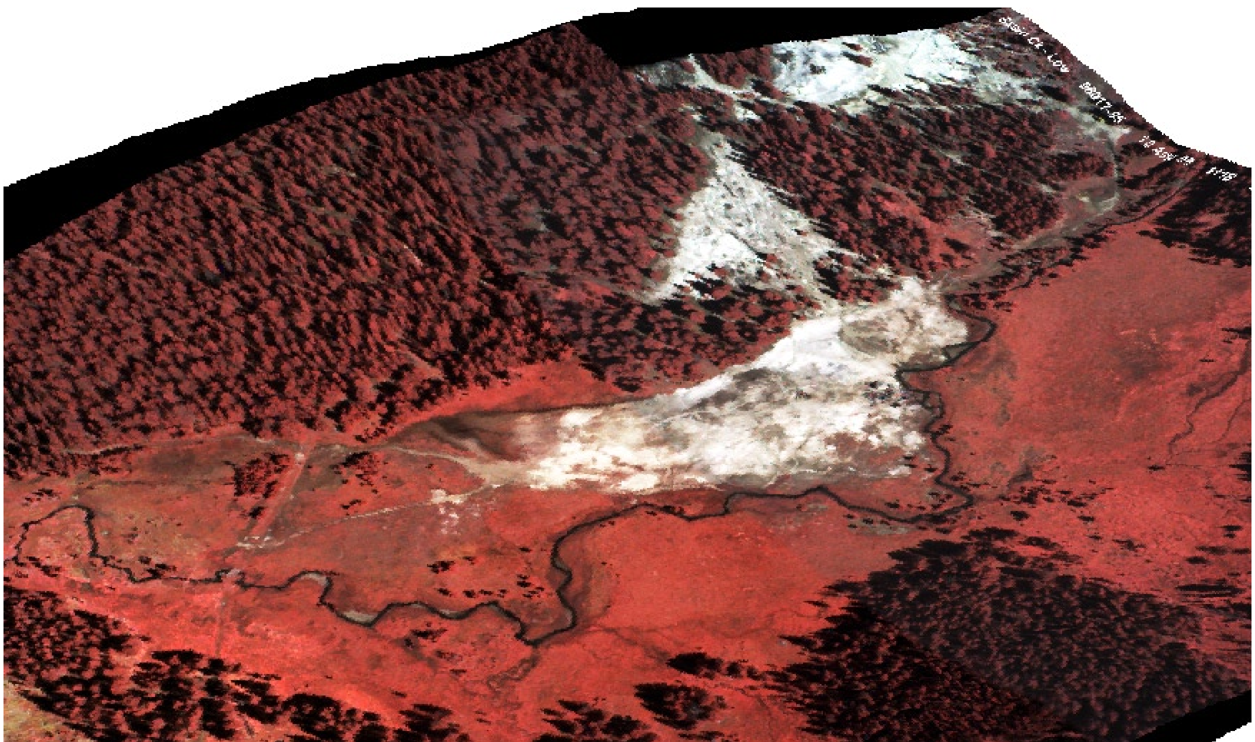
U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Ground Geophysical Study of the Buckeye Mine Tailings, Boulder Watershed, Montana

Robert R. McDougal and Bruce D. Smith



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ABSTRACT

The Buckeye mine site is located in the Boulder River watershed along Basin Creek, in northern Jefferson County, Montana. This project is part of the Boulder River watershed Abandoned Mine Lands Initiative, and is a collaborative effort between the U.S. Geological Survey and Bureau of Land Management in the U.S. Department of the Interior, and the U.S. Forest Service in the U.S. Department of Agriculture. The site includes a large flotation mill-tailing deposit, which extends to the stream and meadows below the mine. These tailings contain elevated levels of metals, such as silver, cadmium, copper, lead, and zinc. Metal-rich fluvial tailings containing these metals, are possible sources of ground and surface water contamination. Geophysical methods were used to characterize the sediments at the Buckeye mine site. Ground geophysical surveys, including electromagnetics, DC resistivity, and total field magnetic methods, were used to delineate anomalies that probably correlate with subsurface metal contamination. Subsurface conductivity was mapped using EM-31 and EM-34 terrain conductivity measuring systems. The conductivity maps represent variation of concentration of dissolved solids in the subsurface from a few meters, to an approximate depth of 30 meters. Conductive sulfides several centimeters thick were encountered in a shallow trench, dug in an area of very high conductivity, at a depth of approximately 1 to1.5 meters. Laboratory measurements of samples of the sulfide layers show the conductivity is on the order of 1000 millisiemens. DC resistivity soundings were used to quantify subsurface conductivity variations and to estimate the depth to bedrock. Total field magnetic measurements were used to identify magnetic metals in the subsurface. The EM surveys identified several areas of relatively high conductivity and detected a conductive plume extending to the southwest, toward the stream. This plume correlates well with the potentiometric surface and direction of ground water flow, and with water quality data from monitoring wells in and around the tailings. The electrical geophysical data suggests there has been vertical migration of high dissolved solids. A DC sounding made on a nearby granite outcrop to the north of the mine showed that the shallow conductivity is on the order of 5 millisiemens/m. Granite underlying the mine tailings, with similar electrical properties as the outcropping area, may be more than 30 meters deep.

INTRODUCTION

Purpose

The Buckeye mine site is located along Basin Creek, in northern Jefferson County, Montana (Figure 1). This project is part of the Boulder River watershed Abandoned Mine Lands Initiative, a collaborative effort between the U.S. Geological Survey and Bureau of Land Management in the U.S. Department of the Interior, and the U.S. Forest Service in the U.S. Department of Agriculture.

Basin Creek, one of the three main tributaries of the Boulder River, has been shown to contribute metals to surface waters in the Boulder River watershed. Wastes from metal-mining related activities have contributed to acid generation and toxic metal loading in the watershed. The main source of contamination, at the Buckeye site, comes from the weathering of a large, well exposed tailings pile during spring snow melt and storm runoff events (Buxton and others, 1997).

During the summers of 1998 and 1999, ground geophysical surveys, including electromagnetic (EM), direct current (DC) resistivity, and total field magnetic methods, were used to examine the location and extent of high conductivities possibly related to metal contamination in the tailings and surrounding area. The geophysical data were also used to examine possible movement of metals associated with local ground water flow.

Historical Background

Vein deposits of gold were discovered at the Buckeye site in 1868. The Buckeye mine and adjacent Enterprise claim were worked during the late 1800's and early 1900's. An on-site gravity mill was used for concentration of the ore. The mined ore contained abundant disseminated and massive pyrite, locally abundant arsenopyrite, sparse chalcopyrite, and sparse local galena and sphalerite. The 1.6 meter thick, sub-vertical Buckeye ore vein was worked through shafts of 30 to 60 meter depths, and similar veins at the Enterprise were worked through a 122 meter vertical shaft (Ruppel, 1963). A mill was built during World War II to re-process the gravity tailings using flotation technology. The resulting tailings cover an area of about 3.3 acres of the Basin Creek floodplain, and have an estimated mass of 8,400 metric tons (Fey and others, 1999).

Geologic and Geohydrologic Setting

The study area is located in a Late Cretaceous plutonic complex known as the Boulder batholith. The emplacement of the batholith progressed from initial mafic plutons to an extensive intermediate-composition main phase to a final alkali-rich felsic composition. The batholith is comprised of fifteen different plutons, but the Butte pluton forms the majority of the outcrop in the region. The dominant rock type in this pluton is a medium-to-coarse grained hornblende-biotite phase, and is classified as a granodiorite-tonalite. The Butte pluton is separated into eastern and western sectors by the Butte-Helena fault zone (O'Neill and others, 2000).

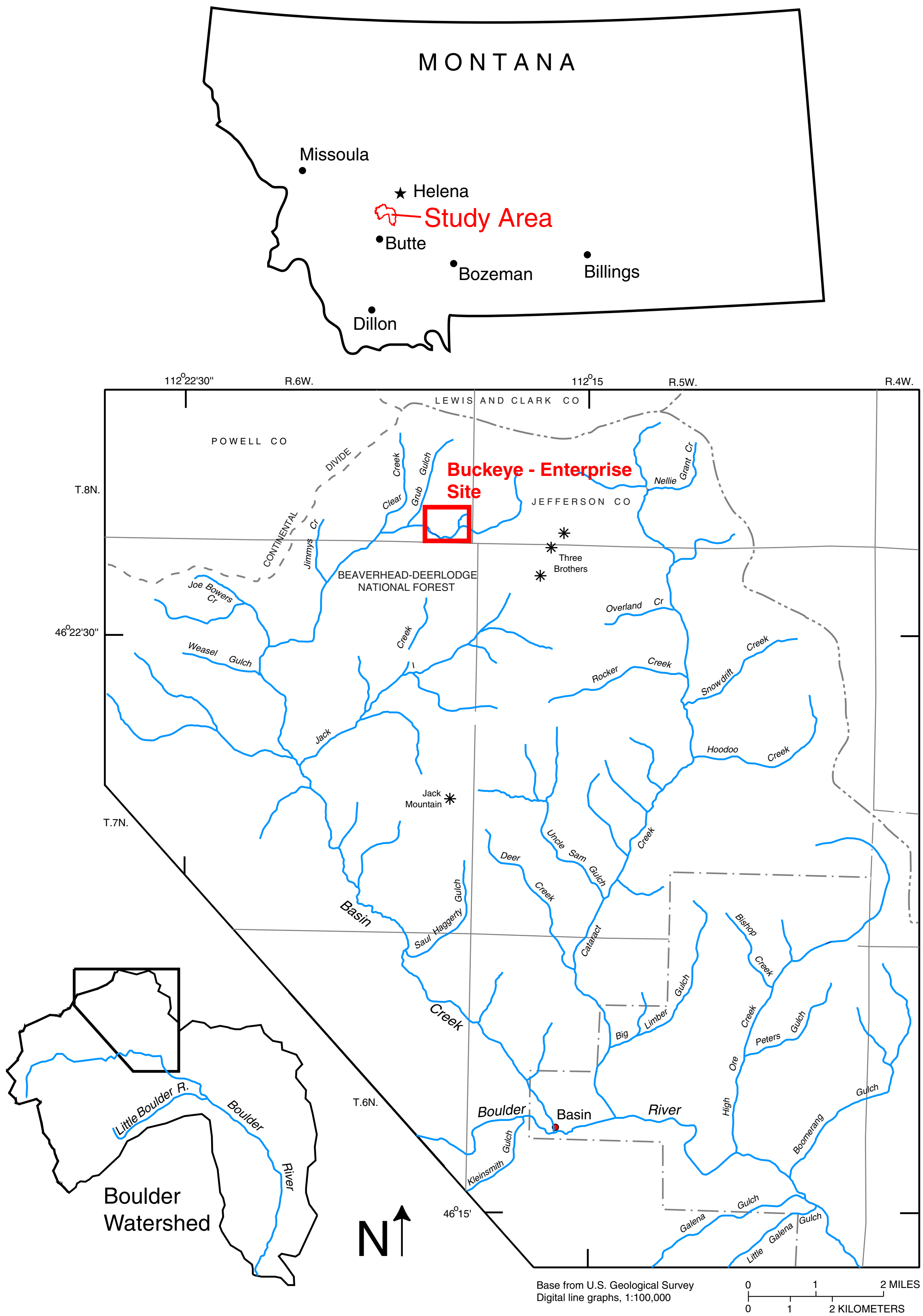

Figure 1. **Location map of the Boulder watershed and Buckeye-Enterprise study area**

In the vicinity of the Buckeye mine, glacial till, volcanic ash beds, and mill tailings overlie the pluton. Monitoring wells in and around the tailings penetrate coarse braided stream deposits, interpreted as glacial outwash sediments. These deposits are overlain by as much as 3 meters of thin stream sand and gravel lenses, and interlayered with levee, bog, and backswamp deposits of organic-rich sand, silt, and clay. A layer interpreted as the 6,700 year old Mazama ash deposit was encountered in one well at a depth of 1.1 meters (3.6 feet) in organic-rich sediments just south of the tailings (M.R. Cannon, written communication).

Outcrops of aplite, formed during late-stage, alkali-rich felsic pluton emplacement (O' Neill and others, 2000), are also found near the mine. The main mineralized Buckeye vein and smaller adjacent veins occur in fault zones cutting the Butte pluton and the late-stage felsic pluton (Ruppel, 1963).

Ground water flow in the study area occurs in two hydrogeologic units. The primary aquifer is composed of till, alluvium, colluvium, swamp deposits, and volcanic ash. This aquifer is unconfined and movement of water is through interconnected pores (primary permeability). Permeability in the granitic rock is low, and ground water movement in this aquifer is through heterogeneous anisotropic faults and fractures (secondary permeability). Fracture permeability in this aquifer is a function of width, density, orientation, and interconnectivity.

Recharge to the ground water system comes from approximately 76 centimeters maximum annual precipitation (mainly as snowfall), and minor recharge from higher elevations to the east. Intense rainstorms can contribute sudden influxes of recharge primarily to the alluvium aquifer (M. R. Cannon, USGS, 1999, unpublished data).

METHODS OF INVESTIGATION

Electromagnetic Surveys

An electromagnetic (EM) survey done in 1998, and extended in 1999, was used to map the subsurface conductivity of the tailings deposit and the surrounding meadows and forested areas. The resulting conductivity maps represent the distribution of conductive materials in the subsurface at depths of a few meters to approximately 30 meters. Measurements at varying depths were achieved by using two different EM instruments, a Geonics EM31 and EM34. The EM31 has a fixed intercoil spacing of 3.7 meters, which results in an exploration depth of approximately 6 meters in the vertical magnetic dipole (VMD) orientation, and approximately 3 meters in the horizontal magnetic dipole (HMD) orientation. The EM34 has variable intercoil spacing. For this survey, the EM34 spacing was set at 10 meters, resulting in an approximate VMD depth of 15 meters, and an approximate HMD depth of 7.5 meters (McNeill, 1980).

A survey grid (Figure 2) was constructed by first selecting an origin point and sighting a north-south baseline through the origin. Baseline stations for the 1998 survey were marked at 30-foot feet intervals, but were changed to 10-meter intervals for the 1999 survey. All east-west stations were measured at 10-meter intervals.

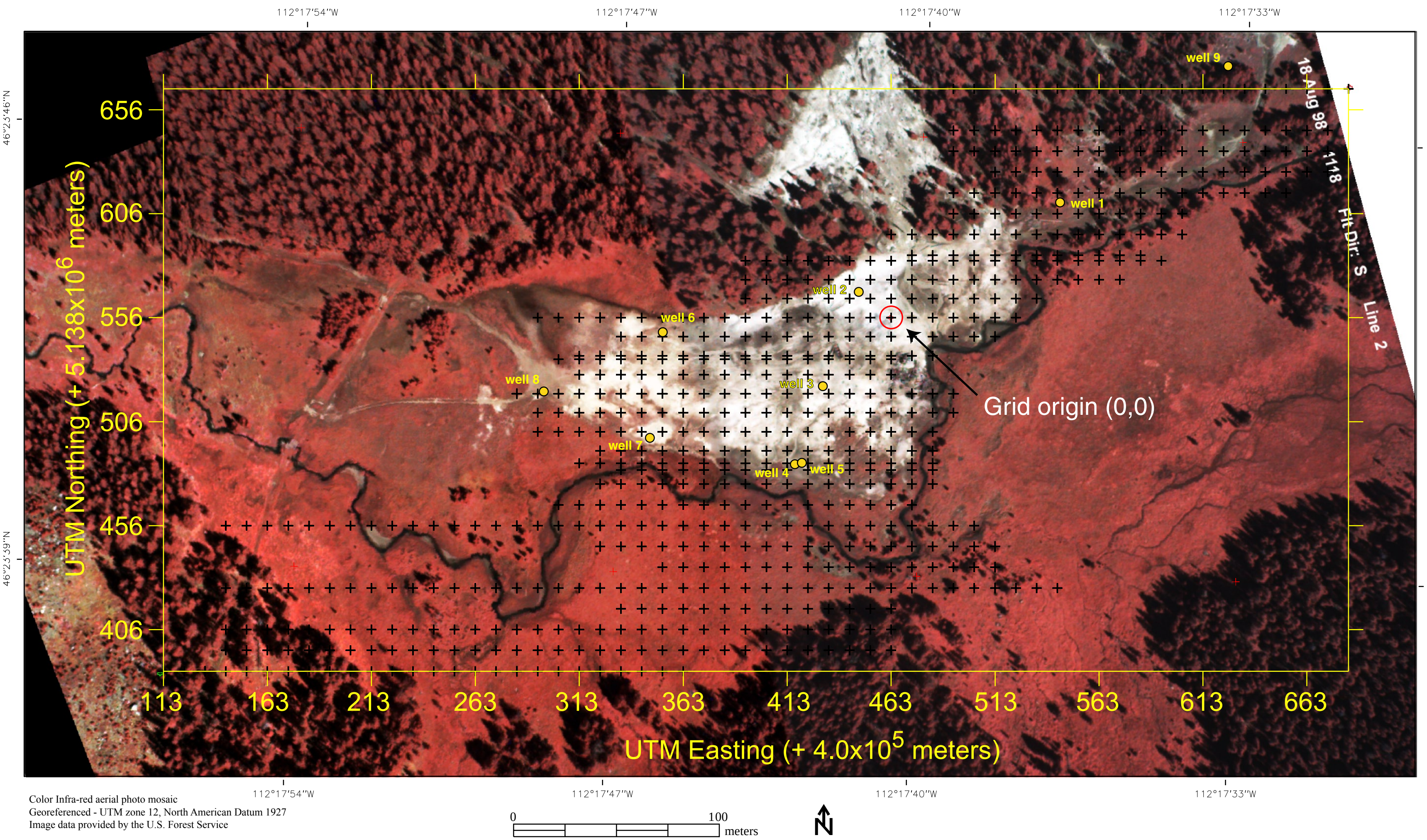

Figure 2. **Site map showing location of test wells and EM survey grid**

DC Resistivity Soundings

In 1999, DC resistivity soundings were made in eight locations (Figure 3) using an ABEM SAS 300 DC resistivity system and a Schlumberger electrode array (Smith and Sole, 2000). Seven of these soundings were made on the flotation tailings to provide detailed information about the subsurface resistivity variations and possibly to define the depth to bedrock. Each of the soundings was done in the vicinity of the test wells that were made for ground water studies. Sounding number eight was made in an area of exposed bedrock about 3 km northwest of the tailings. Current electrodes were spaced incrementally from about 1 meter to 40 meters. The sounding data were interpreted using software from Interpex (RESIXIP version 2.14, 1991) (Interpex, 1993).

Magnetic Survey

During the 1999 field season, a total field magnetic survey of the north-south and east-west base lines (Figure 3) was conducted using a proton precession magnetometer (Telford and others, 1990). Measurements were made at 10-meter intervals. At each station, three measurements were taken consecutively and averaged, to account for diurnal variations in the earth's magnetic field. This reconnaissance survey was intended to detect buried magnetic metallic cultural artifacts, which could be the cause of local EM anomalies. Of particular interest was the area near the grid origin at 0,0 (local coordinates), where preliminary EM results indicated an area of high conductivity.

RESULTS

Data collected from the EM34 survey were used to produce contour maps of conductivity for vertical and horizontal magnetic dipoles. The VMD map (Figure 4) shows an area of negative conductivity near the survey grid origin (0,0), and the HMD map (Figure 5) indicates high conductivity for the same area. The conductivity anomaly was initially thought to be the result of a buried conductive metallic object or caused by lateral heterogeneity in the layered tailings deposits. The total field magnetics survey indicates that several metallic objects at the surface that cause local magnetic anomalies along the north-south magnetic survey line. However, there are no significant sharp magnetic anomalies along the east-west line, and no significant magnetic anomalies were found in the area of the grid origin (0,0) (Figure 6). Therefore, we conclude that buried magnetic metallic cultural artifacts are not a likely source of the high conductivity anomalies in the area of the grid origin.

A 2-meter deep exploration trench, dug near the conductivity anomaly, encountered several layers of oxidized and unoxidized sulfides a few centimeters thick at a depth of 100 to 130 centimeters. Laboratory measurements of subsamples of a core (98-BMF-109) from the trench show that the conductivity of the unoxidized sulfides is on the order of 1,000 millisiemens/m (unpublished data, USGS petrophysics lab). It is likely that the high conductivity anomaly near the grid origin is the result of these sulfide layers and/or high dissolved solids also present in the core. The negative conductivity response seen in the EM34 VMD data may be the result

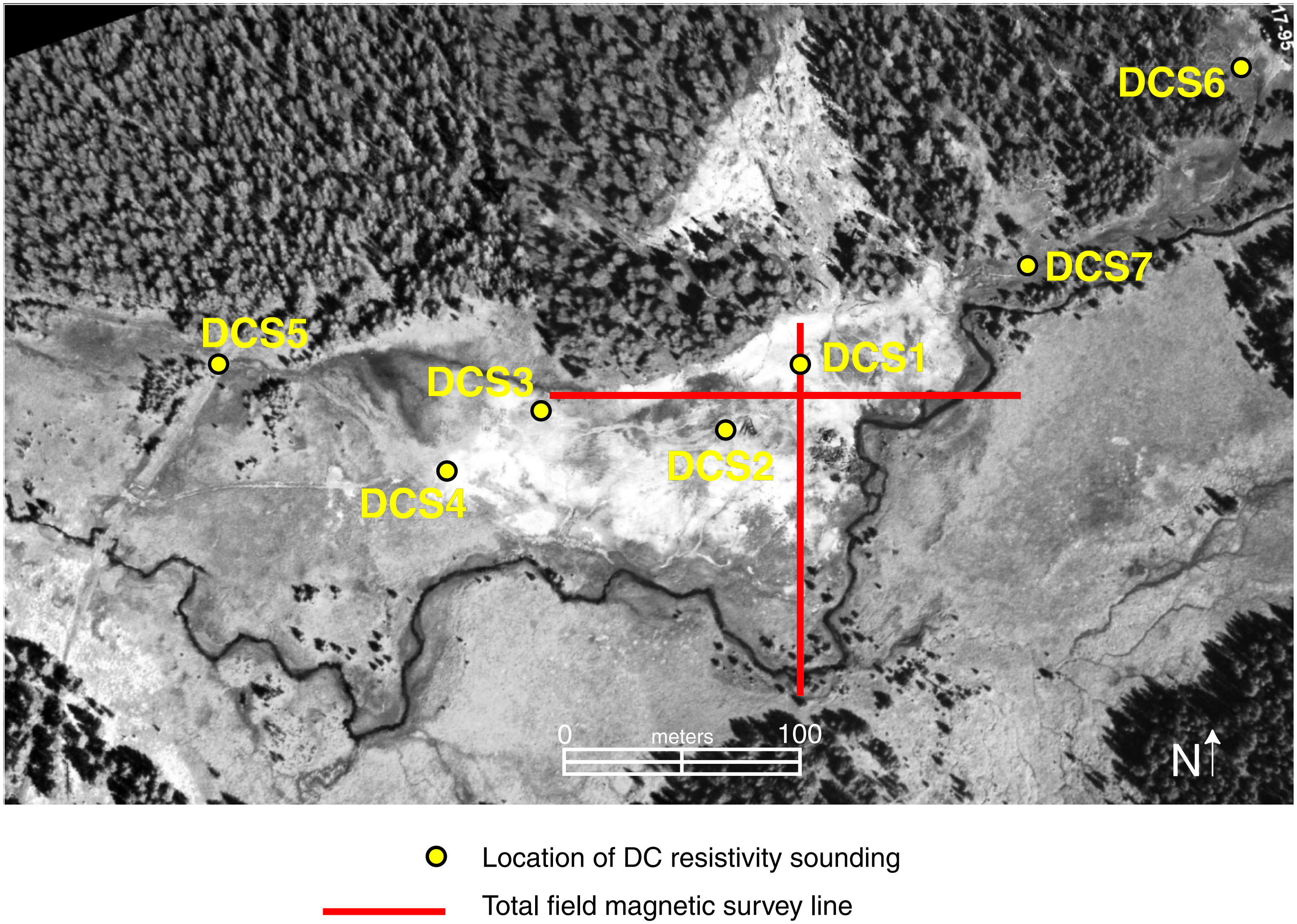

Figure 3. **Location of DC resistivity soundings (DC sounding 8 is off the map to the north) and total field magnetic survey lines**

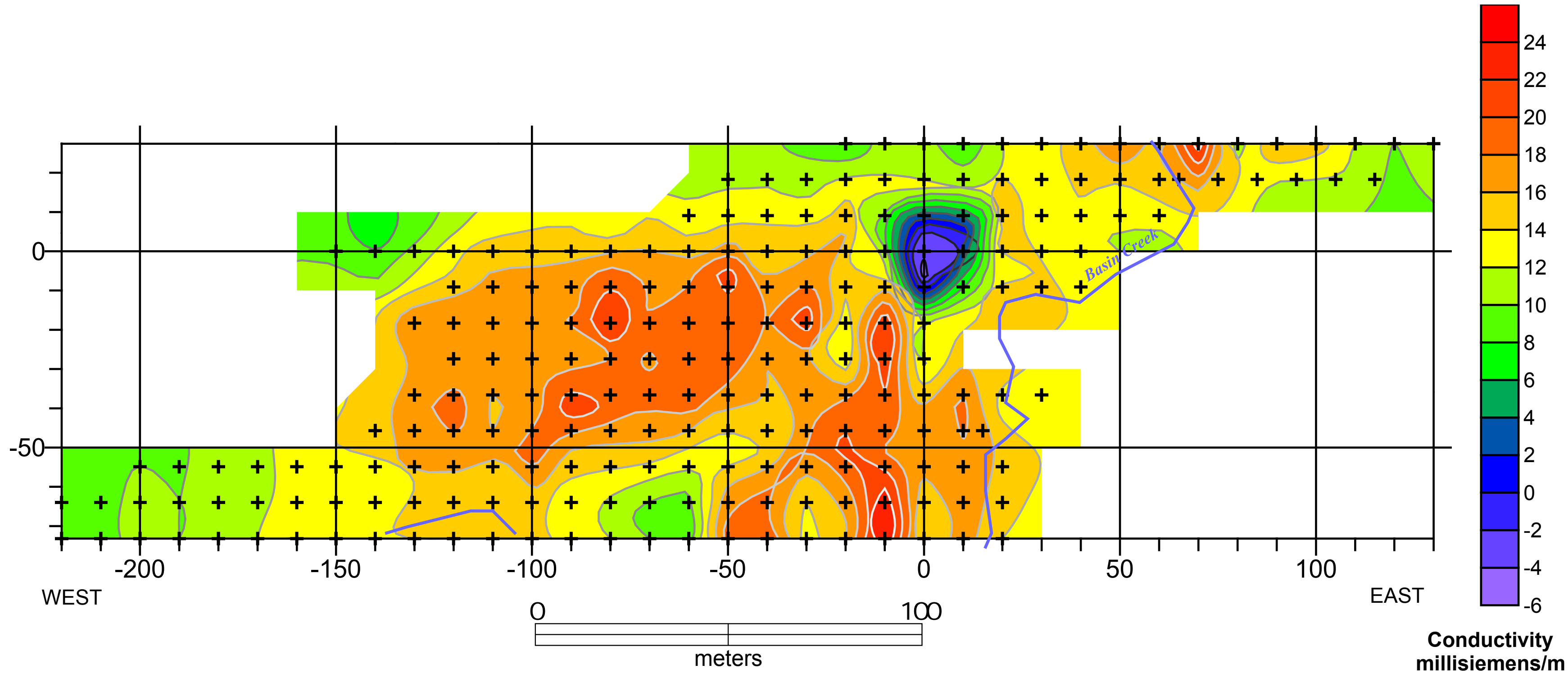

Figure 4. **EM-34 vertical magnetic dipole contour map**

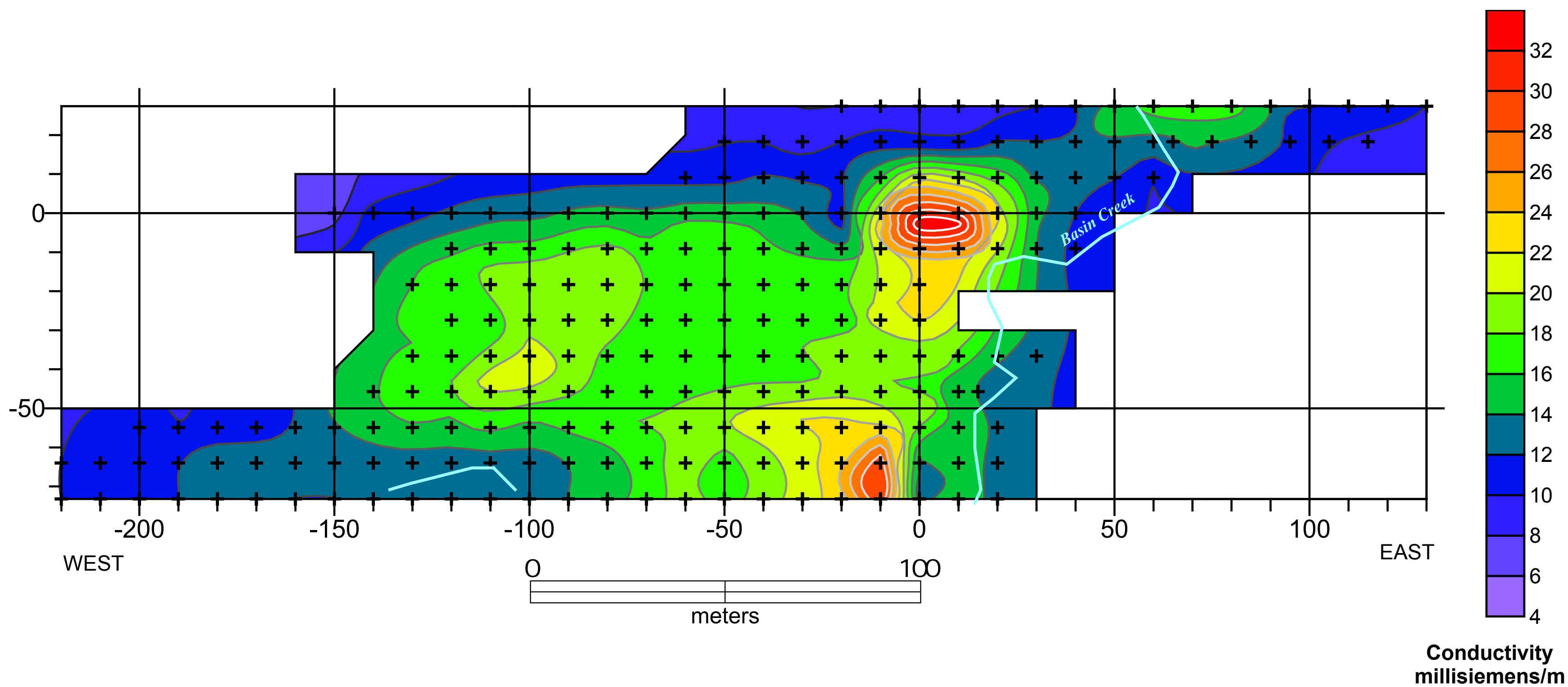

Figure 5. **EM-34 horizontal magnetic dipole contour map**

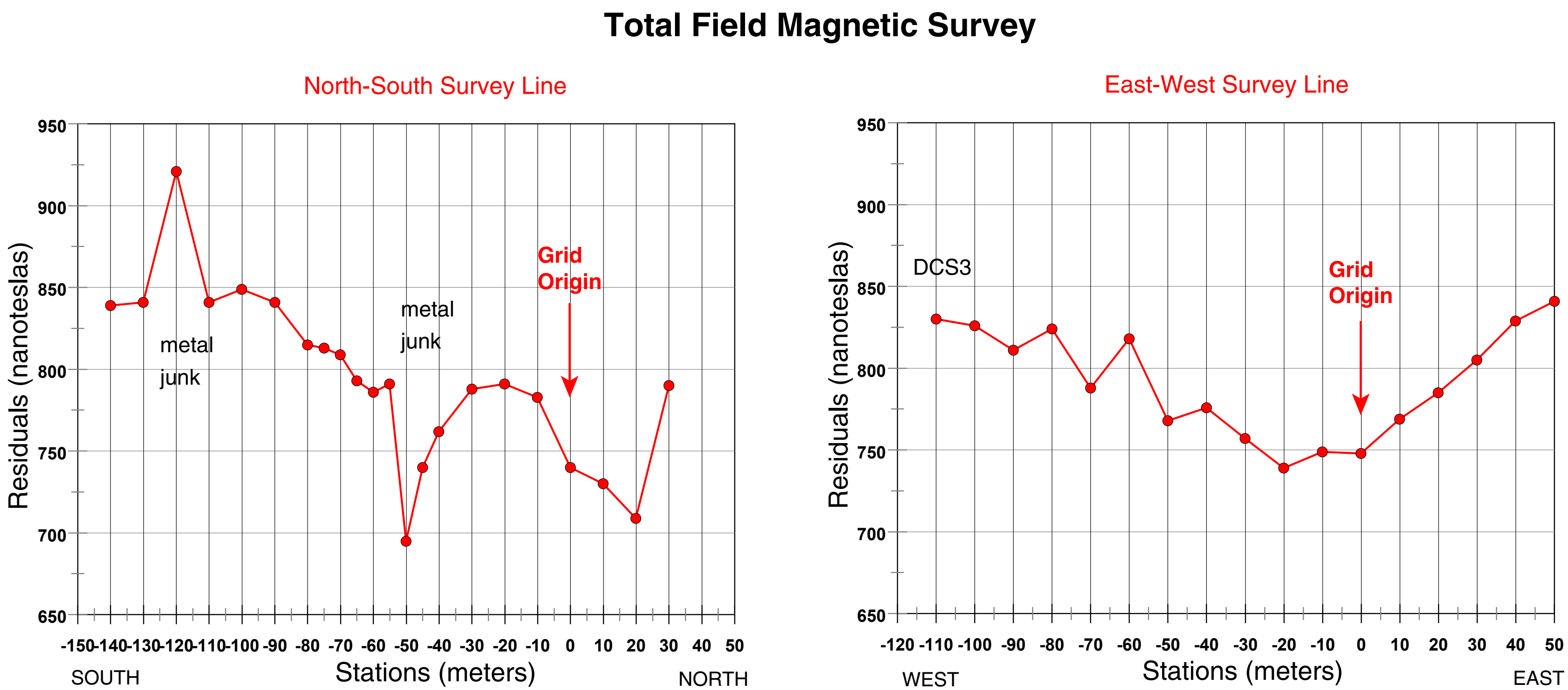

Figure 6. **Graphs of north-south and east-west total field magnetic survey lines**

of the heterogeneous layering of the tailings deposits near the grid origin. Another possible explanation is that the conductivity values, indicated from the core analysis, are high enough to allow for the low induction number approximation to breakdown; at high conductivity values, the approximation of the linear relationship between instrument response and terrain conductivity becomes invalid (McNeill, 1980).

The EM31 VMD (Figure 7) and HMD (Figure 8) contour maps show a similar high conductivity anomaly as seen in the EM34 contour maps. The EM31 VMD and EM34 VMD data show higher conductivity than did the HMD data, indicating increased conductivity with depth. The EM contour maps show an conductive anomaly interpreted as a plume of conductive material extending to the southwest toward the stream. This plume, in terms of depth, position and conductivity, correlates well with the potentiometric surface, direction of ground water flow, and with water quality data from the monitoring wells in and around the tailings. Core samples of tailings and streambed-sediment samples from Basin Creek also show that the highest levels of metals are downstream and in the direction of ground water movement indicated by the electromagnetic data (Fey and others, 1999). The expanded areal coverage of the EM31 survey also indicates areas of high conductivity in the northeast part of the survey area, below the Enterprise claim. This anomaly correlates well with the water analysis from test well #1 (location shown in Figure 2), which is also below the Enterprise tailings and waste rock. Water from test well #1 had a pH of 3.4, and relatively high concentrations of dissolved Al (4780 µg/L), Cd (40 µg/L), Cu (820 µg/L), Pb (36 µg/L), Mn (6060 µg/L), and Zn (4850 µg/L). The dissolved lead concentration of 36 µg/L is the highest of any of the wells sampled (M.R. Cannon, 2000, unpublished data). There was also a surficial seep (observed in July of 1999) of red colored water in the area of the conductivity high.

Another area of relatively high conductivity can be seen in the EM31 VMD contour map (Figure 7) (and to a lesser extent in the HMD map (Figure 8)) southwest of the Buckeye tailings in an area of wet meadows. There are no water quality or well data for this area, but the conductivity could be the result of high dissolved solids deposited during high stream flow conditions, or caused by anomalous clay concentrations in the meadow soils.

Subsurface conductivity as interpreted from the DC soundings is shown in contoured form in a cross-section (Figure 9). Soundings DCS1 and DCS3 (locations shown in Figure 3) were not used in this interpretation because they had marked effects from lateral heterogeneities. For each sounding, the estimated subsurface conductivity was assumed to be located at the mid-point of the interpreted subsurface layer. The layer thicknesses increases at an approximately logarithmic rate since the resolution decreases at a similar rate. Consequently, the depth estimates of conductivity increase logarithmically. The estimate of the conductivity of the last layer should be taken as relatively resistive or conductive since the soundings did not asymptotically approach a constant value at large electrode spacings.

The conductive anomaly in the center of the section (Figure 9) is interpreted to be a plume of high dissolved solids. The plume shows up a little deeper than suggested from drilling and trenching. This may be due to some downward migration of a few meters. The relatively high-interpreted subsurface conductivity at DCS6 is due to an unknown source, but the nearby shallow test well #9 did have high dissolved solids at a somewhat shallower depth.

Sounding DCS8, made on a nearby granite outcrop to the north of the mine showed that the shallow conductivity is on the order of 5 millisiemens/m. None of the interpreted subsurface conductivities are this low except perhaps for DCS2 (Figure 9). Consequently, granite underlying the mine tailings, with similar electrical properties as the outcropping area, may be more than 30 meters deep. However, it is likely that the granite in the stream valley is more weathered and has a higher volume of water than the outcrop area of DCS8. It is also possible that the underlying granite aquifer has fractures that contain clays and/or high dissolved solids, which would produce higher conductivities and consequently place its depth at less than 30 meters.

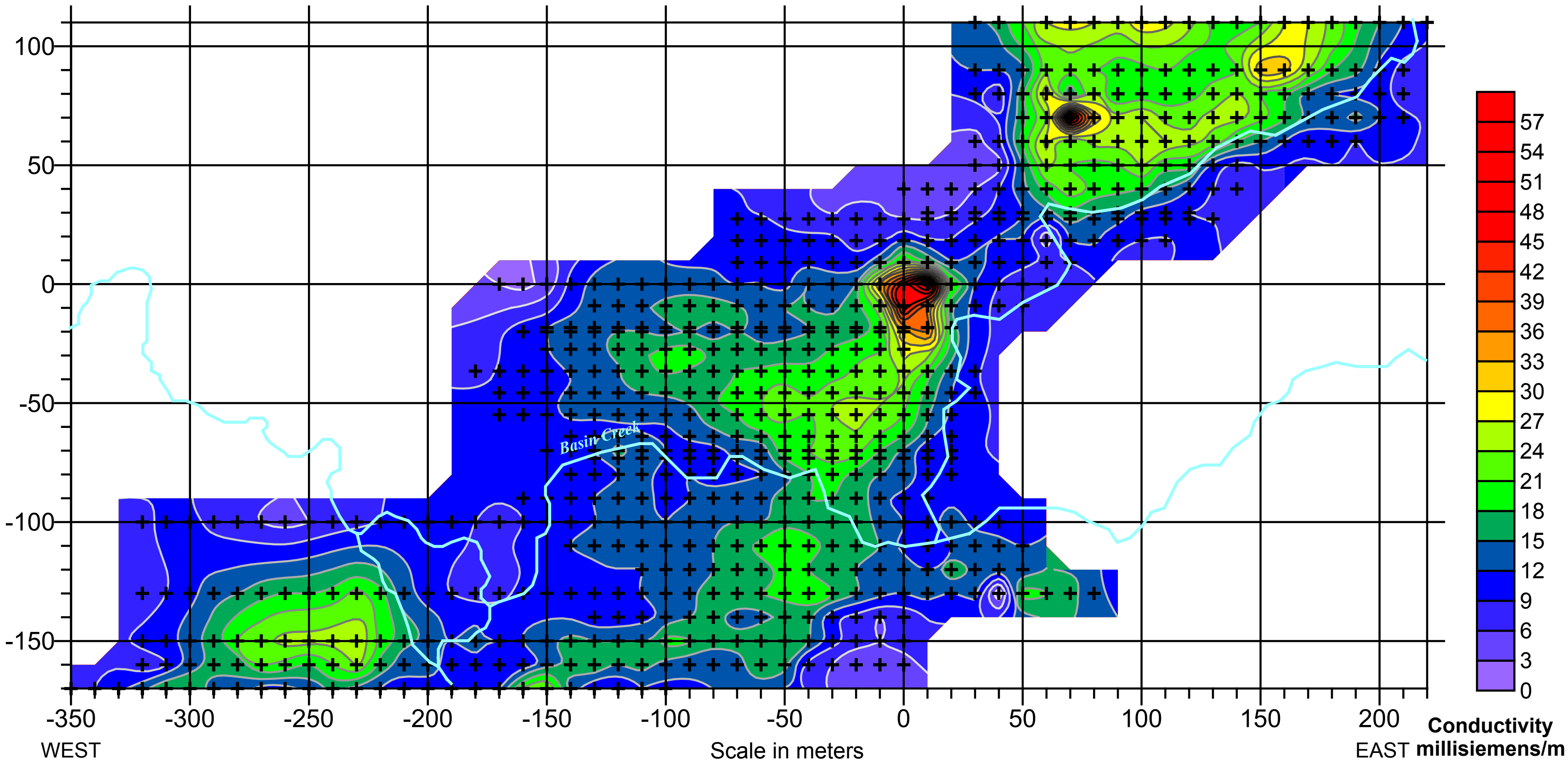

Figure 7. **EM-31 vertical magnetic dipole contour map**

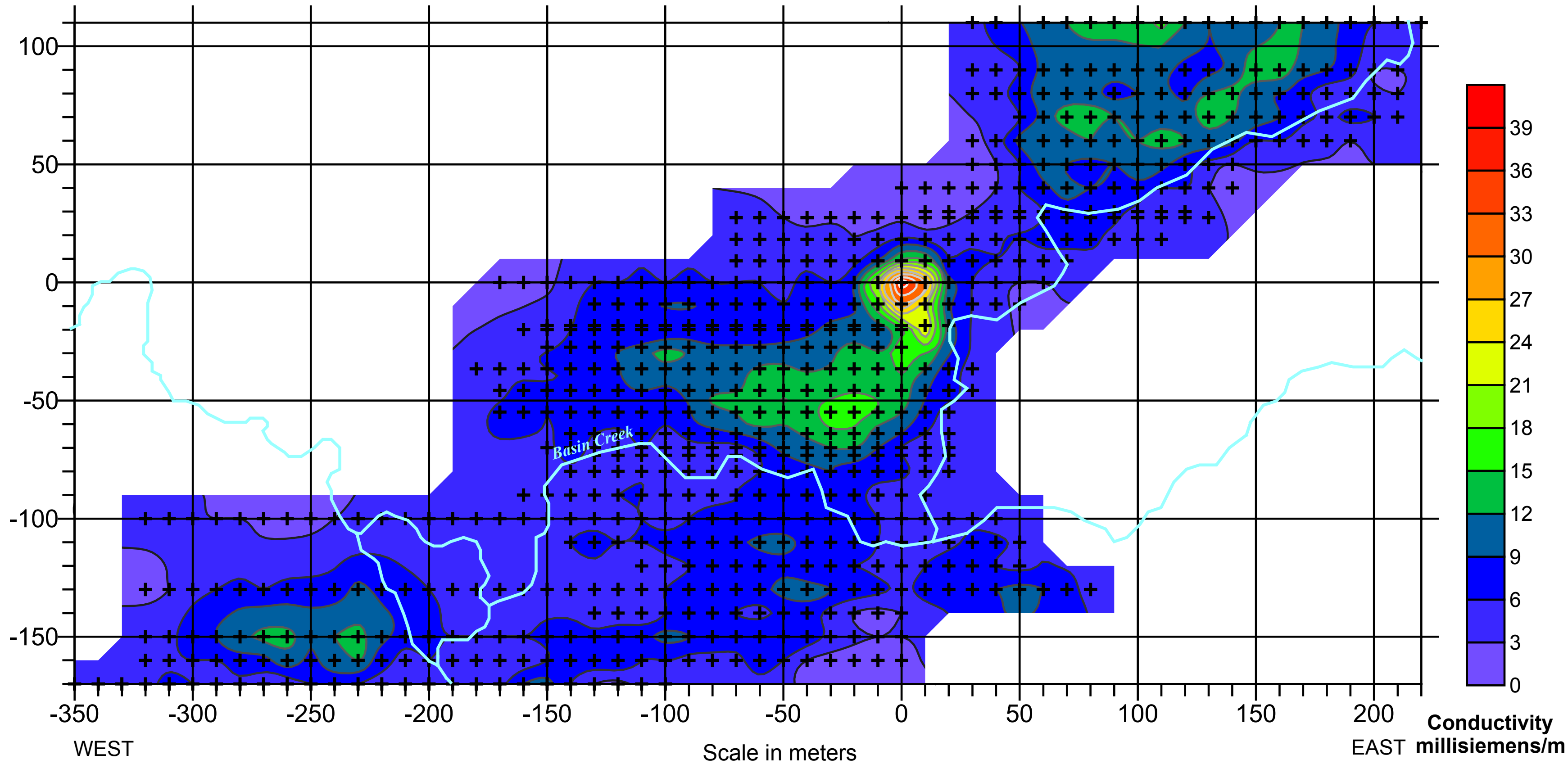

Figure 8. EM-31 horizontal magnetic dipole contour map

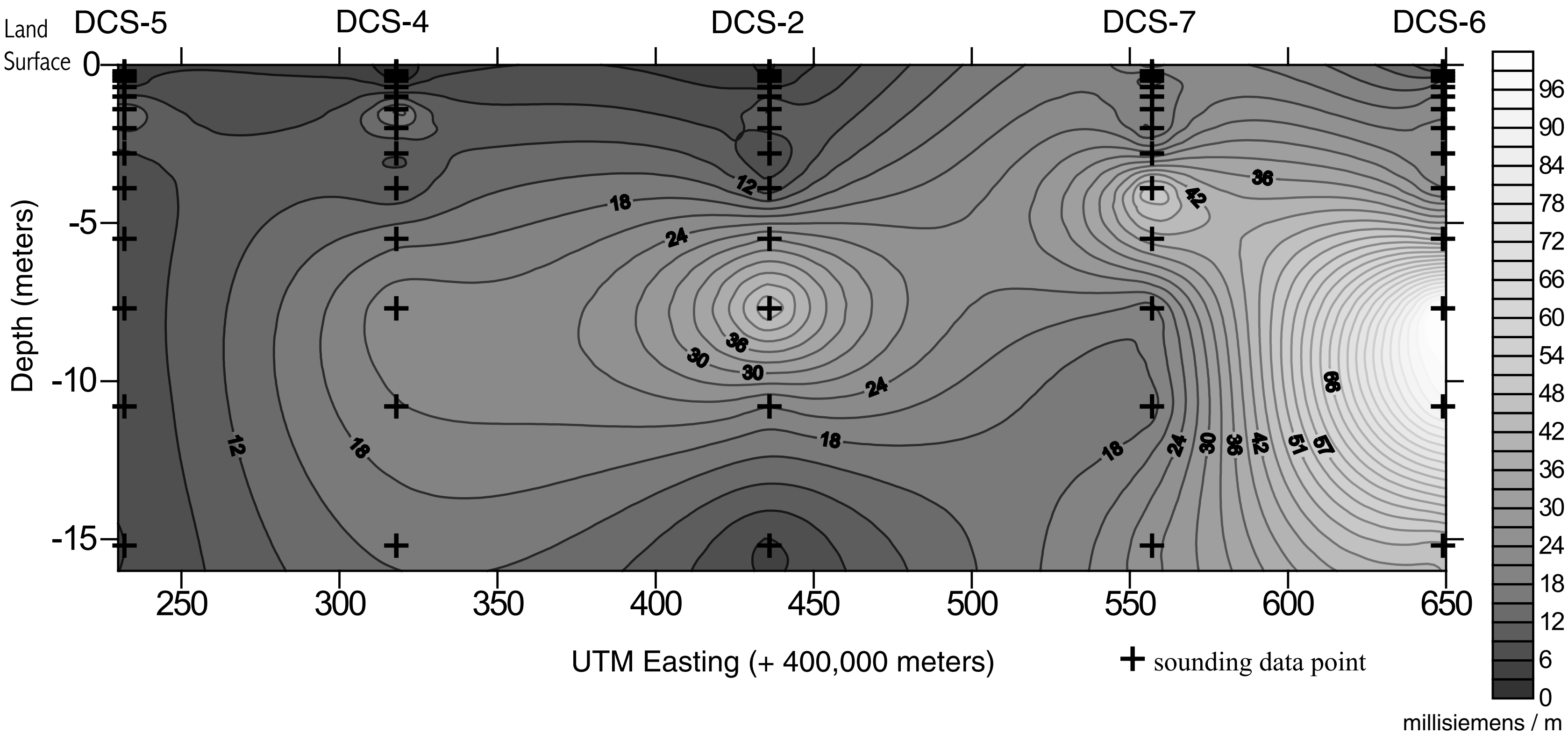

Figure 9. **Subsurface cross-section of DC soundings (depth is plotted with a vertical exaggeration factor of ten)**

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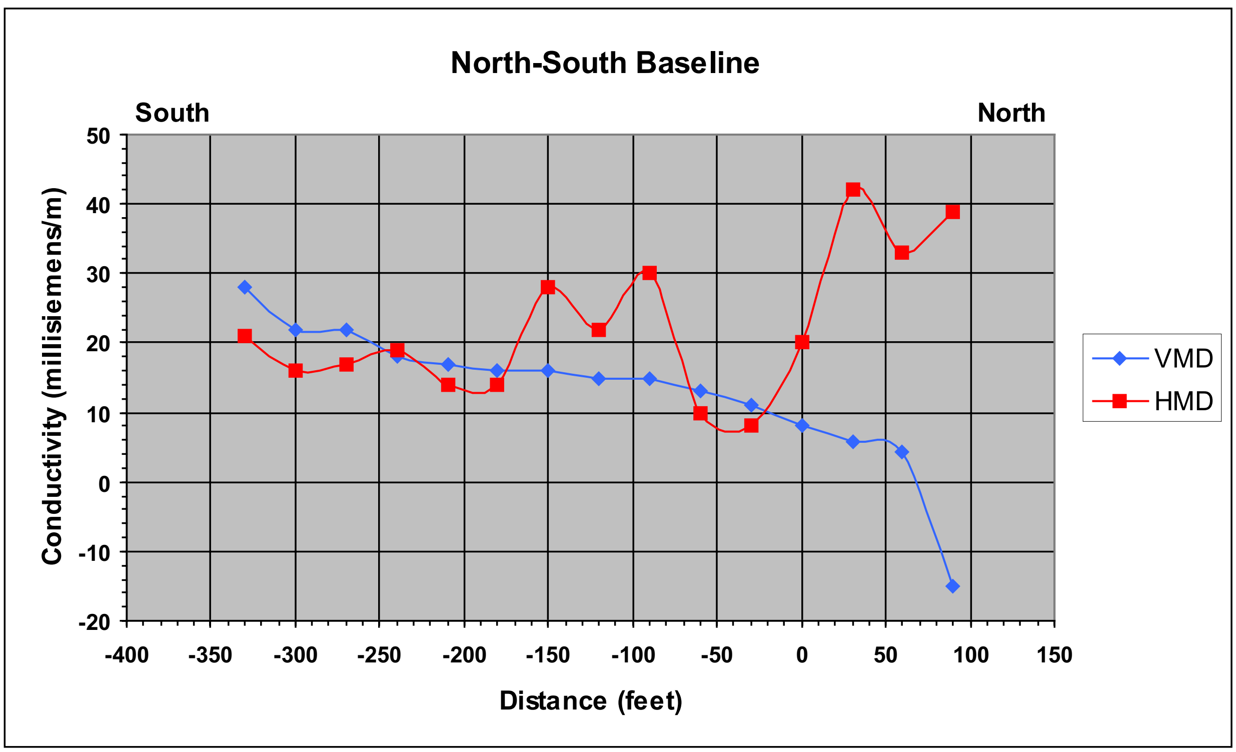
APPENDIX I

EM-34 and EM-31 Data and Plots

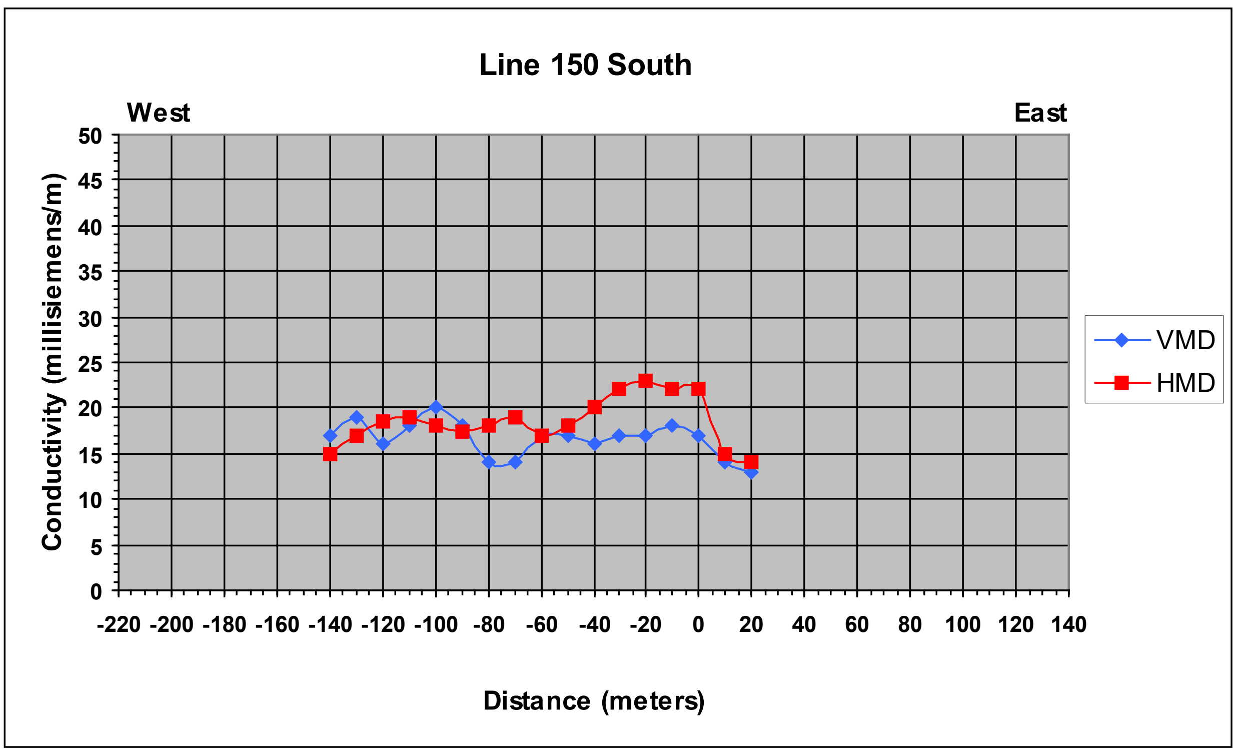
Buckeye Tailings EM34 Survey
NS Base Line (negative South)
10m Coil Centers on station (feet)
July 16, 1998

Station (feet)	VMD (millisiemens/m)	HMD (millisiemens/m)	COMMENTS
-330	28	21	TX at stream flowing EW
-300	22	16	
-270	22	17	
-240	18	19	
-210	17	14	
-180	16	14	
-150	16	28	
-120	15	22	
-90	15	30	
-60	13	10	
-30	11	8	
0	8	20	metal stake
30	5.7	42	
60	4.2	33	
90	-15	39	



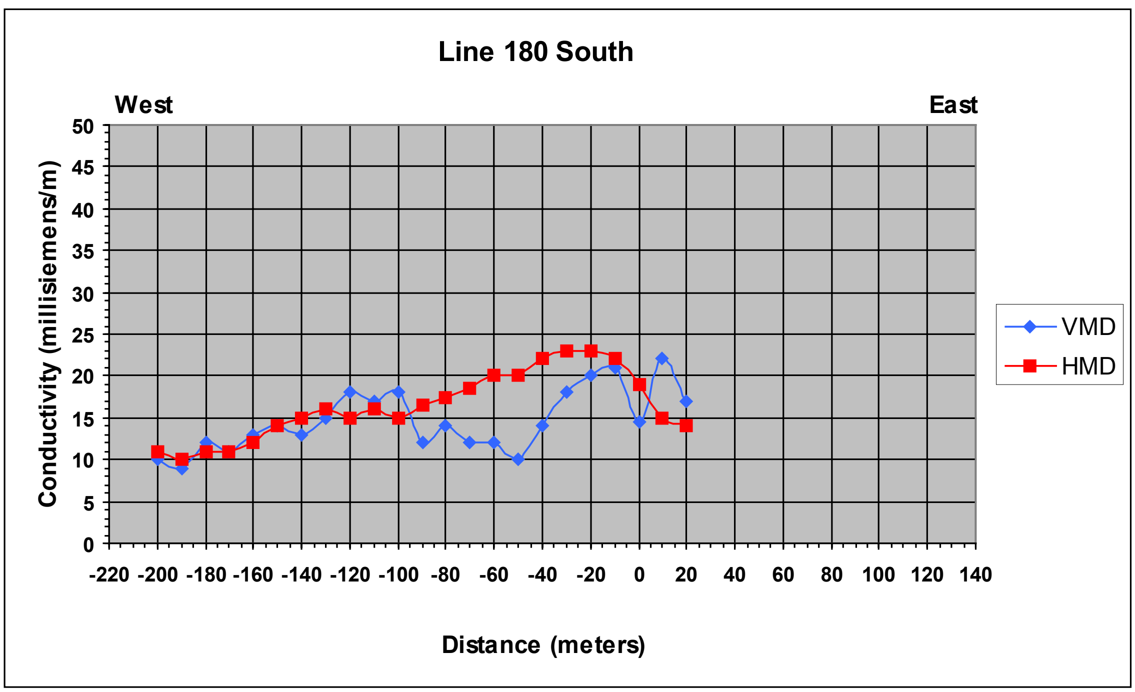
Buckeye Tailings EM34 Survey
Line 150 South (negative west)
10m Coil Centers on station (meters)
July 16, 1998

Station (feet)	VMD (millisiemens/m)	HMD (millisiemens/m)	COMMENTS
-140	17	15	RCV at edge of bog
-130	19	17	
-120	16	18.5	
-110	18	19	
-100	20	18	
-90	18	17.5	
-80	14	18	
-70	14	19	
-60	17	17	
-50	17	18	
-40	16	20	
-30	17	22	
-20	17	23	
-10	18	22	
0	17	22	
10	14	15	
20	13	14	Tx at stream flowing NS



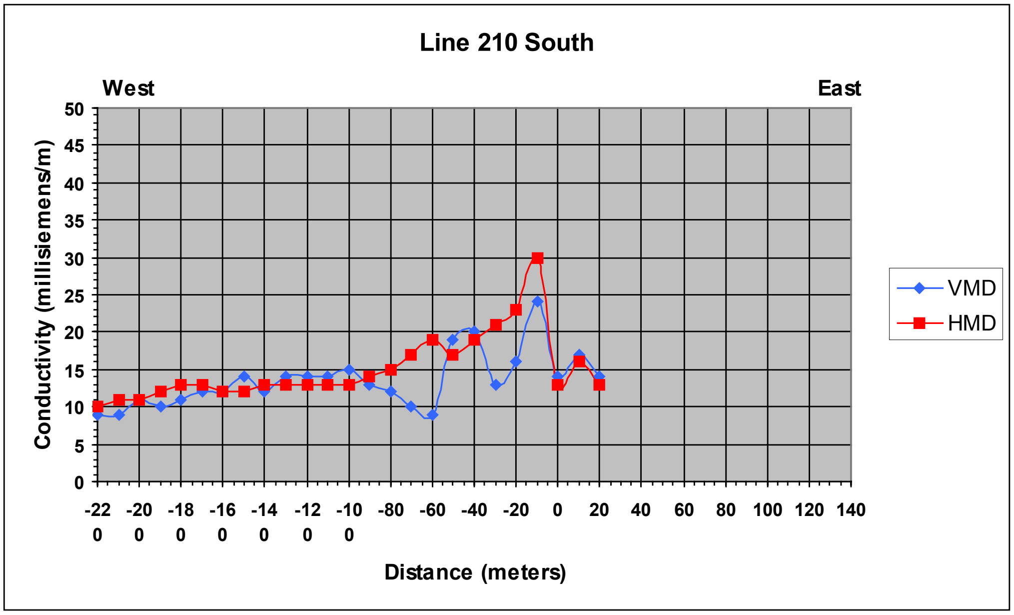
Buckeye Tailings EM34 Survey
Line 180 South (negative west)
10m Coil Centers on station (meters)
July 16, 1998

Station (feet)	VMD (millisiemens/m)	HMD (millisiemens/m)	COMMENTS
-200	10	11	
-190	9	10	
-180	12	11	
-170	11	11	
-160	13	12	
-150	14	14	
-140	13	15	
-130	15	16	
-120	18	15	
-110	17	16	
-100	18	15	
-90	12	16.5	
-80	14	17.5	
-70	12	18.5	
-60	12	20	
-50	10	20	grass area
-40	14	22	
-30	18	23	
-20	20	23	
-10	21	22	
0	14.5	19	
10	22	15	
20	17	14	



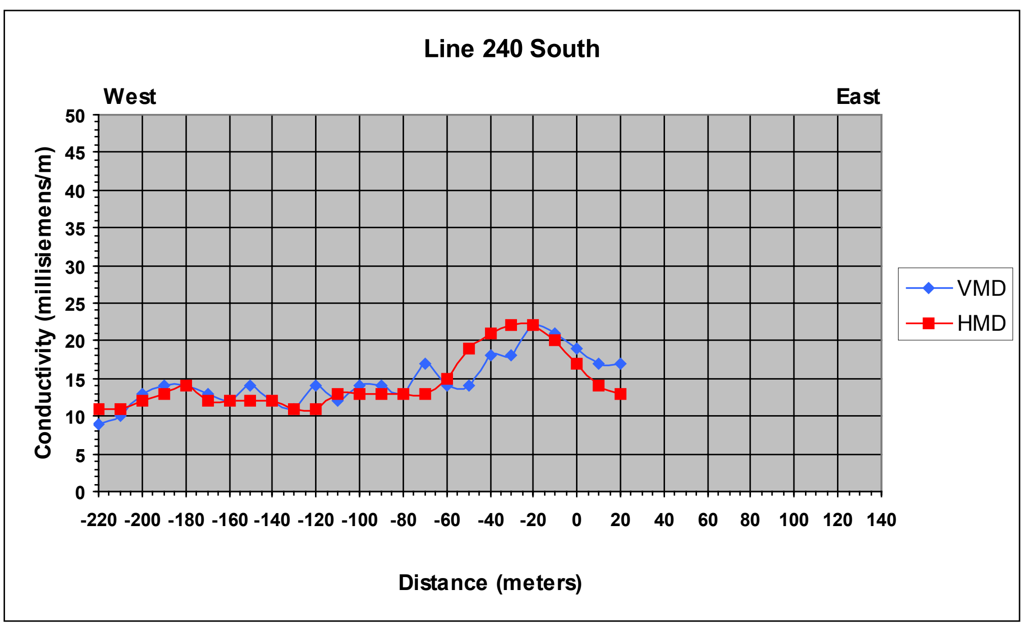
Buckeye Tailings EM34 Survey
Line 210 South (negative west)
10m Coil Centers on station (meters)
July 16, 1998

Station (feet)	VMD (millisiemens/m)	HMD (millisiemens/m)	COMMENTS
-220	9	10	
-210	9	11	
-200	11	11	
-190	10	12	
-180	11	13	
-170	12	13	
-160	12	12	
-150	14	12	
-140	12	13	
-130	14	13	
-120	14	13	
-110	14	13	
-100	15	13	
-90	13	14	
-80	12	15	
-70	10	17	
-60	9	19	
-50	19	17	
-40	20	19	
-30	13	21	
-20	16	23	
-10	24	30	
0	14	13	
10	17	16	grass area start
20	14	13	



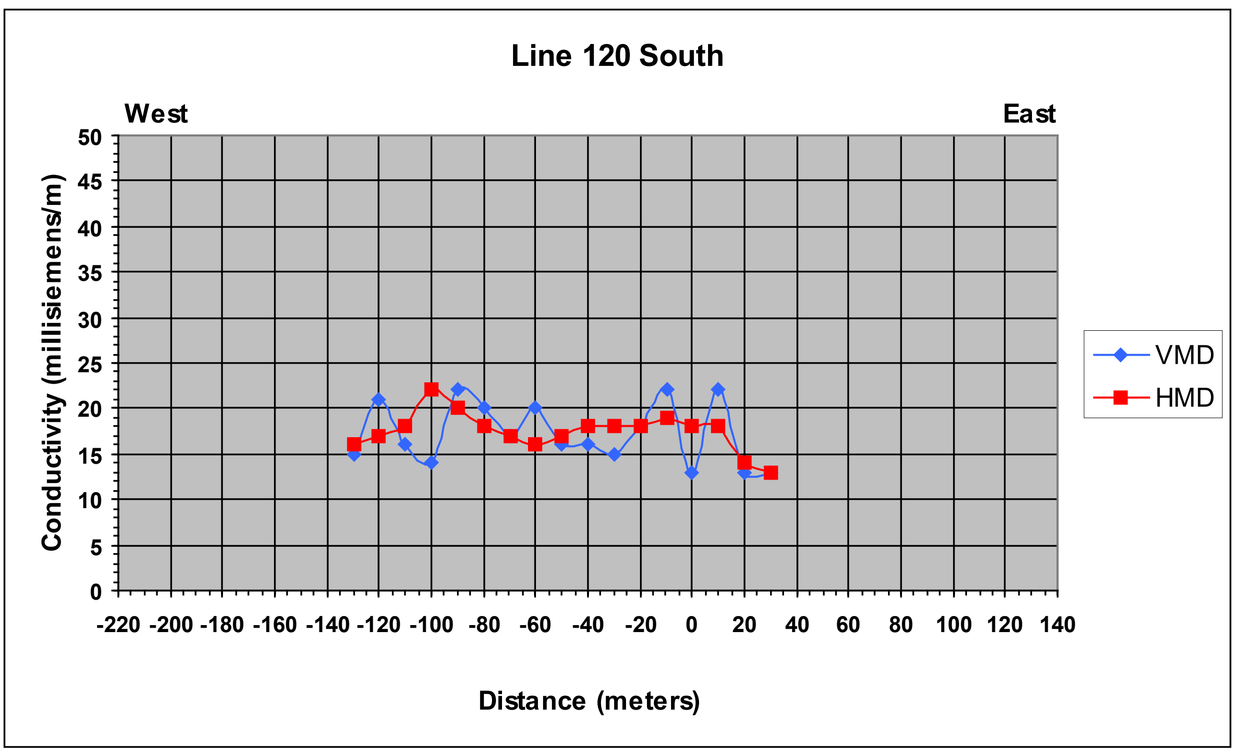
Buckeye Tailings EM34 Survey
Line 240 South (negative west)
10m Coil Centers on station (meters)
July 16, 1998

Station (feet)	VMD (millisiemens/m)	HMD (millisiemens/m)	COMMENTS
-220	9	11	meadow
-210	10	11	
-200	13	12	
-190	14	13	
-180	14	14	
-170	13	12	
-160	12	12	
-150	14	12	
-140	12	12	
-130	11	11	
-120	14	11	
-110	12	13	
-100	14	13	
-90	14	13	grass area
-80	13	13	
-70	17	13	
-60	14	15	
-50	14	19	
-40	18	21	
-30	18	22	
-20	22	22	
-10	21	20	
0	19	17	
10	17	14	
20	17	13	



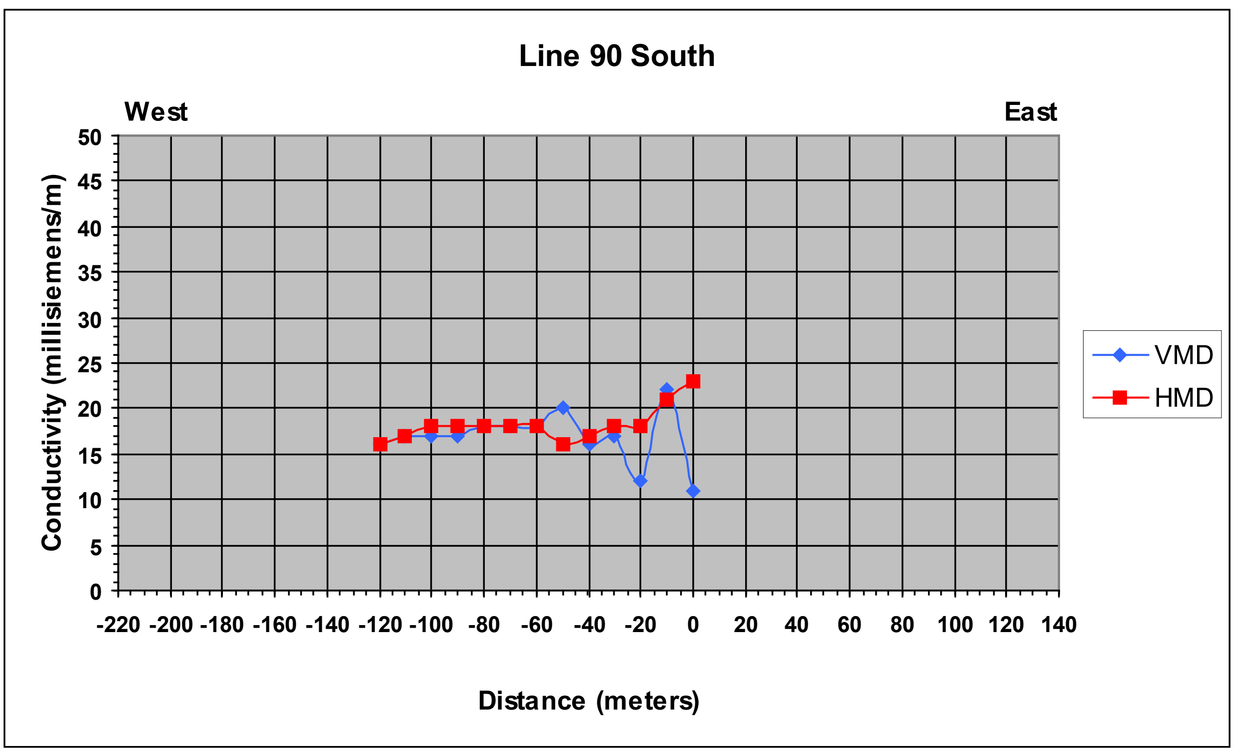
Buckeye Tailings EM34 Survey
Line 120 South (negative west)
10m Coil Centers on station (meters)
July 17, 1998

Station (feet)	VMD (millisiemens/m)	HMD (millisiemens/m)	COMMENTS
-130	15	16	edge of bog
-120	21	17	
-110	16	18	
-100	14	22	
-90	22	20	
-80	20	18	drainage at rcv
-70	17	17	
-60	20	16	metal scraps
-50	16	17	
-40	16	18	
-30	15	18	
-20	18	18	
-10	22	19	
0	13	18	
10	22	18	
20	13	14	
30	13	13	stream



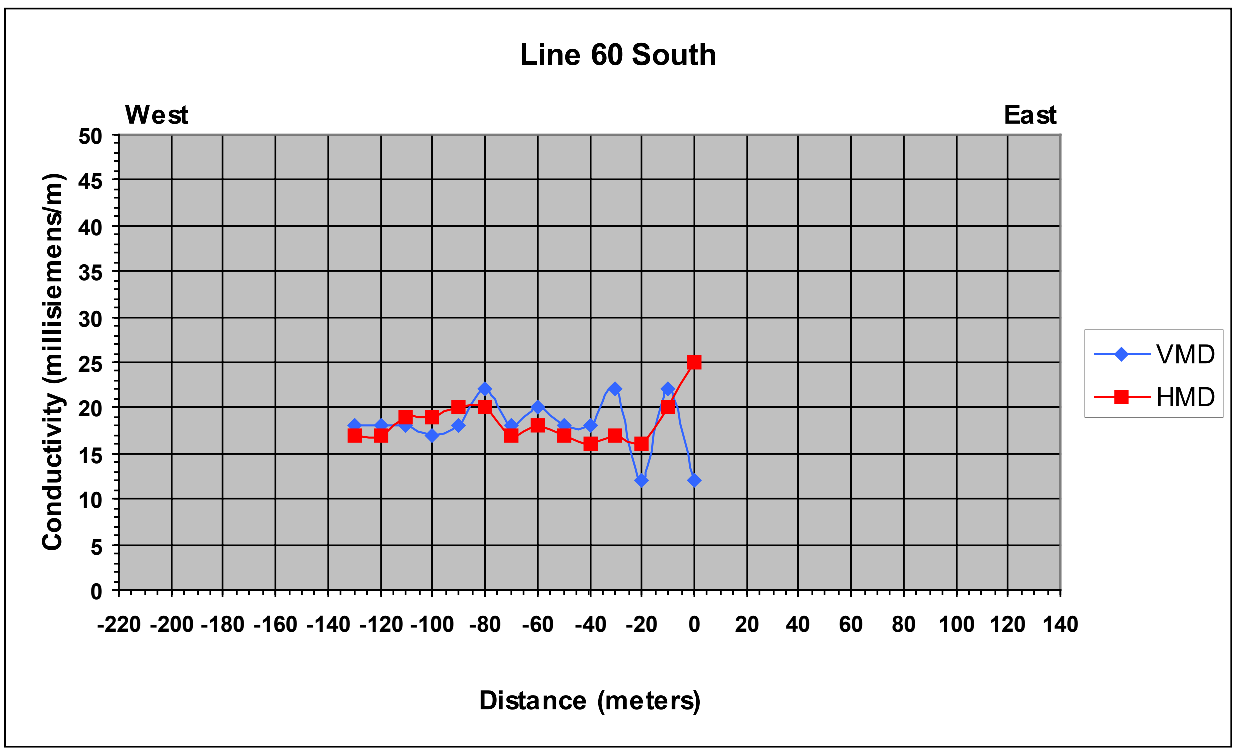
Buckeye Tailings EM34 Survey
Line 90 South (negative west)
10m Coil Centers on station (meters)
July 17, 1998

Station (feet)	VMD (millisiemens/m)	HMD (millisiemens/m)	COMMENTS
-120	16	16	
-110	17	17	
-100	17	18	
-90	17	18	
-80	18	18	
-70	18	18	
-60	18	18	
-50	20	16	
-40	16	17	
-30	17	18	
-20	12	18	
-10	22	21	
0	11	23	



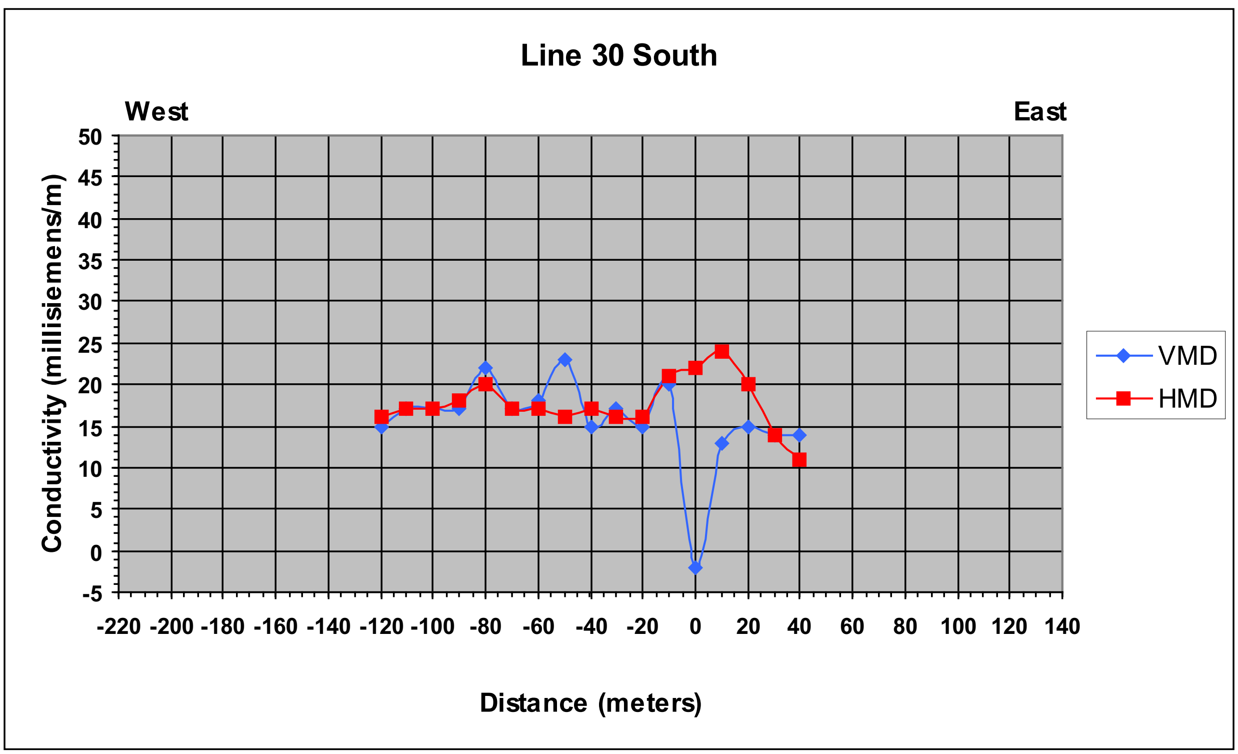
Buckeye Tailings EM34 Survey
Line 60 South (negative west)
10m Coil Centers on station (meters)
July 17, 1998

Station (feet)	VMD (millisiemens/m)	HMD (millisiemens/m)	COMMENTS
-130	18	17	rcv at bog
-120	18	17	
-110	18	19	
-100	17	19	
-90	18	20	
-80	22	20	west edge muck
-70	18	17	
-60	20	18	
-50	18	17	center muck
-40	18	16	
-30	22	17	center junk with metal
-20	12	16	
-10	22	20	
0	12	25	no east due to junk



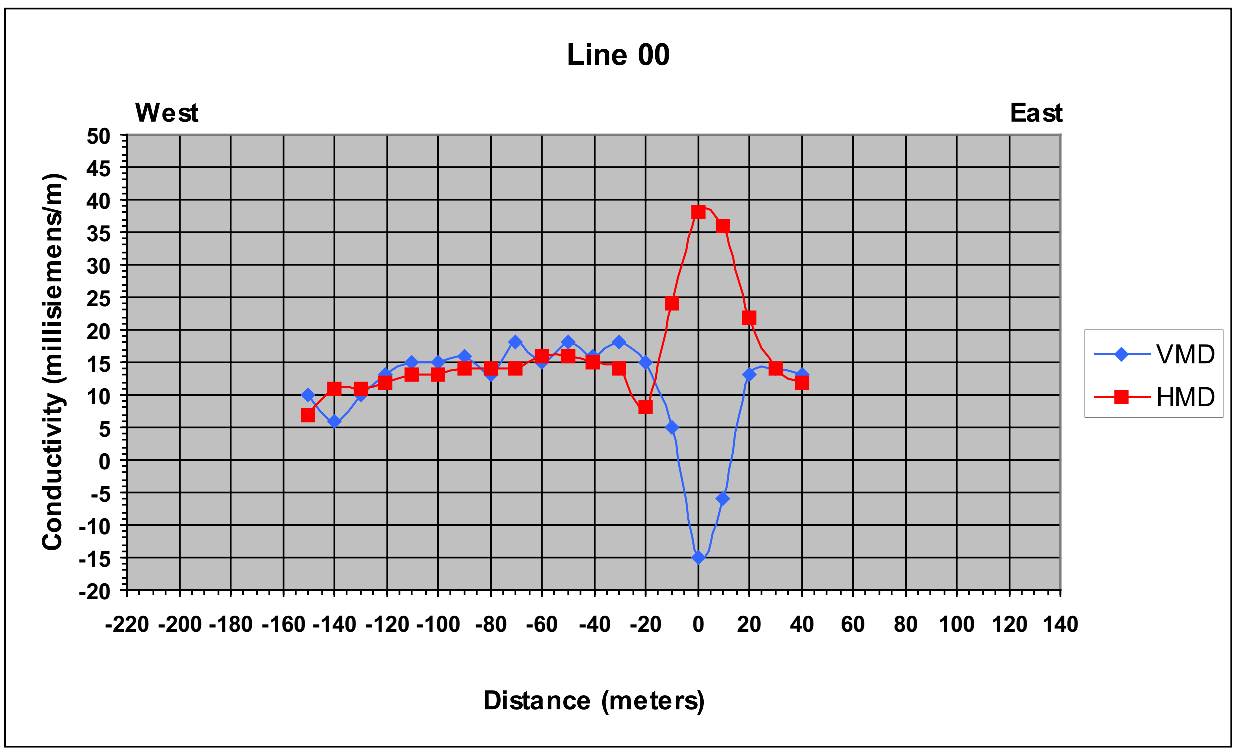
Buckeye Tailings EM34 Survey
Line 30 South (negative west)
10m Coil Centers on station (meters)
July 17, 1998

Station (feet)	VMD (millisiemens/m)	HMD (millisiemens/m)	COMMENTS
-120	15	16	
-110	17	17	
-100	17	17	
-90	17	18	
-80	22	20	
-70	17	17	
-60	18	17	west edge muck
-50	23	16	
-40	15	17	
-30	17	16	mid muck
-20	15	16	east edge muck
-10	20	21	
0	-2	22	
10	13	24	
20	15	20	
30	14	14	line parallel stream
40	14	11	rcv at bend stream



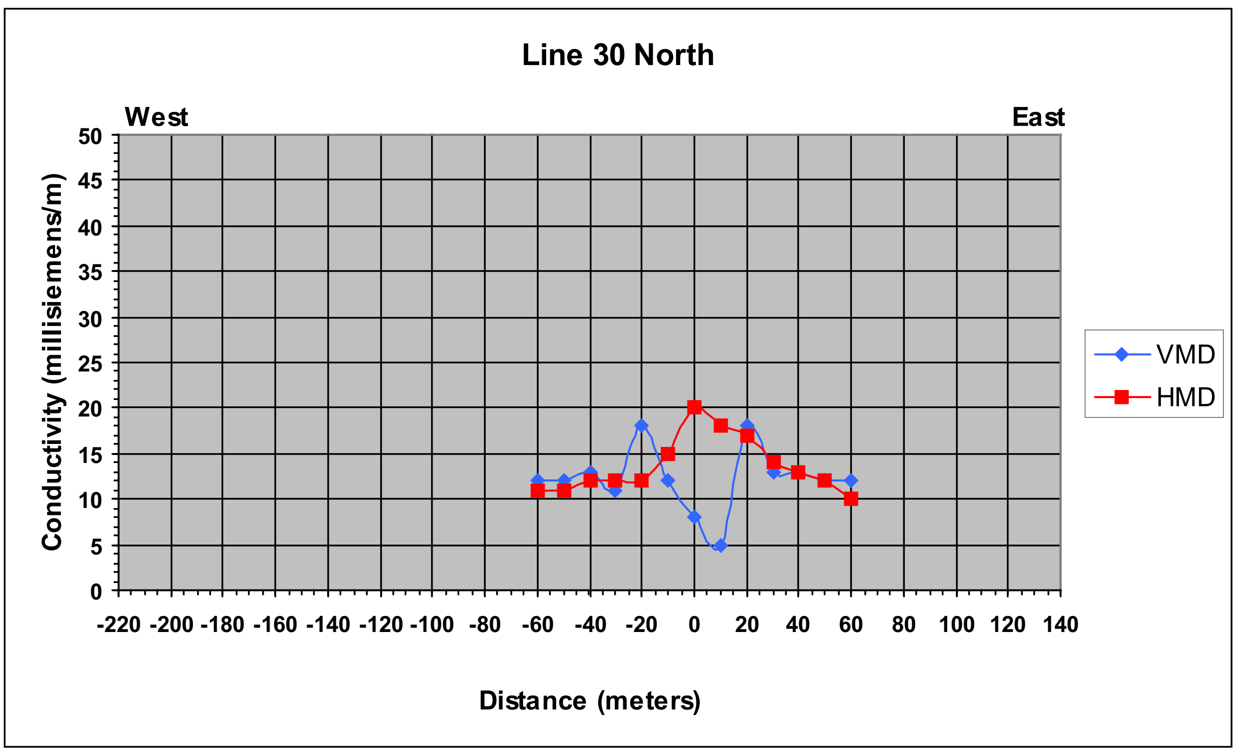
Buckeye Tailings EM34 Survey
Line 00 (negative west)
10m Coil Centers on station (meters)
July 17, 1998

Station (feet)	VMD (millisiemens/m)	HMD (millisiemens/m)	COMMENTS
-150	10	7	
-140	6	11	woods
-130	10	11	
-120	13	12	
-110	15	13	
-100	15	13	spring marsh
-90	16	14	trees
-80	13	14	edge of trees
-70	18	14	
-60	15	16	rcv at large metal object
-50	18	16	west edge muck
-40	16	15	
-30	18	14	east edge muck
-20	15	8	
-10	5	24	
0	-15	38	
10	-6	36	
20	13	22	
30	14	14	
40	13	12	stream



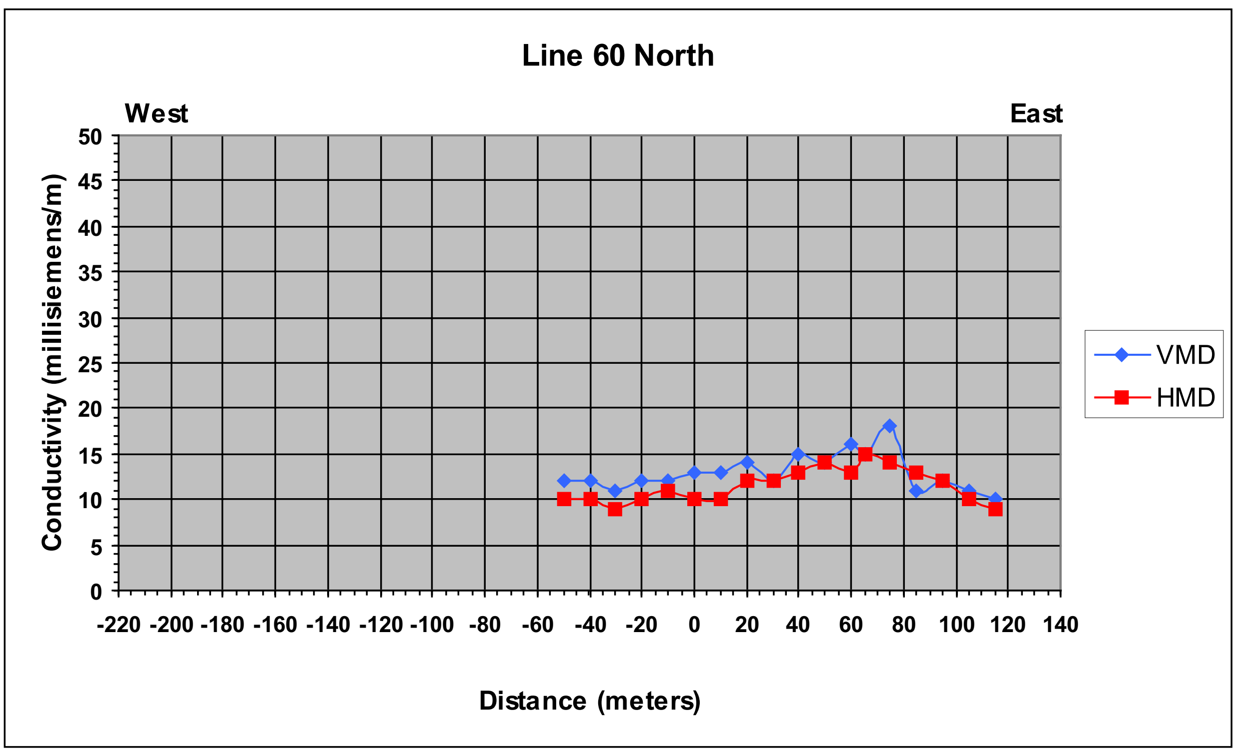
Buckeye Tailings EM34 Survey
Line 30 North (negative west)
10m Coil Centers on station (meters)
July 17, 1998

Station (feet)	VMD (millisiemens/m)	HMD (millisiemens/m)	COMMENTS
-60	12	11	
-50	12	11	forest
-40	13	12	
-30	11	12	center at tree line
-20	18	12	tx at small gulley
-10	12	15	
0	8	20	
10	5	18	
20	18	17	
30	13	14	
40	13	13	
50	12	12	
60	12	10	center at edge of tailing



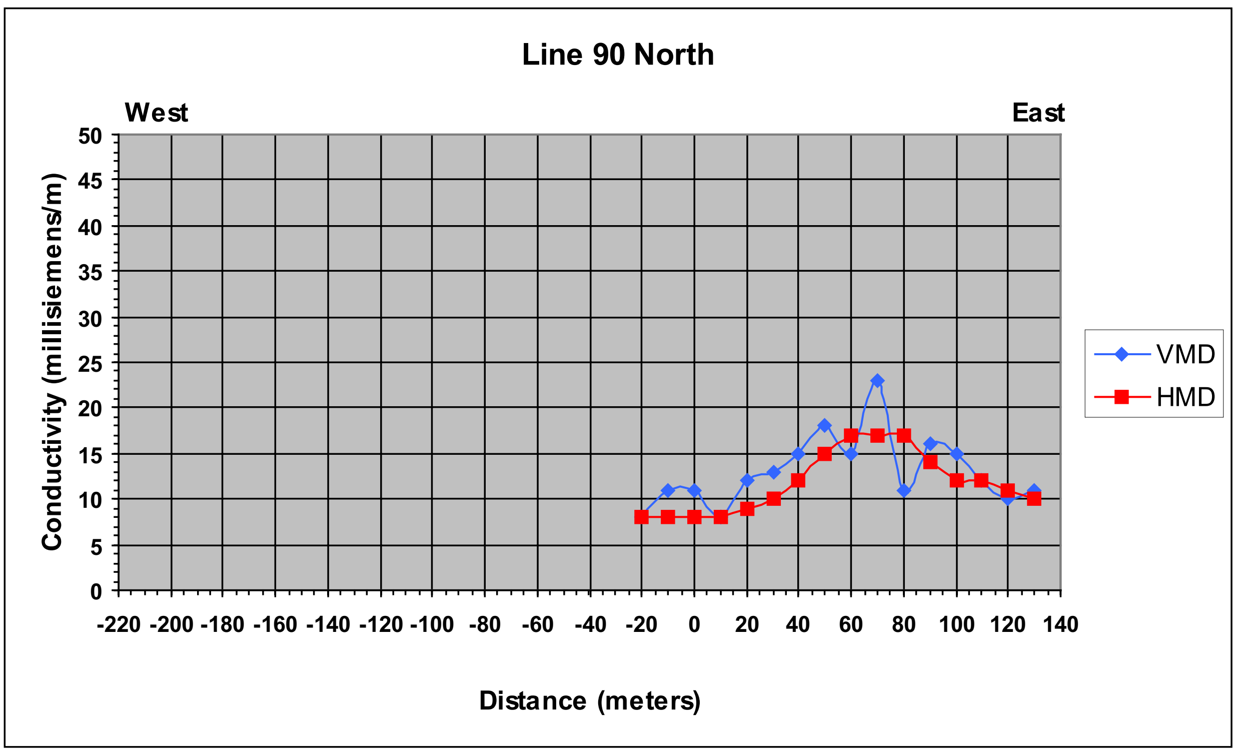
Buckeye Tailings EM34 Survey
Line 60 North (negative west)
10m Coil Centers on station (meters)
July 17, 1998

Station (feet)	VMD (millisiemens/m)	HMD (millisiemens/m)	COMMENTS
-50	12	10	
-40	12	10	
-30	11	9	tree line
-20	12	10	
-10	12	11	
0	13	10	
10	13	10	top muck
20	14	12	
30	12	12	
40	15	13	
50	14	14	
60	16	13	
65	15	15	
75	18	14	stream
85	11	13	
95	12	12	
105	11	10	meadow
115	10	9	



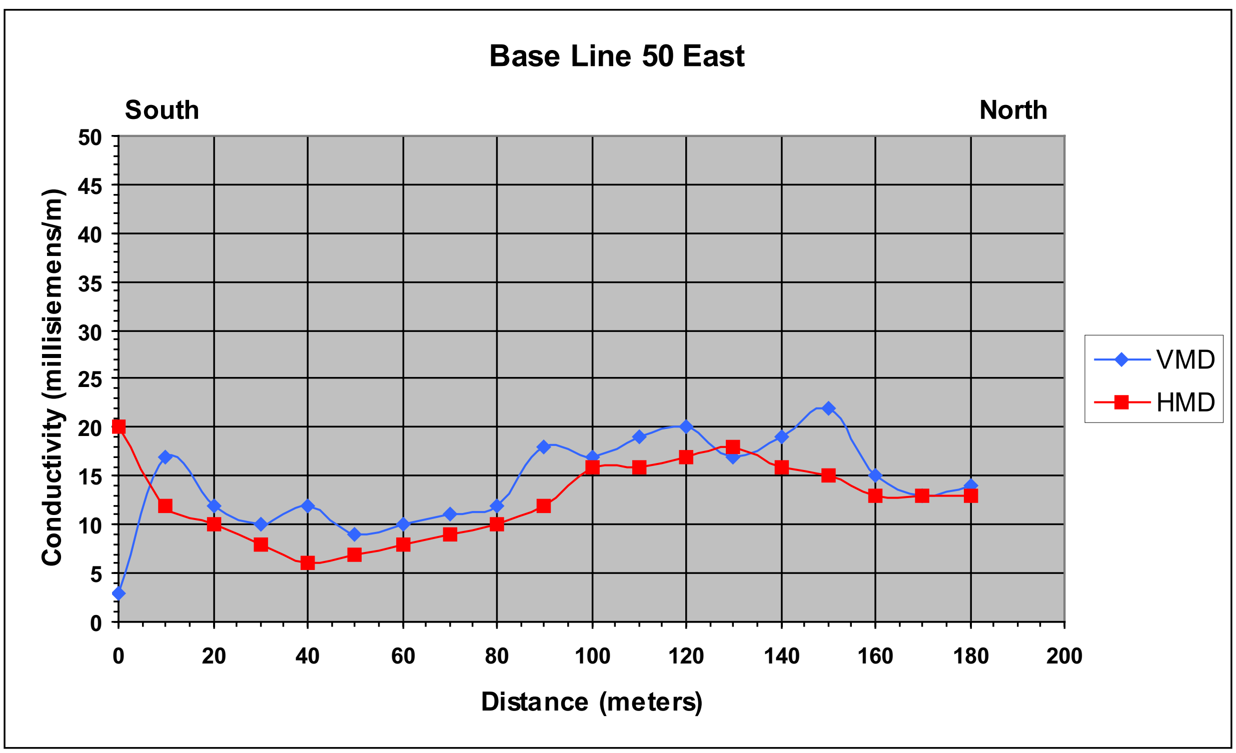
Buckeye Tailings EM34 Survey
Line 90 North (negative west)
10m Coil Centers on station (meters)
July 17, 1998

Station (feet)	VMD (millisiemens/m)	HMD (millisiemens/m)	COMMENTS
-20	8	8	forest
-10	11	8	edge of forest
0	11	8	top of dump delta
10	8	8	
20	12	9	damp dump
30	13	10	
40	15	12	
50	18	15	
60	15	17	east edge of stream
70	23	17	
80	11	17	
90	16	14	
100	15	12	meadow
110	12	12	
120	10	11	
130	11	10	



Buckeye Tailings EM34 Survey
Base Line 50E (positive north)
10m Coil Centers on station (meters)
July 17, 1998

Station (feet)	VMD (millisiemens/m)	HMD (millisiemens/m)	COMMENTS
0	3	20	on line 0 start 50 east
10	17	12	
20	12	10	
30	10	8	
40	12	6	
50	9	7	
60	10	8	
70	11	9	
80	12	10	
90	18	12	
100	17	16	
110	19	16	
120	20	17	
130	17	18	
140	19	16	
150	22	15	
160	15	13	
170	13	13	top of clear area
180	14	13	



Buckeye Mine Site
EM-31 Survey Data

Survey grid X coordinate	Survey grid Y coordinate	VMD millisiemens/m	HMD millisiemens/m	UTM northing $+5.138x10^6$	UTM easting $+4.0x10^5$
130	27.4	9	4	583.4	593
120	27.4	11	6	583.4	583
110	27.4	9	4	583.4	573
100	27.4	10	5	583.4	563
90	27.4	13	6	583.4	553
80	27.4	13	7	583.4	543
70	27.4	17	7	583.4	533
60	27.4	16	7	583.4	523
50	27.4	14	6	583.4	513
40	27.4	12	5	583.4	503
30	27.4	10	5	583.4	493
20	27.4	8	3	583.4	483
10	27.4	7	3	583.4	473
0	27.4	5	2	583.4	463
-10	27.4	7	2	583.4	453
-20	27.4	7	2	583.4	443
-30	27.4	6	2	583.4	433
-40	27.4	7	2	583.4	423
-50	27.4	8	3	583.4	413
-60	27.4	9	4	583.4	403
-70	27.4	10	4	583.4	393
110	18.3	9	4	574.3	573
100	18.3	9	5	574.3	563
90	18.3	9	5	574.3	553
80	18.3	13	7	574.3	543
70	18.3	12	7	574.3	533
60	18.3	1	7	574.3	523
50	18.3	12	6	574.3	513
40	18.3	12	6	574.3	503
30	18.3	11	5	574.3	493
20	18.3	9	4	574.3	483
10	18.3	9	4	574.3	473
0	18.3	12	6	574.3	463
-10	18.3	8	4	574.3	453
-20	18.3	8	3	574.3	443
-30	18.3	10	5	574.3	433
-40	18.3	10	4	574.3	423
-50	18.3	10	4	574.3	413
-60	18.3	12	6	574.3	403
-70	18.3	11	5	574.3	393
70	9.1	9	5	565.1	533
60	9.1	9	5	565.1	523
50	9.1	10	5	565.1	513
40	9.1	11	6	565.1	503
30	9.1	13	7	565.1	493
20	9.1	12	6	565.1	483
10	9.1	18	16	565.1	473
0	9.1	24	16	565.1	463

-10	9.1	14	9	565.1	453
-20	9.1	10	5	565.1	443
-30	9.1	10	5	565.1	433
-40	9.1	11	5	565.1	423
-50	9.1	11	6	565.1	413
-60	9.1	11	5	565.1	403
-70	9.1	11	5	565.1	393
60	0	6	3	556	523
50	0	7	3	556	513
40	0	9	4	556	503
30	0	12	6	556	493
20	0	22	10	556	483
10	0	56	30	556	473
0	0	46	38	556	463
-10	0	33	22	556	453
-20	0	15	9	556	443
-30	0	14	6	556	433
-40	0	15	7	556	423
-50	0	11	5	556	413
-60	0	12	6	556	403
-70	0	12	6	556	393
-80	0	13	6	556	383
-90	0	13	7	556	373
-100	0	13	6	556	363
-110	0	13	7	556	353
-120	0	14	6	556	343
-130	0	13	6	556	333
-140	0	10	5	556	323
-150	0	4	2	556	313
-160	0	2	1	556	303
-170	0	3	1	556	293
50	-9.1	7	3	546.9	513
40	-9.1	8	3	546.9	503
30	-9.1	11	6	546.9	493
20	-9.1	15	9	546.9	483
10	-9.1	36	22	546.9	473
0	-9.1	48	30	546.9	463
-10	-9.1	22	17	546.9	453
-20	-9.1	16	8	546.9	443
-30	-9.1	14	7	546.9	433
-40	-9.1	15	7	546.9	423
-50	-9.1	15	6	546.9	413
-60	-9.1	13	6	546.9	403
-70	-9.1	15	7	546.9	393
-80	-9.1	16	8	546.9	383
-90	-9.1	17	9	546.9	373
-100	-9.1	16	9	546.9	363
-110	-9.1	14	8	546.9	353
-120	-9.1	14	6	546.9	343
-130	-9.1	14	7	546.9	333
20	-18.3	16	10	537.7	483
10	-18.3	40	26	537.7	473
0	-18.3	35	22	537.7	463
-10	-18.3	21	11	537.7	453

-20	-18.3	25	14	537.7	443
-30	-18.3	16	7	537.7	433
-40	-18.3	15	7	537.7	423
-50	-18.3	16	8	537.7	413
-60	-18.3	17	10	537.7	403
-70	-18.3	19	10	537.7	393
-80	-18.3	19	11	537.7	383
-90	-18.3	21	11	537.7	373
-100	-18.3	18	10	537.7	363
-110	-18.3	16	9	537.7	353
-120	-18.3	15	8	537.7	343
-130	-18.3	14	7	537.7	333
-140	-18.3	12	6	537.7	323
-150	-18.3	11	5	537.7	313
0	-27.4	29	19	528.6	463
-10	-27.4	21	12	528.6	453
-20	-27.4	21	15	528.6	443
-30	-27.4	18	11	528.6	433
-40	-27.4	17	11	528.6	423
-50	-27.4	16	10	528.6	413
-60	-27.4	15	9	528.6	403
-70	-27.4	17	10	528.6	393
-80	-27.4	17	10	528.6	383
-90	-27.4	21	12	528.6	373
-100	-27.4	20	14	528.6	363
-110	-27.4	17	10	528.6	353
-120	-27.4	15	9	528.6	343
-130	-27.4	15	7	528.6	333
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-150	-27.4	12	6	528.6	313
30	-36.6	9	5	519.4	493
20	-36.6	13	7	519.4	483
10	-36.6	19	11	519.4	473
0	-36.6	26	15	519.4	463
-10	-36.6	21	11	519.4	453
-20	-36.6	20	11	519.4	443
-30	-36.6	20	12	519.4	433
-40	-36.6	18	12	519.4	423
-50	-36.6	19	12	519.4	413
-60	-36.6	19	13	519.4	403
-70	-36.6	18	10	519.4	393
-80	-36.6	16	10	519.4	383
-90	-36.6	17	10	519.4	373
-100	-36.6	19	11	519.4	363
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30	-45.7	10	6	510.3	493
20	-45.7	12	6	510.3	483

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-60	-45.7	21	15	510.3	403
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-140	-45.7	12	6	510.3	323
-150	-45.7	11	6	510.3	313
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10	-54.9	15	7	501.1	473
0	-54.9	21	12	501.1	463
-10	-54.9	23	13	501.1	453
-20	-54.9	24	16	501.1	443
-30	-54.9	26	16	501.1	433
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-50	-54.9	23	14	501.1	413
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-120	-54.9	14	9	501.1	343
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-140	-54.9	14	8	501.1	323
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10	-64	14	6	492	473
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10	-73.2	12	5	482.8	473
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10	-70	10	5	486	473
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10	-80	10	4	476	473
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-50	-90	16	8	466	413
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40	-110	14	7	446	503
30	-110	14	7	446	493
20	-110	12	5	446	483
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-80	-110	15	7	446	383
-90	-110	14	7	446	373
-100	-110	14	7	446	363
-110	-110	14	6	446	353
-120	-110	13	6	446	343

-130	-110	13	7	446	333
-140	-110	12	6	446	323
50	-120	13	5	436	513
40	-120	14	6	436	503
30	-120	14	7	436	493
20	-120	17	8	436	483
10	-120	12	6	436	473
0	-120	14	6	436	463
-10	-120	14	5	436	453
-20	-120	15	6	436	443
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60	-130	18	9	426	523
50	-130	19	10	426	513
40	-130	1	9	426	503
30	-130	13	8	426	493
20	-130	12	6	426	483
10	-130	13	7	426	473
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-10	-130	13	7	426	453
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-50	-20	14	7	536	413
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-70	-20	15	7	536	393
-80	-20	14	7	536	383
-90	-20	15	7	536	373
-100	-20	14	6	536	363
-110	-20	15	6	536	353
-120	-20	15	7	536	343
-130	-20	14	6	536	333

-140	-20	14	6	536	323
-150	-20	12	5	536	313
-160	-20	11	5	536	303
lines added 7/22/98					
10	30	5	1	586	473
20	30	6	2	586	483
30	30	8	3	586	493
40	30	10	4	586	503
50	30	12	5	586	513
60	30	14	6	586	523
70	30	17	7	586	533
80	30	15	7	586	543
90	30	14	7	586	553
100	30	11	5	586	563
110	30	10	4	586	573
120	30	9	3	586	583
0	40	5	1	596	463
10	40	4	1	596	473
20	40	6	2	596	483
30	40	6	1	596	493
40	40	9	3	596	503
50	40	14	6	596	513
60	40	19	8	596	523
70	40	23	11	596	533
80	40	20	9	596	543
90	40	19	8	596	553
100	40	18	8	596	563
110	40	15	6	596	573
120	40	12	6	596	583
130	40	9	3	596	593
140	40	8	2	596	603
30	50	5	1	606	493
40	50	5	3	606	503
50	50	15	6	606	513
60	50	25	11	606	523
70	50	21	9	606	533
80	50	20	8	606	543
90	50	21	9	606	553
100	50	24	11	606	563
110	50	19	10	606	573
120	50	19	7	606	583
130	50	11	5	606	593
140	50	8	3	606	603
30	60	5	2	616	493
40	60	8	4	616	503
50	60	19	10	616	513
60	60	28	12	616	523
70	60	21	10	616	533
80	60	25	12	616	543
90	60	25	11	616	553
100	60	26	12	616	563
110	60	27	13	616	573
120	60	25	12	616	583
130	60	23	11	616	593

140	60	18	10	616	603
150	60	15	6	616	613
160	60	12	6	616	623
170	60	10	4	616	633
180	60	11	4	616	643
190	60	9	3	616	653
50	70	17	6	626	513
60	70	24	10	626	523
70	70	52	14	626	533
80	70	32	14	626	543
90	70	25	12	626	553
100	70	27	11	626	563
110	70	23	11	626	573
120	70	23	11	626	583
130	70	25	13	626	593
140	70	25	12	626	603
150	70	22	11	626	613
160	70	18	9	626	623
170	70	14	7	626	633
180	70	13	5	626	643
190	70	16	7	626	653
200	70	12	6	626	663
210	70	10	5	626	673
40	80	7	5	636	503
50	80	17	7	636	513
60	80	29	11	636	523
70	80	16	10	636	533
80	80	24	10	636	543
90	80	18	8	636	553
100	80	19	9	636	563
data collected 7/26/99					
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0	-150	7	3	406	463
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-20	-150	7	4	406	443
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-40	-150	15	8	406	423
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-70	-150	16	8	406	393
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-90	-150	18	9	406	373
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-110	-150	15	8	406	353
-120	-150	15	7	406	343
-130	-150	15	7	406	333
-140	-150	16	8	406	323
-150	-150	14	7	406	313
-160	-150	12	6	406	303
-170	-150	12	6	406	293
-180	-150	14	6	406	283
-190	-150	12	6	406	273
-200	-150	14	7	406	263
-210	-150	16	7	406	253
-220	-150	20	10	406	243
-230	-150	27	13	406	233
-240	-150	25	12	406	223
-250	-150	25	10	406	213
-260	-150	25	13	406	203
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-180	-160	10	4	396	283
-190	-160	11	5	396	273
-200	-160	13	6	396	263
-210	-160	13	5	396	253
-220	-160	17	7	396	243
-230	-160	24	12	396	233
-240	-160	21	11	396	223
-250	-160	18	8	396	213
-260	-160	20	11	396	203
-270	-160	21	8	396	193
-280	-160	16	8	396	183
-290	-160	16	6	396	173

-300	-160	14	6	396	163
-310	-160	9	5	396	153
-320	-160	7	3	396	143
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-110	-170	12	4	386	353
-120	-170	9	2	386	343
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-180	-170	10	4	386	283
-190	-170	10	3	386	273
-200	-170	11	4	386	263
-210	-170	11	5	386	253
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-230	-170	14	6	386	233
-240	-170	16	7	386	223
-250	-170	13	6	386	213
-260	-170	11	4	386	203
-270	-170	11	4	386	193
-280	-170	14	5	386	183
-290	-170	14	6	386	173
-300	-170	17	6	386	163
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-320	-170	14	5	386	143
-330	-170	11	4	386	133
-340	-170	9	4	386	123
-350	-170	9	4	386	113
line 130S extension					
-120	-130	10	4	426	343
-130	-130	10	4	426	333
-140	-130	9	4	426	323
-150	-130	10	4	426	313
-160	-130	10	5	426	303
-170	-130	8	3	426	293
-180	-130	8	3	426	283
-190	-130	9	4	426	273
-200	-130	11	6	426	263
-210	-130	13	7	426	253
-220	-130	19	8	426	243
-230	-130	22	10	426	233
-240	-130	19	7	426	223
-250	-130	18	7	426	213
-260	-130	18	7	426	203
-270	-130	17	6	426	193
-280	-130	15	7	426	183
-290	-130	14	6	426	173
-300	-130	11	5	426	163
-310	-130	9	3	426	153
-320	-130	7	2	426	143
line 100S extension					
-140	-100	11	5	456	323
-150	-100	11	5	456	313

-160	-100	9	4	456	303
-170	-100	8	3	456	293
-180	-100	9	4	456	283
-190	-100	10	3	456	273
-200	-100	10	4	456	263
-210	-100	10	4	456	253
-220	-100	9	4	456	243
-230	-100	8	4	456	233
-240	-100	7	3	456	223
-250	-100	6	2	456	213
-260	-100	5	2	456	203
-270	-100	6	2	456	193
-280	-100	7	3	456	183
-290	-100	8	3	456	173
line 80N					
-300	-100	10	4	456	163
-310	-100	10	3	456	153
-320	-100	8	4	456	143
30	80	10	4	636	493
40	80	10	3	636	503
50	80	15	6	636	513
60	80	26	14	636	523
70	80	24	8	636	533
80	80	20	8	636	543
90	80	17	7	636	553
100	80	18	7	636	563
110	80	19	10	636	573
120	80	20	8	636	583
130	80	22	12	636	593
140	80	24	13	636	603
150	80	21	10	636	613
160	80	19	9	636	623
170	80	14	7	636	633
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190	80	11	4	636	653
200	80	11	5	636	663
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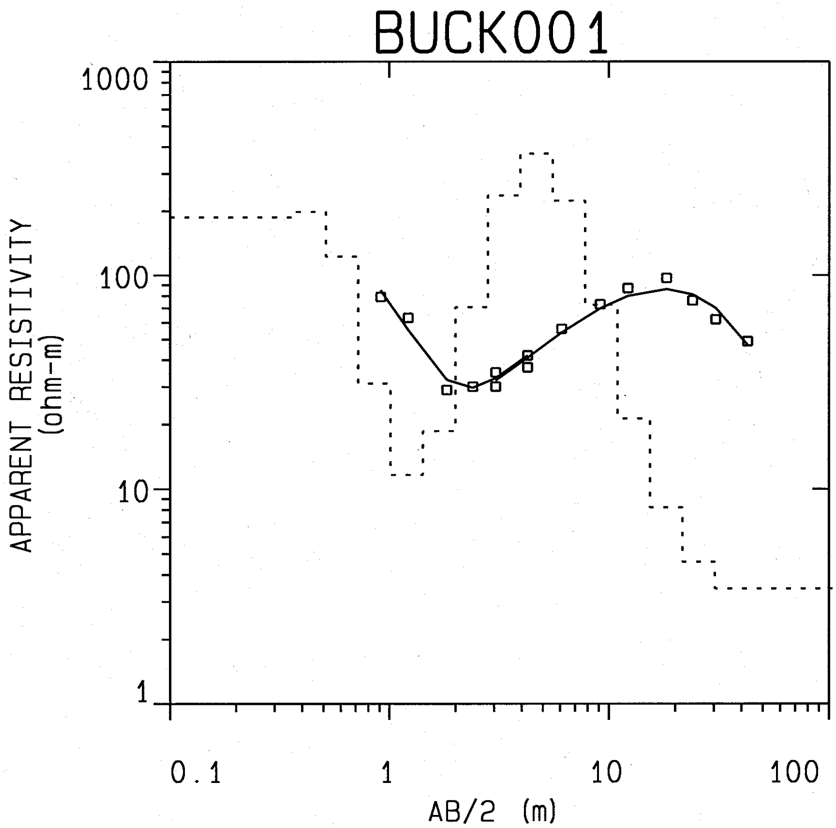
70	90	22	11	646	533
80	90	21	10	646	543
90	90	19	10	646	553
100	90	20	10	646	563
110	90	21	10	646	573
120	90	19	8	646	583
130	90	20	8	646	593
140	90	21	10	646	603
150	90	32	14	646	613
160	90	31	14	646	623
170	90	24	10	646	633
180	90	18	9	646	643
190	90	16	7	646	653

200	90	11	3	646	663
210	90	8	3	646	673
30	110	14	5	666	493
40	110	16	7	666	503
60	110	27	11	666	523
70	110	28	12	666	533
80	110	27	13	666	543
90	110	25	13	666	553
100	110	29	13	666	563
110	110	28	16	666	573
120	110	25	12	666	583
130	110	20	9	666	593
140	110	20	9	666	603
150	110	21	10	666	613
160	110	27	12	666	623
170	110	27	12	666	633
180	110	23	11	666	643
190	110	19	7	666	653
200	110	15	6	666	663
210	110	12	5	666	673
220	110	10	5	666	683

APPENDIX II

DC sounding data and plots

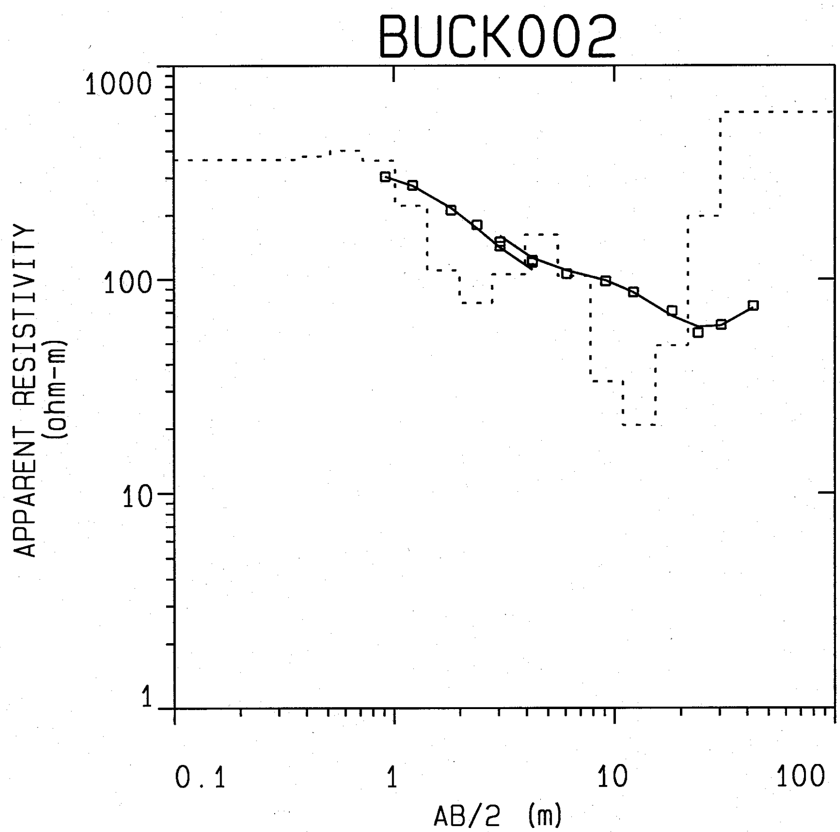


BUCK001 MEASUREMENTS

No.	SPACING	RESISTIVITY
1	0.9140	79.0000
2	1.2200	63.0000
3	1.8300	29.0000
4	2.4000	30.0000
5	3.0500	30.0000
6	4.2600	37.0000
7	3.0500	35.0000
8	4.2600	42.0000
9	6.1000	56.0000
10	9.1400	73.0000
11	12.2000	87.0000
12	18.3000	97.0000
13	24.0000	76.0000
14	30.5000	62.0000
15	42.6000	49.0000

MODEL

LAYER	RESISTIVITY	THICKNESS
1	1.87317E+02	3.65600E-01
2	1.98423E+02	1.47978E-01
3	1.22206E+02	2.07873E-01
4	3.11192E+01	2.92010E-01
5	1.16320E+01	4.10202E-01
6	1.86039E+01	5.76233E-01
7	7.08274E+01	8.09466E-01
8	2.37047E+02	1.13710E+00
9	3.71995E+02	1.59735E+00
10	2.24221E+02	2.24388E+00
11	7.25878E+01	3.15210E+00
12	2.13357E+01	4.42792E+00
13	8.21111E+00	6.22014E+00
14	4.60138E+00	8.73776E+00
15	3.45293E+00	

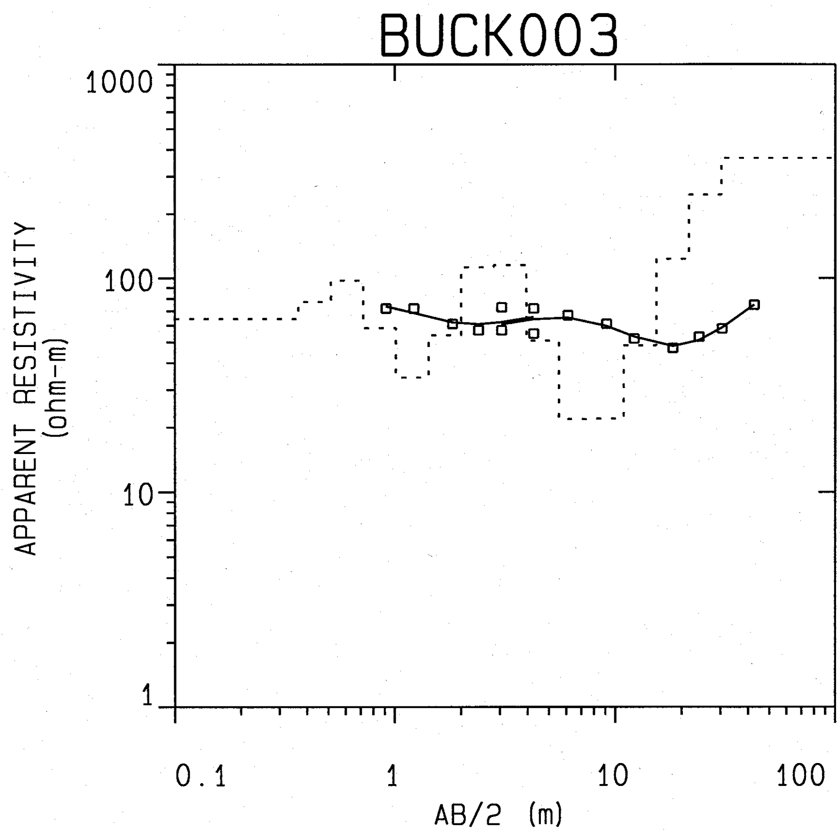


BUCK002 MEASUREMENTS

No.	SPACING	RESISTIVITY
1	0.9140	303.0000
2	1.2200	276.0000
3	1.8300	211.0000
4	2.4000	180.0000
5	3.0500	150.0000
6	4.2600	123.0000
7	3.0500	143.0000
8	4.2600	120.0000
9	6.1000	106.0000
10	9.1400	98.0000
11	12.2000	87.0000
12	18.3000	71.0000
13	24.0000	56.0000
14	30.5000	61.0000
15	42.6000	75.0000

MODEL

LAYER	RESISTIVITY	THICKNESS
1	3.64357E+02	3.65600E-01
2	3.77448E+02	1.47978E-01
3	4.00615E+02	2.07873E-01
4	3.60065E+02	2.92010E-01
5	2.21219E+02	4.10202E-01
6	1.10398E+02	5.76233E-01
7	7.75024E+01	8.09466E-01
8	1.05480E+02	1.13710E+00
9	1.61928E+02	1.59735E+00
10	1.03530E+02	2.24388E+00
11	3.32065E+01	3.15210E+00
12	2.07005E+01	4.42792E+00
13	4.88882E+01	6.22014E+00
14	1.97439E+02	8.73776E+00
15	6.03807E+02	

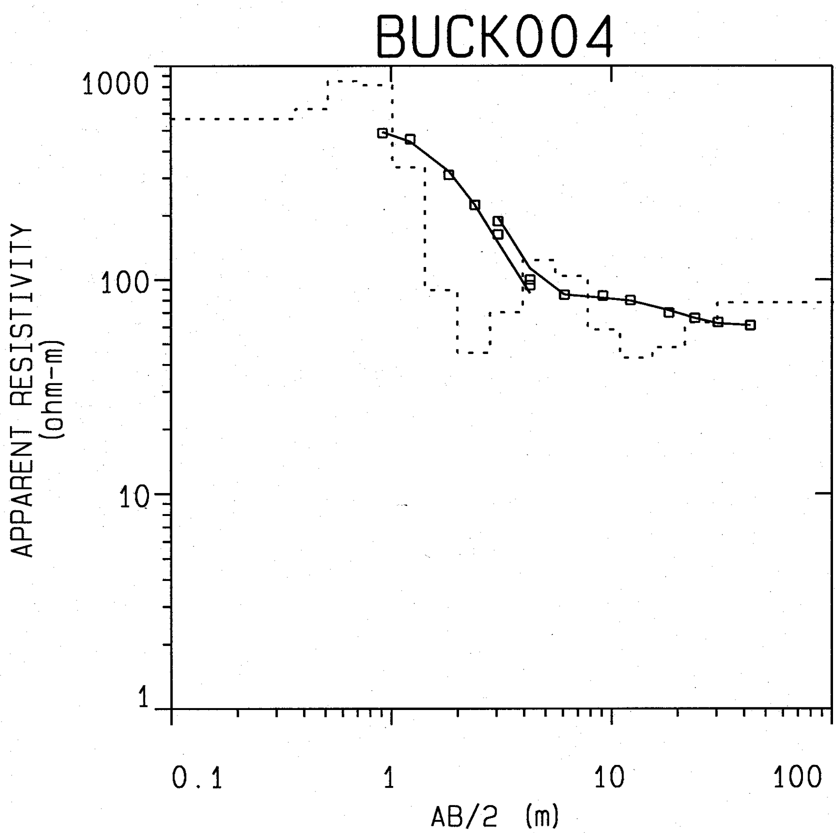


BUCK003 MEASUREMENTS

No.	SPACING	RESISTIVITY
1	0.9140	72.0000
2	1.2200	72.0000
3	1.8300	61.0000
4	2.4000	57.0000
5	3.0500	57.0000
6	4.2600	55.0000
7	3.0500	73.0000
8	4.2600	72.0000
9	6.1000	67.0000
10	9.1400	61.0000
11	12.2000	52.0000
12	18.3000	47.0000
13	24.0000	53.0000
14	30.5000	58.0000
15	42.6000	75.0000

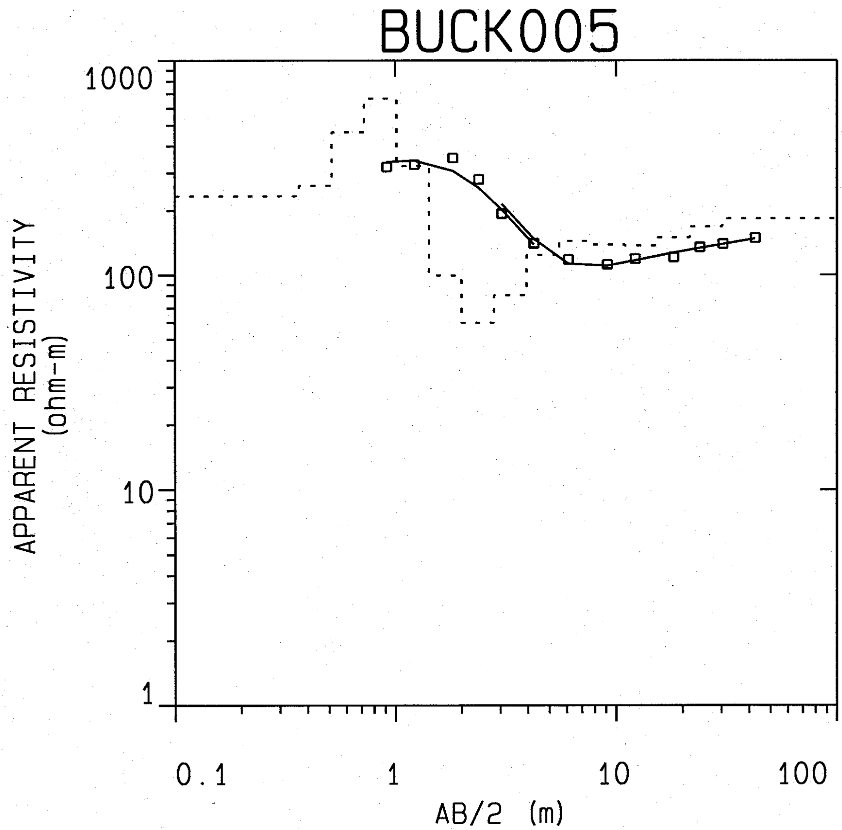
MODEL

LAYER	RESISTIVITY	THICKNESS
1	6.43277E+01	3.65600E-01
2	7.74377E+01	1.47978E-01
3	9.75293E+01	2.07873E-01
4	5.83288E+01	2.92010E-01
5	3.42518E+01	4.10202E-01
6	5.40187E+01	5.76233E-01
7	1.12506E+02	8.09466E-01
8	1.15256E+02	1.13710E+00
9	5.09349E+01	1.59735E+00
10	2.19046E+01	2.24388E+00
11	2.19691E+01	3.15210E+00
12	4.84049E+01	4.42792E+00
13	1.23273E+02	6.22014E+00
14	2.46218E+02	8.73776E+00
15	3.64997E+02	



BUCK004 MEASUREMENTS No.	SPACING	RESISTIVITY
1	0.9140	486.0000
2	1.2200	455.0000
3	1.8300	310.0000
4	2.4000	224.0000
5	3.0500	163.0000
6	4.2600	94.0000
7	3.0500	188.0000
8	4.2600	100.0000
9	6.1000	85.0000
10	9.1400	84.0000
11	12.2000	80.0000
12	18.3000	70.0000
13	24.0000	66.0000
14	30.5000	63.0000
15	42.6000	61.0000

MODEL LAYER	RESISTIVITY	THICKNESS
1	5.66823E+02	3.65600E-01
2	6.29867E+02	1.47978E-01
3	8.49435E+02	2.07873E-01
4	8.12846E+02	2.92010E-01
5	3.36230E+02	4.10202E-01
6	8.92788E+01	5.76233E-01
7	4.53656E+01	8.09466E-01
8	7.01755E+01	1.13710E+00
9	1.23437E+02	1.59735E+00
10	1.04038E+02	2.24388E+00
11	5.82229E+01	3.15210E+00
12	4.29415E+01	4.42792E+00
13	4.80725E+01	6.22014E+00
14	6.29248E+01	8.73776E+00
15	7.80700E+01+02	

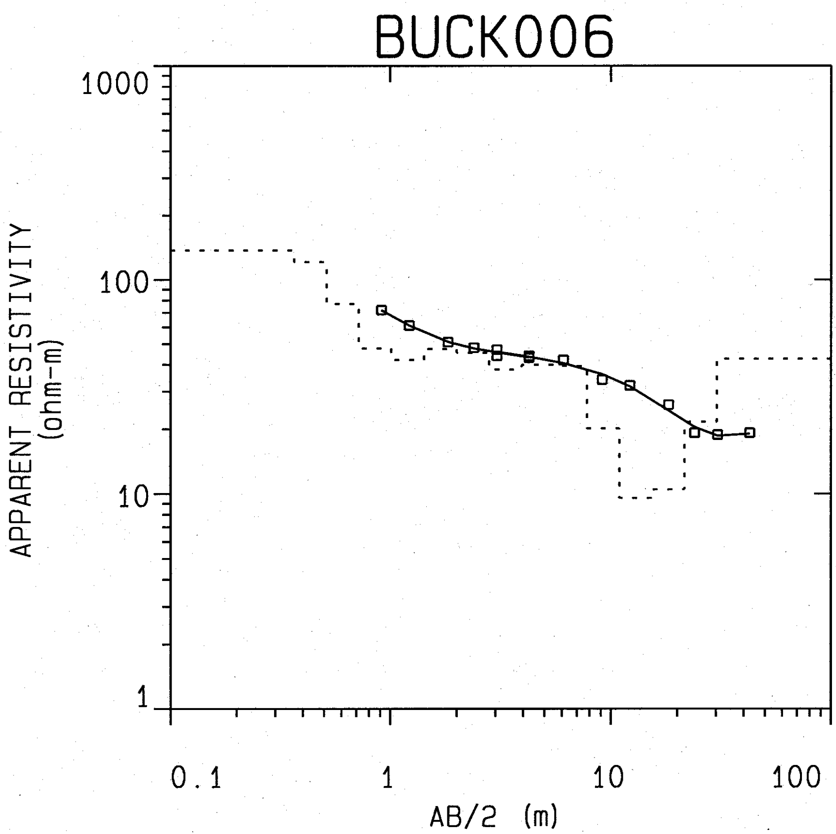


BUCK005 MEASUREMENTS

No.	SPACING	RESISTIVITY
1	0.9140	320.0000
2	1.2200	328.0000
3	1.8300	352.0000
4	2.4000	280.0000
5	3.0500	193.0000
6	4.2600	140.0000
7	3.0500	194.0000
8	4.2600	141.0000
9	6.1000	118.0000
10	9.1400	112.0000
11	12.2000	119.0000
12	18.3000	121.0000
13	24.0000	135.0000
14	30.5000	140.0000
15	42.6000	149.0000

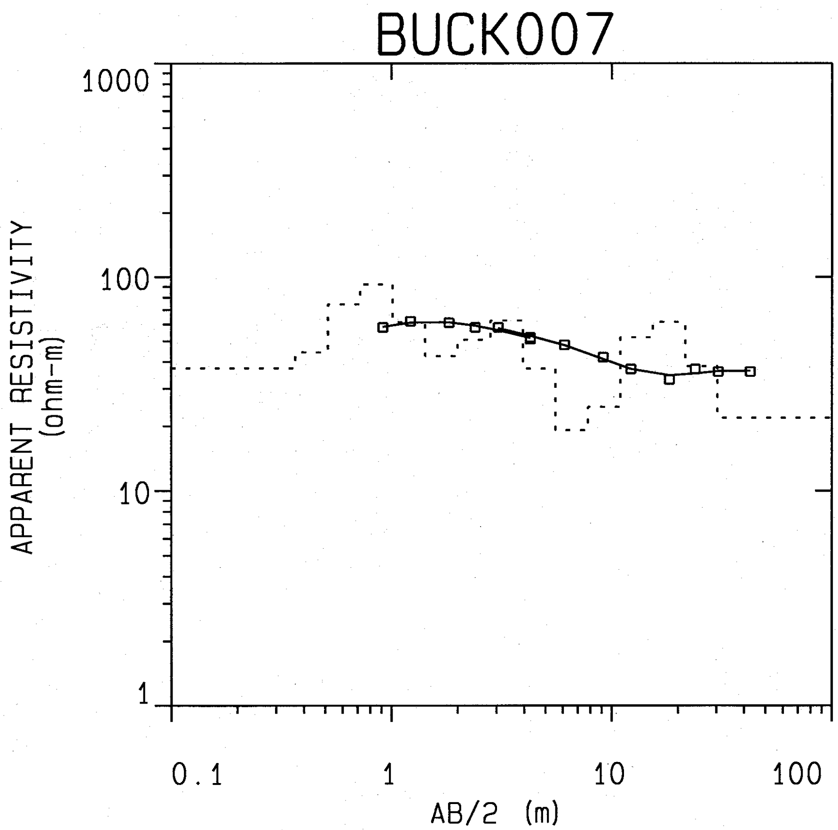
MODEL

LAYER	RESISTIVITY	THICKNESS
1	2.33770E+02	3.65600E-01
2	2.61624E+02	1.47978E-01
3	4.63922E+02	2.07873E-01
4	6.65814E+02	2.92010E-01
5	3.22571E+02	4.10202E-01
6	9.95901E+01	5.76233E-01
7	5.96935E+01	8.09466E-01
8	8.04169E+01	1.13710E+00
9	1.23875E+02	1.59735E+00
10	1.44354E+02	2.24388E+00
11	1.38623E+02	3.15210E+00
12	1.37339E+02	4.42792E+00
13	1.49756E+02	6.22014E+00
14	1.68173E+02	8.73776E+00
15	1.83427E+02	



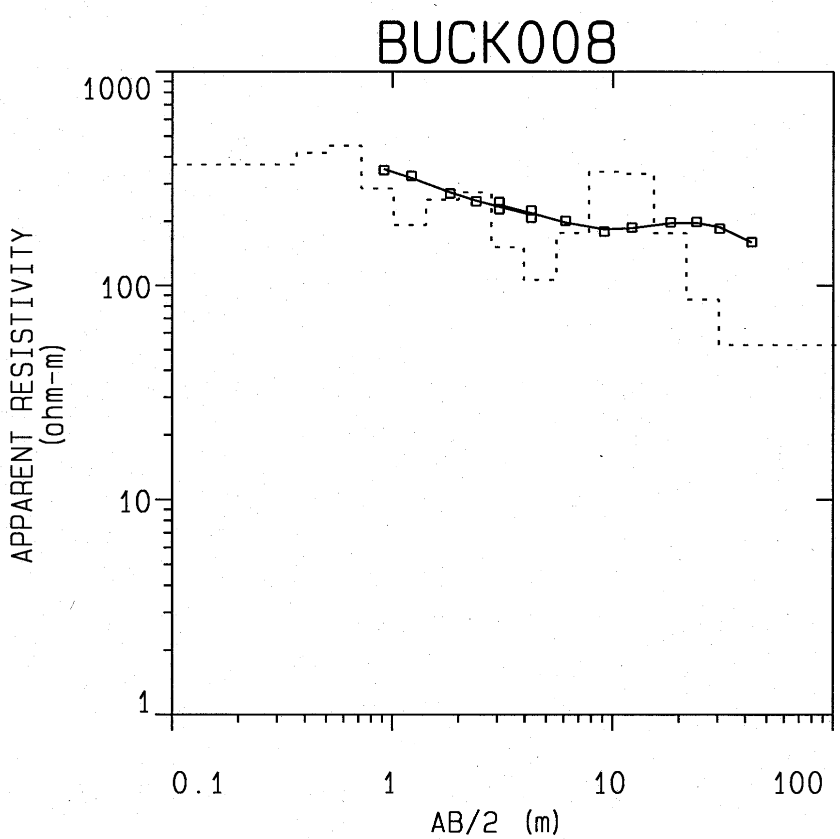
BUCK006 MEASUREMENTS		
No.	SPACING	RESISTIVITY
1	0.9140	72.0000
2	1.2200	61.0000
3	1.8300	51.0000
4	2.4000	48.0000
5	3.0500	44.0000
6	4.2600	43.0000
7	3.0500	47.0000
8	4.2600	44.0000
9	6.1000	42.0000
10	9.1400	34.0000
11	12.2000	32.0000
12	18.3000	26.0000
13	24.0000	19.2000
14	30.5000	18.8000
15	42.6000	19.2000

MODEL		
LAYER	RESISTIVITY	THICKNESS
1	1.37382E+02	3.65600E-01
2	1.21110E+02	1.47978E-01
3	7.71219E+01	2.07873E-01
4	4.76077E+01	2.92010E-01
5	4.21650E+01	4.10202E-01
6	4.73280E+01	5.76233E-01
7	4.54903E+01	8.09466E-01
8	3.79765E+01	1.13710E+00
9	3.99283E+01	1.59735E+00
10	3.93633E+01	2.24388E+00
11	2.01716E+01	3.15210E+00
12	9.54774E+00	4.42792E+00
13	1.04726E+01	6.22014E+00
14	2.16201E+01	8.73776E+00
15	4.25187E+01	



BUCK007 MEASUREMENTS No.	SPACING	RESISTIVITY
1	0.9140	58.0000
2	1.2200	62.0000
3	1.8300	61.0000
4	2.4000	58.0000
5	3.0500	58.0000
6	4.2600	51.0000
7	3.0500	58.0000
8	4.2600	52.0000
9	6.1000	48.0000
10	9.1400	42.0000
11	12.2000	37.0000
12	18.3000	33.0000
13	24.0000	37.0000
14	30.5000	36.0000
15	42.6000	36.0000

MODEL LAYER	RESISTIVITY	THICKNESS
1	3.73127E+01	3.65600E-01
2	4.43767E+01	1.47978E-01
3	7.45348E+01	2.07873E-01
4	9.22531E+01	2.92010E-01
5	6.13027E+01	4.10202E-01
6	4.25103E+01	5.76233E-01
7	5.07170E+01	8.09466E-01
8	6.23716E+01	1.13710E+00
9	3.71111E+01	1.59735E+00
10	1.91516E+01	2.24388E+00
11	2.46239E+01	3.15210E+00
12	5.21613E+01	4.42792E+00
13	6.14807E+01	6.22014E+00
14	3.80829E+01	8.73776E+00
15	2.19074E+01	



BUCK008 MEASUREMENTS

No.	SPACING	RESISTIVITY
1	0.9140	347.0000
2	1.2200	326.0000
3	1.8300	270.0000
4	2.4000	248.0000
5	3.0500	228.0000
6	4.2600	208.0000
7	3.0500	246.0000
8	4.2600	225.0000
9	6.1000	201.0000
10	9.1400	179.0000
11	12.2000	187.0000
12	18.3000	198.0000
13	24.0000	199.0000
14	30.5000	185.0000
15	42.6000	160.0000

MODEL

LAYER	RESISTIVITY	THICKNESS
1	3.68783E+02	3.65600E-01
2	4.17822E+02	1.47978E-01
3	4.51357E+02	2.07873E-01
4	2.85119E+02	2.92010E-01
5	1.92182E+02	4.10202E-01
6	2.52496E+02	5.76233E-01
7	2.72983E+02	8.09466E-01
8	1.51531E+02	1.13710E+00
9	1.06301E+02	1.59735E+00
10	1.76436E+02	2.24388E+00
11	3.41726E+02	3.15210E+00
12	3.34113E+02	4.42792E+00
13	1.76282E+02	6.22014E+00
14	8.60708E+01	8.73776E+00
15	5.26416E+01	

APPENDIX III

Total Field Magnetic Survey Data

North-south Baseline

Station	Field Strenth (nanoteslas)	Comments
30	790	
20	709	
10	730	
0	740	
-10	783	
-20	791	
-30	788	
-40	762	
-45	740	
-50	695	metal junk
-55	791	
-60	786	
-65	793	
-70	809	
-75	813	metal junk
-80	815	
-90	841	
-100	849	
-110	841	
-120	921	
-130	841	
-140	839	woods

Line 0 East-West

Station	Field Strength (nanoteslas)	Comments
-110	830	test well #6
-100	826	
-90	811	
-80	824	
-70	788	
-60	818	
-50	768	
-40	776	
-30	757	
-20	739	
-10	749	
0	748	
10	769	
20	785	
30	805	
40	829	
50	841	
60	823	
70	851	
75	869	