Hydrogeology and Physical Characteristics of Water Samples at the Red River Aluminum Site, Stamps, Arkansas, April 2001

By John B. Czarnecki, Gregory P. Stanton, and David A. Freiwald

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CONTENTS

ILLUSTRATIONS

TABLES

Hydrogeology and Physical Characteristics of Water Samples at the Red River Aluminum Site, Stamps, Arkansas, April, 2001

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ABSTRACT

The Red River Aluminum site near Stamps, Arkansas, contains waste piles of salt cake and metal byproducts from the smelting of aluminum. The waste piles are subjected to about 50 inches of rainfall a year, resulting in the dissolution of the salts and metal. To assess the potential threat to underlying ground-water resources at the site, its hydrogeology was characterized by measuring water levels and field parameters of water quality in 23 wells and at 2 surface-water sites. Seventeen of these monitor wells were constructed at various depths for this study to allow for the separate characterization of the shallow and deep ground-water systems, the calculation of vertical gradients, and the collection of water samples at different depths within the flow system. Lithologic descriptions from drill-hole cuttings and geophysical logs indicate the presence of interbedded sands, gravels, silts, and clays to depths of 65 feet. The regionally important Sparta aquifer underlies the site. Water levels in shallow wells indicate radial flow away from the salt-cake pile located near the center of the site. Flow in the deep system is to the west and southwest toward Bodcau Creek. Water-level data from eight piezometer nests indicate a downward hydraulic gradient from the shallow to deep systems across the site. Values of specific conductance (an indicator of dissolved salts) ranged from 215 to 196,200 microsiemens per centimeter and indicate that saline waters are being transported horizontally and vertically downward away from the site.

INTRODUCTION

In cooperation with the U.S. Environmental Protection Agency (USEPA), the U.S. Geological Survey (USGS) performed a reconnaissance hydrogeological study of the Red River Aluminum site located at Stamps, Arkansas (fig. 1). The site contains waste piles of salt and metal byproducts from the smelting of aluminum. The waste is subjected to rainfall, resulting in dissolution of the salts and metals (RMT, Inc., 2000). Brines from the piles flow into canals. Prior to the site remediation work by the USEPA, these canals fed two ponds (fig. 2). Furthermore, the surface water poses a threat to underlying ground-water resources, particularly the regionally important Sparta aquifer, part of whose recharge is derived from the area.

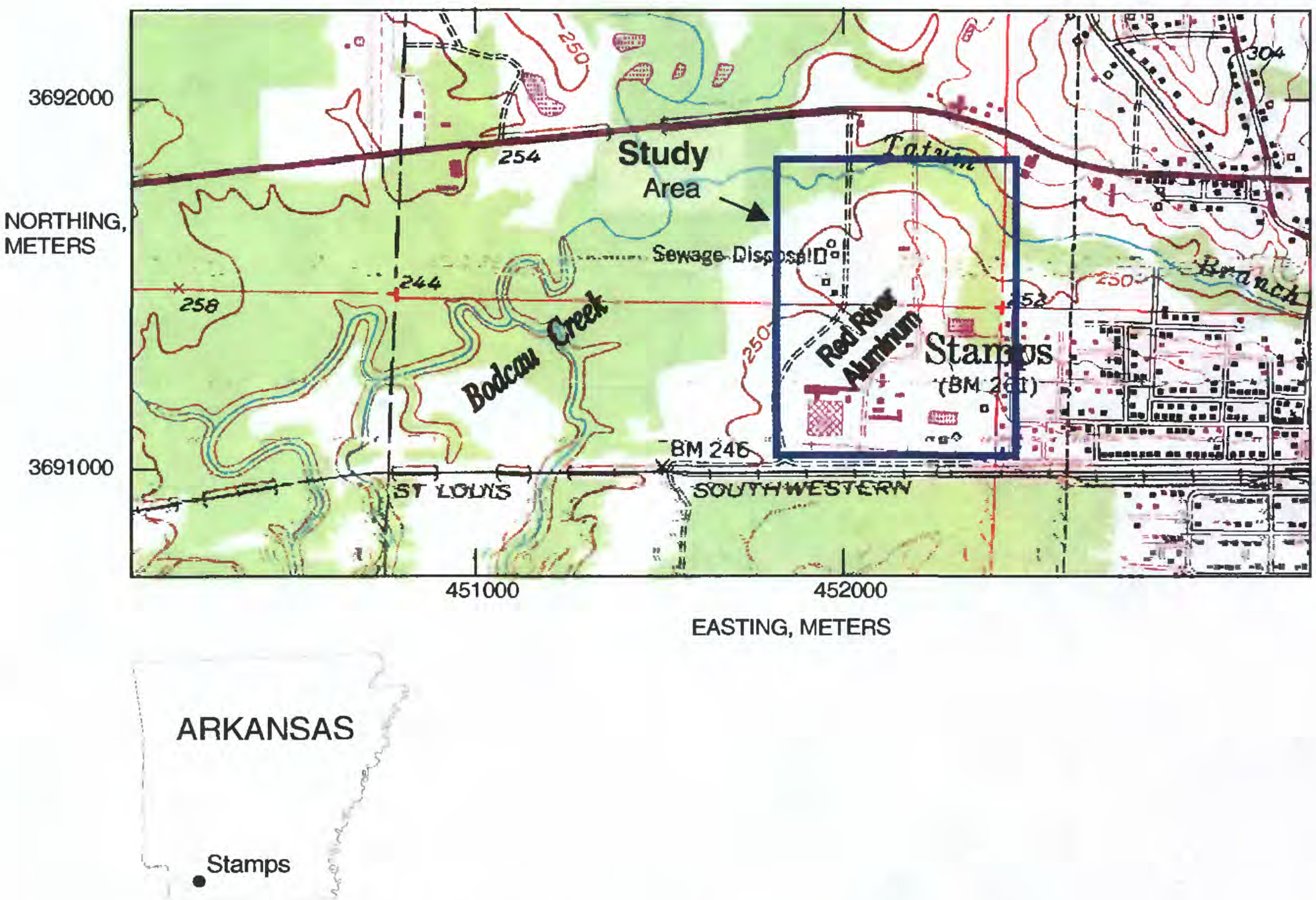


Figure 1. Location of study area.

The study area (which includes the property previously owned by the Red River Aluminum Company) is east of Bodcau Creek, mostly south of Tatum Branch of Bodcau Creek, north of the St. Louis-Southwestern Railroad, and west of the city of Stamps. Forest areas surround the site. The topographic relief of the study site is about 10 feet (ft). Part of the site lies at a local topographic high point, and the salt cake stored on the site has been piled on top of this topographic high. Surface-water runoff (from the over 50 inches of precipitation per year, Freiwald, 1985) occurs radially from the topographic high until it is intercepted by man-made or natural drainages.

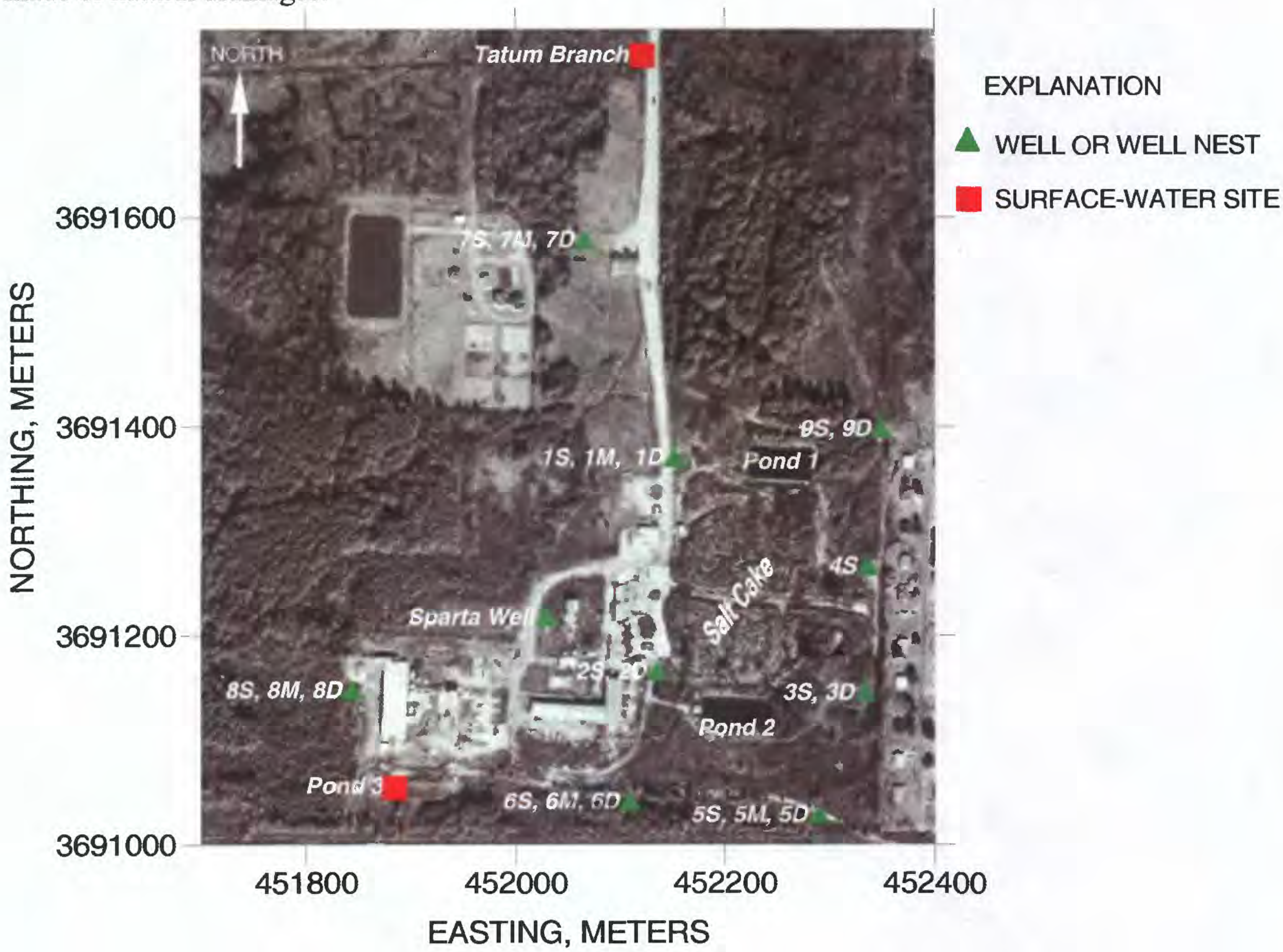


Figure 2. Monitor wells and water-level measuring locations. Well nests are sites with multiple number/letter designations.

Georgia Pacific originally used the site as a sawmill (Mark Robinson, Georgia Pacific, oral commun., January 8, 2001). Most of the sawmill water was obtained from water mains connected to the city of Stamps water system. One well completed within the Sparta aquifer 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 oriented between the two ponds. These two ponds have subsequently been drained, lined with fly ash, and infilled with salt cake (Pat Hammack, U.S. Environmental Protection Agency, oral commun., March 2001).

In 1979, Red River Aluminum Company occupied the site and began extracting and recovering aluminum from primary aluminum-production drosses. 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 by gravity. The remaining salt cake was gathered into piles between the two ponds (Woodward-Clyde Consultants, 1992).

A 3,164-ft deep injection well was constructed onsite in 1992 and screened within the Tokio Formation. A permit was issued from USEPA 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.

Purpose and Scope

The purpose of this report is to determine and document (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. Analyses of specific ions of dissolved constituents are not part of this study. A preliminary conceptual model of flow has been developed, and a brief evaluation of the extent of salt movement based on specific-conductance data is provided. The work presented in this report provides a basis for future sampling and analysis of water samples for major ions and metals, and the development of numerical models of ground-water flow and transport.

Previous Investigations

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-ft 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 (MW-3D) to a depth of 45 ft below land surface. The RMT investigation suggested that the shallow wells drilled by Woodward-Clyde Consultants terminated in a shallow perched-water body, and that the deeper monitor well, MW-3D, was completed in the first saturated sand zone. The results from this investigation showed elevated salt concentrations in ground- and surface-water samples.

Methods

Hydrogeologic characterization of the site was done by using existing monitor-well data and by constructing additional wells at various locations around the site (fig. 2). General lithologic descriptions were made during auger drilling from cuttings emerging at land surface. Wells were constructed in nests using solid-stem auger-drilling methods to depths as great as 64 ft. Individual boreholes were screened using 5 ft of 2-inch diameter flush-joint PVC screen in the deep wells and 2.5 ft of 2-inch diameter flush-joint PVC screen in the moderate- and shallow-depth monitor wells. Screen slot size selected was 0.010 inch. Screened intervals were backfilled with 0.024-inch diameter sand, and bentonite pellets were added above the sand pack to isolate the screened interval. The average depths below land surface of the bottom of the screened intervals were 10, 22, and 51 ft for shallow (S), moderate (M), and deep (D) monitor wells, respectively.

Newly drilled wells were developed using airlifting to remove cuttings and stimulate flow into the wells. Hydraulic testing was performed on selected wells using slug tests (Hvorslev, 1951) that ranged from a few minutes to 12 hours in duration. The test consisted of measuring displaced water levels in a well by quickly lowering a weighted displacer (slug) into the water column, and monitoring the recovery of water levels using a water-level recording system. In the analysis of data collected, water-level displacement is plotted against time, from which values of hydraulic conductivity are estimated. Water sampling was done in all the monitor wells using a dedicated PVC bailer following well purging and water-level recovery.

Borehole geophysical methods were used in deep wells to characterize the stratigraphy and water quality at the site. Deep wells were geophysically logged using natural gamma and electromagnetic-induction conductivity measurements. Natural gamma and conductivity measurements were used to confirm stratigraphic information gained in cuttings descriptions. Conductivity measurements that seem high were used to delineate possible zones where highly mineralized water may be contained in sediments at the site.

Acknowledgments

USGS staff performed all fieldwork. Of particular significance was the contribution provided by Ralf Montanus in his tireless and conscientious attention to drilling, sampling, and water-level monitoring. Pat Hammack (USEPA On Scene Coordinator) was helpful in providing logistical support during site visits.

HYDROGEOLOGY

Lithology

Based on a driller's log for a 351-ft deep well (Sparta Well, fig. 2) drilled for Georgia Pacific onsite and logs for numerous shallower wells drilled subsequently, the upper 190 ft 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 this log to occur at depths between 190 to 288 ft below land surface, and is overlain by a clay unit 66 to 190 ft below land surface.

A more detailed investigation of the shallow wells drilled onsite reveals that from land surface to a depth of about 10 to 20 ft, sediments consist of sandy clays, gravels, and minor silts. This is underlain by a dense, sometimes brittle clay unit between 20 to 30 ft thick, which is underlain by an unconsolidated fine sand with a thickness of at least 20 ft.

Geophysical logs of the deep boreholes are presented in the Supplemental Data section at the end of this report. Natural gamma logs are helpful in interpreting the presence of clays. Electrical conductance is an excellent indicator of the presence of brines resulting from leaching of the salt cake. The logs include a general lithologic description based on cuttings collected during auger drilling.

Water Levels

A reconnaissance of wells in the vicinity of the Red River Aluminum site was made by reviewing USGS well files, visiting neighboring land owners and businesses, and talking to officials of the city of Stamps. Wells were sought that were completed in the upper 100 ft of the Quaternary terrace deposits. However, no such wells were available, probably because the city of Stamps provides municipal water to its residences and businesses, thus making shallow wells unnecessary.

Water levels were measured in all wells onsite and are listed in table 1. Several of the shallow drillholes were very slow to yield water because of the poorly transmissive materials in which they were completed; in fact, at the time some of the wells were cased, there was no measurable water in them. However, after a period of several days, all monitor wells (including those completed in clays) had measurable water levels. All measuring points at wells were surveyed to allow the calculation of water-level altitude. Water-level altitudes were used to determine the potential for vertical and horizontal components of flow. Vertical gradients were calculated as the difference in water level altitude divided by the difference in the altitude of the center of the screen depth using water levels from two or three adjacent wells screened at different depths to form eight piezometer nests.

Water levels were measured on March 22, 2001, in all wells following the construction of all new monitor wells and later on April 11, 2001, before water sampling. In general, water-level change was less than 0.5 ft during this period for most of the wells. However, wells

MW-1M, MW-5M, MW-7S, and MW-9S rose 5.65, 2.34, 1.1, and 1.22 ft, respectively, during this period as water continued to enter these wells through low permeability clays. Water levels from the moderate-depth wells were not used to produce contours of water-level altitudes because wells MW-1M and MW-5M were considered not to reflect ambient conditions and there were insufficient moderate-depth wells to prepare a meaningful map.

Shallow Ground-Water System

Water-level data indicate that flow occurs radially away from the salt-cake pile within the shallow ground-water system. Water-level altitudes measured in the shallow wells onsite are shown in figure 3. Water-level altitudes within the shallow system are highest toward the salt-cake pile (the highest surface onsite) and decrease away from the pile. Because of the shallow depths of the screened intervals of these wells (average depth of about 10 ft below land surface) and because no distinct confining unit was encountered in these boreholes, the system is considered to represent the water table. Included in this rendering of the water table are two surface water points: the northern-most point (242.7 ft altitude) at Tatum Branch of Bodcau Creek; and the southwestern-most point (255.2 ft altitude) at pond 3 (fig. 2). Hydraulic gradient is variable and ranges from about 0.005 in the southwestern part of the site to about 0.02 in the northern part. Hydraulic gradient is the hydraulic-head loss in feet per foot of ground-water travel through the porous medium (Driscoll, 1986, p. 74).

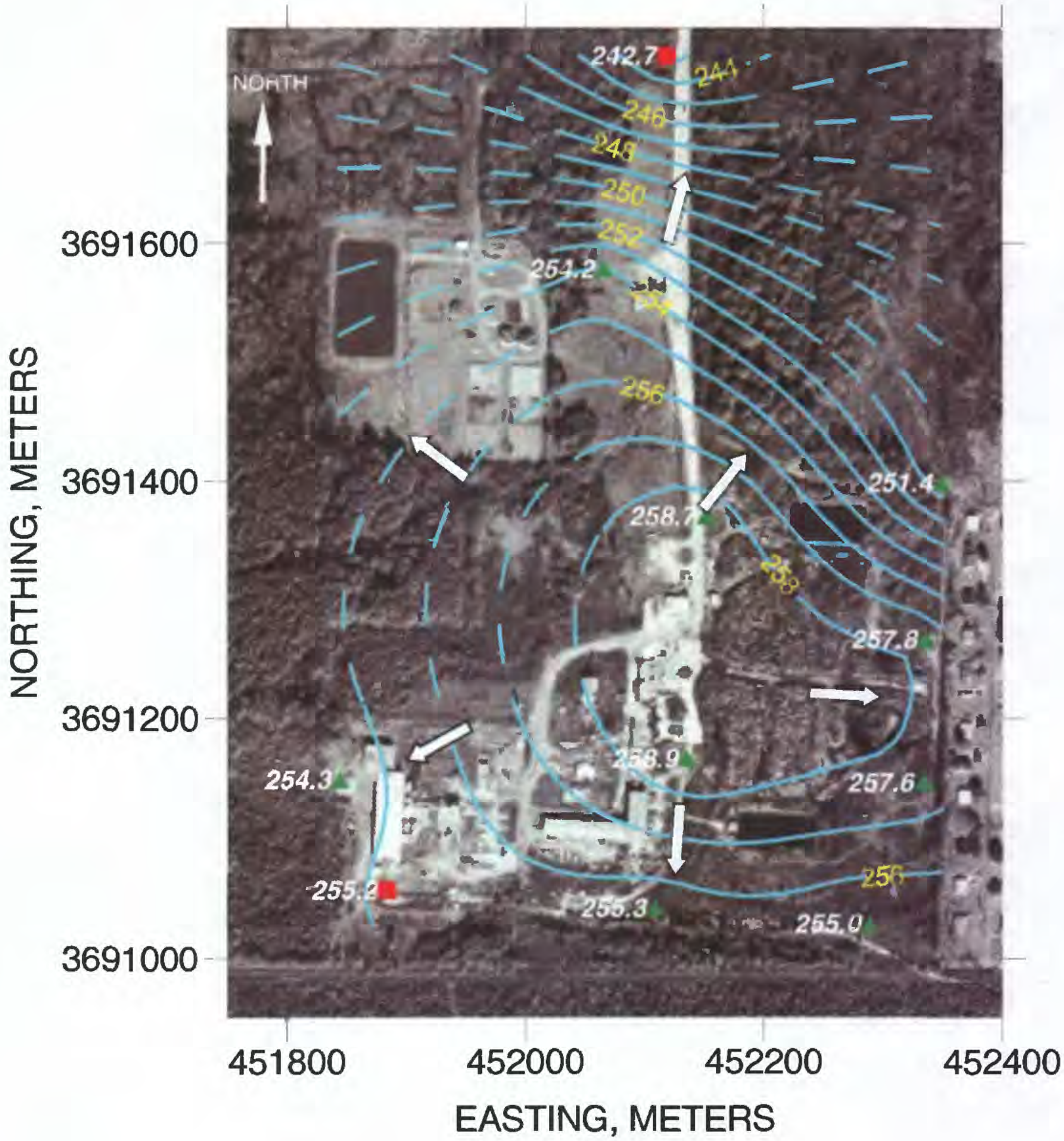
Deep Ground-Water System

Lateral flow direction of ground water in the deep system, in contrast to the shallow system, is west to southwest toward Bodcau Creek (fig. 4). The midpoint depths of the screened intervals of the deep wells average 48.5 ft below land surface. The horizontal hydraulic gradient across the deep system is about 0.003.

Table 1. Water-level measuring point locations, well construction data, and water levels
[N/A, data unavailable or not applicable]

Well or site name	UTM easting (meters)	UTM northing (meters)	Well depth (feet)	Midpoint altitude of screen (feet)	Measuring point altitude (feet)	Borehole diameter (inches)	Casing diameter (inches)	Screen length (feet)	Depth to water below measuring point on 4/11/01 (feet)	Depth to water below land surface (feet)	Water-level altitude (feet)
MW-1D	452152.53	3691363.30	59	207	262.90	7.50	2	5.0	18.24	16.64	244.66
MW-1M	452150.68	3691365.72	26	239	263.15	7.50	2	2.5	13.00	11.30	250.15
MW-1S	452151.24	3691370.91	13	256	263.05	10.25	4	10.0	4.35	1.85	258.70
MW-2D	452115.58	3691186.21	54	209	259.85	7.50	2	5.0	16.06	14.87	243.79
MW-2S	452135.27	3691166.60	14	252	260.45	10.25	4	10.0	1.58	-0.02	258.87
MW-3D	452310.25	3691128.40	45	224	264.50	6.00	2	10.0	16.87	13.47	247.63
MW-3S	452333.23	3691146.61	13	255	262.95	10.25	4	10.0	5.32	3.12	257.63
MW-4S	452336.00	3691266.99	8	256	261.40	10.25	4	5.0	3.60	1.50	257.80
MW-5D	452291.74	3691027.67	43	218	258.40	8.25	2	5.0	10.91	9.70	247.49
MW-5M	452290.51	3691028.57	21	238	258.45	7.50	2	2.5	3.54	2.23	254.91
MW-5S	452288.98	3691029.16	11	249	258.70	7.50	2	2.5	3.73	2.07	254.97
MW-6D	452105.12	3691042.28	49	212	257.65	7.50	2	5.0	14.13	12.88	243.52
MW-6M	452106.95	3691042.00	22	237	257.35	7.50	2	2.5	3.60	2.70	253.75
MW-6S	452109.38	3691042.32	11	248	258.10	7.50	2	2.5	2.75	1.33	255.35
MW-7D	452064.52	3691575.12	60	202	259.35	7.50	2	5.0	12.90	11.40	246.45
MW-7M	452061.12	3691579.35	22	238	258.55	7.50	2	2.5	6.34	5.26	252.21
MW-7S	452066.01	3691578.79	11	249	258.85	7.50	2	2.5	4.62	3.55	254.23
MW-8D	451842.88	3691154.57	64	196	257.95	7.50	2	5.0	16.68	15.65	241.27
MW-8M	451843.21	3691151.83	20	242	259.95	8.25	2	2.5	5.84	2.84	254.11
MW-8S	451843.84	3691149.10	11	248	257.95	7.50	2	2.5	3.62	2.52	254.33
MW-9D	452349.04	3691396.62	38	225	260.50	7.50	2	5.0	12.45	11.25	248.05
MW-9S	452349.03	3691398.45	12	249	259.20	7.50	2	2.5	7.81	7.31	251.39
Sparta Well	452029.03	3691218.57	286	-16	259.35	N/A	6	20.0	51.38[1]	51.38	207.97
Tatum Branch	452118.49	3691756.34	N/A	N/A	243.65	N/A	N/A	N/A	1.[2]	N/A	242.65
Pond 3	451883.44	3691057.47	N/A	N/A	255.20	N/A	N/A	N/A	0.[3]	N/A	255.20

[1] Measurement made on January 2, 2001.
[2] Visual estimate.
[3] Water-surface altitude was surveyed directly.



EXPLANATION

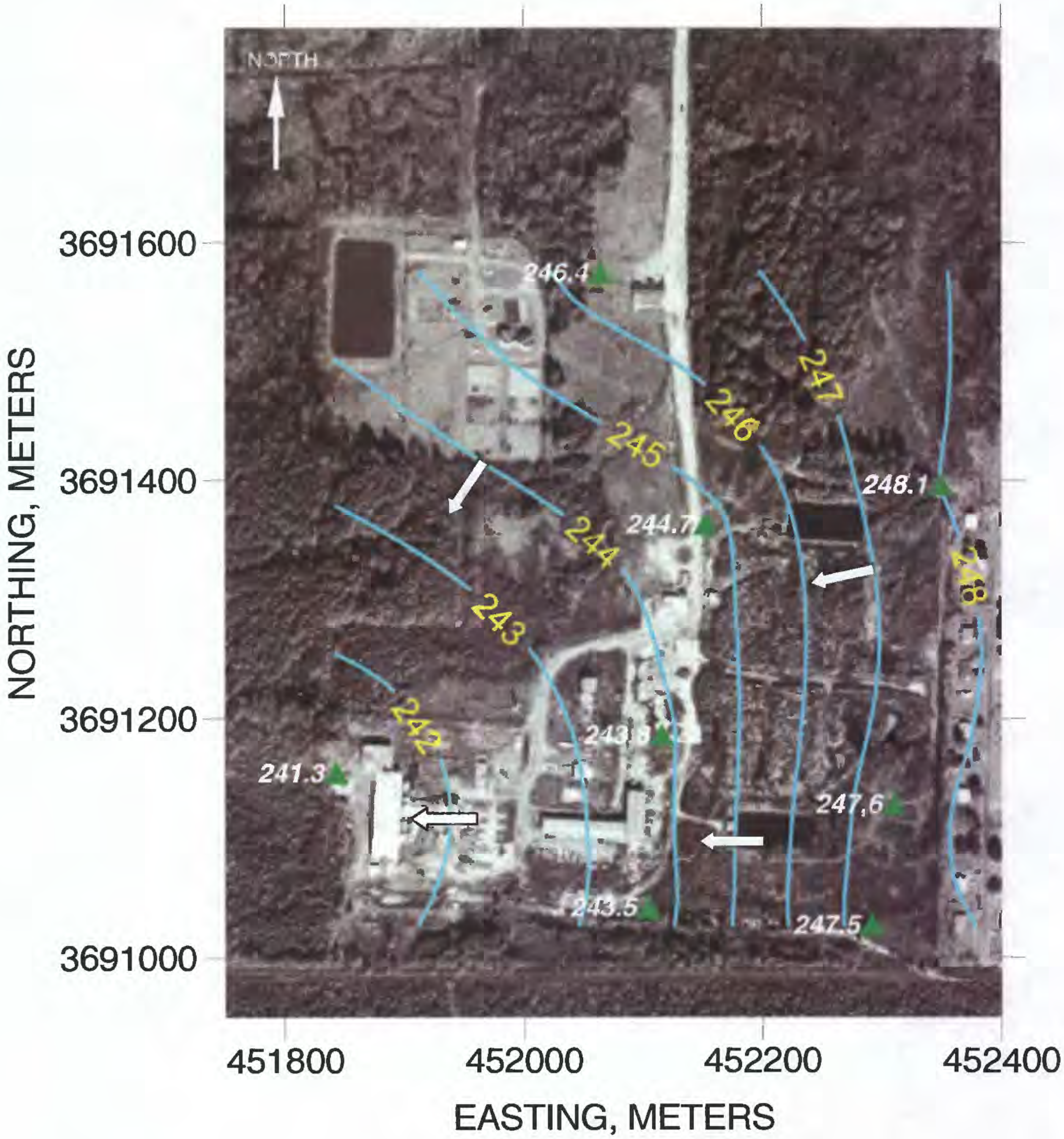
256 — WATER TABLE CONTOUR—Shows altitude of water table, April 11, 2001. Dashed where approximately located. Contour interval, 1 foot. Datum is sea level

255.0 — WELL LOCATION—Number is water-level altitude, in feet above sea level

255.2 — SURFACE-WATER SITE—Number is water-level altitude, in feet above sea level

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.



EXPLANATION

242 POTENTIOMETRIC CONTOUR—Shows altitude to which water in tightly cased wells will rise based on water-level data collected, April 11, 2001. Contour interval, 1 foot. Datum is sea level

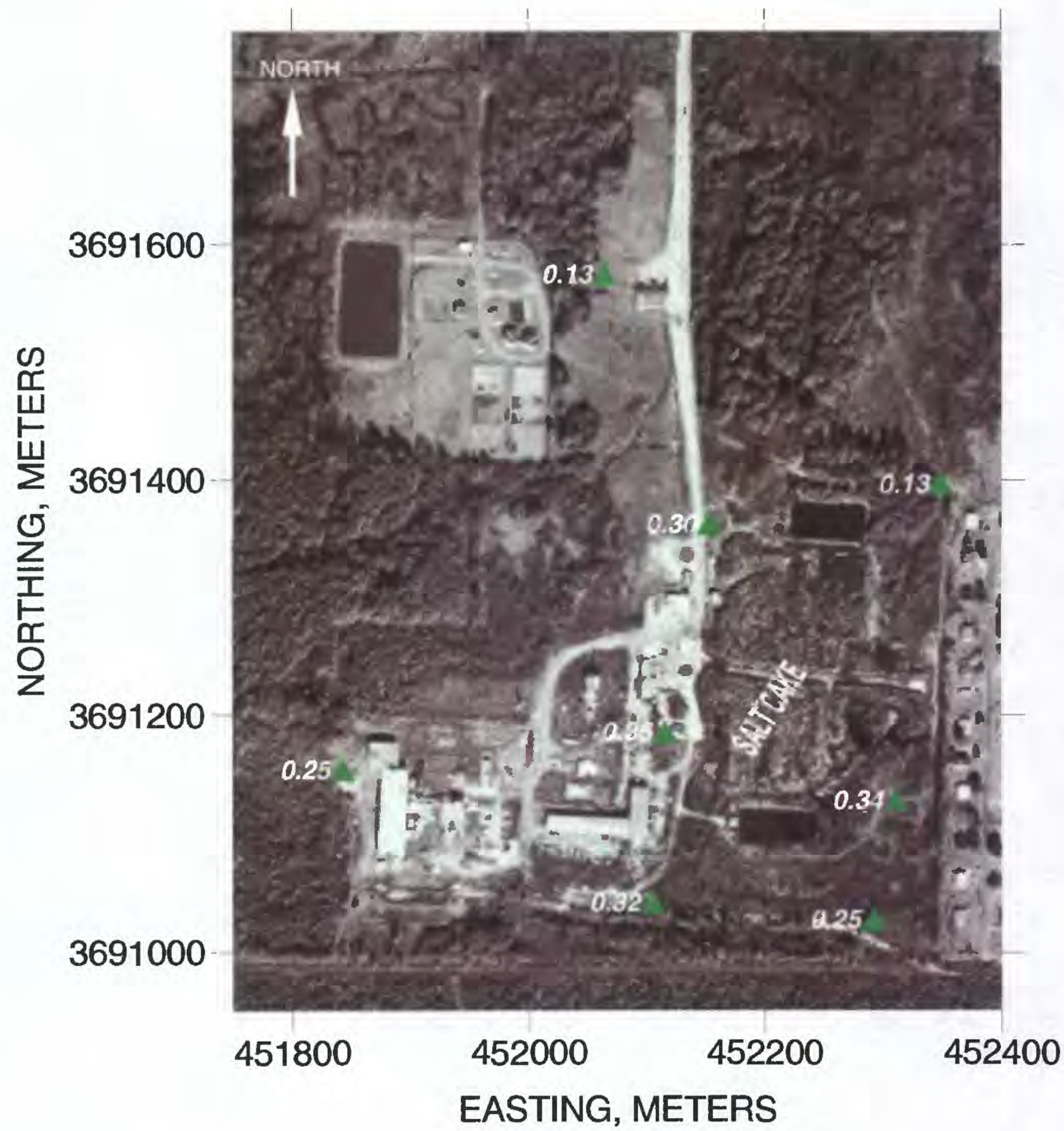
241.3 ▲ WELL LOCATION—Number is water-level altitude, in feet above sea level

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.

Vertical Hydraulic Gradients

A comparison of water levels between the shallow (fig. 3) and deep (fig. 4) ground-water systems onsite shows a considerable decrease in water-level altitude in the deep system. This condition indicates the potential for downward flow and is consistent with the regional hydrogeologic setting as being a recharge area for the Sparta aquifer. The water-level altitude in the Sparta Well (fig. 2) was the lowest of all the wells measured onsite (207.97 ft on January 2, 2001).



Explanation

0.32 ▲ LOCATION OF WELL NEST—Value is vertical hydraulic gradient and represents the decrease in hydraulic head in feet for a unit change in depth in feet

Figure 5. Vertical hydraulic gradients.

Vertical hydraulic gradients were estimated at eight well-nest locations onsite by computing the slope of the line of best fit through water-level altitude data versus the midpoint of the well-screen altitude for each well nest using water-level data collected on April 11, 2001 (fig. 5). There is a larger downward gradient toward the center of the site, indicating the potential for downward migration of saline water from the salt cake. Although the vertical hydraulic gradients are larger than the horizontal gradients for either the shallow or deep systems, this only indicates the potential for flow, and does not reflect the rate of flow. The rate of flow will be discussed in the next section of this report.

Table 2. Physical characteristics of water samples and hydraulic conductivity
[μS/cm, microsiemens per centimeter at 25 degrees Celsius; all water samples were collected on April 12, 2001; N/A, data not available]

Well or site name	Temperature (degrees Celsius)	pH	Specific conductance (μS/cm)	Log of specific conductance	Date of hydraulic test	Hydraulic conductivity (feet/day)
MW-1D	19.6	7.01	9,200	3.96	March 28, 2001	0.01
MW-1M	18.7	7.30	73,400	4.87	March 28, 2001	0.01
MW-1S	16.8	7.15	43,300	4.64	March 29, 2001	20.9, 23.1[1]
MW-2D	21.1	6.52	4,550	3.66	March 29, 2001	0.6
MW-2S	19.5	3.62	196,200	5.29	March 29, 2001	3.4
MW-3D	17.1	7.11	2,760	3.44	N/A	N/A
MW-3S	17.9	4.73	51,400	4.71	N/A	25.4[1]
MW-4S	20.9	9.22	92,000	4.96	N/A	N/A
MW-5D	16.3	6.80	4,750	3.68	March 29, 2001	0.2
MW-5M	16.1	6.37	6,500	3.81	March 29, 2001	0.1
MW-5S	18.8	5.90	6,110	3.79	March 29, 2001	0.1
MW-6D	17.4	7.11	1,480	3.17	March 29, 2001	0.9
MW-6M	19.7	6.49	12,870	4.11	March 29, 2001	0.05
MW-6S	18.8	5.51	6,170	3.79	March 29, 2001	0.02
MW-7D	17.4	5.76	215	2.33	March 28, 2001	3.2
MW-7M	16.8	6.51	6,600	3.82	March 28, 2001	0.5
MW-7S	16.4	6.17	668	2.82	March 28, 2001	0.2
MW-8D	20.0	6.98	1,680	3.23	March 29, 2001	0.08
MW-8M	20.0	6.25	10,490	4.02	March 29, 2001	0.4
MW-8S	19.3	5.57	4,480	3.65	March 29, 2001	0.01
MW-9D	15.9	6.54	2,620	3.42	N/A	N/A
MW-9S	14.8	3.77	58,400	4.77	N/A	N/A
Tatum Branch	18.0	6.85	272	2.43	N/A	N/A
Pond 3	21.4	7.48	11,550	4.06	N/A	N/A
Pond 3 (bottom sample)	25.3	8.37	39,000	4.59	N/A	N/A

[1] Value from test by Woodward-Clyde Consultants (1992).

Hydraulic Testing

A wide range of hydraulic-conductivity values resulted from slug tests done in the various lithologic units encountered onsite (very tight clays to transmissive, well sorted gravels). Values of hydraulic conductivity (table 2), from slug testing obtained using the technique of Hvorslev (1951), reflect conditions in the immediate vicinity of the borehole and may be affected by factors such as incomplete well development, clogged screens, or gravel pack spanning a larger interval than that of the screen. This later condition may explain the relatively large values of hydraulic conductivity in wells MW-1S and MW-3S. However, drillers' logs of wells MW-1M and MW-1D (which are located adjacent to well MW-1S) revealed a well sorted gravel layer near the screened depth of MW-1S, but was not recorded in the log for MW-1S (Woodward Clyde Consultants, 1992). The presence of gravels would explain the large value of hydraulic conductivity (20.9 ft/d) for well MW-1S. These gravels likely represent a buried stream-channel deposit that could provide a preferential flow path for saline water away from the salt-cake pile. However, the lateral extent of these gravels is unknown.

Ground-water flow rates may be estimated from values of the hydraulic conductivity and hydraulic gradient using Darcy's law, which can be written as

$$V = K\,I \qquad (1)$$

where V is the specific discharge, or Darcy velocity, in ft/d;
K is the hydraulic conductivity of the saturated material, in ft/d; and
I is the hydraulic gradient, in ft/ft.

Values of Darcy velocity for the shallow, moderate-depth, and deep flow systems are listed in Table 3. The Darcy velocity may be used to calculate water-particle velocity by dividing by porosity. However, values of porosity were not obtained during this study. Volumetric flow may be calculated across a given cross-sectional area by multiplying that area times the Darcy velocity.

Table 3. Example calculations of Darcy velocity

Flow system	Direction of flow	Average hydraulic conductivity, K (feet per day)	Hydraulic gradient, I (feet per feet)	Darcy velocity, V (feet per day)
Shallow	Horizontal	7	0.02[1]	0.1
Moderate	Vertical	0.2	.3[2]	0.06
Deep	Horizontal	0.8	.003[3]	0.002

[1] Estimated for flow path out the north of figure 3.
[2] Average of values shown on figure 5.
[3] Estimated for flow path from east to west on figure 4.

Borehole Geophysical Logging

Natural gamma and electromagnetic-induction logs were recorded in deep wells at the site to characterize subsurface stratigraphy and water quality. These logs are shown in figures 9A-H in the Supplemental Data section at the end of this report. Geophysical logs were recorded through 2-inch diameter PVC casing and screen. The elevation datum for each well was land surface. Geophysical probe calibration was performed in a conductivity-free environment prior to going to the site. Each geophysical log was run twice for comparison of repeatability and quality control purposes.

Natural Gamma Logs

Natural gamma emissions vary with lithologic differences in sediments. Clays occurring in sediments contain minerals that generally emit higher levels of gamma particles producing higher count rates on logs. Sand units that contain little or no clay generally emit low levels of gamma particles producing lower count rates on logs. Natural gamma was recorded in counts per second (cps) and was used to corroborate drill cutting descriptions used for determining relative clay content and the top of the deep sand unit penetrated by deep monitor wells.

Electromagnetic-Induction Logs

Electromagnetic-induction geophysical methods measure the electromagnetic conductivity of sediments and the water contained in pore space. The measurements are presented as conductivity in units of millimhos per meter (mmhos/m) and inversely, resistivity in units of ohm-meters (ohm-m). Quartz sand units are generally less conductive (slightly more resistivity). Clays are generally more conductive (lower resistivity) materials because of "bound water" in the clay minerals. Fluids contained in pore spaces of sands can greatly affect the conductivity measured depending on the dissolved solids contained in the fluids. Higher concentrations of dissolved solids contained in pore water cause a higher conductivity response on the electromagnetic–induction log. The electromagnetic-induction logs were used to corroborate drill-cutting descriptions and to qualitatively assess the conductivity of water contained in the pore space of sandy sediments.

Borehole Geophysical Log Evaluation

Each geophysical log was evaluated with respect to repeatability, lithologic response, and water-quality effects. Log calibration and repeatability were within acceptable limits, indicating that probe responses were reliable and accurate. Lithologic response was acceptable and generally corroborated cuttings description information and stratigraphic contacts inferred while drilling.

Electromagnetic-induction logs indicated that several wells intersected a zone of highly conductive water in the shallow strata, while others did not. Wells MW-7D and MW-8D are considered to represent ambient conditions and serve as background wells. The following section contains several observations pertaining to anomalies apparent on the geophysical logs.

MW-1D

The geophysical logs recorded in well MW-1D indicate some anomalies in the electromagnetic-induction measurements probably associated with highly conductive ground water contained in the shallow sand/gravel strata between 7 and 17 ft from land surface datum (LSD). In this zone, conductivity ranges from about 1,000 to 1,950 mmhos/m whereas the background wells show conductivities in the range of 50 to 150 mmhos/m in this zone. The sand/gravel unit does not occur in the background wells, but a typical value of conductivity for sandy clays on the site is less than 150 mmho/m (for example, see log for MW-2D). Water samples collected in MW-1S (the shallow well in this well nest) have a very high specific conductance of 43,300 microsiemens/cm (μS/cm). The two slight conductivity peaks in MW-1D, at about 34 and 37 ft below LSD, are most likely lithologic responses associated with thin hardpan clays.

MW-3D

The geophysical logs recorded in well MW-3D indicate some anomalies in the electromagnetic-induction measurements. At about 2.5 to 3 ft below LSD, a resistivity high appears at the upper-most measurement. This response is probably associated with the steel protective casing cemented into the upper part of the well. Electromagnetic responses are erratic in the presence of metals and typically appear as resistivity peaks or conductivity peaks. A response of greater importance occurs at about 7 to 10 ft below LSD, as a conductivity high (about 600-800 mmhos/m), and is probably associated with highly conductive ground water contained in the bottom portion of the shallow sand unit. Water samples collected in MW-3S, the shallow well in this well nest, have a very high specific conductance of 51,400 μS/cm.

Another electromagnetic-induction anomaly occurs at 34 ft below LSD. The resistivity value exceeds 200 ohm-m in this zone. This anomaly might be related to well construction; however, limited information is available regarding well construction or completion because the well was not constructed as a part of this investigation. This anomaly possibly is associated with the mineralogy of the filter-pack material used in well completion. No other logs collected on the site exhibit resistivity measurements that approach this level.

MW-7D and MW-8D

The geophysical logs recorded in MW-7D exhibit responses of natural conditions of water quality and lithology. Slightly higher resistivity zones at 6 to 8 ft and at 36 ft below LSD to the bottom of the log show the effects of sandy sediments containing ground water of lower specific conductance as exhibited by water samples collected from this well nest. MW-7S has a screen midpoint of about 10 ft from LSD and contained water with a specific conductance of 668 μS/cm. MW-7D has a screen midpoint of about 57 ft from LSD and contained water with a specific conductance of about 215 μS/cm. MW-8D shows similar effects with slightly higher specific conductance values.

MW-9D

The geophysical logs recorded in well MW-9D indicate some anomalies probably associated with highly conductive ground water contained in the shallow sand/gravel strata between 6 and 10 ft below LSD. In this zone, conductivity measurements approach 900 mmhos/m whereas the background wells show conductivities in the range of 50 to 150 mmhos/m in this zone. Water samples collected in MW-9S, the shallow well in this well nest, have a very high specific conductance of about 58,400 µS/cm.

PHYSICAL CHARACTERISTICS OF WATER SAMPLES

Water samples were collected and analyzed onsite for temperature, pH, and specific conductance (table 2, fig. 6). No samples were collected from the Sparta Well because there was no commercial electrical service available onsite to provide power to its submersible pump, and access to collect a water sample by bailing was restricted.

Water temperature (fig. 6A) varies similarly for deep, moderate, and shallow ground-water samples. In contrast, pH (fig. 6B) and specific conductance (fig. 6C) vary considerably between the deep and shallow systems; moderate-depth ground-water values lie between the deep and shallow ground-water values. There is some overlap of values of specific conductance between the deep and shallow samples indicating the possible flow of shallow ground water into the deeper system. The wide range in conductance values contrasts ambient, background conditions (for example, MW-7S and MW-7D, which are sufficiently far from the salt cake and appear not to have become contaminated by salt) and the local influence of the salt cake on the ground water (for example, MW-1S which is highly contaminated).

Specific conductance is an indicator of dissolved solids in the ground water and is directly affected by the presence of the salt cake. The spatial distribution of specific conductance is plotted in figures 7 and 8 for the shallow and deep ground-water systems. Specific conductance values range from 215 to 196,200 µS/cm; therefore, logarithmic values are used to contour and to compare directly the deep and shallow systems. The contour pattern for specific conductance in the shallow system (fig. 7) is very similar to the contour pattern for the water-level altitude map in figure 3. Specific conductance decreases with distance from the salt-cake area indicating that dissolved salts are moving outward from the source in the direction of shallow ground-water flow.

Similarly, transport of dissolved salts was observed in the deep system, although to a considerably lesser extent. Downward migration of dissolved salts likely is slowed by the presence of low-permeability clay layers between the shallow and deep systems. Unlike the shallow system, the contour pattern for specific conductance in the deep system (fig. 8) is dissimilar to the contour pattern for the water-level altitude map in figure 4. This dissimilarity may reflect the shorter residence time of the salts within the deeper system, providing insufficient time to develop a salt plume.

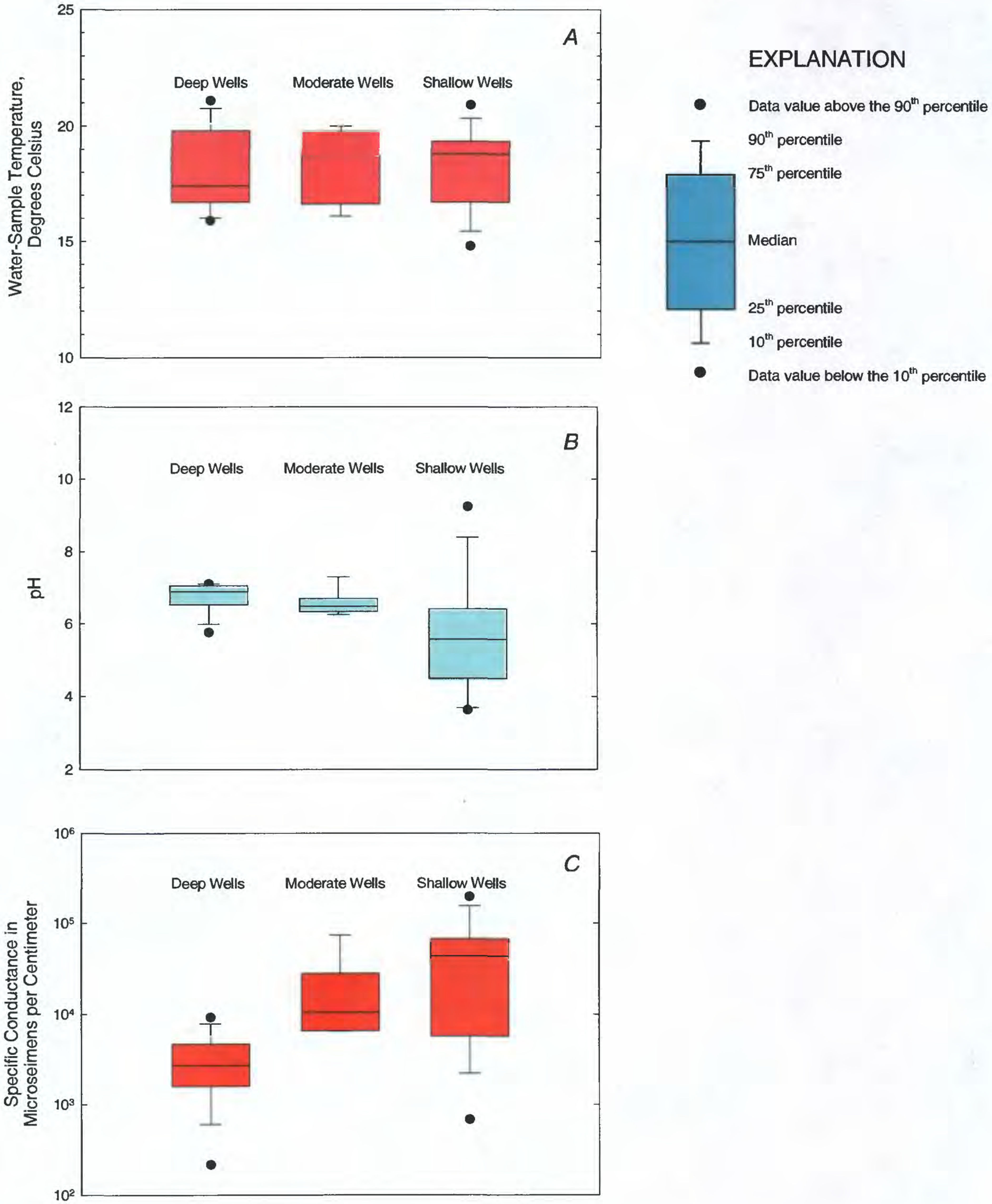
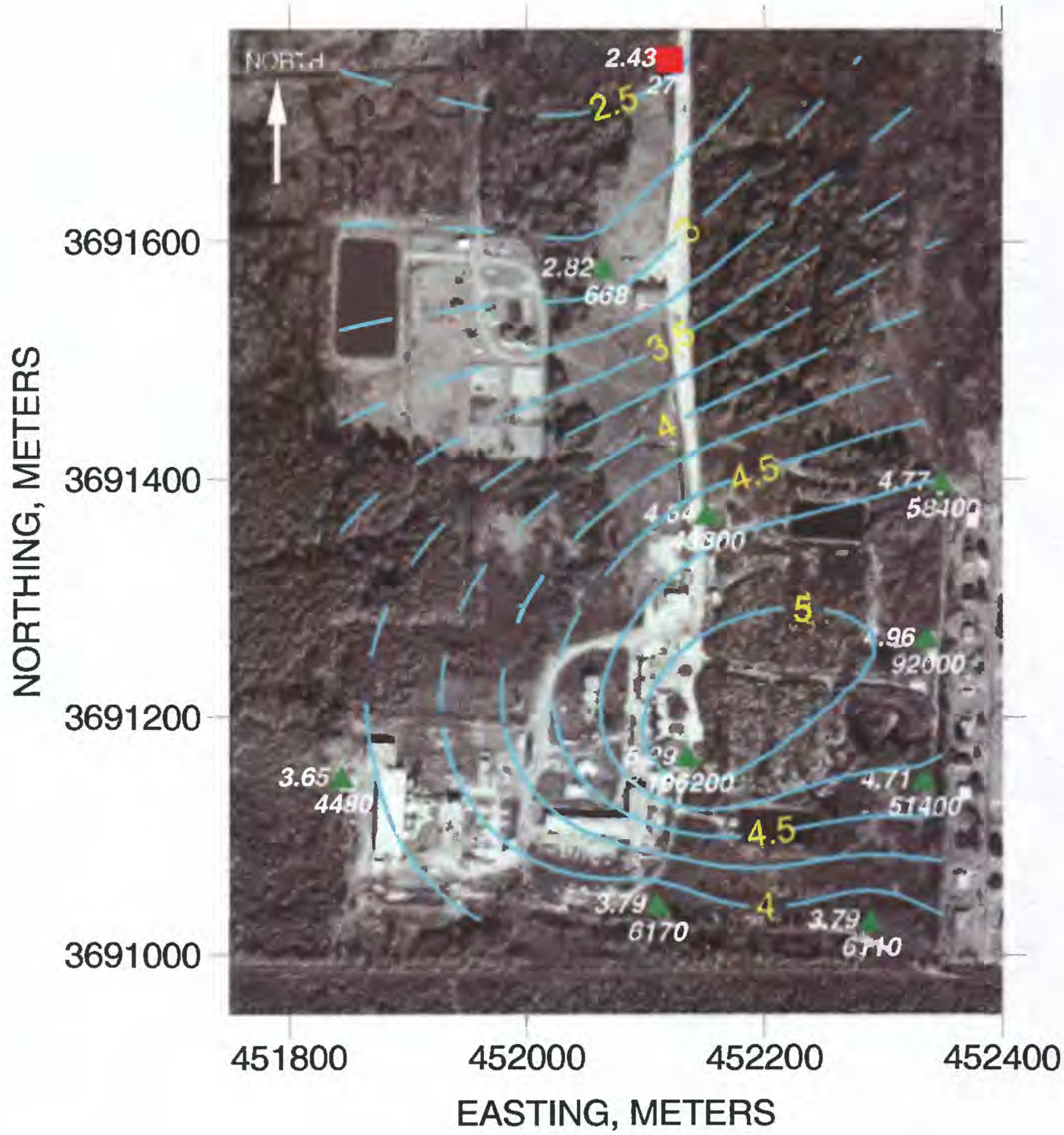


Figure 6. Plots of (A) temperature, (B) pH, and (C) specific conductance of ground-water samples.



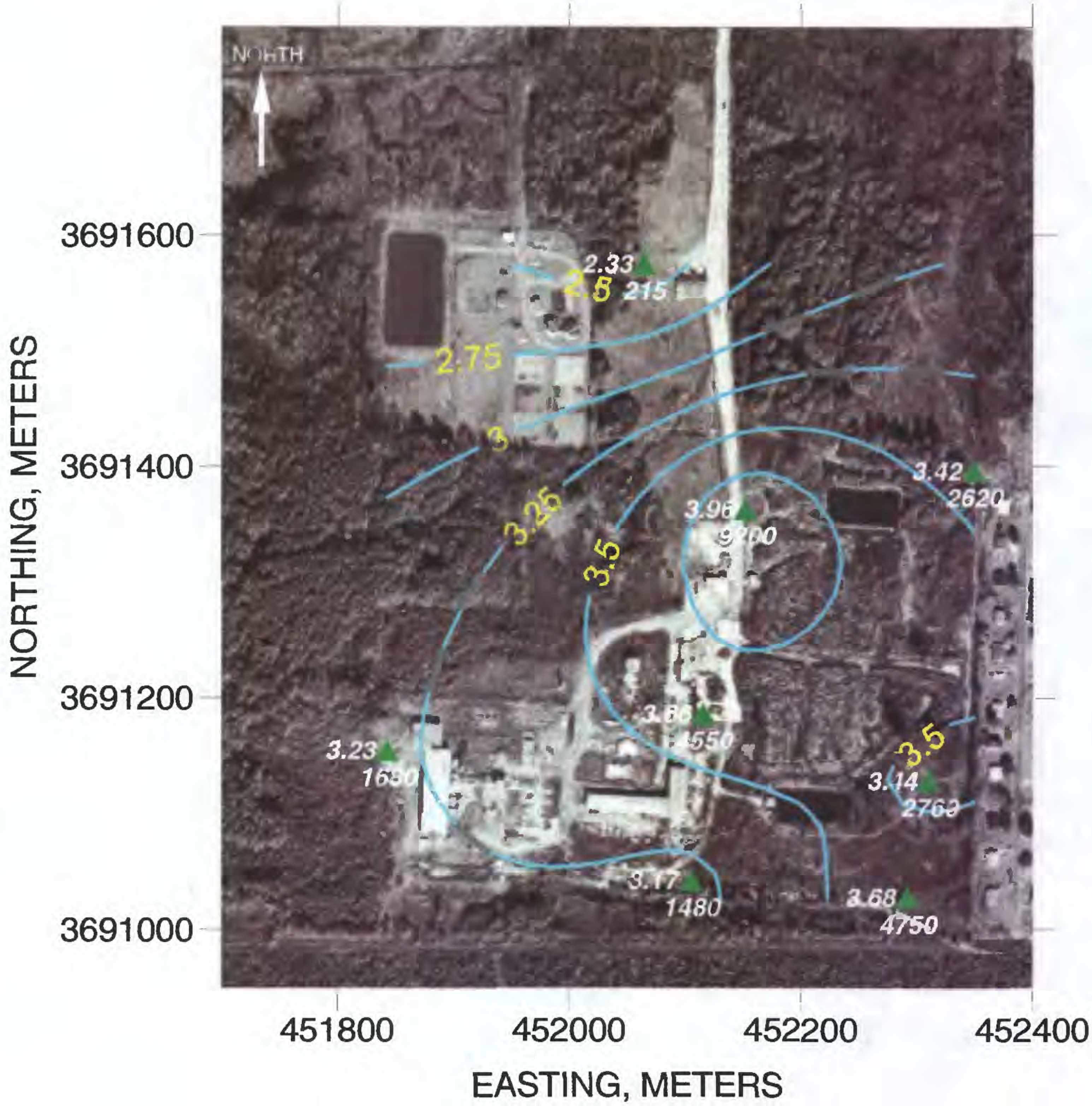
EXPLANATION

LINE OF EQUAL VALUE OF LOG SPECIFIC CONDUCTANCE—Dashed where approximately located. The value when raised to the power 10 yields conductance in microsiemens per centimeter at 25 degrees Celsius (for example, a value of **4** corresponds to 10^4 or 10,000 microsiemens per centimeter)

3.79 ▲ *6110* WELL LOCATION—Number at bottom of symbol is value of specific conductance in microsiemens per centimeter. Value at left of symbol is log specific conductance

2.43 ■ *272* SURFACE-WATER SITE— Number at bottom of symbol is value of specific conductance in microsiemens per centimeter. Value at left of symbol is log specific conductance

Figure 7. Specific conductance of the shallow ground-water system.



EXPLANATION

LINE OF EQUAL VALUE OF LOG SPECIFIC CONDUCTANCE—Dashed where approximately located. The value when raised to the power 10 yields conductance in microsiemens per centimeter at 25 degrees Celsius (for example, a value of **3** corresponds to 10^3 or 1,000 microsiemens per centimeter)

3.68 ▲ 4750 — WELL LOCATION—Number at bottom of symbol is value of specific conductance in microsiemens per centimeter. Value at left of symbol is log specific conductance

Figure 8. Specific conductance of the deep ground-water system.

CONCEPTUAL MODEL

Based on the data collected for this study, ground water within the shallow system flows radially away from the topographic high (the salt cake pile) and carries with it dissolved salt. Some of this water discharges in Tatum Branch of Bodcau Creek and in Pond 3 onsite. Also, a downward component of flow occurs from the shallow system into the deeper system, but to a lesser extent because of the presence of underlying low permeability clays. Flow within the deep system moves west and south toward Bodcau Creek. The potential for downward flow into the Sparta aquifer exists, the extent to which this occurs is unknown.

No evidence of perched water was observed onsite, that is, no zone of partial saturation was observed below the shallow flow system. 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 (MW-1M and MW-5M) were still recovering weeks after construction.

The average depth of the shallow wells onsite is about 10 ft and depths to water in these wells range from about 0 to 7.3 ft below land surface. Based on these shallow depths to water in the shallow wells and in some of the moderate-depth wells, it appears likely that ground water supplied some of the water to Ponds 1 and 2 (both ponds were constructed more than 10 ft deep—substantially below the water table (Woodward-Clyde Consultants, 1992)). Because some salt cake was used to infill the depressions that formed Ponds 1 and 2, and because saturated conditions still exist, highly concentrated brines likely have developed as a result. Furthermore, the filled-in depression that was formerly Pond 1 is in the vicinity of a buried stream channel with highly transmissive gravels such as were observed in the construction of monitor well MW-1D. These gravels could provide a preferential flow path for saline-water transport. However, the lateral extent of such a buried stream channel was not characterized, but likely could be identified using two-dimensional surface-resistivity geophysical surveys.

Currently, the salt cake onsite is uncovered and surrounded by a low-permeability berm to contain surface runoff. However, the salt cake is subject to additional inundation and dissolution by rainfall. Based on current data, the resulting saline water likely will be transported laterally and vertically through the shallow and deep ground-water systems. The planned capping of the salt-cake pile with an engineered barrier should help to divert rainfall away from the salt cake. Water-saturated salt cake will persist for some time even after the salt cake is capped with an engineered barrier, providing a source for additional saline water input to the ground-water system. Construction of the cap will limit vertical recharge through the covered salt cake pile, eventually causing the water table to lower somewhat. However, even if the areas below former Ponds 1 and 2 are capped, the presence of saturated salt cake and concentrated brines at the bottom of these former ponds will persist, and provide a contaminant source to the ground water.

SUMMARY AND CONCLUSIONS

Water-level data from 23 wells completed within the shallow, moderate, and deep flow systems, and data from 2 surface-water sites were used to describe ground-water flow direction at the Red River Aluminum site. Waste piles of salt cake at the site are subjected to about 50 inches of rainfall a year, resulting in the dissolution of the salts and metal. Water-level altitudes from shallow wells indicate radial flow away from the salt cake in all directions within the shallow ground-water system. In contrast, flow within the deep system occurs to the west and southwest toward Bodcau Creek. A downward vertical gradient exists at each of eight piezometer nests constructed onsite, indicating the potential for downward ground-water flow. The largest measured downward gradient (0.35) occurred near the western edge of the salt cake.

Specific conductance of ground water ranges from 215 to 196,200 μS/cm across the study area. Specific conductance decreases with distance from the salt-cake area indicating that dissolved salts are moving outward from the source in the direction of shallow ground-water flow. Primary transport of saline water occurs within the shallow flow system based on specific-conductance data from water samples and from geophysical logging. However, elevated specific conductance in water from the deep wells is evidence that downward flow and migration of saline water has occurred into the deep system. It is unknown if any saline water has been transported into the underlying Sparta aquifer, because no water samples were obtained. However, it might be possible in the future to power an existing submersible pump currently installed in the Sparta Well using an external electrical generator.

The planned capping of the salt-cake pile with an engineered barrier will help to divert rainfall away from the salt cake. Water-saturated salt cake will persist for some time even after the salt cake is capped with an engineered barrier, providing a source for additional saline water input to the ground-water system. Construction of the cap will limit vertical recharge through the covered salt cake pile, eventually causing the water table to lower somewhat. However, even if the areas below former Ponds 1 and 2 are capped, the presence of saturated salt cake and concentrated brines at the bottom of these former ponds will persist, and provide a contaminant source to the ground water.

A better understanding of the fate of the saline waters beneath the salt cake could result from collection of additional data and additional data analysis. Key, but lacking, data for this analysis are the hydraulic properties of the Sparta aquifer (190 to 288 ft deep) and of its overlying confining bed (66 to 190 ft deep), and an analysis of water samples from the Sparta aquifer identify the possible migration of saline water into this important regional aquifer. Data suggest that high concentrations of saline waters exist directly beneath the salt-cake pile to a depth of about 60 feet. Detailed high-resolution water sampling vertically through the contaminated area to the Sparta aquifer could be used to accurately characterize the vertical extent of the saline water migration. Simulation of existing water-level, lithologic, and specific-conductance data would require the use of digital models which then could be used to more completely characterize flow and transport offsite and to predict the fate of water quality in the future.

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SUPPLEMENTAL DATA

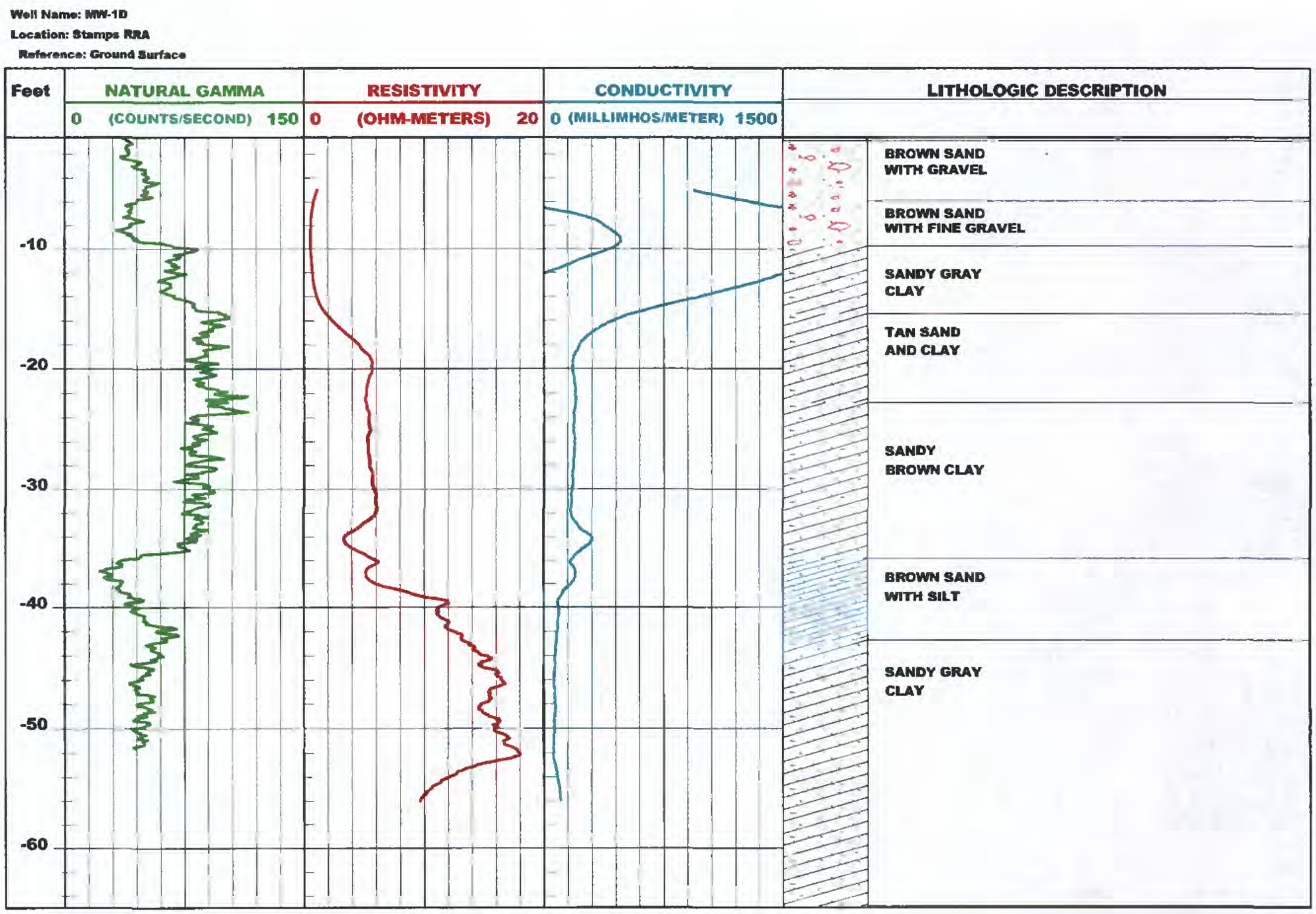

Figure 9A. Geophysical log of monitor well 1D.

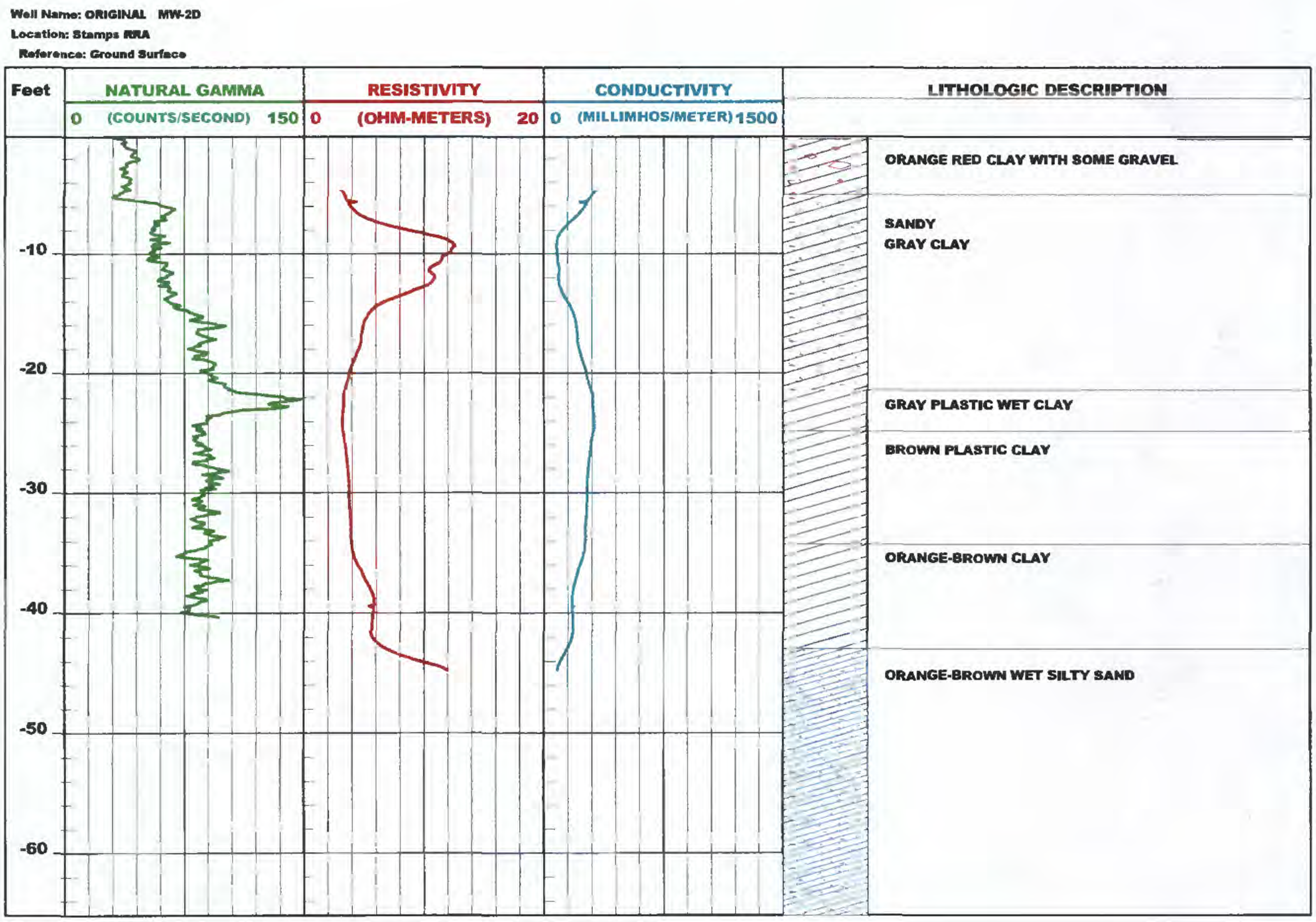

Figure 9B. Geophysical log of monitor well 2D.

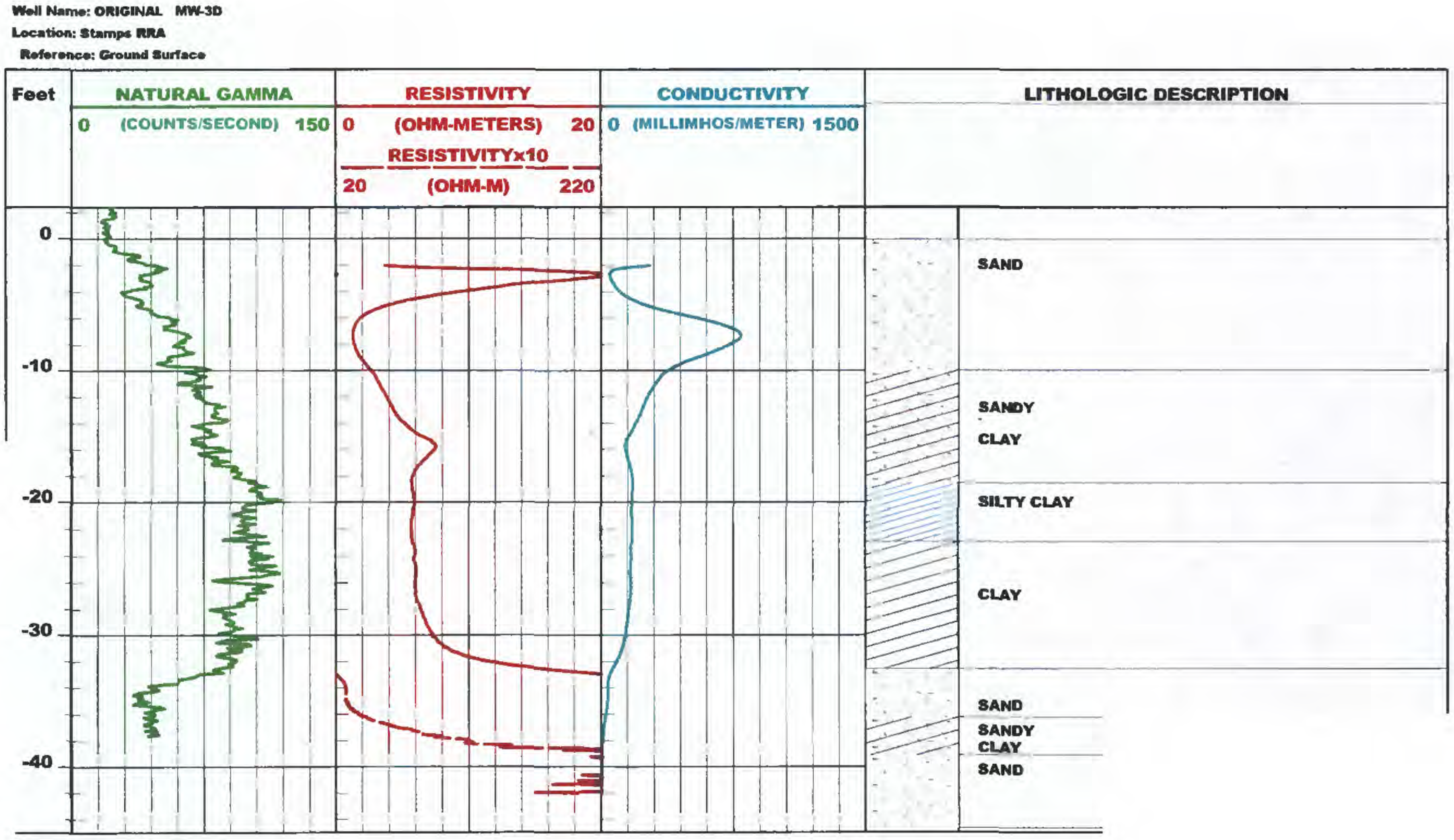

Figure 9C. Geophysical log of monitor well 3D.

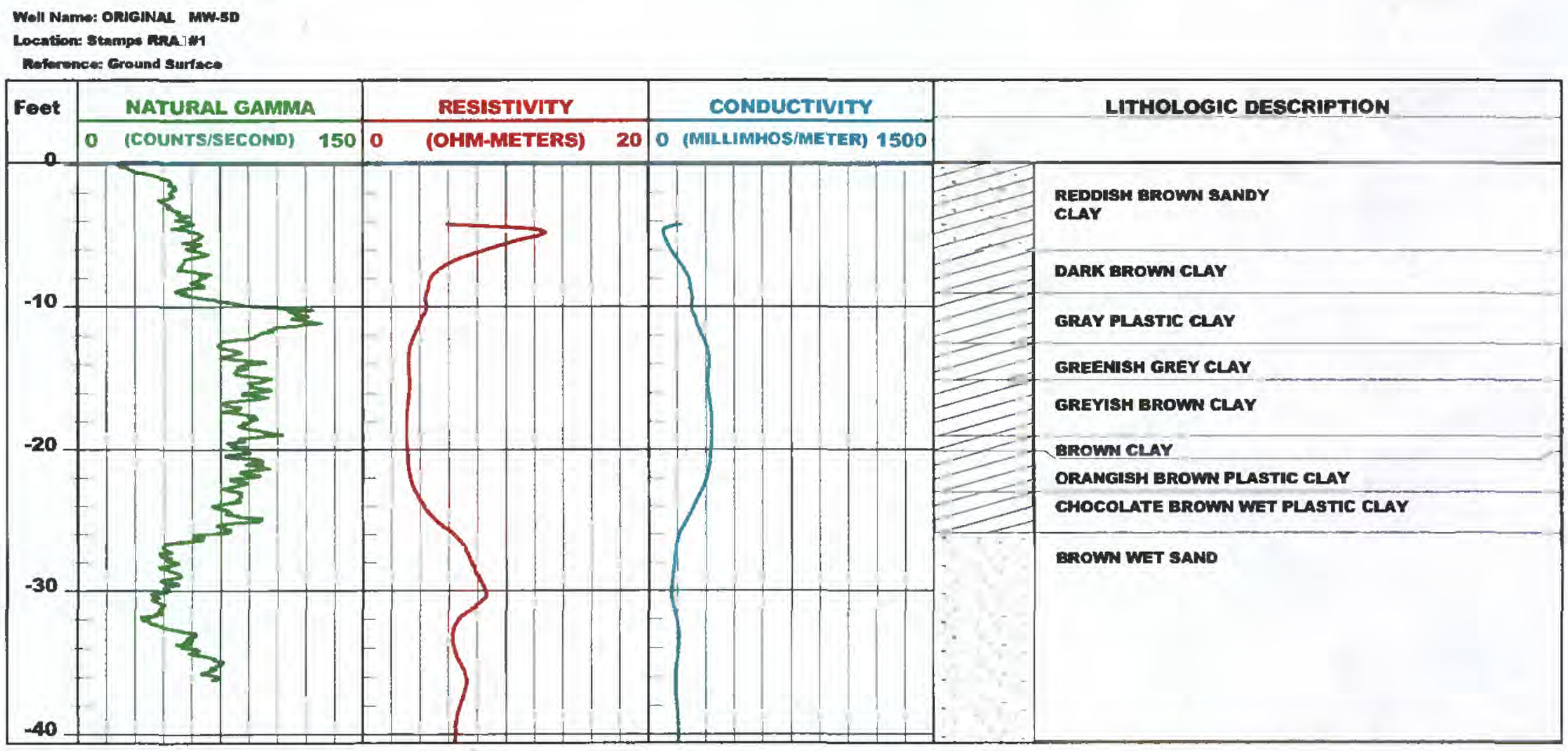

Figure 9D. Geophysical log of monitor well 5D.

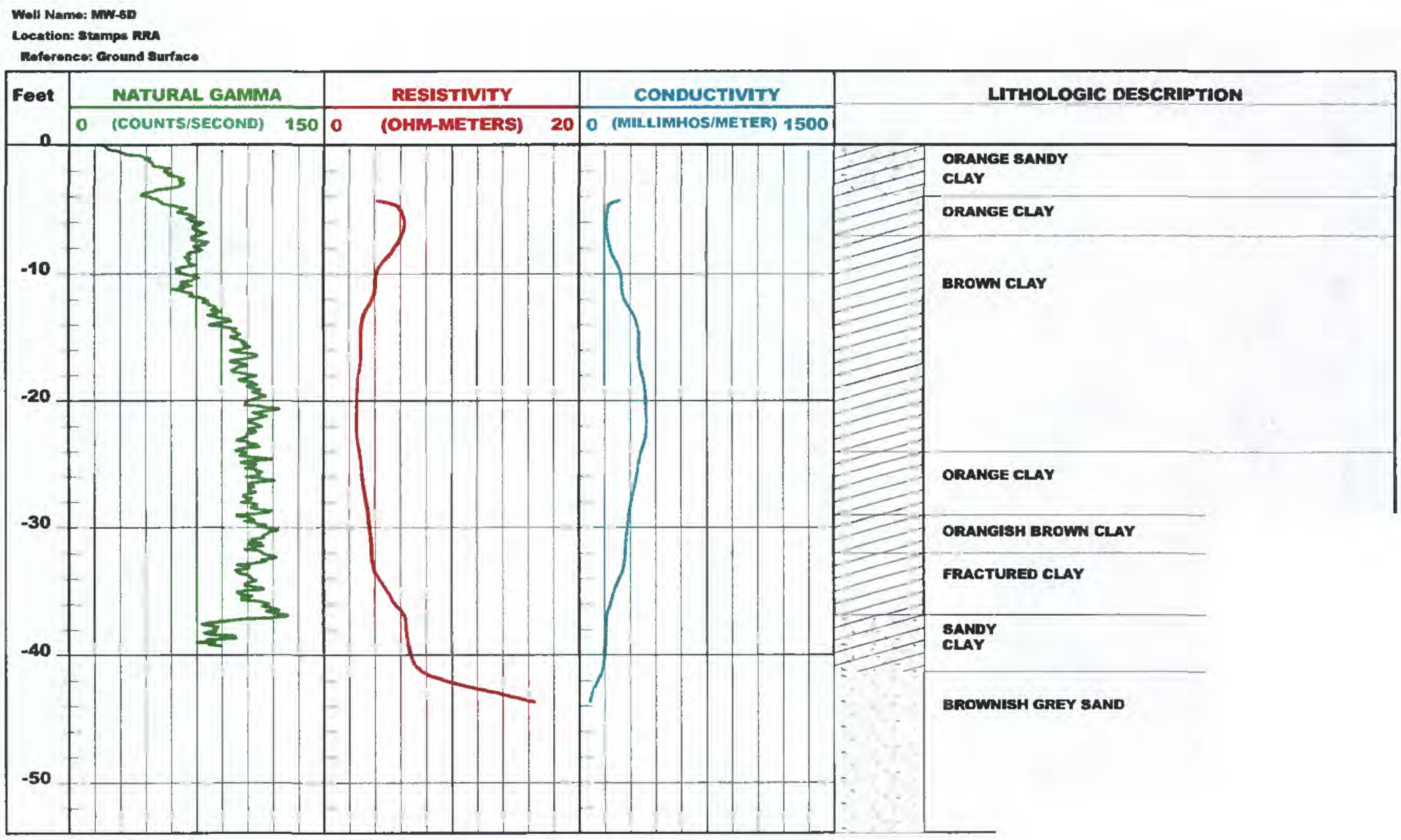

Figure 9E. Geophysical log of monitor well 6D.

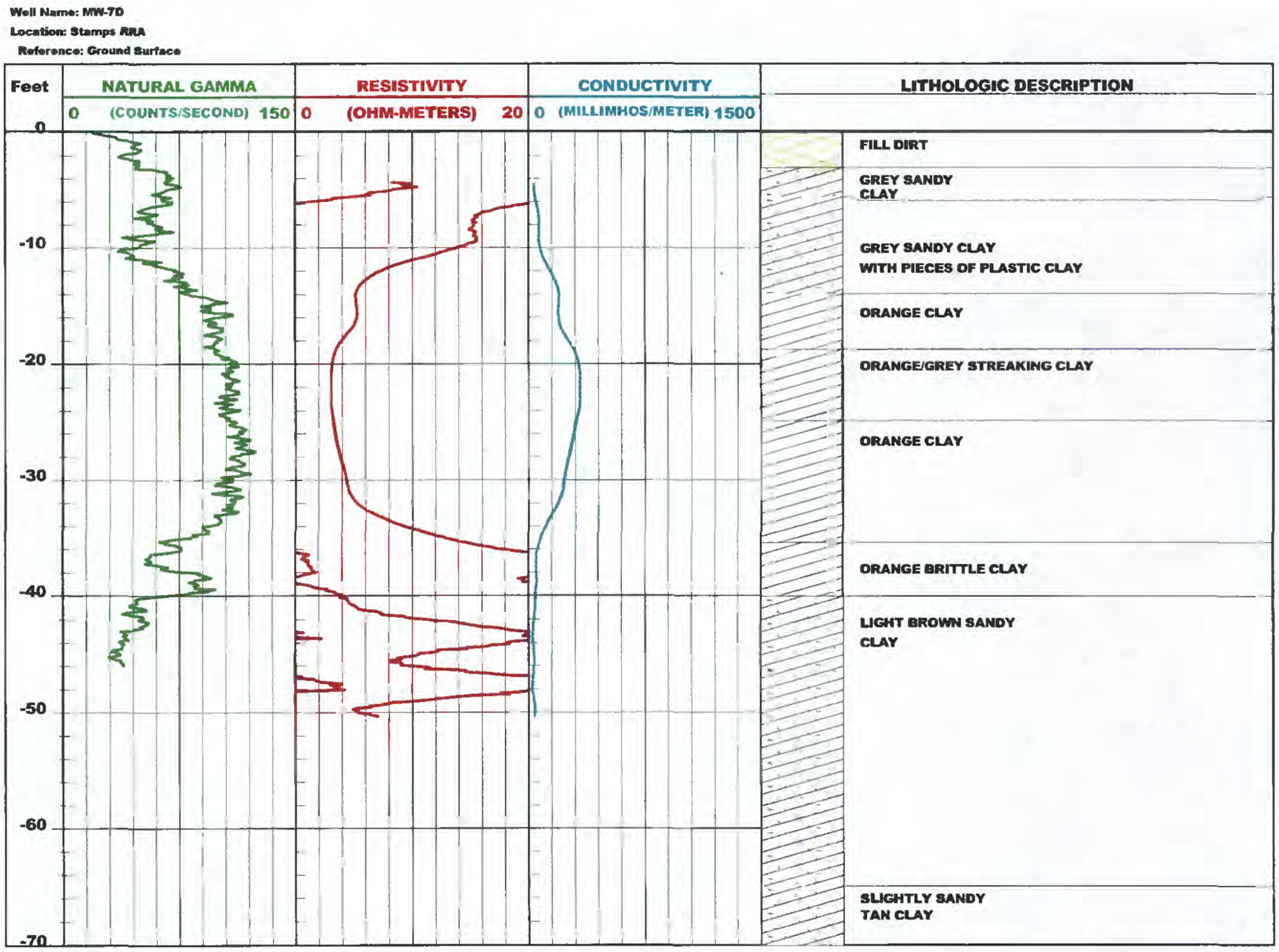

Figure 9F. Geophysical log of monitor well 7D.

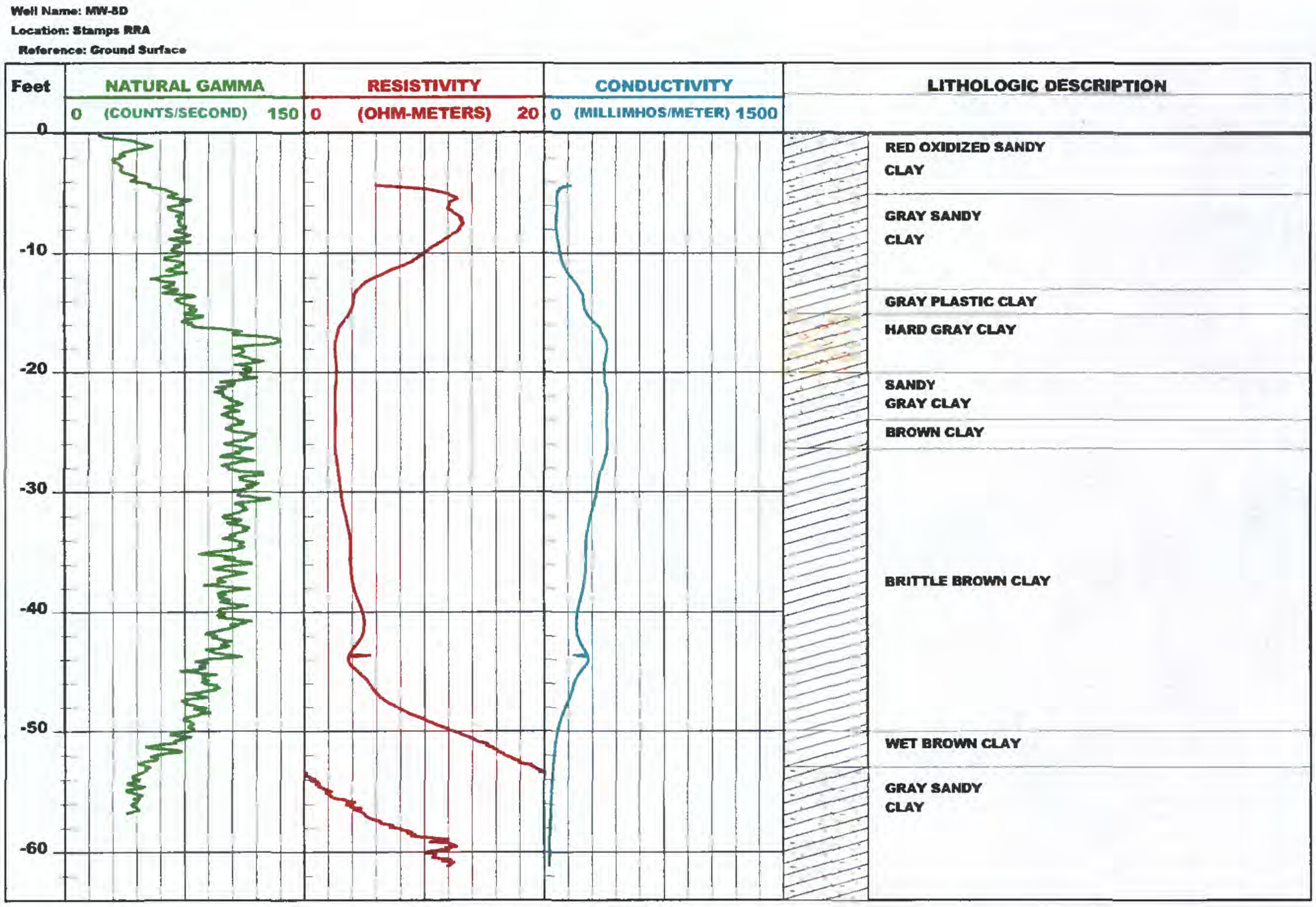

Figure 9G. Geophysical log of monitor well 8D.

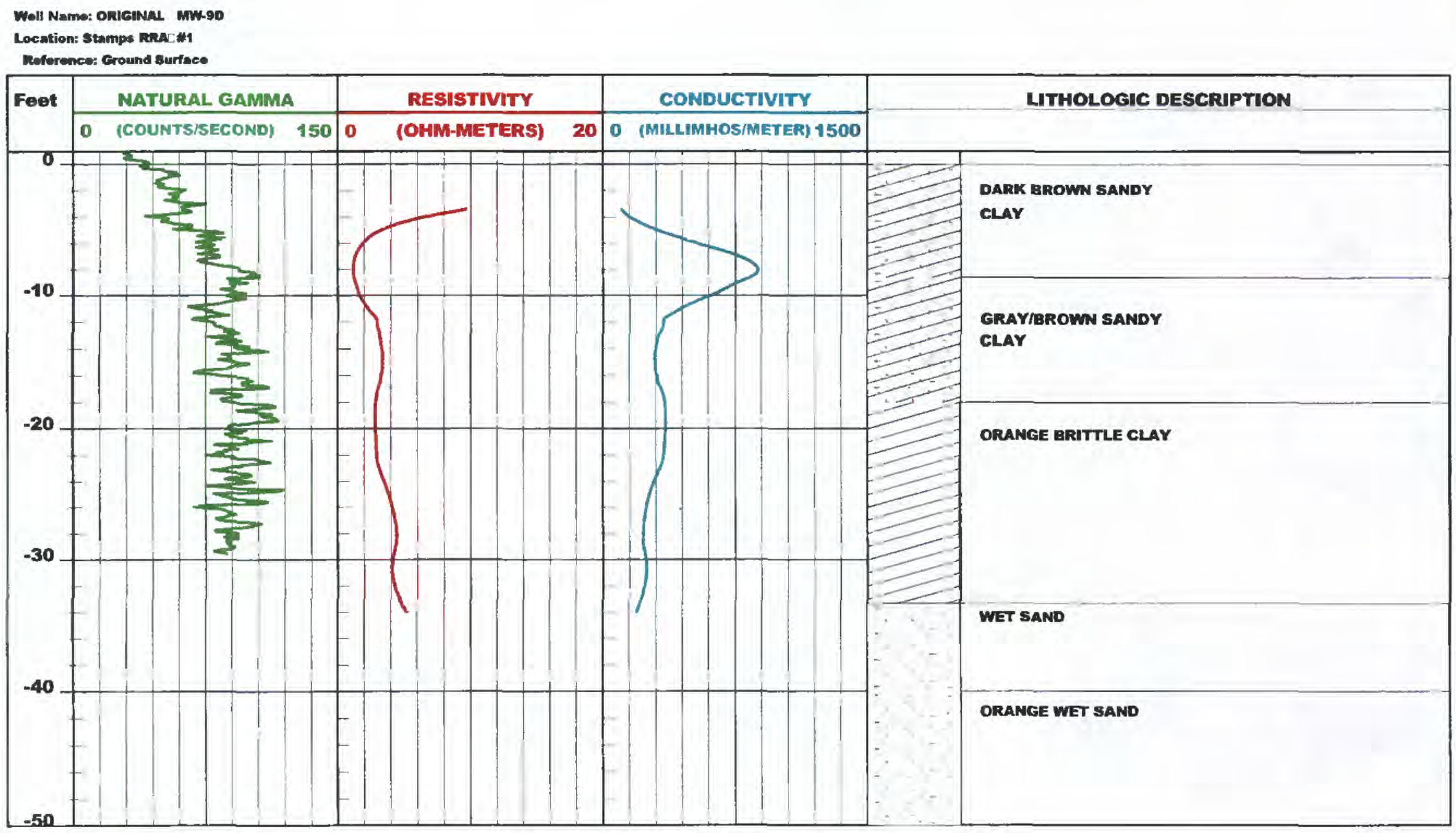

Figure 9H. Geophysical log of monitor well 9D.