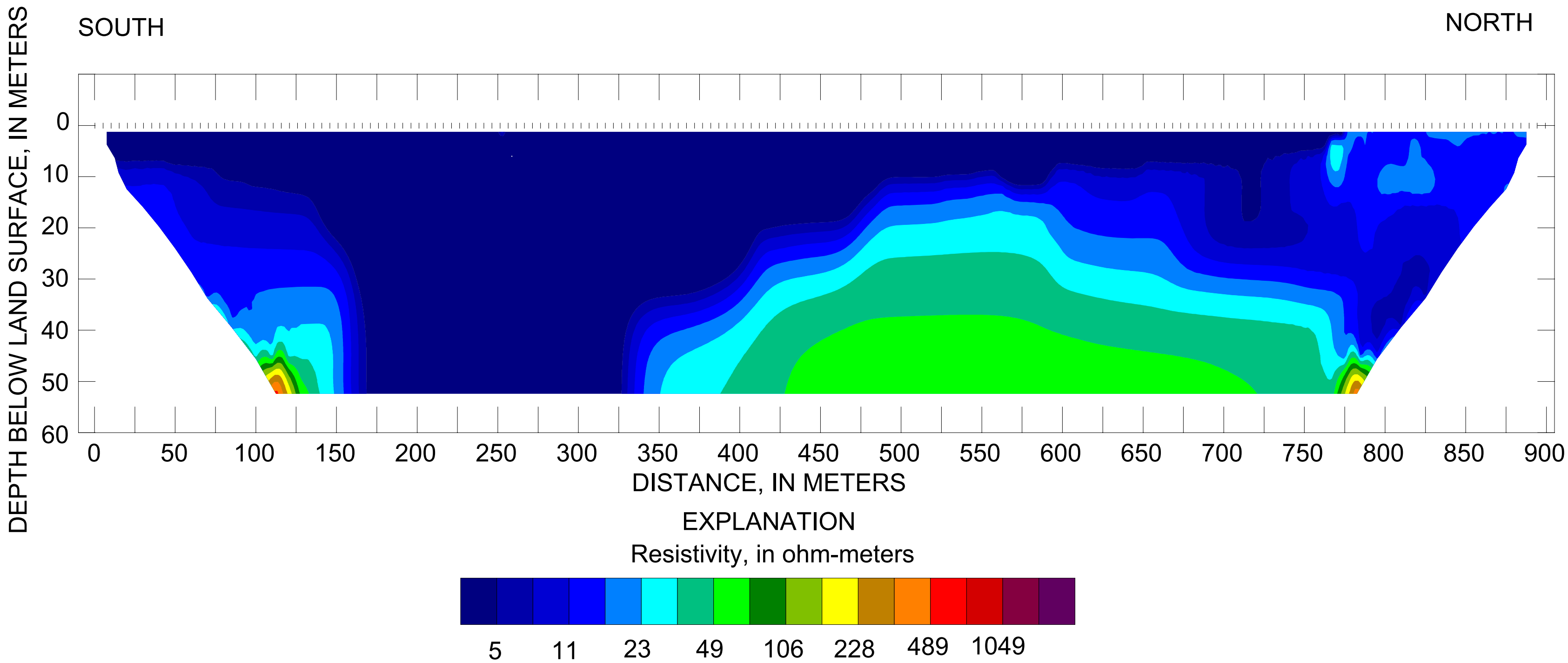


Figure 7a. Inversion resistivity section of modeled resistivity line 2.

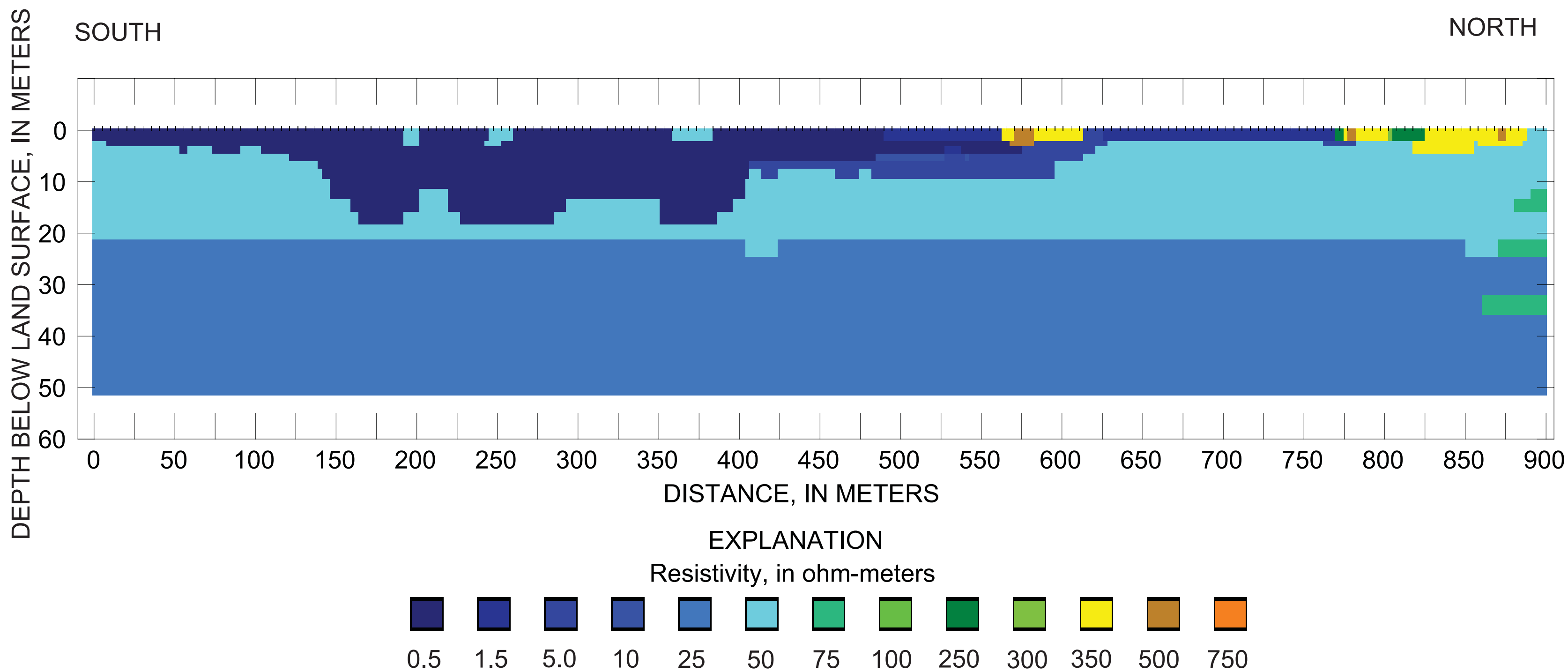


Figure 7b. Model grid of resistivity line 2.

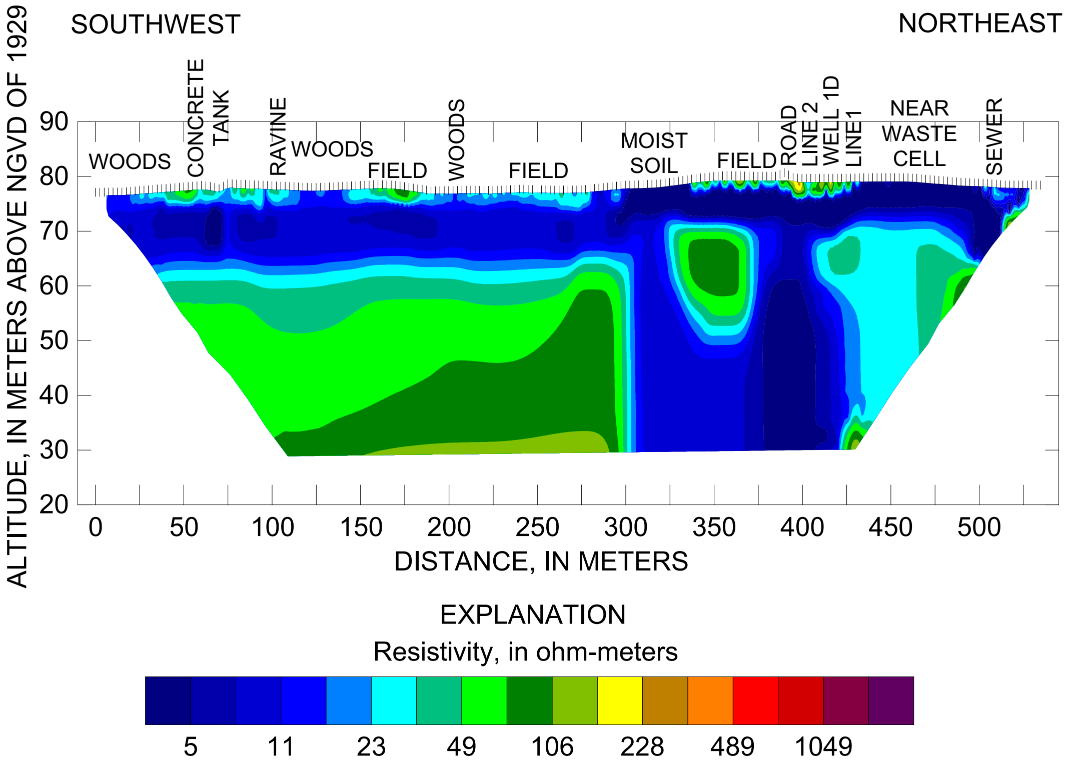


Figure 8. Inverted resistivity section of two-dimensional, direct-current resistivity line 3 field data.

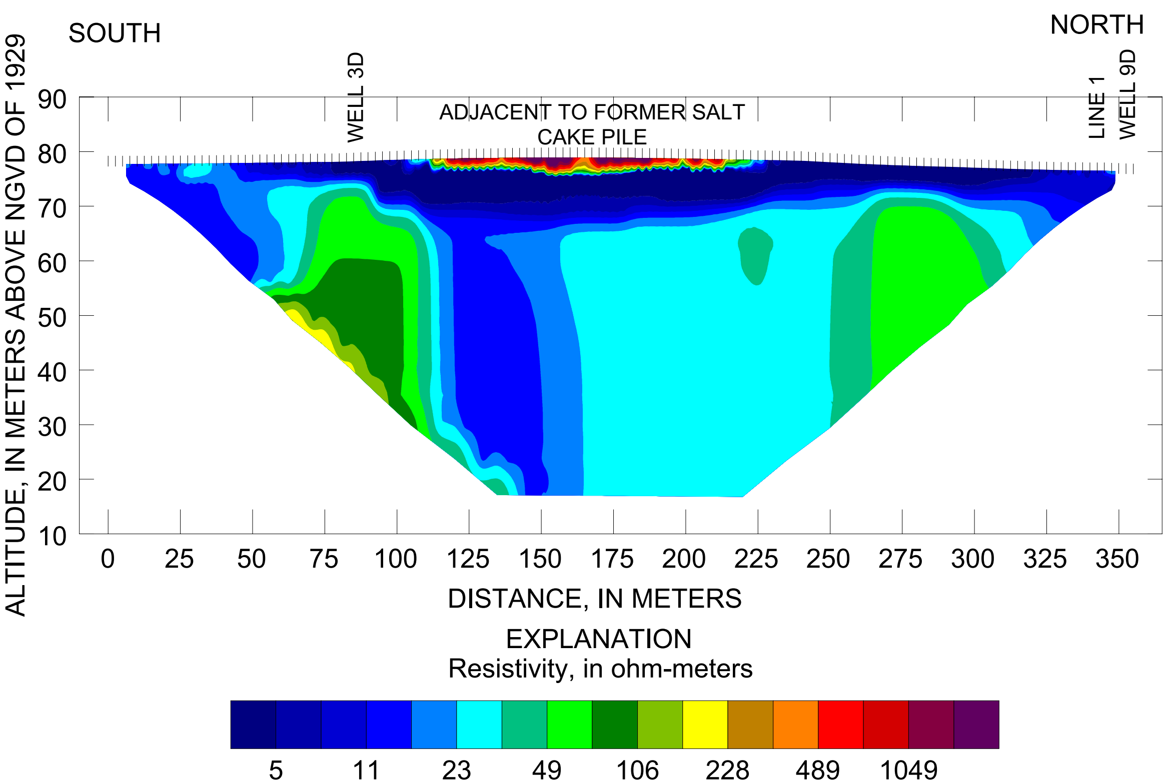


Figure 9. Inverted resistivity section of two-dimensional, direct-current resistivity line 4 field data.

Resistivity Line 5

Resistivity line 5 traces along the side of Worthen Street in Stamps, Arkansas, in a south-north trend, beginning at Ellis Street, to the end of Worthen Street (figs. 2 and 10). The line was constructed in the east ditch adjacent to the asphalt surface of Worthen Street and crossed the asphalt surfaces of 1st Street, 2nd Street, and 3rd Street (figs. 2 and 10). This line was modeled with a finite-difference grid model to aid in interpretation of the inverted field data (figs. 11a and 11b). The input model grid (fig. 11b) was created on the basis of the known geology and the results and interpretations of borehole geophysical data. Although no well data adjacent to the line were available, well data from nearby wells onsite were used. Terrace deposits were modeled as the two uppermost layers with a resistivity of 50 ohm-meters in uncontaminated sediments and extended to about 21 meters (68.9 feet) below land surface. The clay-rich Cook Mountain Formation is modeled as 25 ohm-meters and extends from 21 meters (68.9 feet) below land surface to the bottom of the model. Model data were inverted to represent the inversion section resistivity of field data in figure 10, and results shown in figure 11a.

Modeled inversion results (fig. 11a) indicate a near-surface high resistivity zone (greater than 500 ohm-meters) from 30 to 210 meters (98.4 to 689 feet) on the inversion resistivity section. This zone of high resistivity probably is caused by dry gravel material present in this area. The terrace deposits present in the north part of the model appear as a lower resistivity media possibly caused by higher clay content. This model produced a non-unique solution showing no salt-water contamination in the terrace deposits, the Cook Mountain Formation, or Sparta Sand beneath Worthen Street.

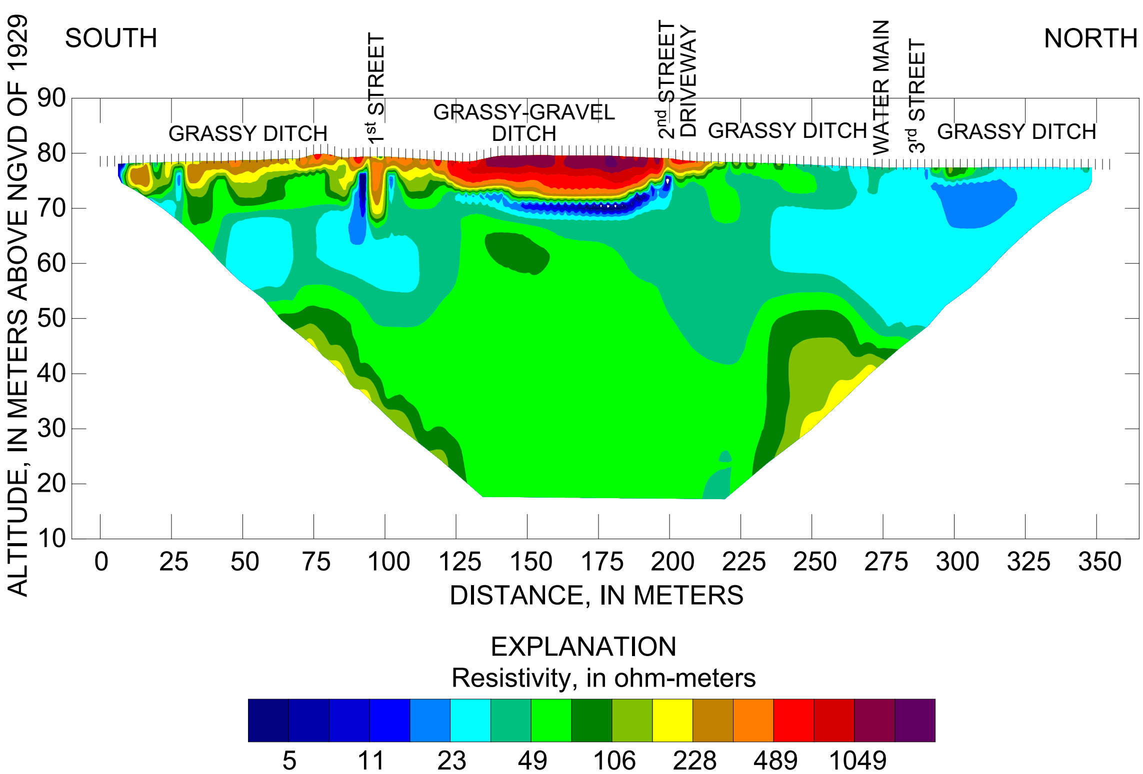


Figure 10. Inverted resistivity section of two-dimensional, direct-current resistivity line 5 field data.

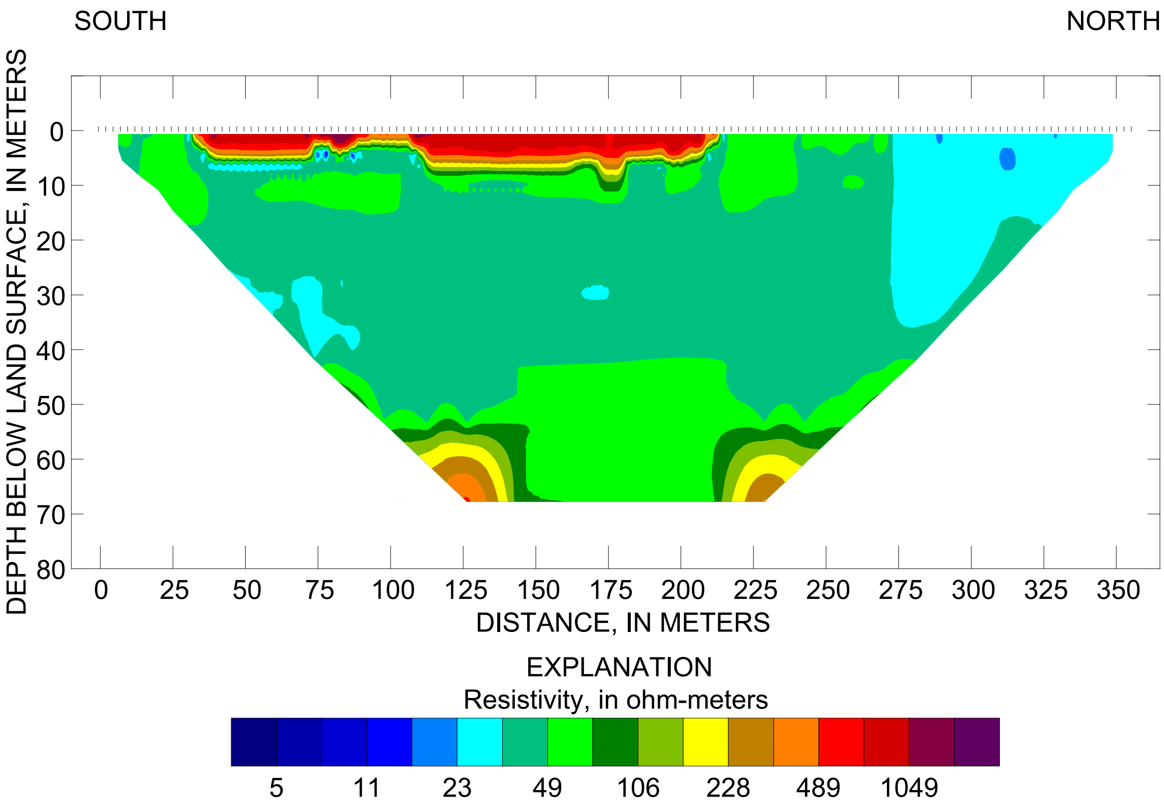


Figure 11a. Inversion resistivity section of modeled resistivity line 5.

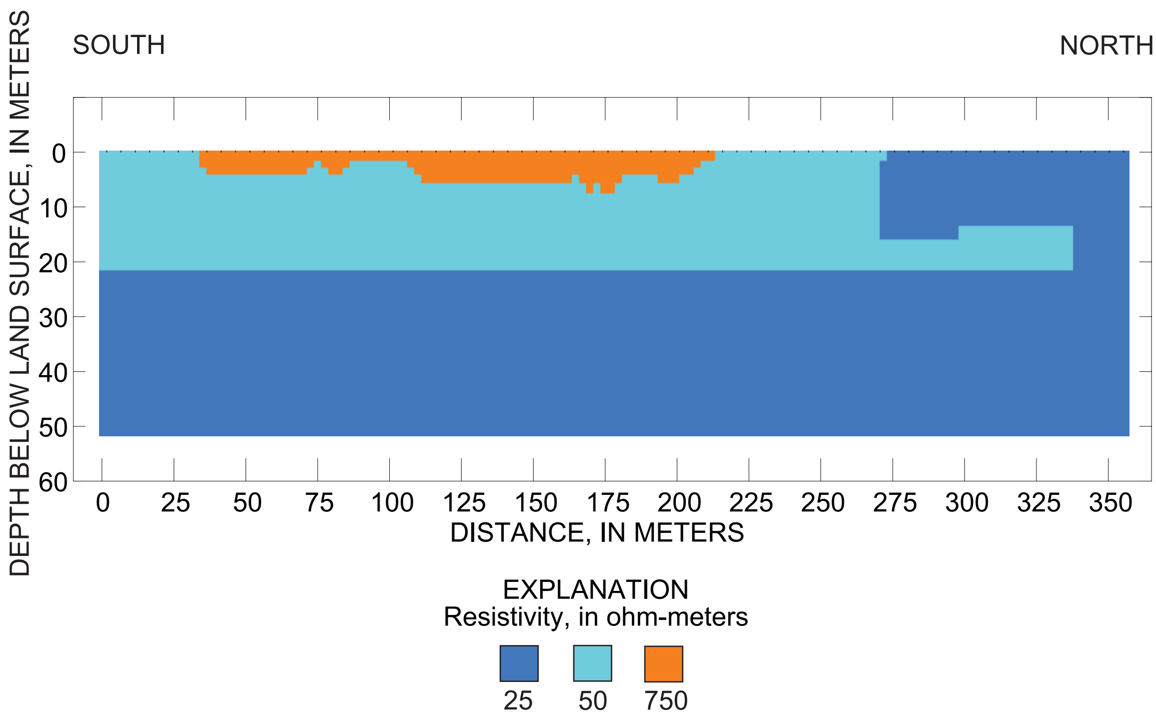


Figure 11b. Model grid of resistivity line 5.

SUMMARY AND CONCLUSIONS

The Red River Aluminum site at Stamps, Arkansas, once contained exposed waste piles of salt and metal byproducts (referred to as salt cake) from the smelting of aluminum. The salt cake was subjected to rainfall, resulting in dissolution and transport of the salts and metals. Brines from the piles flowed into canals and ponds and overland flow moved radially away from a topographic high occurring onsite until it was intercepted by man-made or natural drainages. The presence of brine within the shallow ground-water system has been documented based on specific conductance of ground water as high as 196,200 µS/cm at 25 degrees Celsius. Water-level measurements indicate the depth to water below land surface ranges from about 1.2 to 3.9 feet (0.37 to 1.19 meters) in shallow monitor wells and about 10.5 to 17.1 feet (3.2 to 5.2 meters) in deep monitoring wells.

A surface-geophysical investigation of the Red River Aluminum site was conducted to determine the areal extent and depth of contamination and the depth to the Cook Mountain Formation. The two-dimensional, direct-current resistivity method identified resistivities less than 5 ohm-meters in the subsurface along four resistivity lines within the site. Data with resistivity values of 5 ohm-meters or less were considered to be anomalies and were interpreted as possible areas of salt contamination. Data from the resistivity lines indicate both near-surface and deeper subsurface salt contamination. One line located east of the site yielded data that indicated no salt contamination. Sections from two of the five data sets were modeled using a three-layer, finite-difference resistivity model. The input model grids were constructed on the basis of the known geology and the results and interpretations of borehole geophysical data. The clay-rich Cook Mountain Formation is modeled as 25 ohm-meters and extends from 21 meters (68.9 feet) below land surface to the bottom of the model (about 52 meters (170.6 feet)). The models were used to aid in the interpretation of the resistivity data.

Data from resistivity line 1, trending west to east across the site, identified an area of possible salt contamination near the surface approximately 250 meters (820.1 feet) in length. Low resistivity values approximately 40 meters (131.2 feet) in length range at an altitude of 50 to 60 meters (154 to 196.9 feet) and correspond to the waste cell.

Resistivity line 2, trending south to north across the site, indicated an area of possible salt contamination near the surface approximately 775 meters (2,542.8 feet) in length and deep subsurface area of low resistivity values approximately 270 meters (885.9 feet) in length adjacent to the waste cell. A three-layer resistivity model was developed for line 2. Model resistivity data indicate that the total depth of salt contamination in the area adjacent to the waste cell is about 18 meters (59.1 feet) below land surface. The model resistivity data input simulated the depths of the Cook Mountain Formation.

Resistivity line 3, trending southwest to northeast, detected two low resistivity anomalies. The dominant anomaly occurs near land surface and is approximately 200 meters (656.2 feet) in length. This near-surface zone of contamination possibly is associated with transport of saltwater through a zone of large hydraulic conductivity such as a gravel layer. A small anomaly occurs at the southwestern end of the line and corresponds to a concrete tank on the surface.

Resistivity line 4 extends along the east boundary of the site. One anomaly was identified to be approximately 215 meters (about 705 feet) in length and ranges from 0 to 10 meters (0 to 32.8 feet) from land surface. This low resistivity zone probably is associated with infiltration of precipitation through the salt cake material, which was stored adjacent to the line 4 location.

Unlike the other resistivity lines, line 5 was located off the Red River Aluminum site to the east. Data from the inverted resistivity sections and the resistivity model indicate no saltwater contamination. Resistivity modeling simulated the depth to the Cook Mountain Formation in the inversion model.

REFERENCES

Czarnecki, J.B., Stanton, G.P., and Freiwald, D.A., 2001, Hydrogeology and physical characteristics of water samples at the Red River Aluminum Site, Stamps, Arkansas, April 2001: U.S. Geological Survey Open-File Report 01-201, 30 p.

Degnan, J.R., Moore, R.B., and Mack, T.J., 2001, Geophysical investigations of well fields in characterize fractured-bedrock aquifers in southern New Hampshire: U.S. Geological Survey Water-Resources Investigations Report 01-4183, 54 p.

Freiwald, D.A., 1985, Average annual precipitation and runoff for Arkansas, 1951-80: U.S. Geological Survey Water-Resources Investigations Report 84-4363, 1 plate.

Haeni, F.P., Lane, J.W., Jr., and Lieblich, D.A., 1993, Use of surface-geophysical and borehole radar methods to detect fractures in crystalline rocks, Mirror Lake Area, Grafton County, New Hampshire, in Hydrogeology of Hard Rocks, International Association of Hydrologists, XXIVth Congress, Oslo, Norway, June 1993, Proceedings: Oslo, Norway, International Association of Hydrologists, 11 p.

Loke, M.H., 2002, Rapid 2D resistivity forward modeling using the finite-difference and finite element methods: M.H. Loke, 28 p.

——— 2003, Rapid 2D resistivity and IP inversion using the least-squares method: Geoelectrical Imaging 2-D and 3-D - Geotomo Software, 123 p.

Ludwig, A.H., 1972, Water resources of Hempstead, Lafayette, Little River, Miller, and Nevada Counties, Arkansas: U.S. Geological Survey Water-Supply Paper 1998, 41 p.

Powers, C.J., Wilson, Joanna, Haeni, F.P., and Johnson, C.D., 1999, Surface-geophysical characterization of the University of Connecticut landfill, Storrs, Connecticut: U.S. Geological Survey Water-Resources Investigations Report 99-4211, 34 p.

RMT Inc., 2000, Red River Aluminum site supplemental investigation and feasibility study, Stamps, Arkansas: 51 p.

Woodward-Clyde Consultants, 1992, Untitled consultant's report to Red River Aluminum, Inc. #89B164C: 41 p.

Weston, Roy F., Inc., 2001, Removal report for Red River Aluminum, Stamps, Lafayette County, Arkansas for USEPA Region 6: Document control no. 12632.2001.0297, 2206 p.

SUPPLEMENTAL DATA

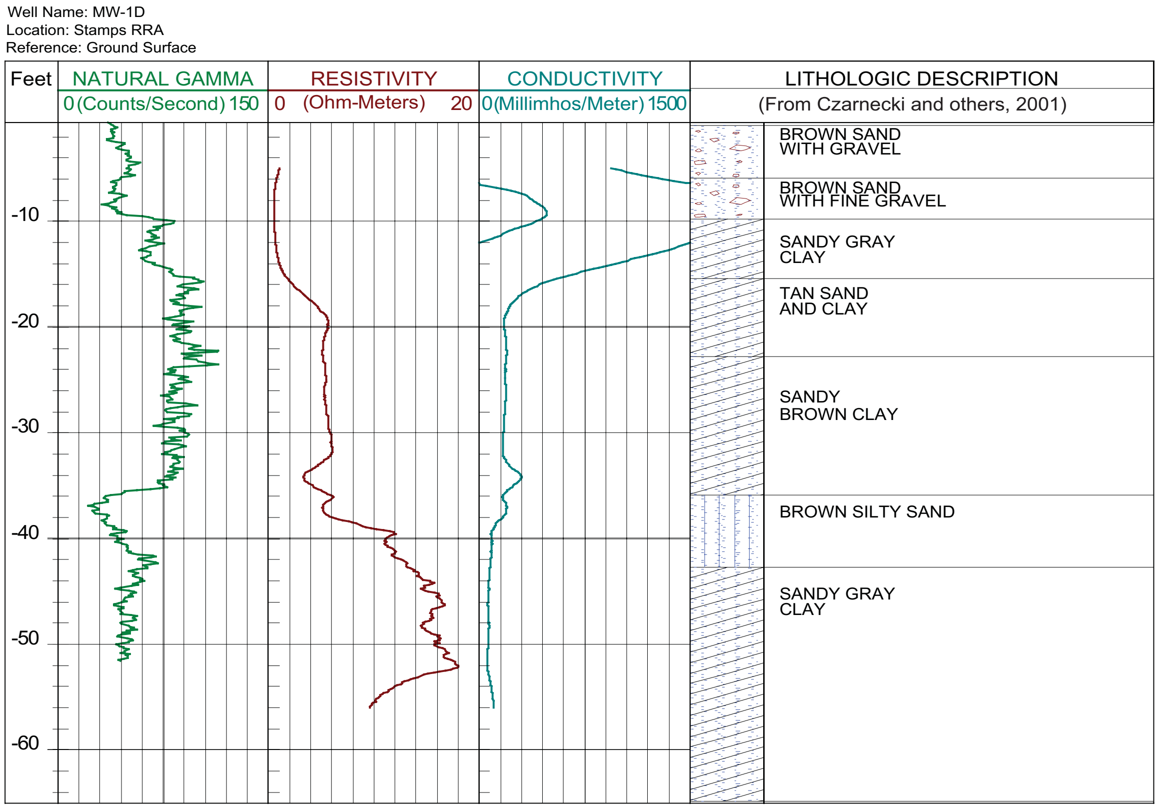


Figure 12a. Geophysical log of monitor well 1D.

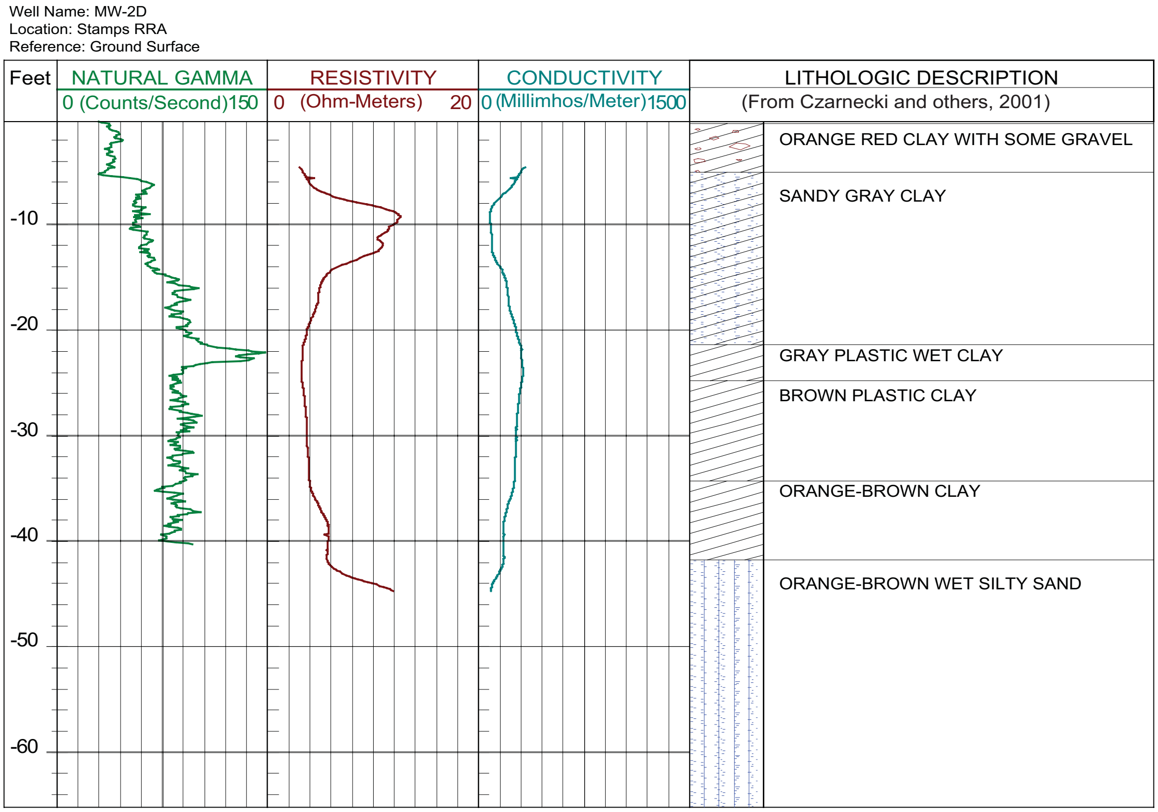


Figure 12b. Geophysical log of monitor well 2D.

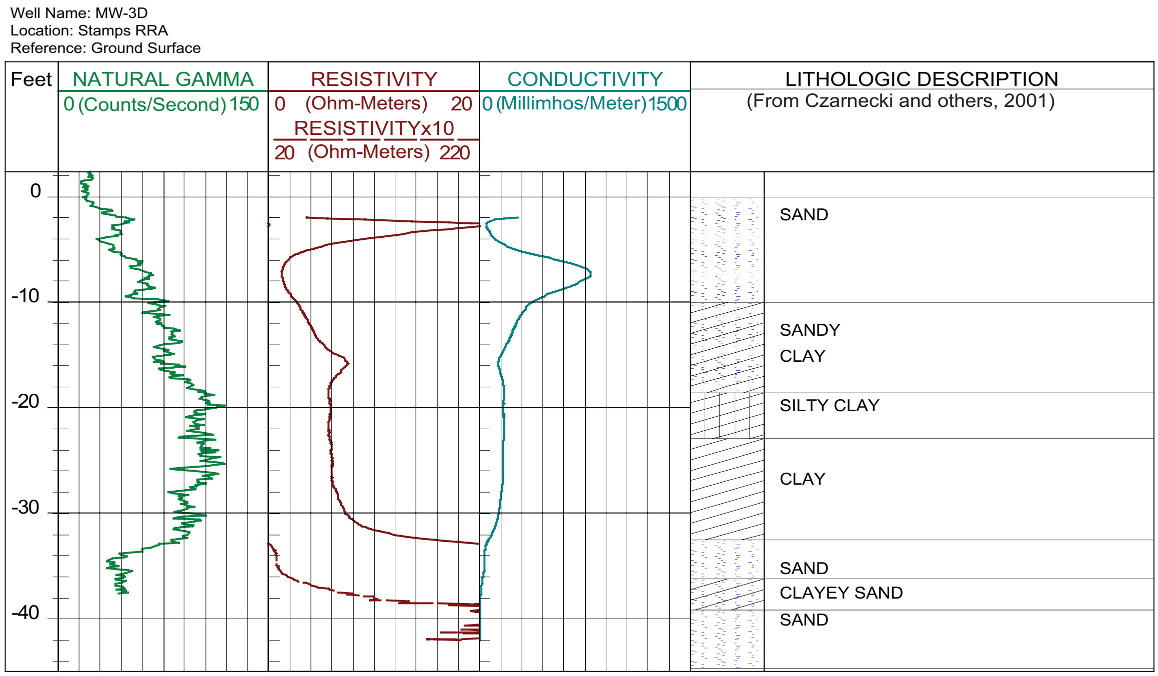


Figure 12c. Geophysical log of monitor well 3D.

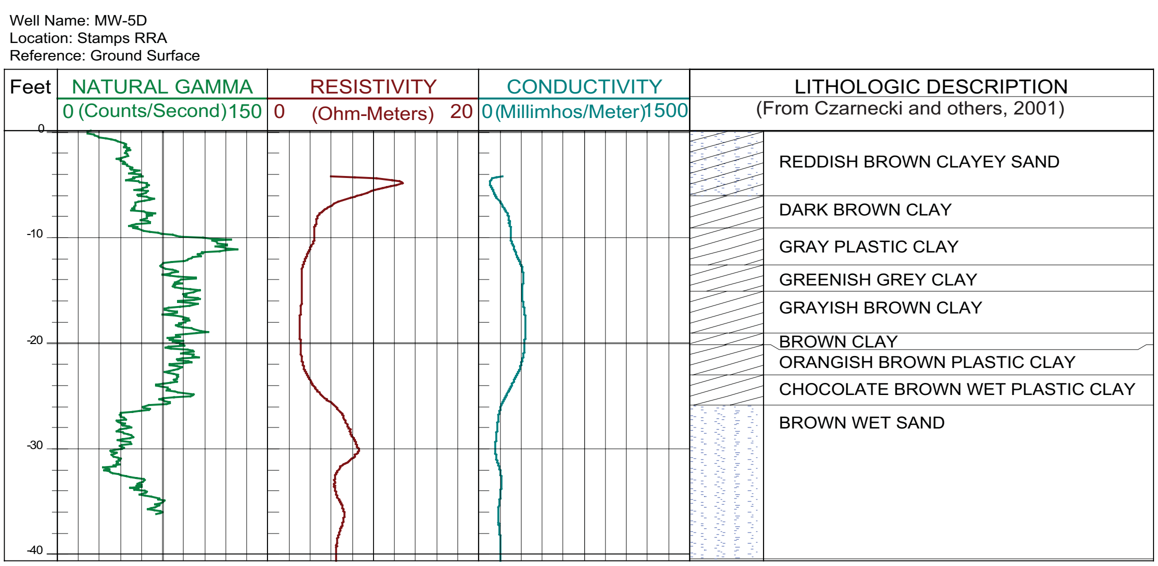


Figure 12d. Geophysical log of monitor well 5D.

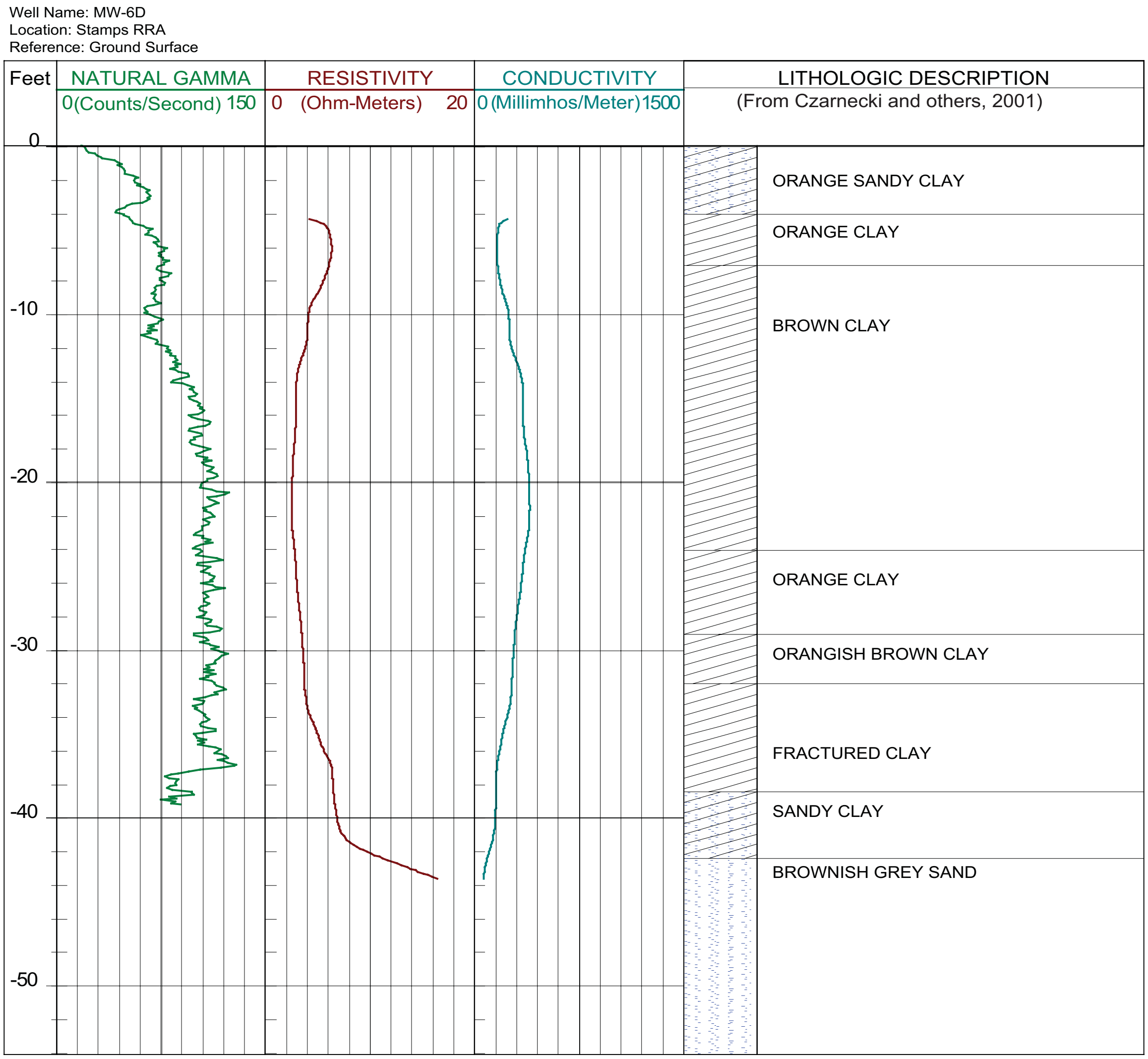


Figure 12e. Geophysical log of monitor well 6D.

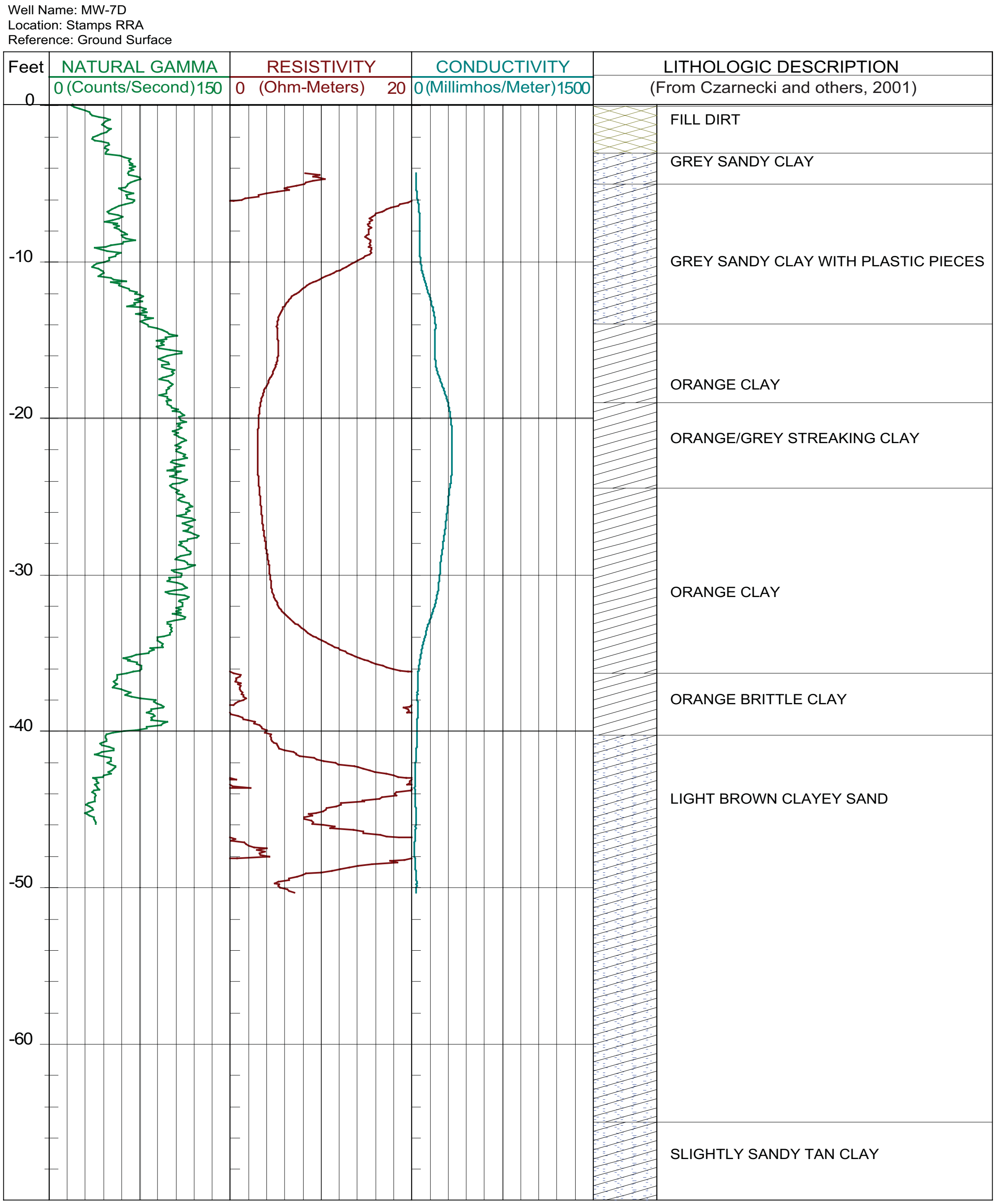


Figure 12f. Geophysical log of monitor well 7D.

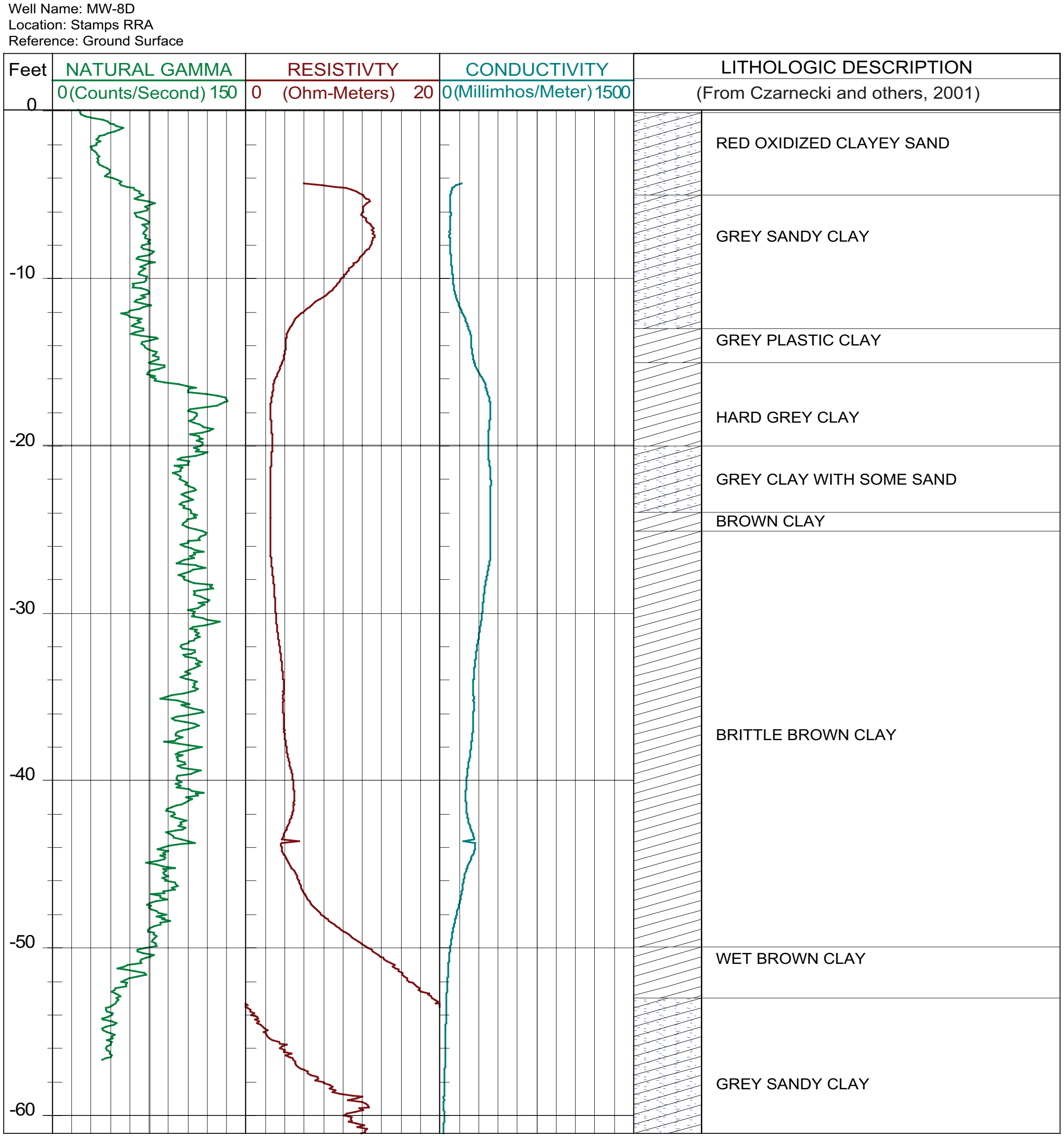


Figure 12g. Geophysical log of monitor well 8D.

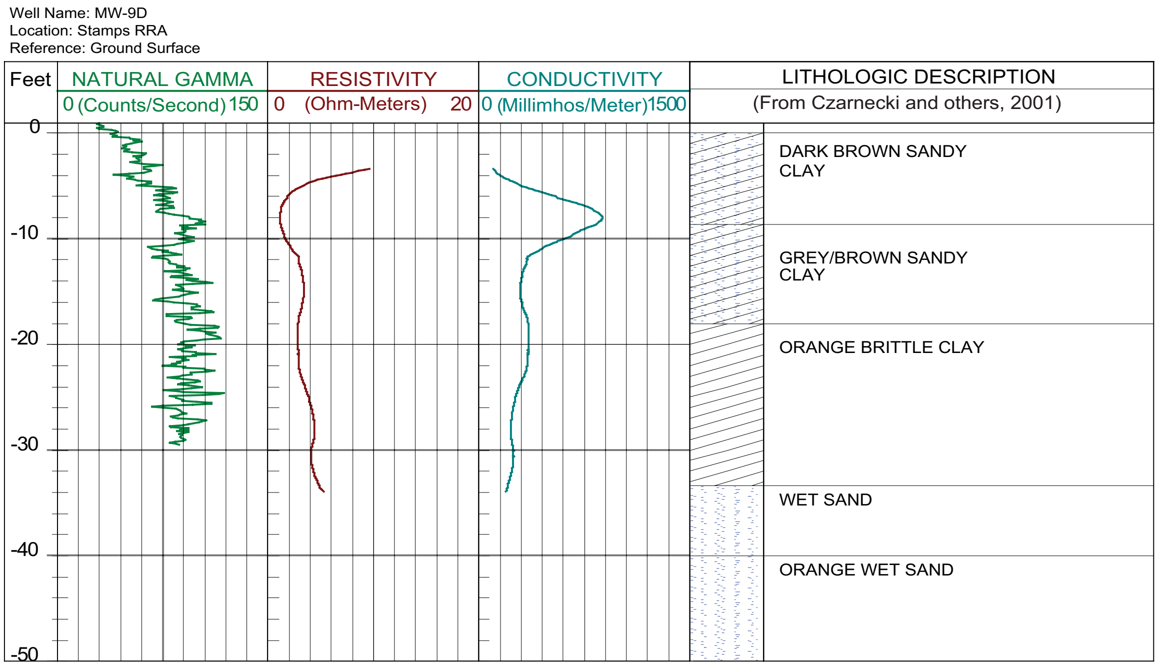


Figure 12h. Geophysical log of monitor well 9D.

Stanton, G.P., Kress, Wade, Hobza C.M., and Czarnecki, J.B.—POSSIBLE EXTENT AND DEPTH OF SALT CONTAMINATION IN GROUND WATER USING GEOPHYSICAL TECHNIQUES, RED RIVER ALUMINUM SITE, STAMPS, ARKANSAS, APRIL 2003
U.S. Geological Survey Water-Resources Investigations Report 03-4292