Geophysical Surveys near Sierra Vista, Arizona

Geophysics Field Camp 2004

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1. Abstract

Five different geophysical methods were used near Sierra Vista, Arizona in order to determine the presence or absence of impermeable silt-clay layers in reference to a proposed water-retention system. Geophysical investigations were conducted at Woodcutters 3 and Basin Floor 1 (both approximately one kilometer long north-south and east-west transects), and School Basin (10 meter by 50 meter area where only TEM data were collected). Magnetic, VLF, seismic, EM 31 and 34, and TEM survey data were collected on February 28th and 29th and March 20th and 21st of 2004. Magnetic and VLF surveys conducted at the Woodcutters 3 and Basin Floor 1 sites had relatively flat profiles that indicated only a few single-station anomalies with little difference between the two sites. Seismic survey data produced velocities in two-layer earth models that were similar between the two sites in the upper 5 meters, again indicating little difference between the sites. The EM 31 and 34 surveys, with depths of investigation in the 3-6 meter range, measured higher ground conductivity values in the upper 10 meters at the Woodcutters 3 site. This agreed with shallow borehole data from the Woodcutters 3 and Basin Floor 1 sites. The higher ground conductivity is indicative of higher water content, which may be due to the increased percentage of clay. For the TEM surveys, conducted at all three sites and with depths of investigations in the 0-50 meter range, it was found that a low resistivity layer at 30-50 meter depth resides at the Basin Floor 1 site. This layer is deeper than the available borehole data. At both sites the borehole data do not show definitive clay layers, making it difficult to correlate the high conductivity values with clay content percentages.

2. Introduction

Geophysical surveys were conducted near Sierra Vista, Arizona by students from the University of Arizona's Geological Engineering 416/516 class, Geophysical Field Methods. These surveys were conducted on February 28th and 29th and March 20th and 21st of 2004. The Field Camp work is related to a larger hydrogeology investigation that is led by the United States Geological Survey (USGS) and is funded by the Upper San Pedro Partnership and the Bureau of Land Management. Fort Huachuca, which contributes funds to the Partnership activities, funded all of the Field Camp expenses.

The purpose of these geophysical investigations was to map a suspected low permeability silt and clay layer, which is a poor substrate for prospective artificial recharge locations. The desired result of these surveys was to identify geophysical techniques that can be used to map the distribution of the low-permeability layer.

Our surveys were conducted at three locations: Woodcutters 3, Basin Floor 1 and the proposed School Basin artificial recharge site. Site locations are shown in Figure 2.1. At the Woodcutters 3 and Basin Floor 1 sites transient electromagnetic (TEM), seismic, magnetic, very low frequency (VLF), and electromagnetic (EM 31 and 34) surveys were performed. At the School Basin site, only TEM surveys were conducted. These surveys were done to help better understand borehole data taken at the Woodcutters 3 and the Basin Floor 1 sites. Subsurface borehole data show that the Basin Floor 1 electrical conductivity varies with depth, spanning the 10-25 mS/m range for the 2 to11 meter depth, and then jumping to the 25-65 mS/m range for the last 11 to 14 meters. In contrast, the Woodcutters 3 electrical conductivity stays in the 25-60 mS/m range for the entire 2 to 22 meters. The lithology of the two boreholes is also different with depth. Basin Floor

1 consists, on average, of 10% gravel and 90% sand down to a depth of 8 meters, and then changes to 10% silt/clay, 10% gravel, and 80% sand for the remaining 8 to 14 meter depth. On the other hand, Woodcutters 3 remains at approximately 25% silt/clay and 75% sand throughout its entire 22 meter depth.

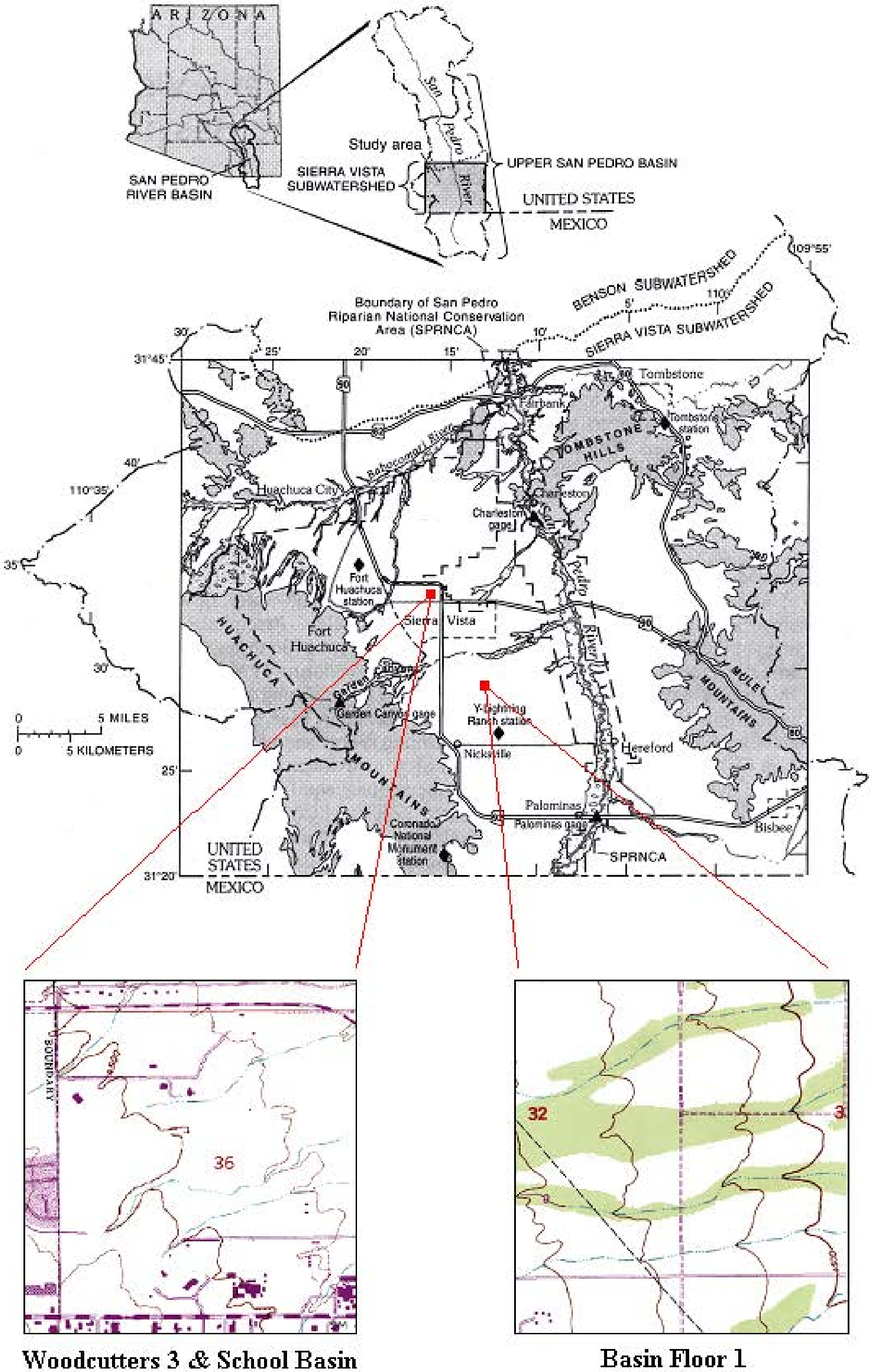

Figure 2.1. Sierra Vista subwatershed area and site locations (top figures modified from ref. #1, site locations taken from ref. #2).

3. Transient Electromagnetic (TEM) Surveys

3.1 Introduction and Location

Transient electromagnetic (TEM) surveys were conducted at all three site locations. TEM surveys utilize a battery current source and transmitter coil to induce current flow in the ground. When there is a conductor present in the subsurface, the primary field from the transmitter induces eddy currents in the conductor, in turn producing a secondary magnetic field. By measuring the decaying magnetic field at the receiver, an estimate can be made of current flow within the earth as a function of time. This allows the resistivity of the subsurface to be determined. The TEM method is described in greater detail in the U.S. Army Corps of Engineers manual No. 1110-1-1802 (ref. #3). In the interest of our survey, it was desired to find areas of greater conductivity as clays tend to be more conductive. By noting broad areas with high conductivity measurements or areas where the clay material may be located, one can identify sites inappropriate for the application of artificial recharge.

At the Woodcutters 3 site, Figure 3.1, the survey ran from 400 meters west to 200 meters east. At the Basin Floor 1 site, Figure 3.2, data were collected from 500 meters south to 200 meters north, and from the 0-meter station to 500 meters west. All surveys were performed at 50 meter intervals along the survey lines. Deviation from actual survey flags and points on the location map were made due to unsatisfactory terrain conditions (such as heavy vegetation) and to avoid noise from nearby power lines. At the School Basin site, Figure 3.3, 5 surveys were laid out in a line with each successive loop having a common side, which was moved by “flipping over” the loop configuration.

3.2 Instrumentation and Field Procedures

The TEM surveys consisted of a 10 x 10 meter transmitter loop with a 5 x 5 meter receiver loop located at the center. A Zonge Engineering GDP 32^{II} multi-function receiver, NT-20 NanoTEM transmitter, and NTEMBAT battery pack were the instruments employed. Measurements included Wn (delay time after turnoff, in μs), Mag1 (voltage in receiver loop, in μV), and Rho1 (field estimate of apparent resistivity, in Ω-m). Other parameters of the investigation included a pulse repetition rate of 32 Hz, 256 stacks, and a transmitter output of 3 amperes of current at 12 volts DC. Logarithmic plots of voltage versus time and depth versus resistivity for all the survey data are provided in Appendix A. The data were then inverted using Zonge Engineering's smooth-inversion modeling program. These inversion models are provided in Figures 3.4-3.7.

3.3 Data Processing and Interpretation

Figures 3.4 to 3.7 show that the majority of the surveyed areas display generally resistive subsurface properties, with the maximum depth of investigation for all surveys being on the order of 50 meters. However, Figure 3.4 (Basin Floor 1) exhibits areas of higher conductivity from station 4, corresponding to 50 meters north, through station 15, corresponding to 500 meters south, at a depth of approximately 25 meters and greater below the ground surface. This broad, highly conductive structure is a possible location for the clay material in question. Further borehole investigation would be recommended to determine if indeed it is the same clay material found in nearby exploratory boreholes. We note that this conductive structure lines up with the semi-conductive region located at the 0-meter east station of the Basin Floor 1 site in Figure 3.5. This mark corresponds with the 0-meter north station in Figure 3.4 and confirms the presence of a conductive body to the south. We conclude from the other inversion models at the Woodcutters 3 (Figure 3.6) and School Basin (Figure 3.7) sites, that the clay material is not present in high enough amounts or at shallow enough depths to be detected with the TEM surveys performed. Since the depth of investigation is on the order of 2-3 times the loop size, larger loop configurations would be needed to analyze greater depths. The depth of investigation that was used in this TEM survey, however, is optimum for the hydro-geological objectives that were specified by the USGS.

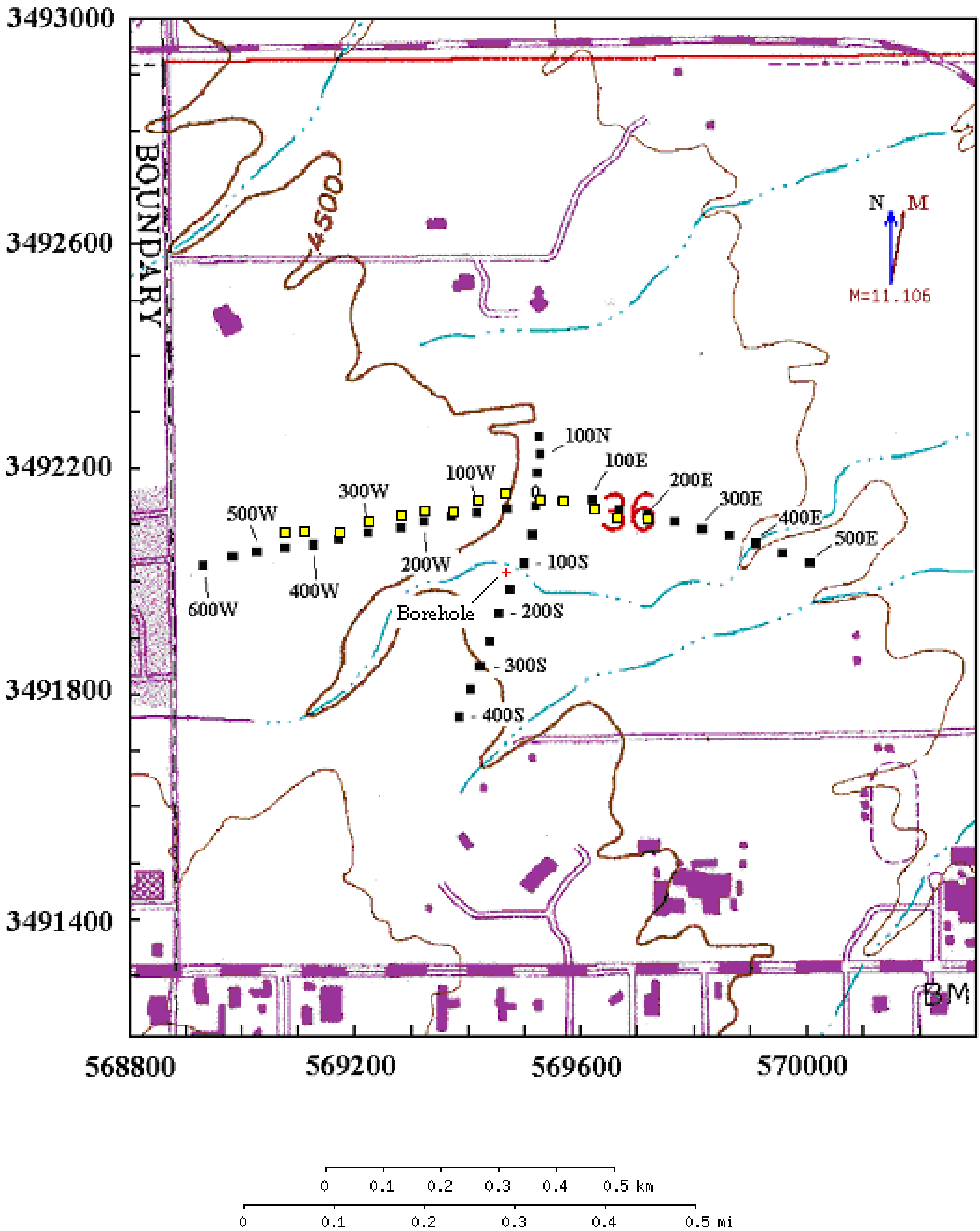

Figure 3.1. Woodcutters 3 TEM survey location map. The small squares are the TEM sites.

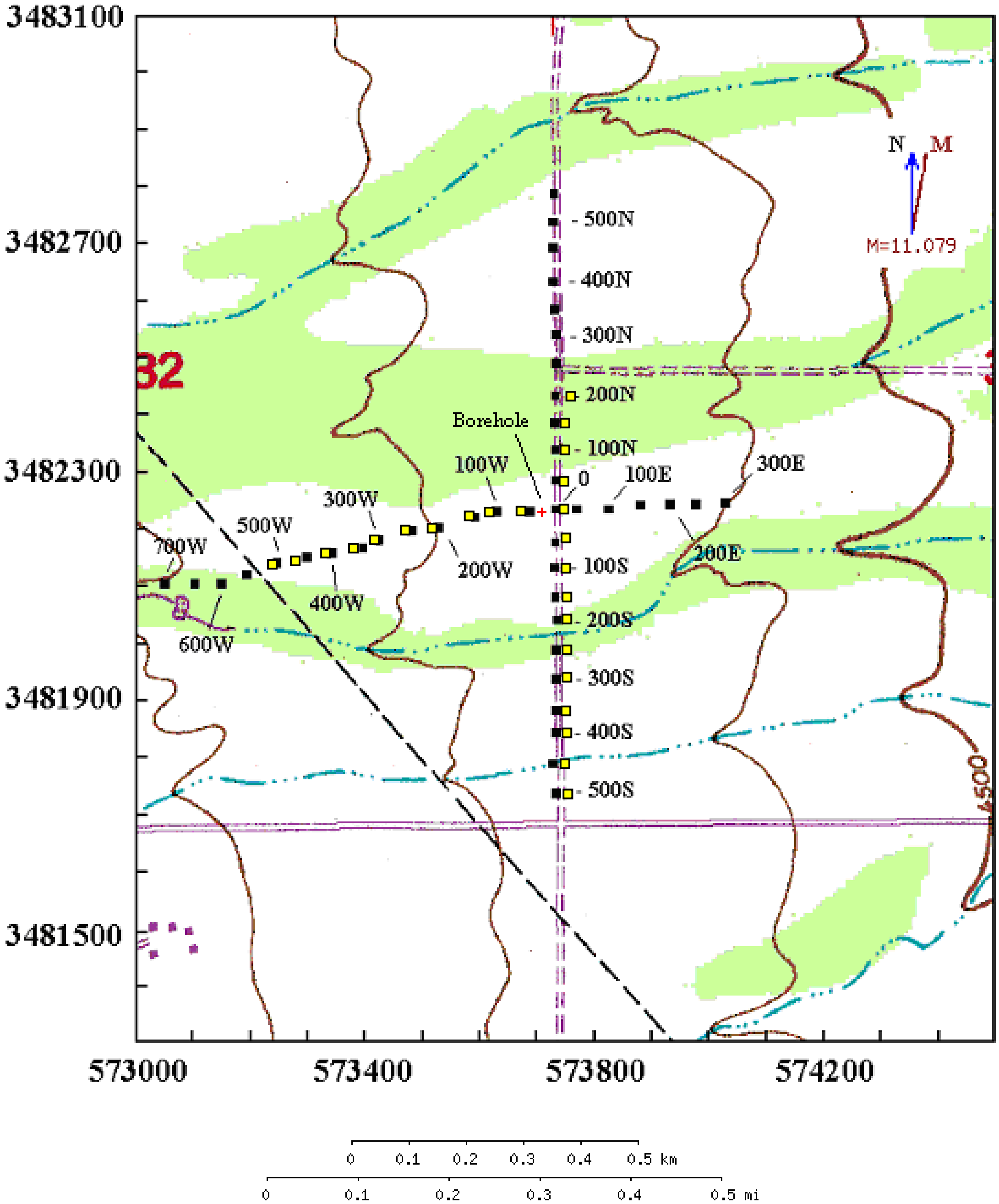

Figure 3.2. Basin Floor 1 TEM survey location map. The small squares are the TEM sites.

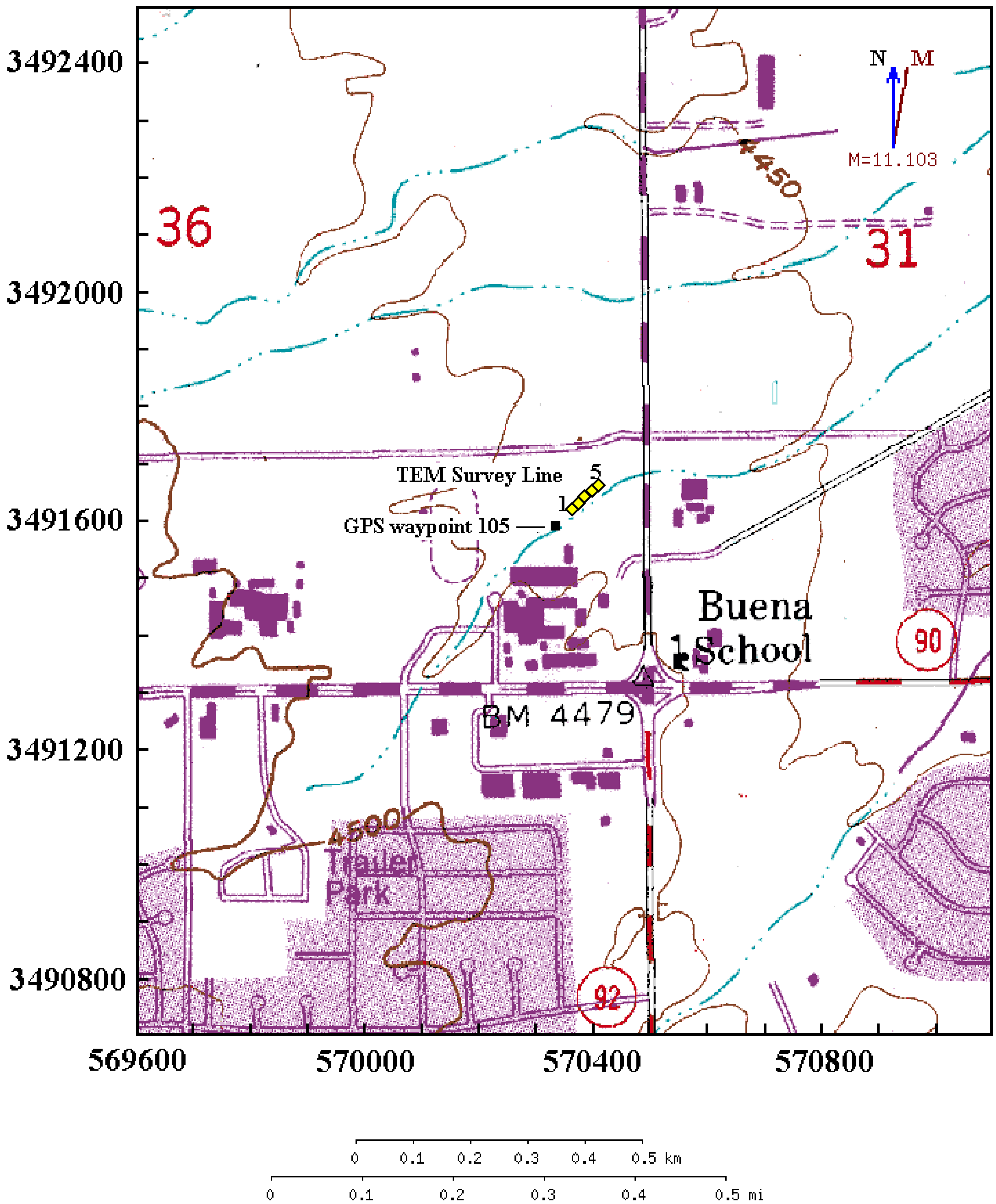

Figure 3.3. School Basin TEM survey location map. The small squares are the TEM sites.

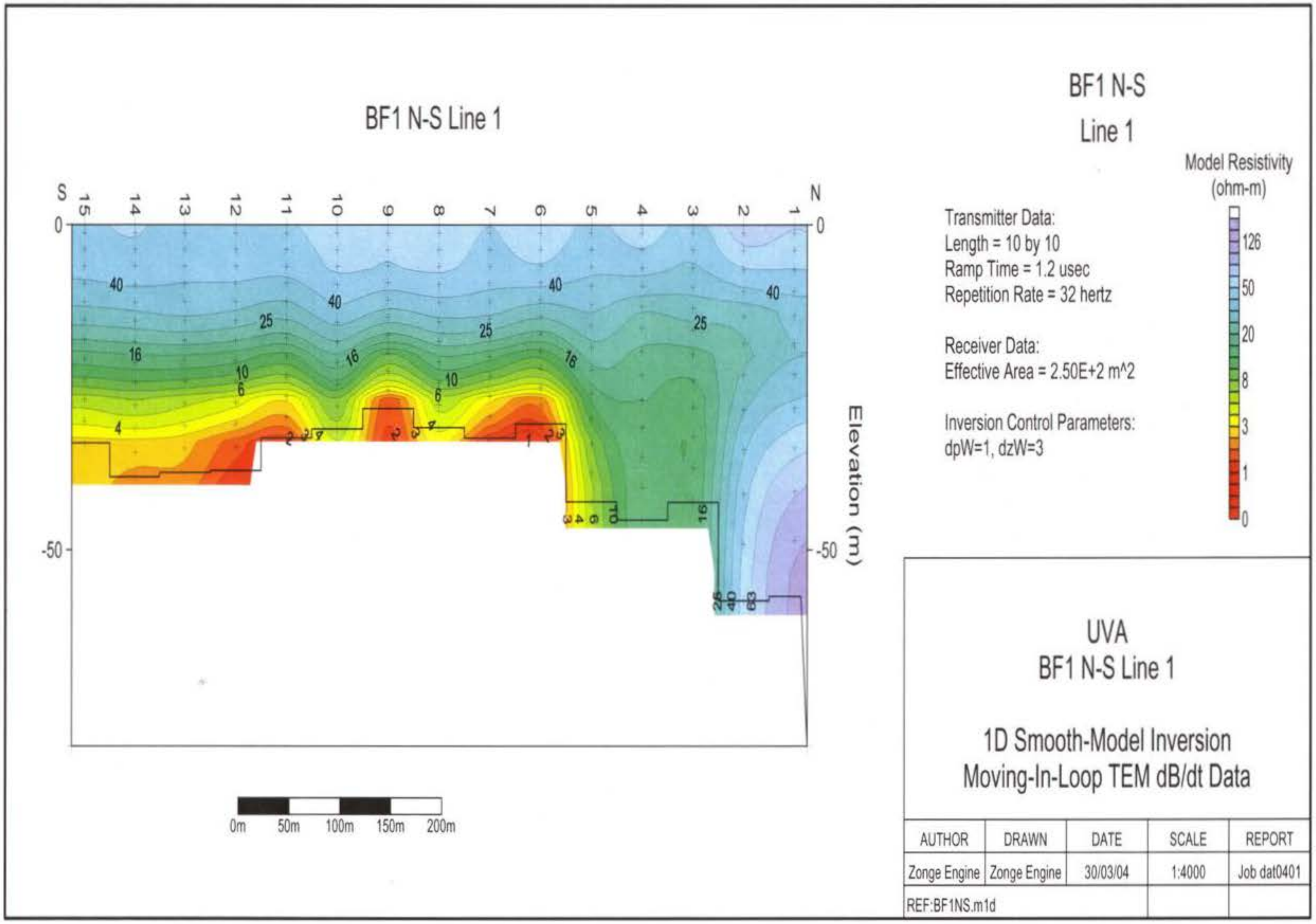

Figure 3.4. Basin Floor 1 north-south survey smooth-model inversion.

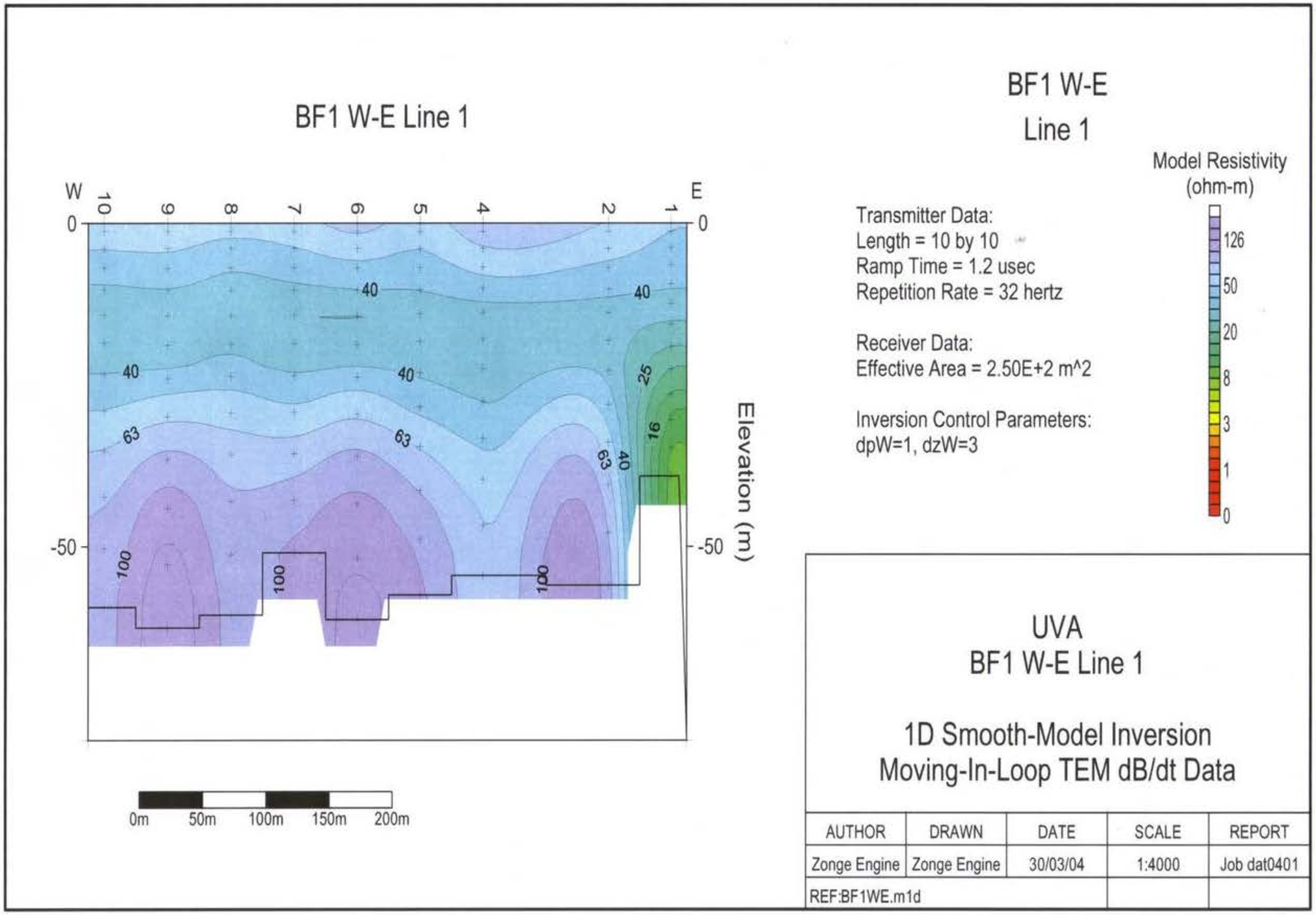

Figure 3.5. Basin Floor 1 east-west survey smooth-model inversion.

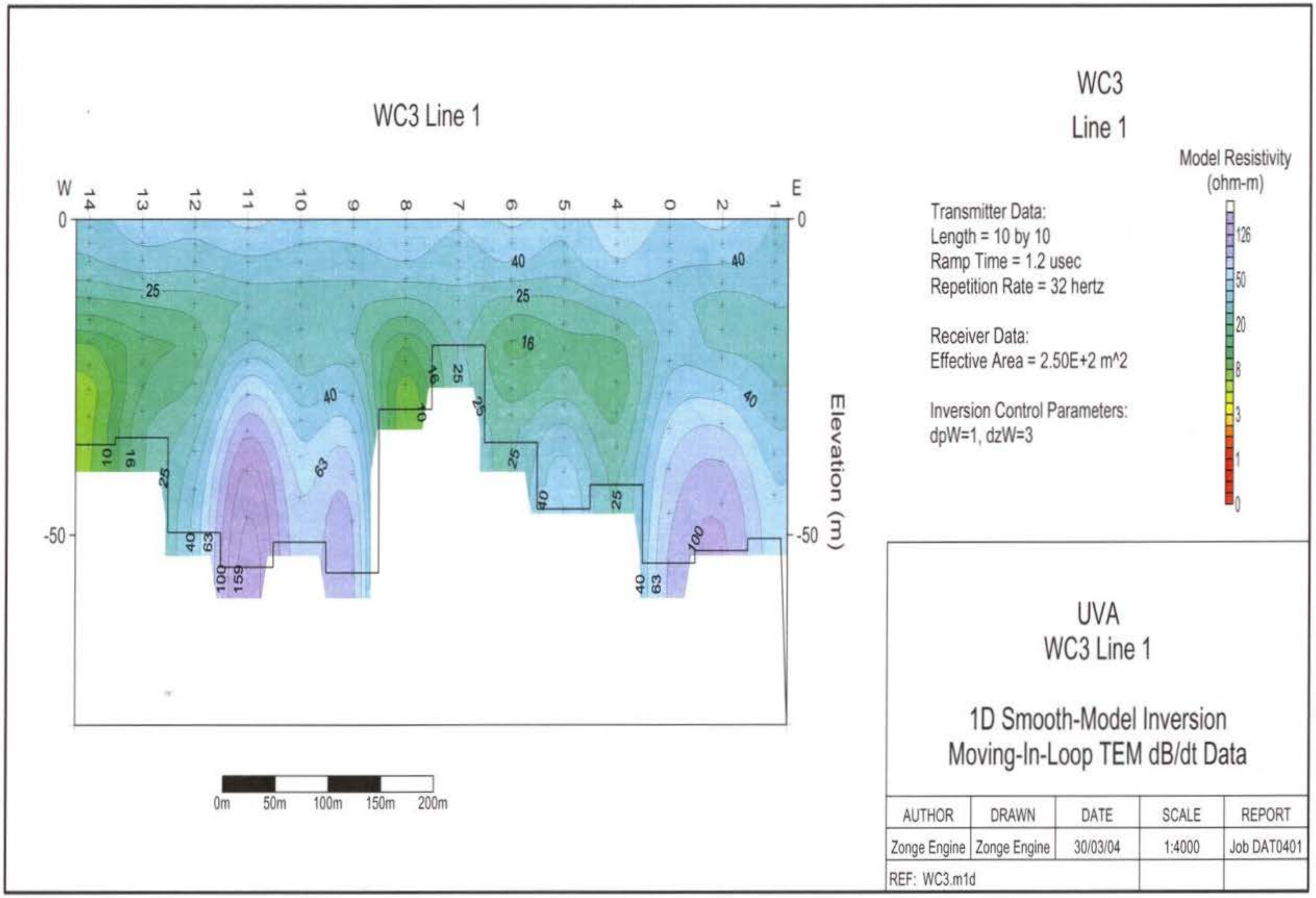

Figure 3.6. Woodcutters 3 east-west survey smooth-model inversion.

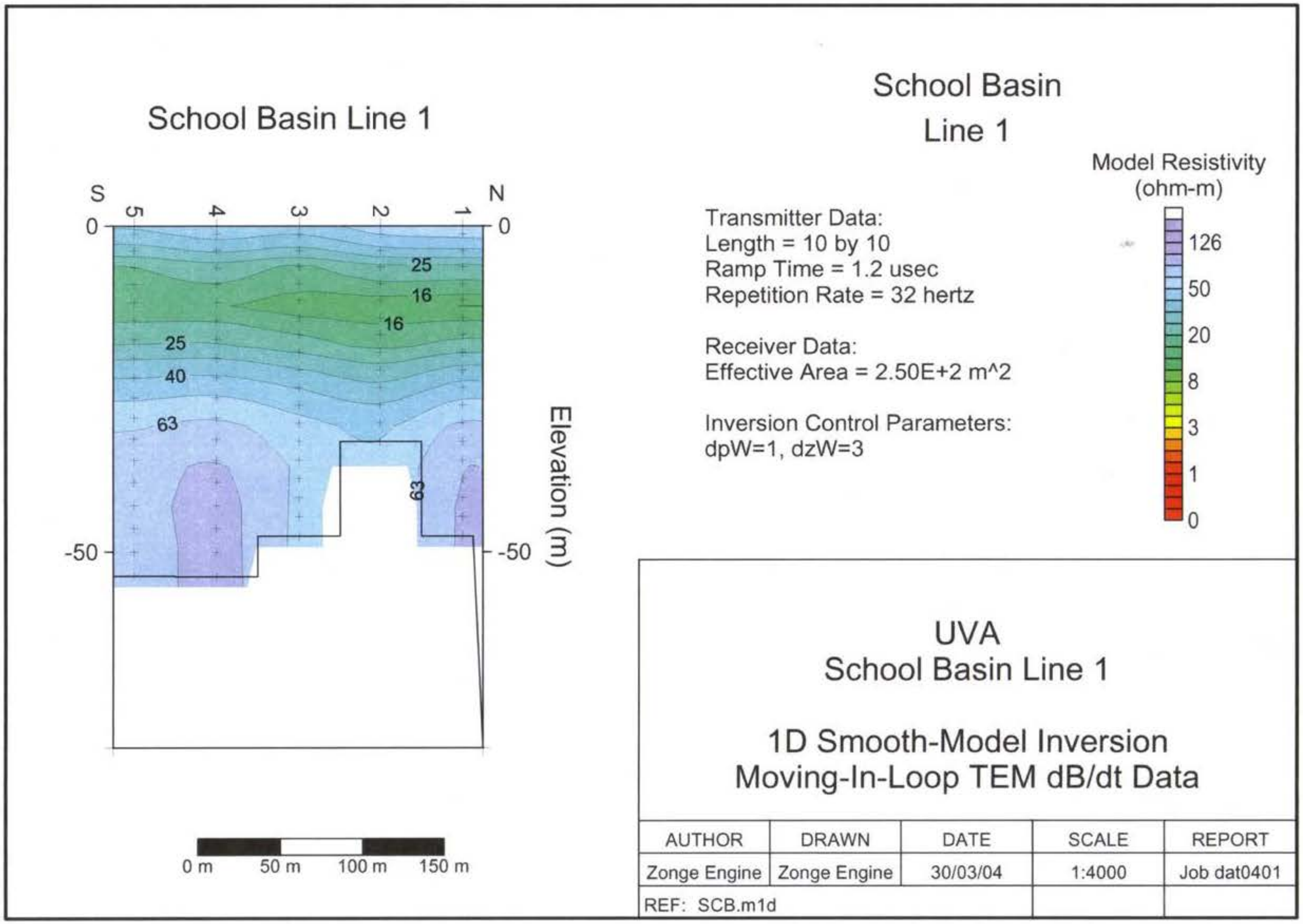

Figure 3.7. School Basin north-south survey smooth-model inversion.

4. Seismic Surveys

4.1 Introduction and Location

Two seismic surveys were conducted at both the Woodcutters 3 and Basin Floor 1 sites. Seismic surveys were conducted from the 0-meter station to 278 meters west, and from the 0-meter station to 282 meters south at the Woodcutters 3 site, as shown in Figure 4.1. At the Basin Floor 1 site, seismic data were collected from the 0-meter station to 278 meters south and from 94 meters west to 94 meters east, as shown in Figure 4.2. The energy source was a 5-lb sledgehammer and steel plate resulting in a shallow depth of investigation, generally less than 5 meters for the top-most layer. For each spread, the velocities of the two layers were calculated in addition to the depth of the first layer.

4.2 Instruments and Field Procedures

A Geometrics StrataView Exploration seismograph was used to investigate the seismic response of an inferred clay layer at depth. In each seismic spread, 48 geophones (with a 14 Hz resonant frequency response) were used, with a spacing interval of 2 meters between adjacent geophones.

At the Woodcutters 3 site, a seismic survey (Survey 1) with three spreads of 48 geophones was conducted in a west-east orientation on 2/28/2004. An overlap of 2 geophones between seismic spreads was employed, resulting in data collection at geophones from the 0-meter station to 278 meters west. For each spread, the response to a total of nine shots was recorded. Four shots were recorded at 5 and 10 meters off both ends of each spread, and five additional shots were taken between geophones 8 and 9, 16 and 17, 24 and 25, 32 and 33, and 40 and 41.

On 3/20/2004, a second seismic survey (Survey 2) was conducted at the Woodcutters 3 site. This consisted of three spreads along a north-south orientation. There was no overlap of geophones between the three spreads, which were south of the 0-meter station. Nine shots were taken for each spread. Four shots were recorded at 0 and 10 meters off both ends of each spread, and five shots were taken between geophones 8 and 9, 16 and 17, 24 and 25, 32 and 33, and 40 and 41.

At the Basin Floor 1 site, a seismic survey (Survey 3) with three spreads of 48 geophones was conducted in a north-south orientation on 2/29/2004. An overlap of 2 geophones was employed between adjacent seismic spreads, resulting in data collection at geophones between the 0-meter station and 278 meters south. For each spread, the response to a total of nine shots was recorded. Four shots were at 5 and 10 meters off both ends of each spread, and five additional shots were taken between geophones 8 and 9, 16 and 17, 24 and 25, 32 and 33, and 40 and 41.

A second survey (Survey 4) was conducted at the Basin Floor 1 site on 3/21/2004. This consisted of two spreads along a west-east orientation. There was no overlap of geophones between the two spreads, resulting in data collection at geophones between the 0-meter station and 94 meters west, and 10 meters and 104 meters east. Nine shots were taken for each spread. Four shots were recorded at 0 and 10 meters off both ends of each spread, and five shots were taken between geophones 8 and 9, 16 and 17, 24 and 25, 32 and 33, and 40 and 41.

4.3 Data Processing and Interpretation

From the traces of the 48 geophones, the first arrival times to the geophones were determined using the Rimrock Geophysics SIPIK and Geometrics SeisImager software packages. Time versus distance plots and an earth model of the velocities were subsequently developed with the SeisImager software. Data for both Basin Floor 1 and Woodcutters 3 are compiled in Figures 4.3-4.17.

Figures 4.3-4.12 are graphs of travel time versus distance plots created using the Rimrock and SeisImager software and the first-break picks. Both versions of the software produced similar subsurface velocities and depths of investigation. Figures 4.13-4.16 display the velocity models generated from the first-break picks using SeisImager. No velocity model is shown for the first spread of Survey 2, the north-south survey at Woodcutters 3. For the sparse data collected for this spread we were unable to create a velocity model.

For the Basin Floor 1 north-south survey, the average depth to the bottom of the first layer is only about 3 meters and up to a total of 13 meters for maximum depth of investigation. Spreads 1, 2, and 3 from Figure 4.13 show very similar velocities with respect to the first and second layer. The north site, Woodcutters 3, also shows similar velocities for both the first and second layer. However, at Woodcutters 3 there is more variability in velocity within each layer, as shown in Figure 4.17. The first layer difference between velocities is only about 150 meters per second and in the second layer there is only a difference of a few meters per second. This similarity between velocities at both study sites leads to the conclusion that the two layers are the same material at both sites.

The seismic velocities, in general, fit the borehole data. The closest fit between borehole data and seismic velocities is at Basin Floor 1, where seismic velocities increase at depth, as does the silt and clay. The depth of velocity change (~ 4 meters) in the seismic profile does not exactly fit the appearance (~8 meters) of the silt and clay layer. At Woodcutters 3 the velocities stay fairly constant in each layer, as would be expected by the evidence of a continual silt and clay layer seen in the borehole. The ratio of clay/silt to sand is constant with depth.

Both survey sites were analyzed with west-to-east trending shot locations. To gain a better understanding of the extent and depth of a possible clay layer between the two sites, a north-to-south trending survey is suggested. Also, larger geophone spacing and a larger energy source are recommended to determine the depth of the second layer and what role this layer plays in the water infiltration for the city of Sierra Vista.

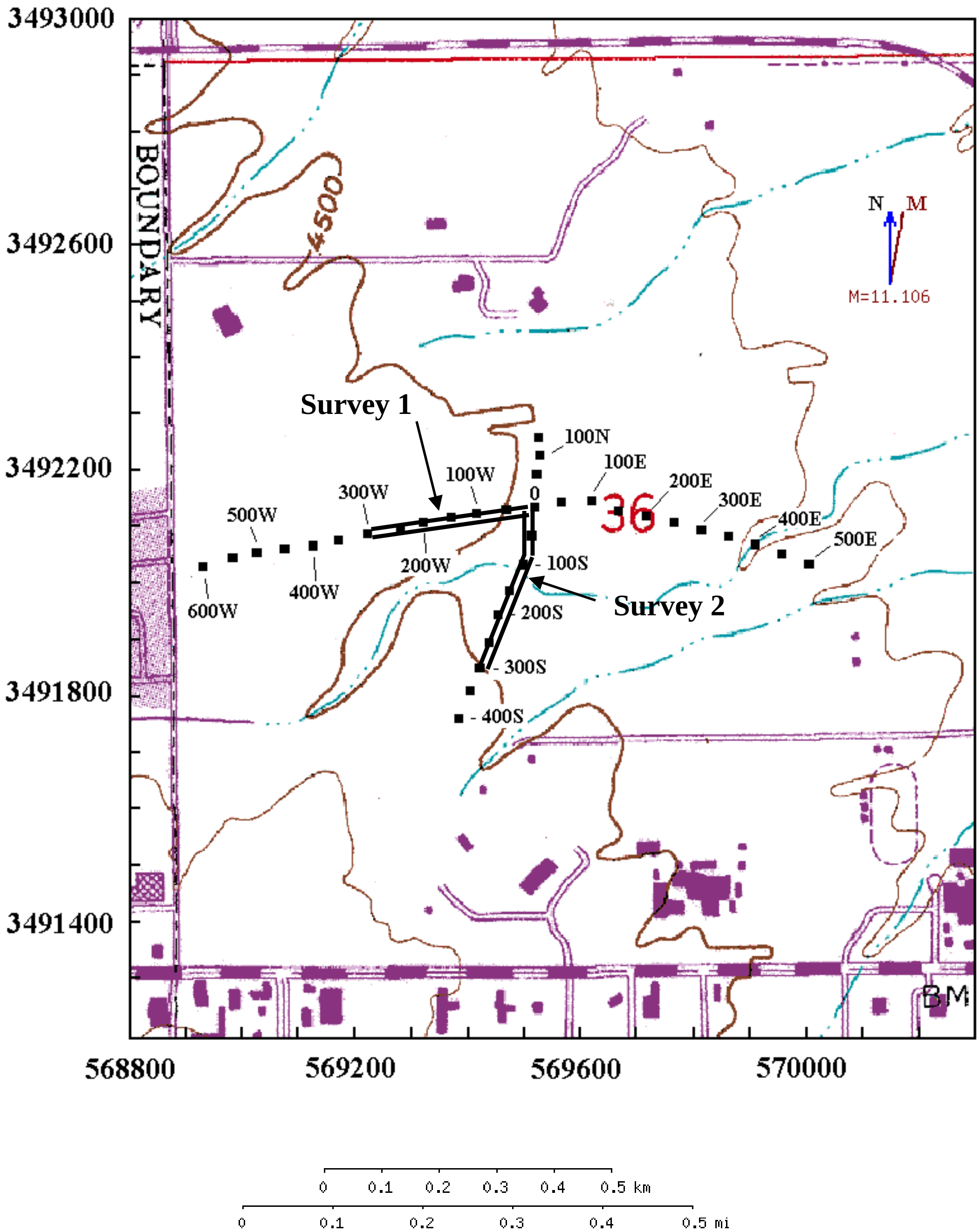

Figure 4.1. Location map for the seismic surveys at Woodcutters 3. Seismic survey locations are shown with a solid double line. Survey 1 was taken along a west-east transect. Survey 2 was taken along a north-south transect.

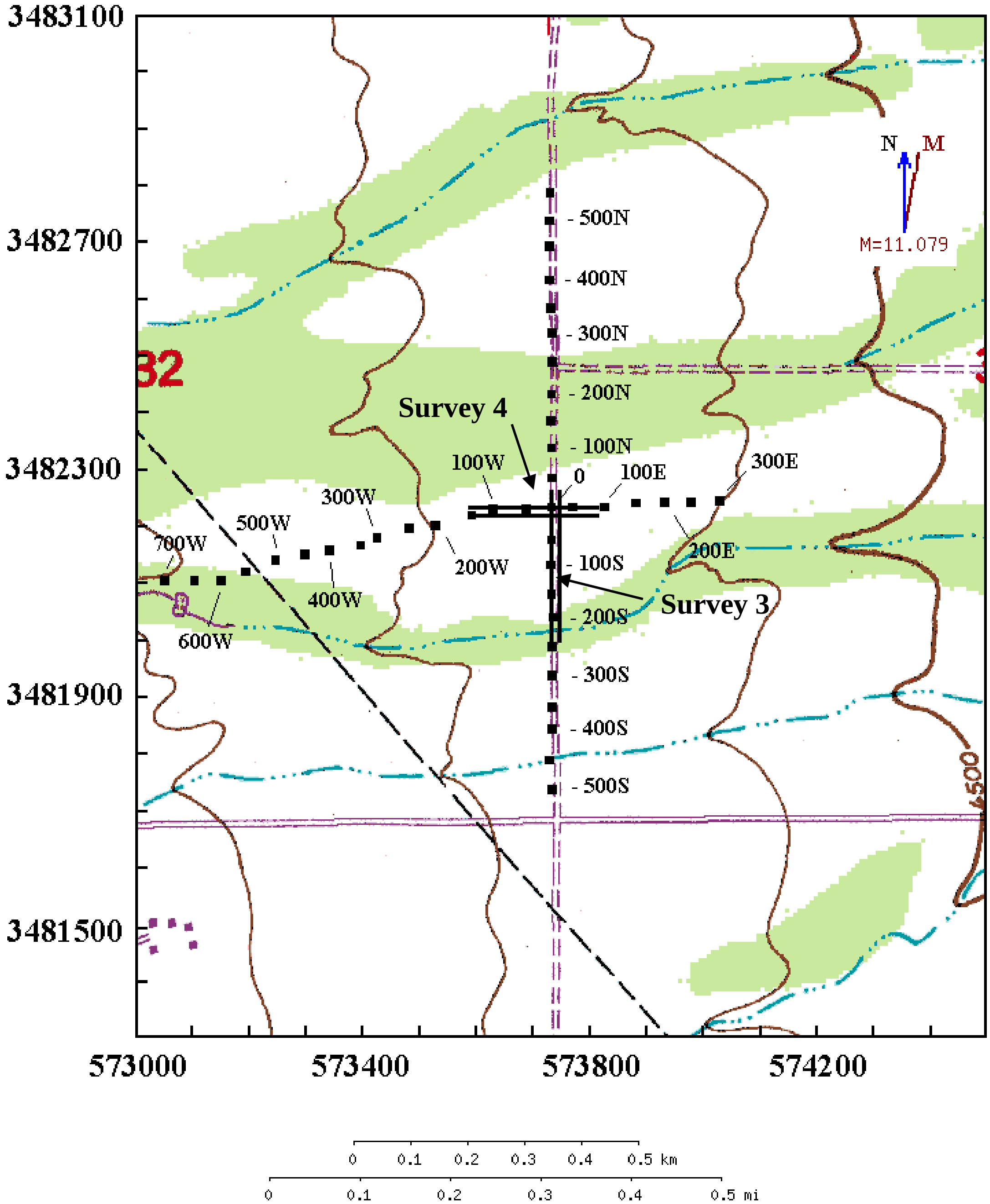

Figure 4.2. Location map for seismic surveys for Basin Floor 1. Seismic survey locations are shown with a solid double line. Survey 3 was taken along a west-east transect. Survey 4 was taken along a north-south transect.

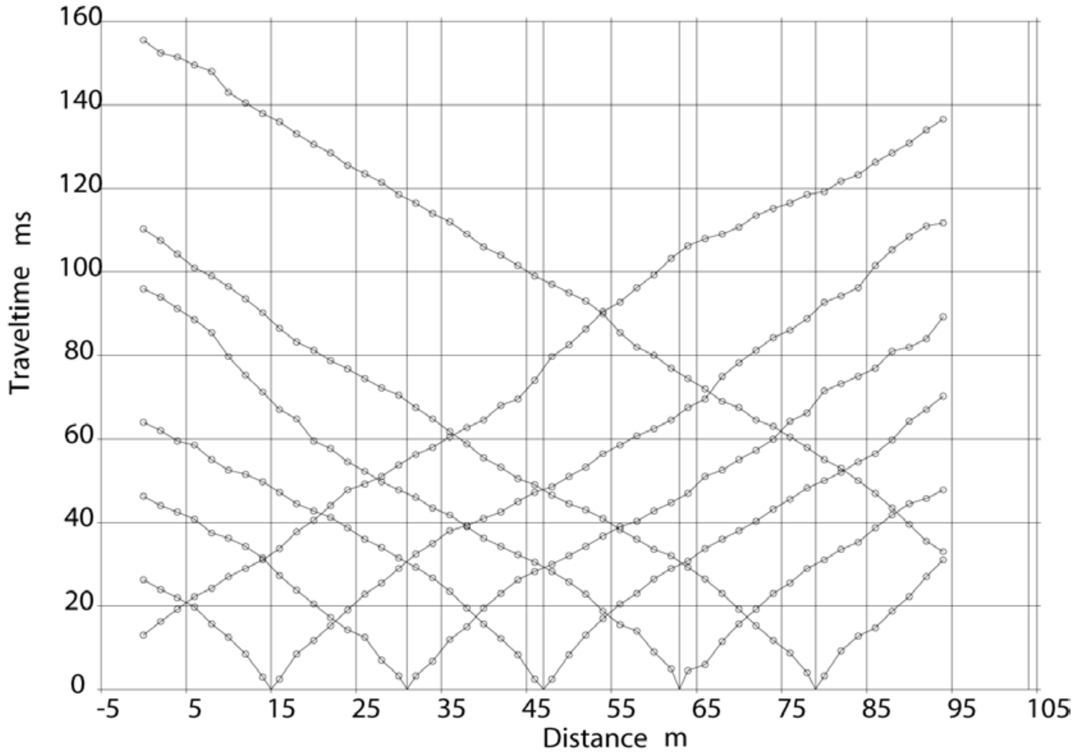

Figure 4.3. Travel time versus distance values of the first-break picks for spread 1 at the Woodcutters 3 site. Survey 1 was taken along a west-east transect.

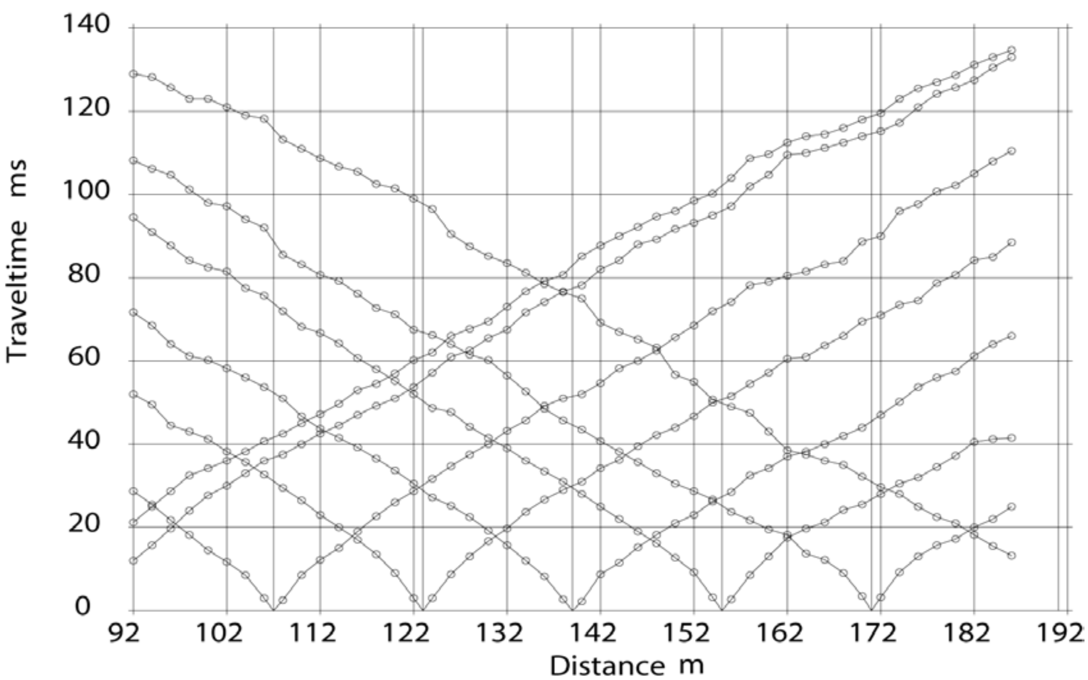

Figure 4.4. Travel time versus distance values of the first-break picks for spread 2 at the Woodcutters 3 site. Survey 1 was taken along a west-east transect.

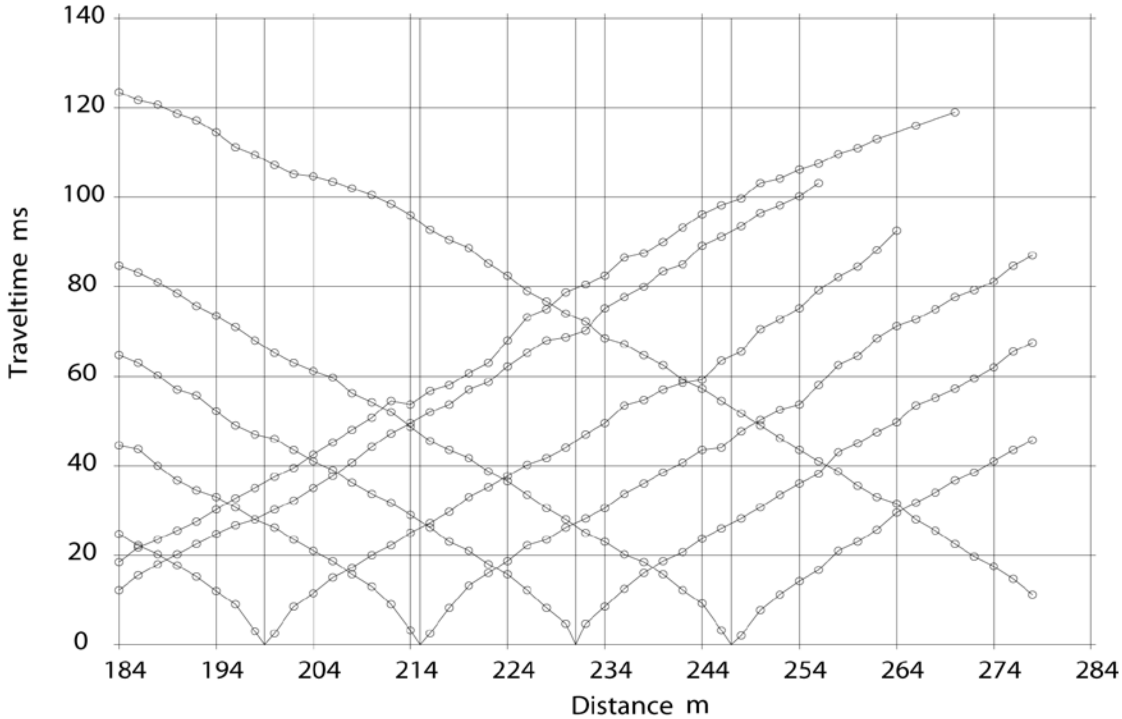

Figure 4.5. Travel time versus distance values of the first-break picks for spread 3 at the Woodcutters 3 site. Survey 1 was taken along a west-east transect.

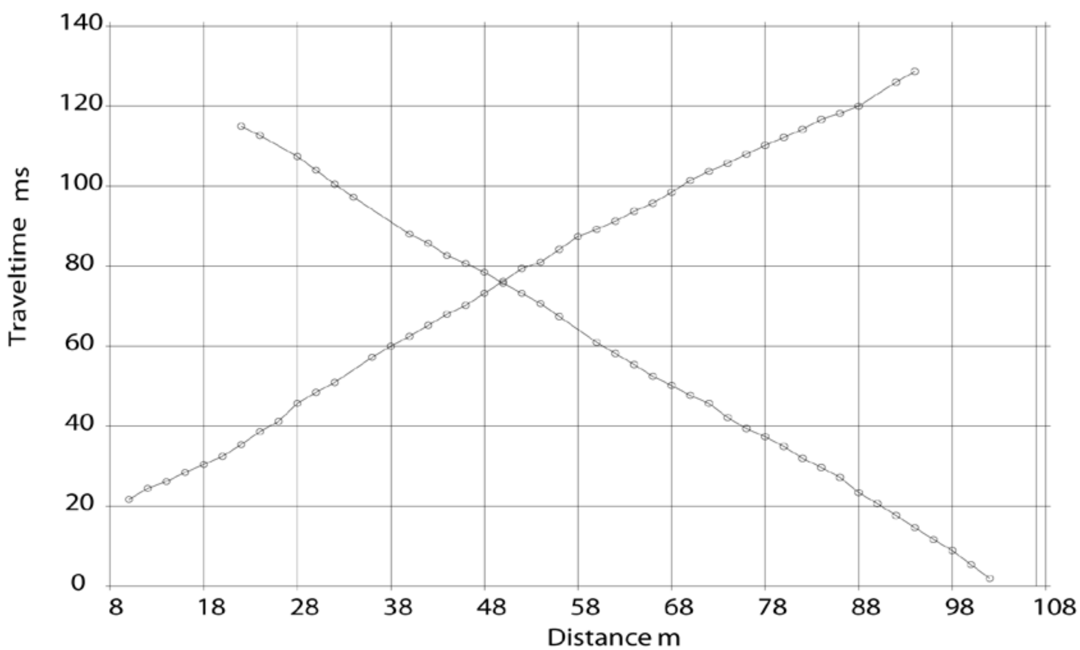

Figure 4.6. Travel time versus distance values of the first-break picks for spread 1 at the Woodcutters 3 site. Survey 2 was taken along a north-south transect.

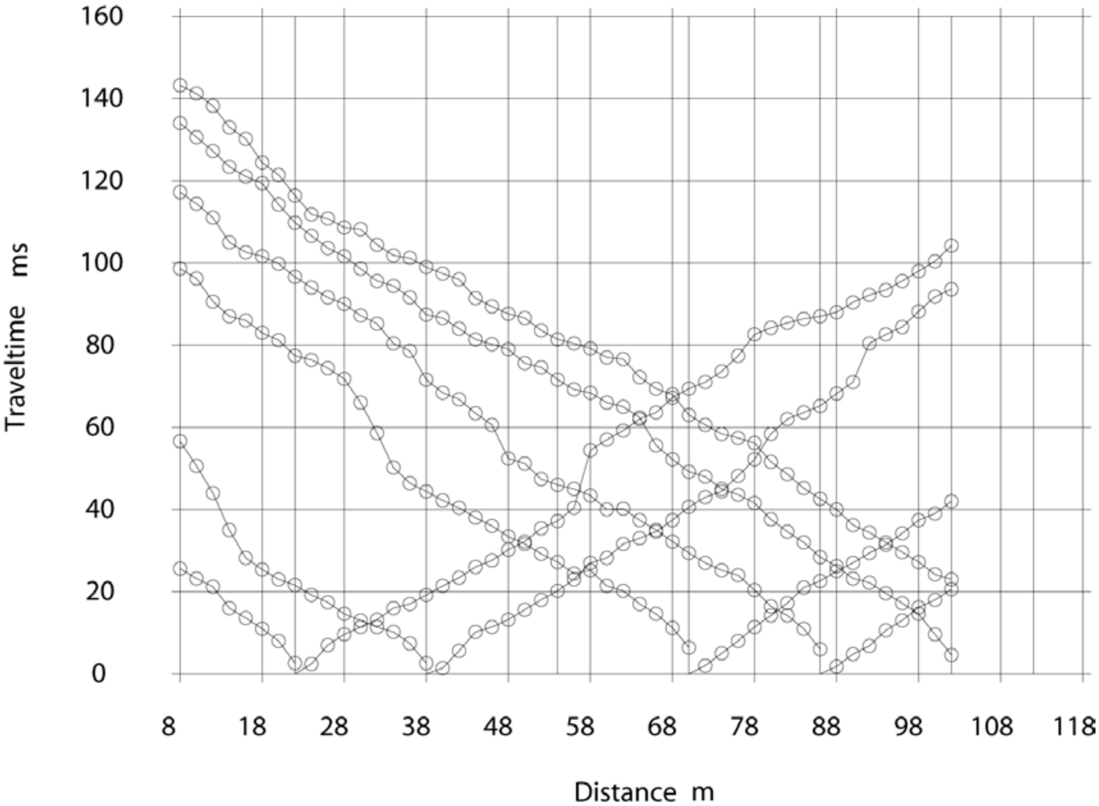

Figure 4.7. Travel time versus distance values of the first-break picks for spread 3 at the Woodcutters 3 site. Survey 2 was taken along a north-south transect.

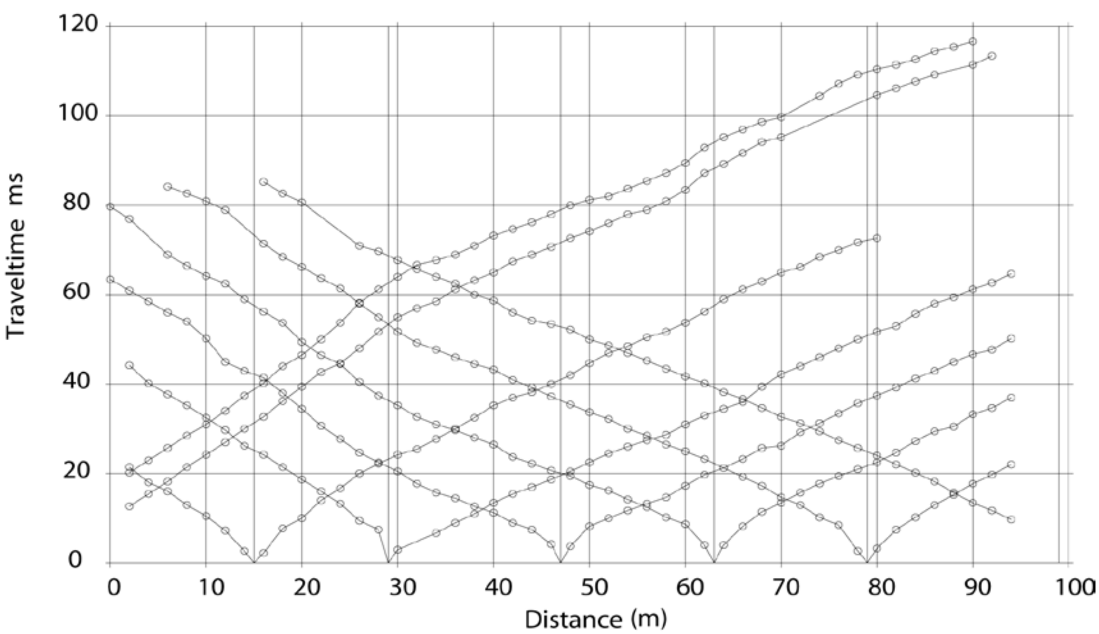

Figure 4.8. Travel time versus distance values of the first-break picks for spread 1 at the Basin Floor 1 site. Survey 3 was taken along a north-south transect.

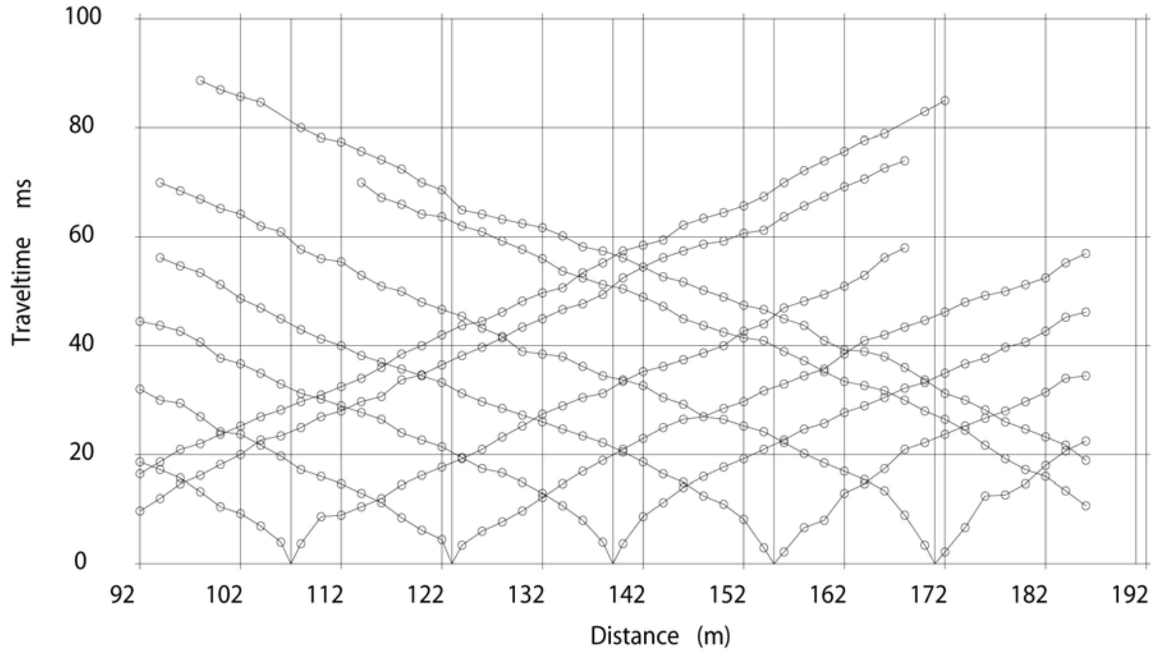

Figure 4.9. Travel time versus distance values of the first-break picks for spread 2 at the Basin Floor 1 site. Survey 3 was taken along a north-south transect.

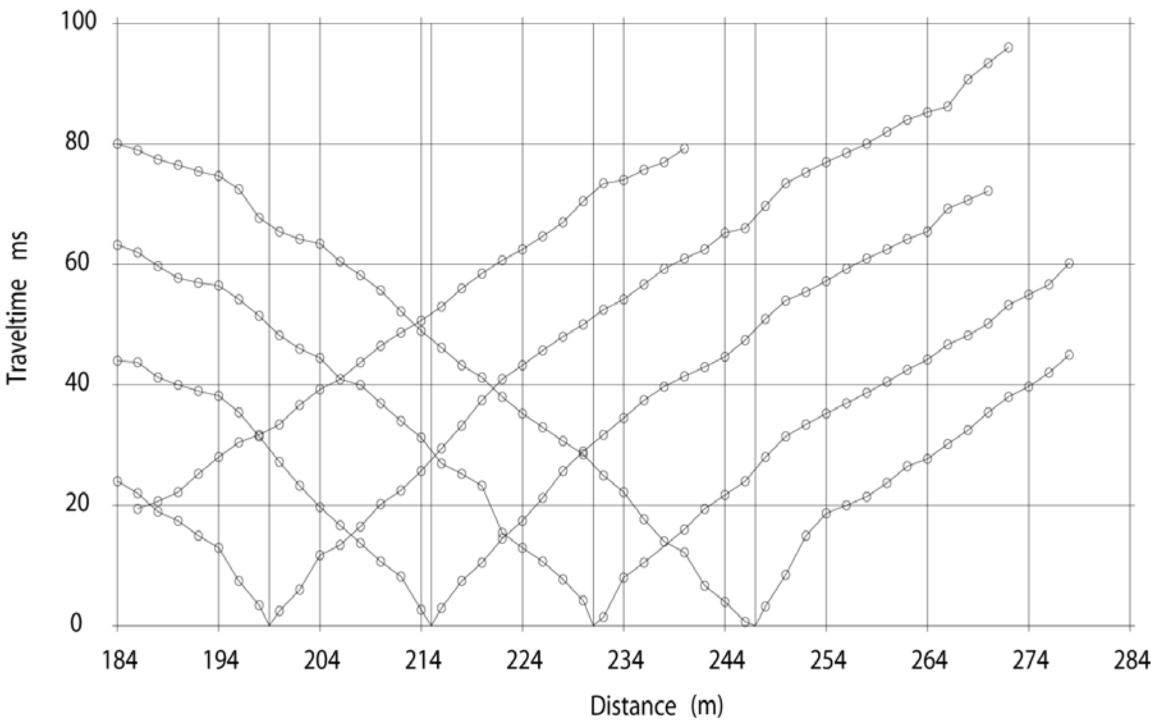

Figure 4.10. Travel time versus distance values of the first-break picks for spread 3 at the Basin Floor 1 site. Survey 3 was taken along a north-south transect.

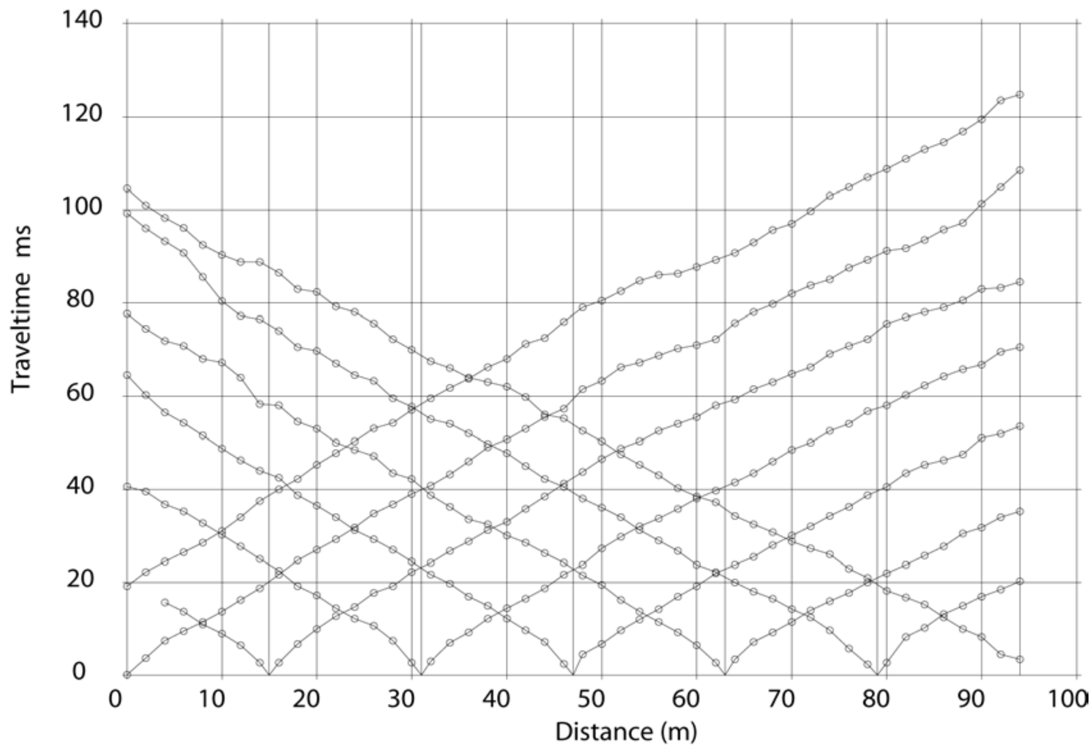

Figure 4.11. Travel time versus distance values of the first-break picks for spread 1 at the Basin Floor 1 site. Survey 4 was taken along a west-east transect.

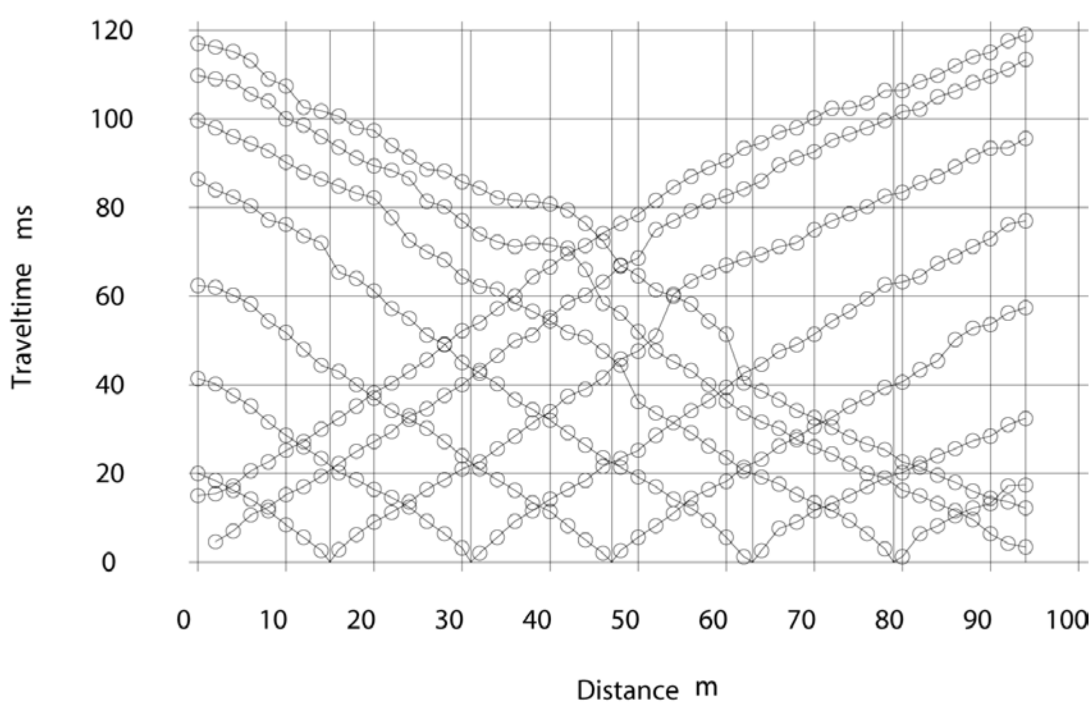

Figure 4.12. Travel time versus distance values of the first-break picks for spread 2 at the Basin Floor 1 site. Survey 4 was taken along a west-east transect.

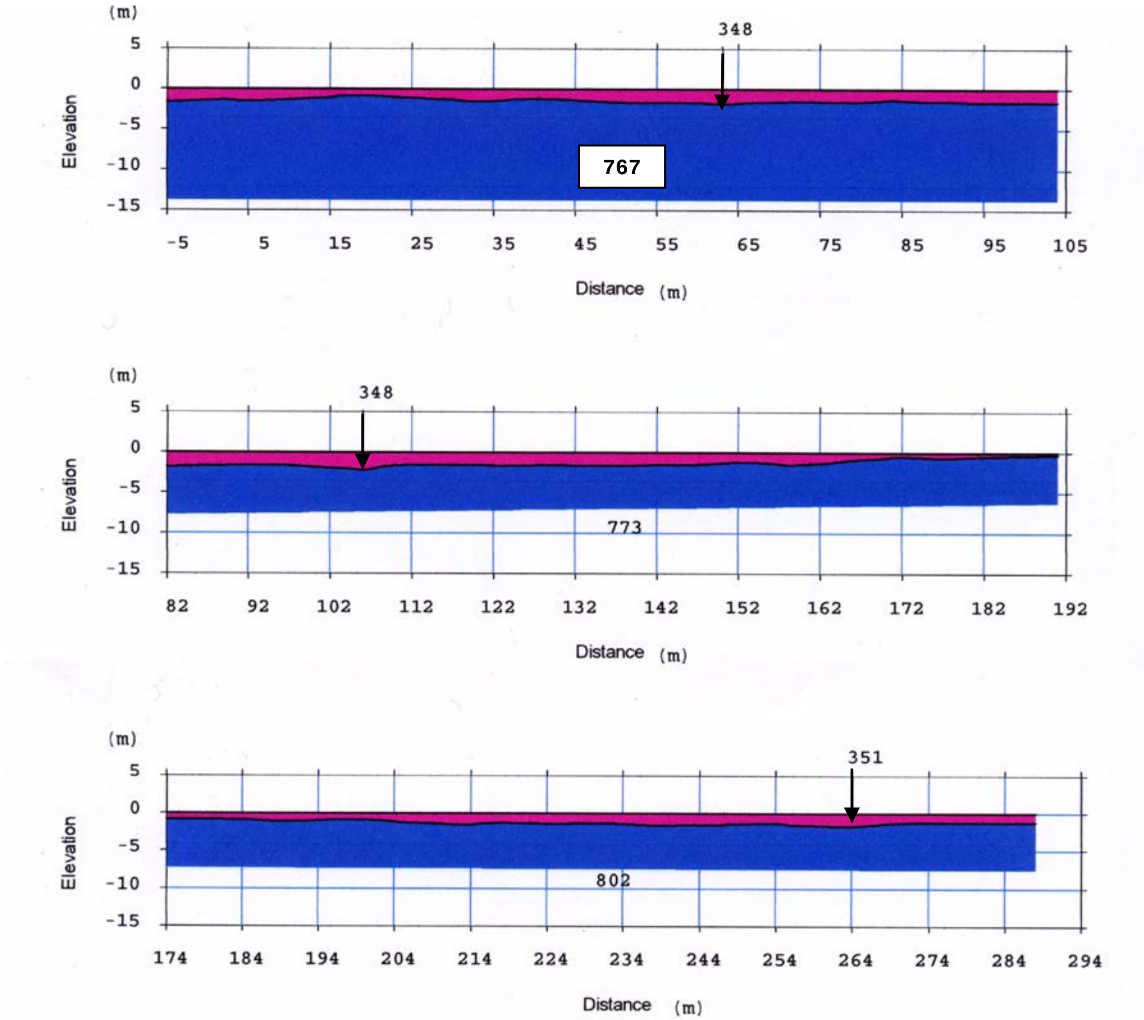

Figure 4.13. Calculated earth models and velocities from Woodcutters 3 on 2/28/04. Survey 1 was taken along west-east transect. The top most model is calculated from the first spread. The middle model is calculated from the second spread, and the bottom model is calculated from the third spread.

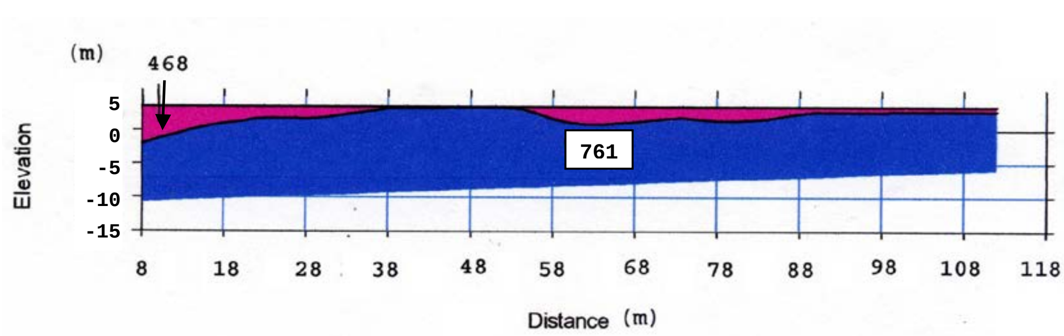

Figure 4.14.Calculated earth models and velocities from Woodcutters 3 on 3/20/04. Survey 2 was taken along north-south transect. The model is calculated from the third spread.

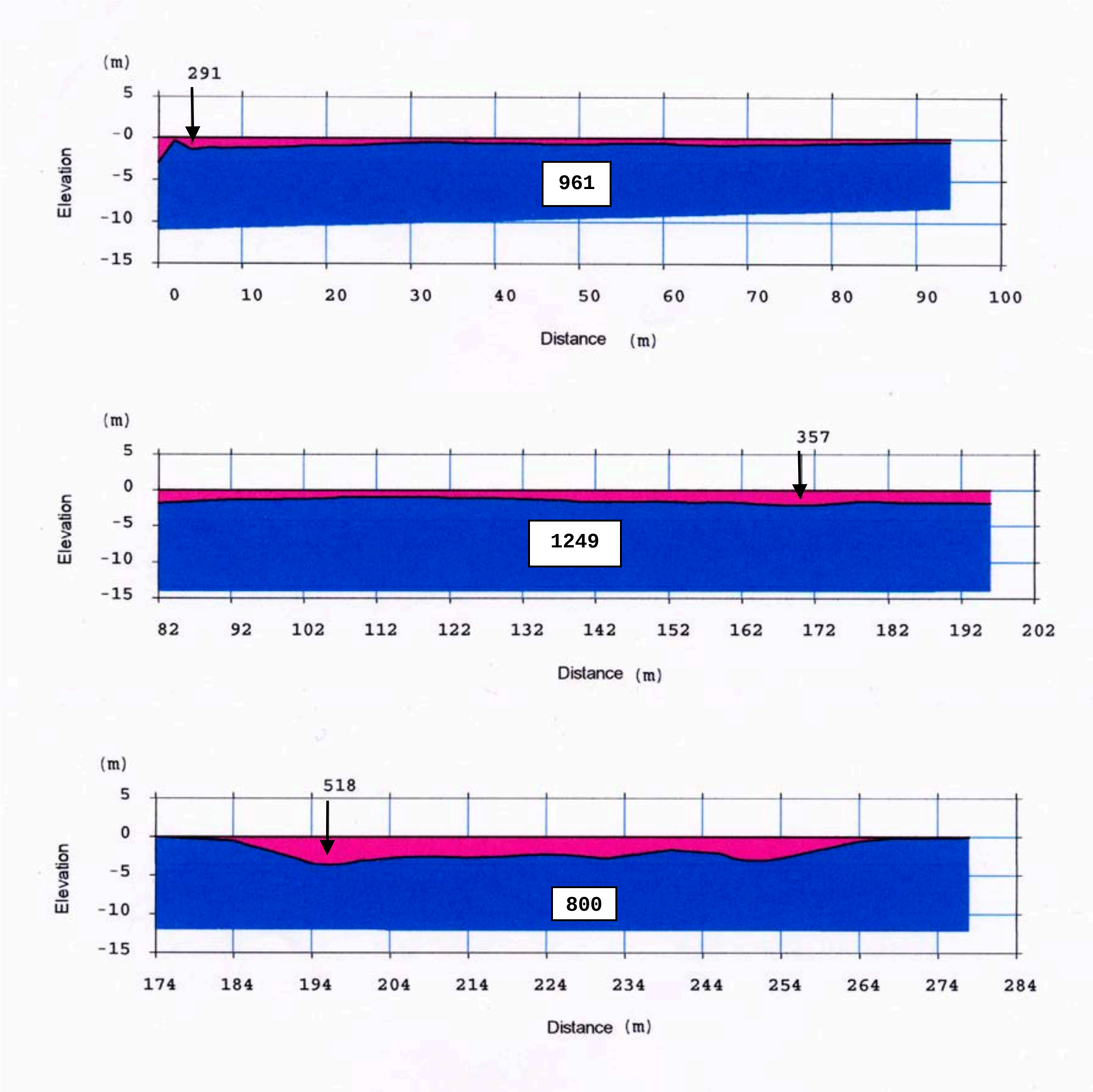

Figure 4.15. Calculated earth models and velocities from Basin Floor 1 on 2/29/04. Survey 3 was taken along north-south transect. The top most model is calculated from the first spread. The middle model is calculated from the second spread, and the bottom model is calculated from the third spread.

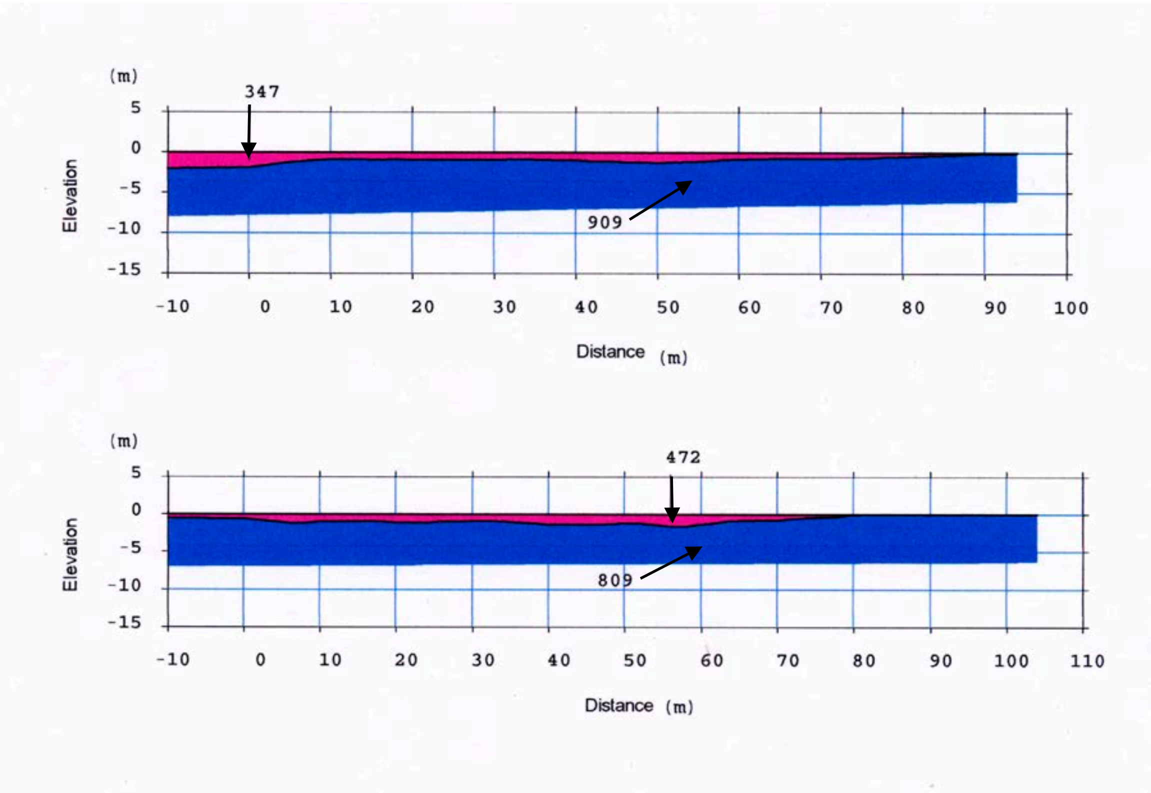

Figure 4.16. Calculated earth models and velocities from Basin Floor 1 on 3/21/04. Survey 4 was taken along west-east transect. The top most model is calculated from the first spread. The bottom model is calculated from the second spread.

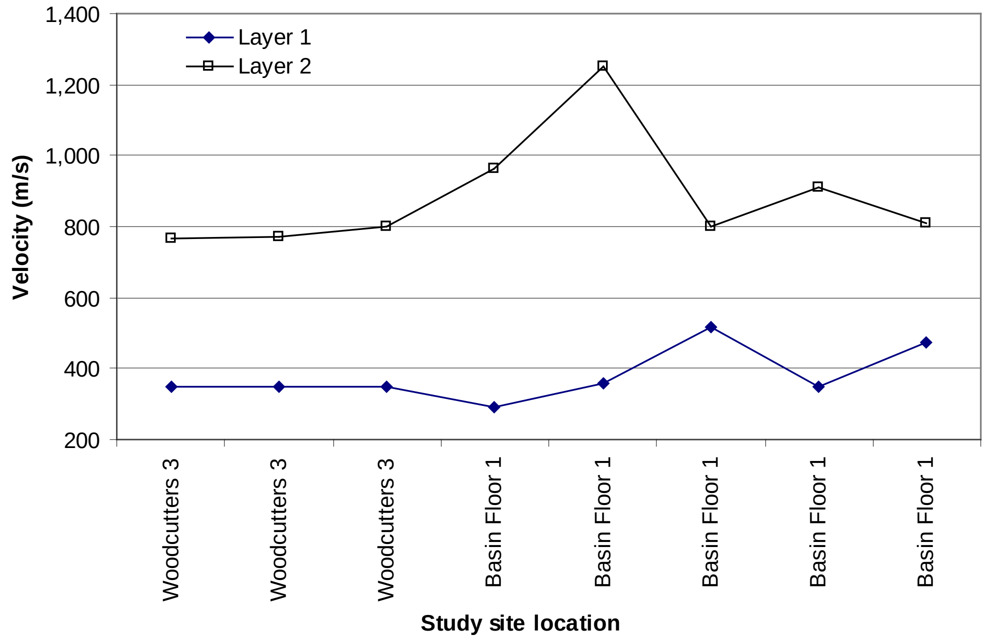

Figure 4.17. Velocities for layer 1 and layer 2 at Woodcutters 3 and Basin Floor 1.

5. Electromagnetic (EM 31 and 34) Surveys

5.1 Introduction and Location

Electromagnetic Surveys were conducted using both a Geonics EM31 MK2 and EM34 instrument. The EM31 and EM34 instruments determine subsurface conductivity, which can help determine the presence, and constrain the depth of, any impermeable clay layers in the subsurface.

Surveys were performed at both the Basin Floor 1 and Woodcutters 3 sites. At each site, an approximately north-south oriented line was surveyed and marked every 50 meters. An east-west oriented line was also surveyed at each site, which crossed the north-south line and was also marked every 50 meters. The dimensions of the transects in each direction differ at each site, but can be easily determined from the location maps of each site. Operators took measurements at approximately 10 meter intervals along most transects. At the Woodcutters 3 site, Figure 5.1, EM31 measurements of both parallel and perpendicular quadrature field were made every 10 meters on an east-west line. The EM34 surveys were conducted along the northern transect, and along the entire east-west line. At the Basin Floor 1 site, Figure 5.2, data were collected with the EM31 every 10 meters along the entire east-west survey line in both parallel and perpendicular dipole orientations. This survey line ran from 300 meters east to 700 meters west of the 0-meter station. At this same site, the EM34 survey was done along the western transect only, but in both horizontal and vertical dipole orientations. Measurements could be made in a variety of orientations, which will be described fully in the next section. Measurements in some orientations were taken less frequently to speed the process, but were always taken at least every 50 meters.

5.2 Instrumentation and Field Procedures

The EM31 consists of a single piece of equipment, with a data logger and operator centered between transmitter and receiver coils, with the coils located 3.66 meters apart from each other. The depth of investigation of the EM31 instrument is on the order of 3 meters for the horizontal loop orientation and 6 meters for the vertical loop orientation. The EM34 consists of separate transmitter and receiver coils that require two persons to operate, with the spacing of coils being dependent on the distance between the two operators. The spacing of the coils dictates the depth of exploration, with depth increasing as coil spacing increases. In this case, the EM34 has a greater depth of exploration, with the coil spacing being held constant at 10 meters throughout the surveys. The depth of investigation for the EM34 was on the order of 7.5 meters for the horizontal loop orientation and 15 meters for the vertical loop orientation. The EM31 could be used in several different orientations. Whenever the data logger faced up towards the operator, the coils were oriented in a horizontal plane, and were therefore vertical dipoles. Whenever the instrument was rotated so that the data logger faced out horizontally, the coils were oriented vertically, and were horizontal dipoles. Vertical dipoles have a greater sensing depth than horizontal dipoles. The orientation of the boom could also be used to observe ground response anisotropy. The default orientation of the boom was parallel to the line being surveyed, and was called “in-line”. If the instrument was turned so that the boom was perpendicular to the line of the survey, we called this “perpendicular”. This was usually a test of anisotropy of the ground. Using these orientations together with the horizontal and vertical dipoles orientations, the EM31 could be used in four different orientations. Further description of EM31 and EM34 measurement parameters and procedures can be found in the U.S. Army Corps of Engineers manual No. 1110-1-1802 (ref. #3).

Plots for the EM31 surveys are shown for the Woodcutters 3 site in Figure 5.3, and for the Basin Floor 1 site in Figure 5.4. For the EM34 surveys, plots are provided as Figures 5.5 and 5.6 for Woodcutters 3 east-west transect, and Figure 5.7 for the northern transect of the Woodcutters 3 site. For the Basin Floor 1 site, Figures 5.8 and 5.9 provide EM34 measurements received at this site. These plots display relative contribution to the secondary magnetic field, and therefore conductivity, below the surface.

5.3 Data Processing and Interpretation

Analysis of the plots from the EM surveys at the Basin Floor 1 site indicate the presence of some conductive material. As can be noted from Figures 5.4, 5.8, and 5.9 there is a significant change in amplitude around the 150 meter west station. The steep nature of this anomaly would indicate that this is not a widespread conductor, but something that is very small in size. We conclude that this anomaly is probably due to buried metallic scrap, as opposed to a broader geologic structure such as the clay material in question. The steep anomaly located around the 400 meter east station on the Woodcutters 3 plot in Figures 5.5 and 5.6 is attributed to an exposed grade control structure in the channel that is likely reinforced with rebar.

With the exception of these very narrow anomalies, there are only very small variations in conductivity evident in these plots. We observed lateral variations at Basin Floor 1, which are shown in Figures 5.4 and 5.9. In Figure 5.4, the EM31 data show a broad low anomaly along the western line that rose into a plateau-shaped high along the eastern transect. Figure 5.9 shows mildly undulating EM34 profiles along the western line. No north-south transects were measured with either instrument at Basin Floor 1.

Since both instruments were used to collect data along the western line of Basin Floor 1, we can use their absolute values to compare vertical variations in conductivity. EM31, with a depth of investigation of 6 meters, shows the lowest conductivity values, which are in the vicinity of 7 mS/m, as shown in Figure 5.4. EM34 measures down to 7.5 meters in its horizontal dipole position, and measures a slightly higher value of about 9 mS/m, as shown in Figure 5.9. In its vertical dipole position, EM34 investigates to a depth of 15 meters, and we see an increase to 13 mS/m, indicated in Figure 5.9. In addition to some mild lateral variations, the electromagnetic techniques measure a steady increase in conductivity with depth at this site.

We also observed lateral variations at Woodcutters 3, which are shown in Figures 5.3, 5.6, and 5.7. In Figure 5.3, the EM31 data show a slightly increasing trend as we move away from the center along the eastern line. Data were collected in both the horizontal and vertical dipole position, as well as parallel and perpendicular to the survey line. There is no significant difference between any of these values, which indicates two things. First, there is low anisotropy throughout the top 6 meters of the ground, and two, the conductivity does not vary significantly between 3 and 6 meters. Figure 5.6 shows a low anomaly in the EM34 data collected along the entire east-west transect; this anomaly is centered around the center point. This low anomaly has roughly the same magnitude in the horizontal and dipole positions, but the profiles are offset by about 4 mS/m. The northern transect of EM34 is shown in Figure 5.7, and shows a gradually increasing trend as you move away from the center. This agrees with the low anomaly seen in the east-west transect, and indicates that at Woodcutters 3 the lowest conductivity values are in the vicinity of the center point, increasing outward in at least three directions.

We also observe vertical variations at Woodcutters 3. Down to 6 meters depth, EM31 measures values of about 6 mS/m. EM34 measures values of about 14 mS/m at 7.5 meters depth, and about 17 mS/m at 15 meters down. As at Basin Floor 1, we see an increase in conductivity with depth at Woodcutters 3. Although at Basin Floor 1 it was a steady increase, at Woodcutters 3 the largest increase was concentrated between 6 and 7.5 meters depth.

The electromagnetic techniques show that conductivity increases with depth at both sites. At Woodcutters 3, the conductivity increases at the greatest rate between 6 and 7.5 meters deep. Although we expect conductivity to increase with depth simply based on compaction and moisture increases, higher rates of increase may indicate the presence of clay. In addition, these techniques reveal a low conductivity anomaly located near the center point of our surveyed lines at Woodcutters 3. A lateral anomaly such as this may be the result of lateral variations in lithology in the top 15 meters of the ground. Although neither technique unequivocally shows subsurface lithology, there are several observations that may be indicative of such lithologic changes.

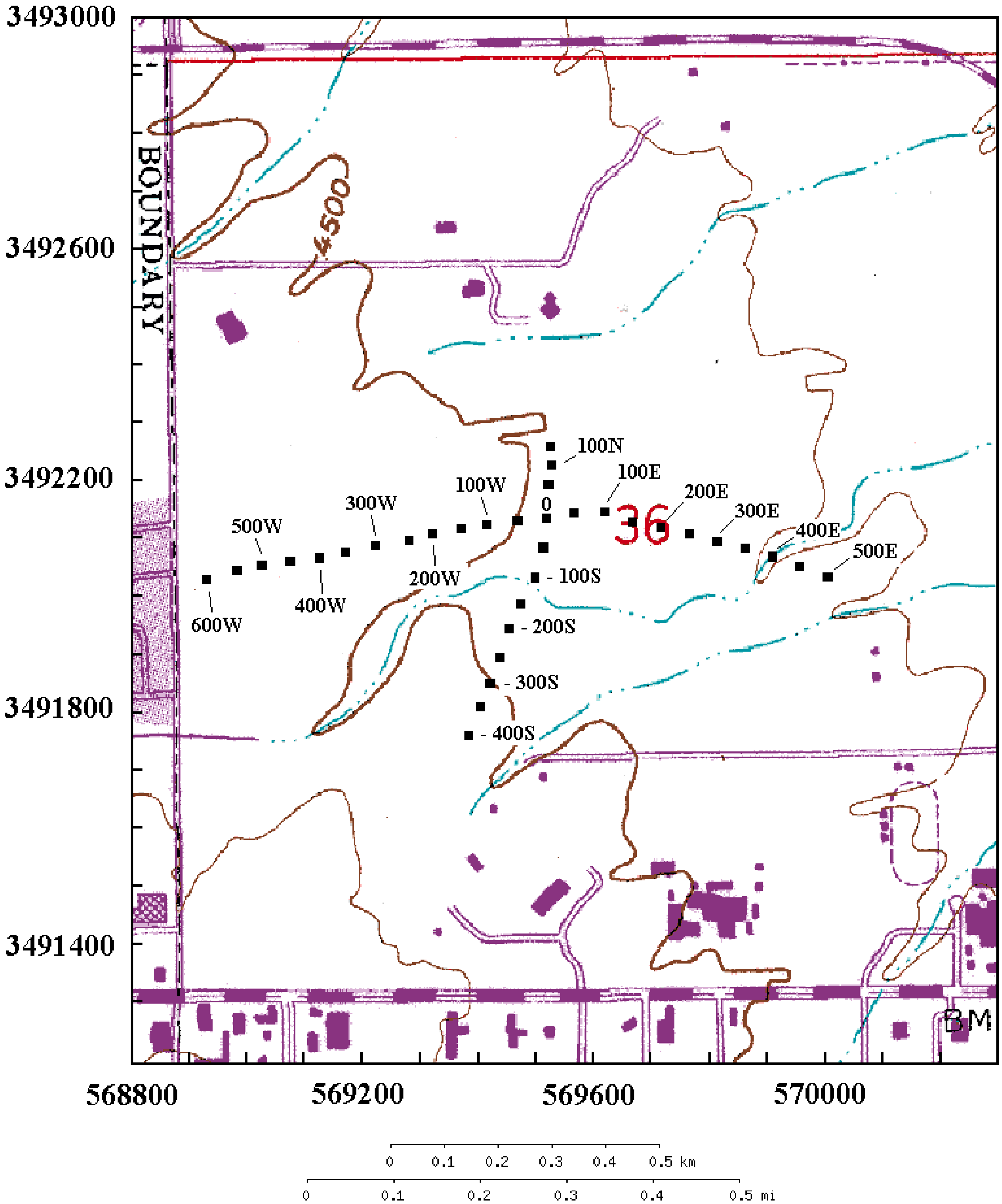

Figure 5.1. Woodcutters 3 location map.

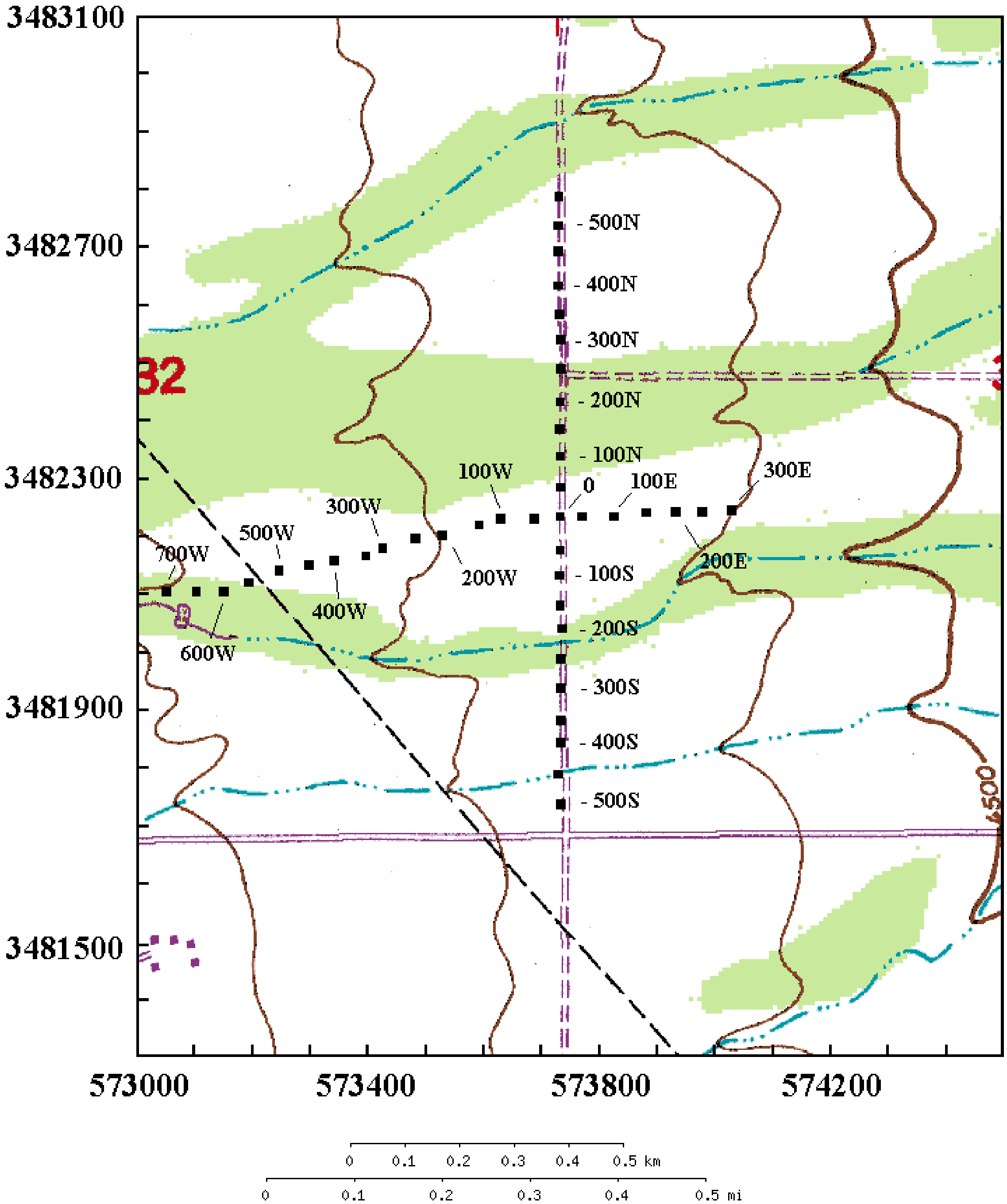

Figure 5.2. Basin Floor 1 location map.

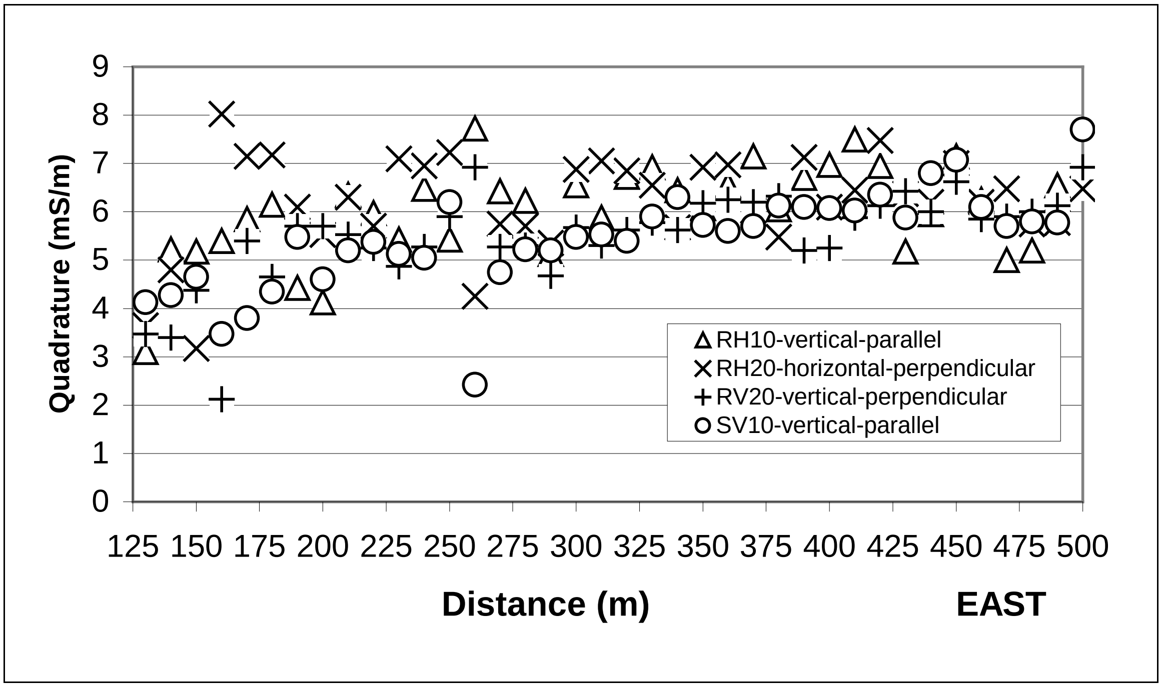

Figure 5.3. Quadrature measured in vertical dipole positions across the east-west transect of Woodcutters 3.

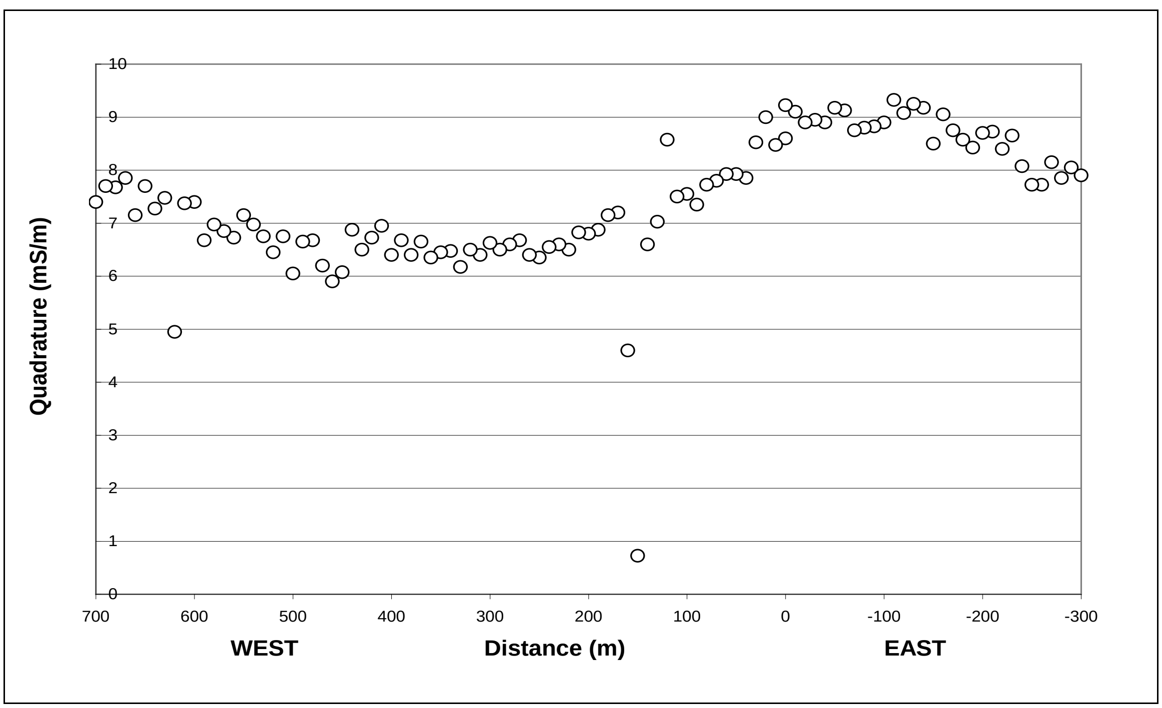

Figure 5.4. Quadrature measured in vertical dipole positions across the entire east-west transect of Basin Floor 1.

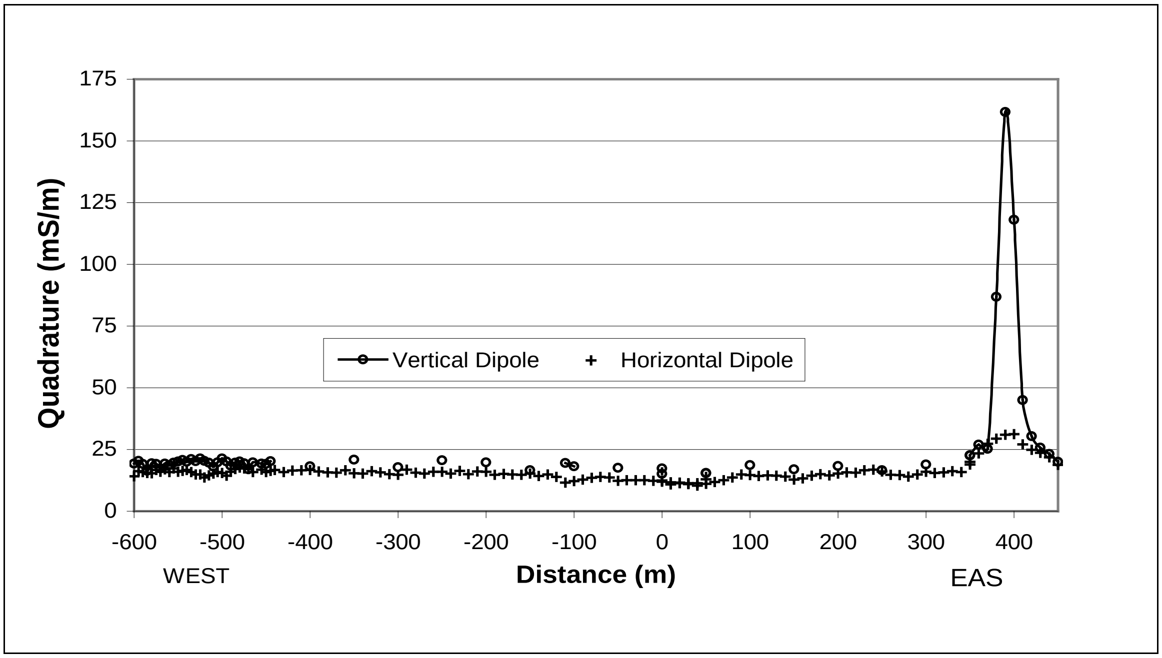

Figure 5.5. Quadrature measured in both horizontal and vertical dipole positions across the entire east-west transect of the Woodcutters 3 site. This figure shows the full range of values, which highlights the presence of a strong underground anomaly at about 395 meter position.

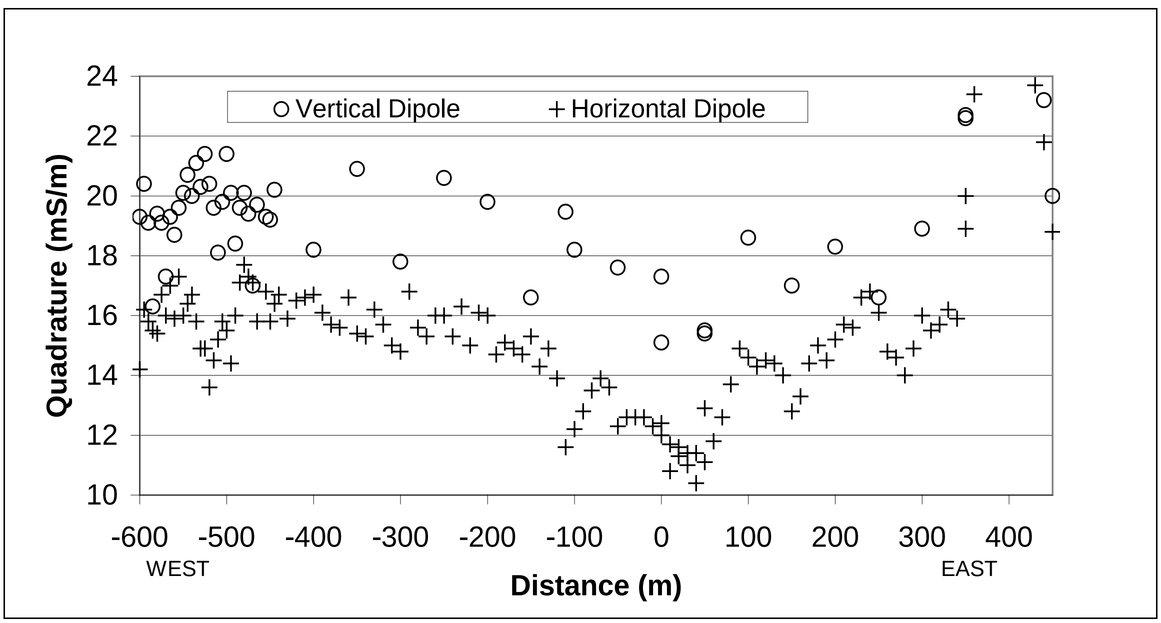

Figure 5.6. Same data as shown in Figure 5.5, but the range in quadrature values has been narrowed to highlight the subtle variations that could be ascribed to lateral variations in subsurface lithology.

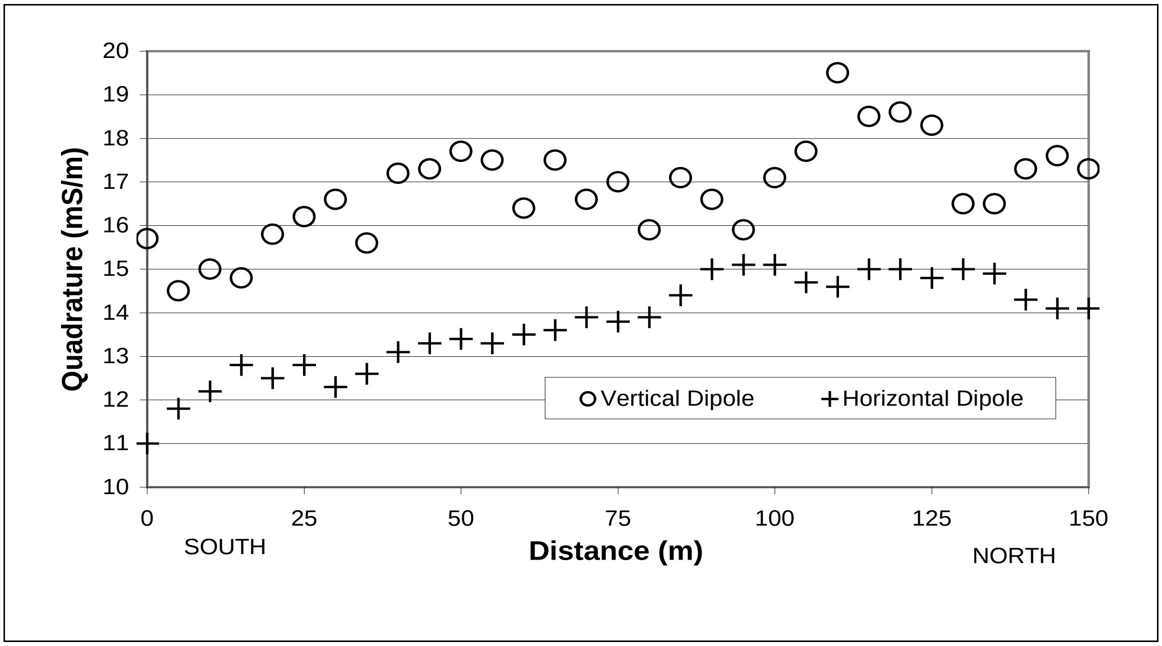

Figure 5.7. Quadrature measured in both horizontal and vertical dipole positions across the entire northern transect of the Woodcutters 3 site. No strong anomalies were observed, but a steady increase in quadrature was seen for both orientations towards the north.

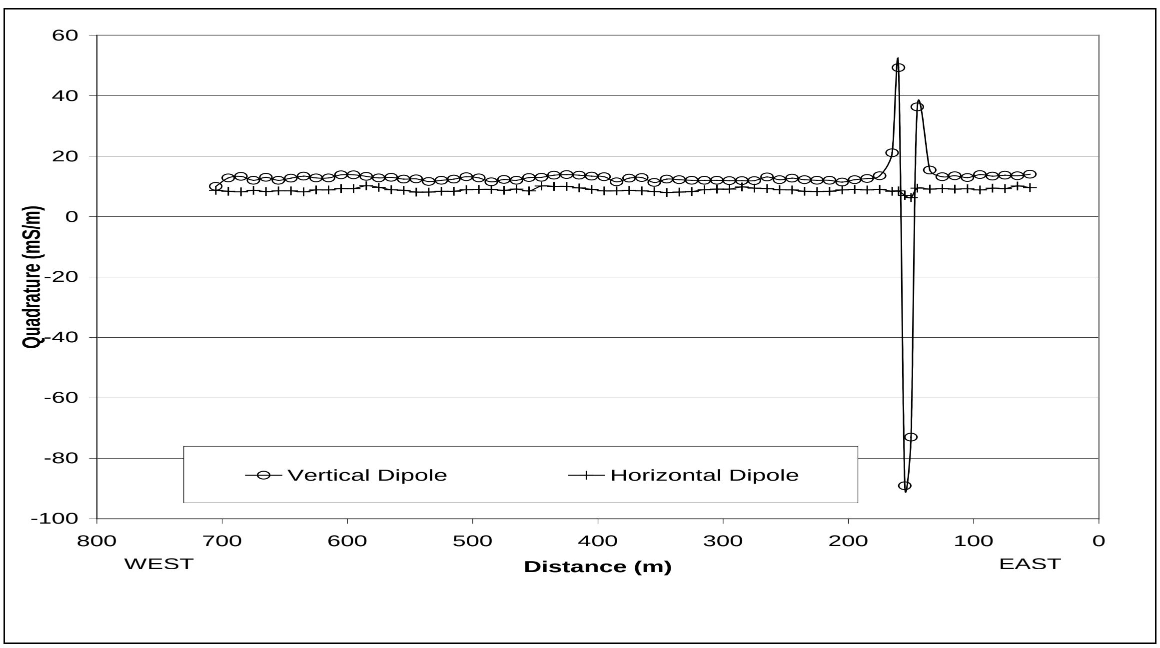

Figure 5.8. Quadrature measured in both orientations across the western transect at the Basin Floor 1 site. This figure shows the full range of values, which highlights a strong anomaly at about 150 meters. This anomaly was also seen in the magnetic total-field and VLF measurements.

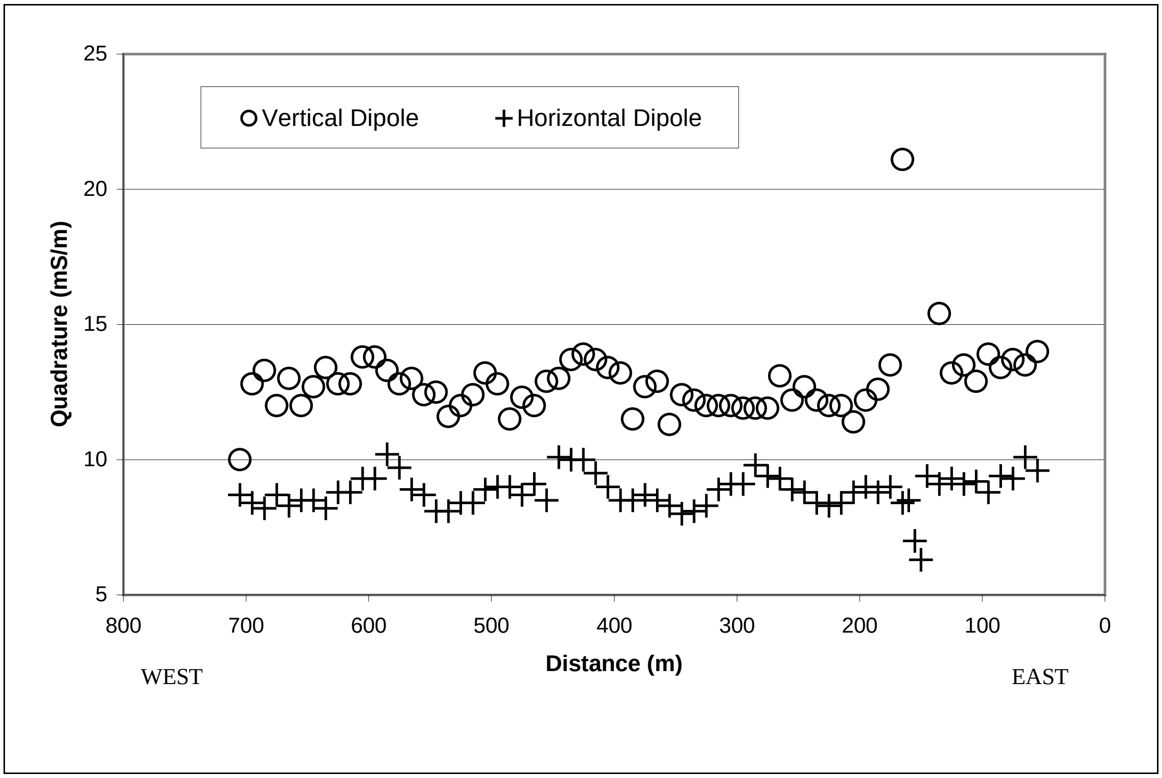

Figure 5.9. Same data as shown in Figure 5.8, but the range in quadrature values has been narrowed to highlight subtle variations that could be ascribed to lateral variations in subsurface lithology.

6. Magnetic, Vertical Gradient, and VLF Surveys

6.1 Introduction and Location

Magnetic, vertical gradient, and VLF surveys were conducted at both the Woodcutters 3 and Basin Floor 1 sites. One survey was performed at the Woodcutters 3 site along a west-east transect, as shown in Figure 6.1. Readings were taken at 50 meter intervals from the 50 meter west base station to 500 meters west and from 50 meters east to 500 meters east. Two surveys were conducted at the Basin Floor 1 site, as shown in Figure 6.2. One survey ran along a north-south transect from 200 meters north to 500 meters south. The second survey ran along a west-east transect from the 100 meter west base station to 700 meters west and from 50 meters east to 300 meters east. The readings for both surveys were also taken at 50 meter intervals.

6.2 Instrumentation and Field Procedures

Data were collected using an EDA OMNI Plus proton-precision magnetometer and VLF receiver. The magnetometer consists of a console and sensor on a 2.4 meter tall staff. The magnetometer displays readings for magnetic, gradient, and VLF readings at each station. VLF readings consisted of quadrature, in-phase, field strength, and tilt measurements for each station. The measurements were taken at two different frequencies, 24 kHz (F1), and 24.8 kHz (F2), corresponding to the frequencies of transmitters at Cutler, Maine and Jim Creek, Washington.

Measurements taken along the north-south transect at Basin Floor 1 were offset by a distance of 50 meters east of the borehole to eliminate any possible influence from the electric utility lines in the survey area. Base station measurements were taken at a point 20 meters south of the 0-meter station to minimize the influence of the vehicles and other equipment in the area. The station at the 450 east meter mark was also offset by 15 meters to minimize the effects of an old wire fence in the area. Base station readings were repeated a total of three times at the Woodcutters 3 site and six times at the Basin Floor 1 site to account for drift in the measurements.

6.3 Data Processing and Interpretation

The VLF data for both sites have been plotted in Figures 6.3-6.6. Figures 6.3a and 6.3b compare the in-phase profiles for the two frequencies F1 and F2 for the east-west and north-south Basin Floor 1 sites and the east-west Woodcutters 3 site. Figures 6.4a and 6.4b are the quadrature profiles, Figures 6.5a and 6.5.b the field strength profiles, and Figures 6.6a and 6.6b are the corresponding tilt profiles. The magnetic profiles are shown in Figure 6.7 and the vertical gradient profiles in Figure 6.8. Both the VLF and the magnetic profiles show an anomaly at the Basin Floor 1 site located at the 150 meter west station. This anomaly was also found in the Basin Floor 1 east-west TEM plot (since removed) and has been attributed to a buried metal object. Figure 6.8 shows three single-point anomalies that were found in the north-south Basin Floor 1 vertical gradient profile at the 50 meter, 250 meter, and 400 meter south stations. There are no corresponding anomalies at these locations in any of the VLF profiles or the magnetic profile, so these three data points presumably are due to local interference from buried metal objects. Comparison of the VLF and vertical gradient profiles between the Basin Floor 1 and Woodcutters 3 sites show no differences between the two sites. All the VLF and vertical gradient profiles for both the Basin Floor 1 and Woodcutters 3 sites are relatively featureless and have flat profiles. There is no apparent correlation with any of the known geologic structures on either site. Thus, according to the magnetic and VLF data the two sites are indistinguishable. While the two sites do show a difference in their magnetic profiles, this can be attributed to their different locations and the measurements being made on different days.

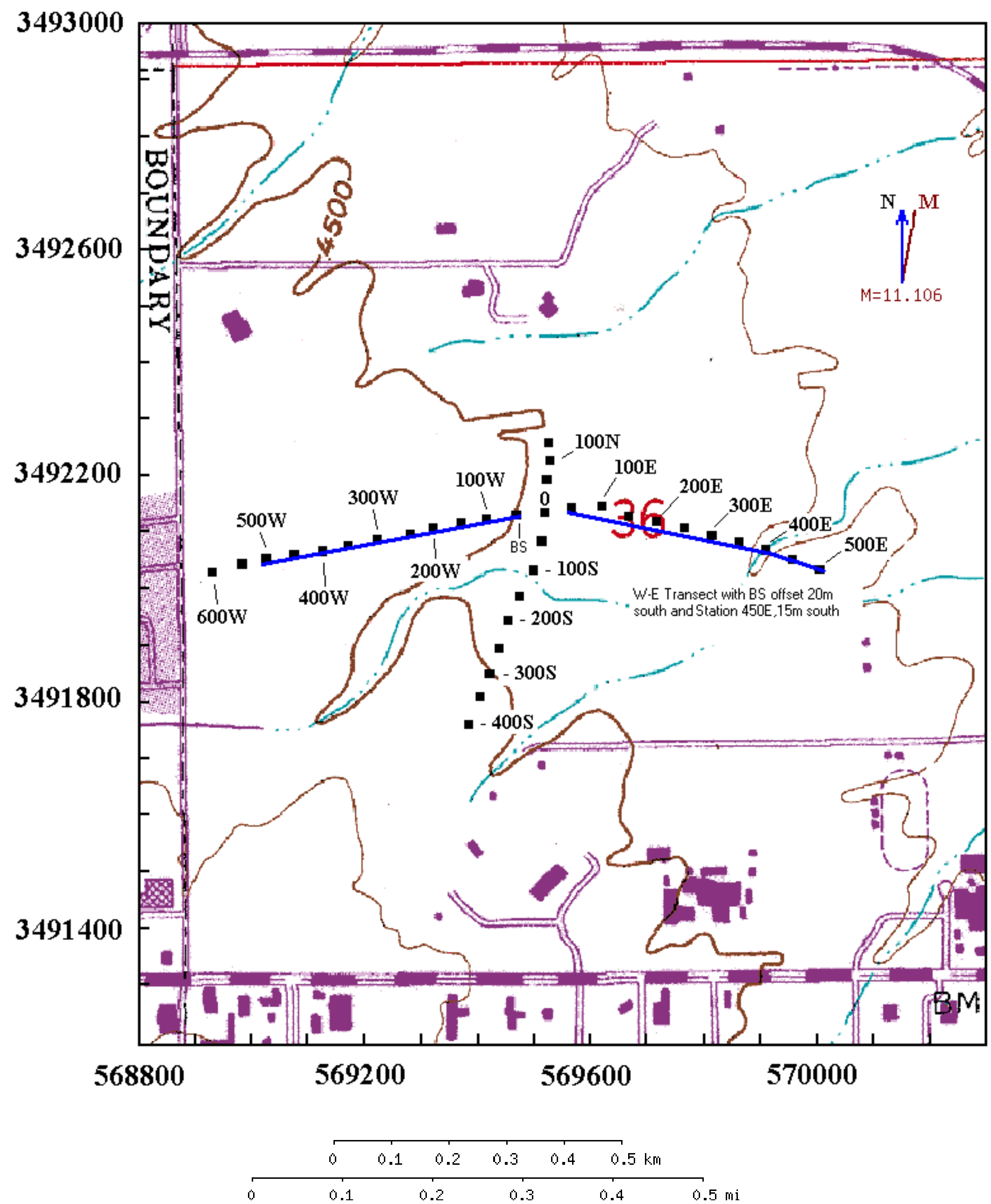

Figure 6.1. Woodcutters 3 location map for magnetic, vertical gradient, and VLF surveys.

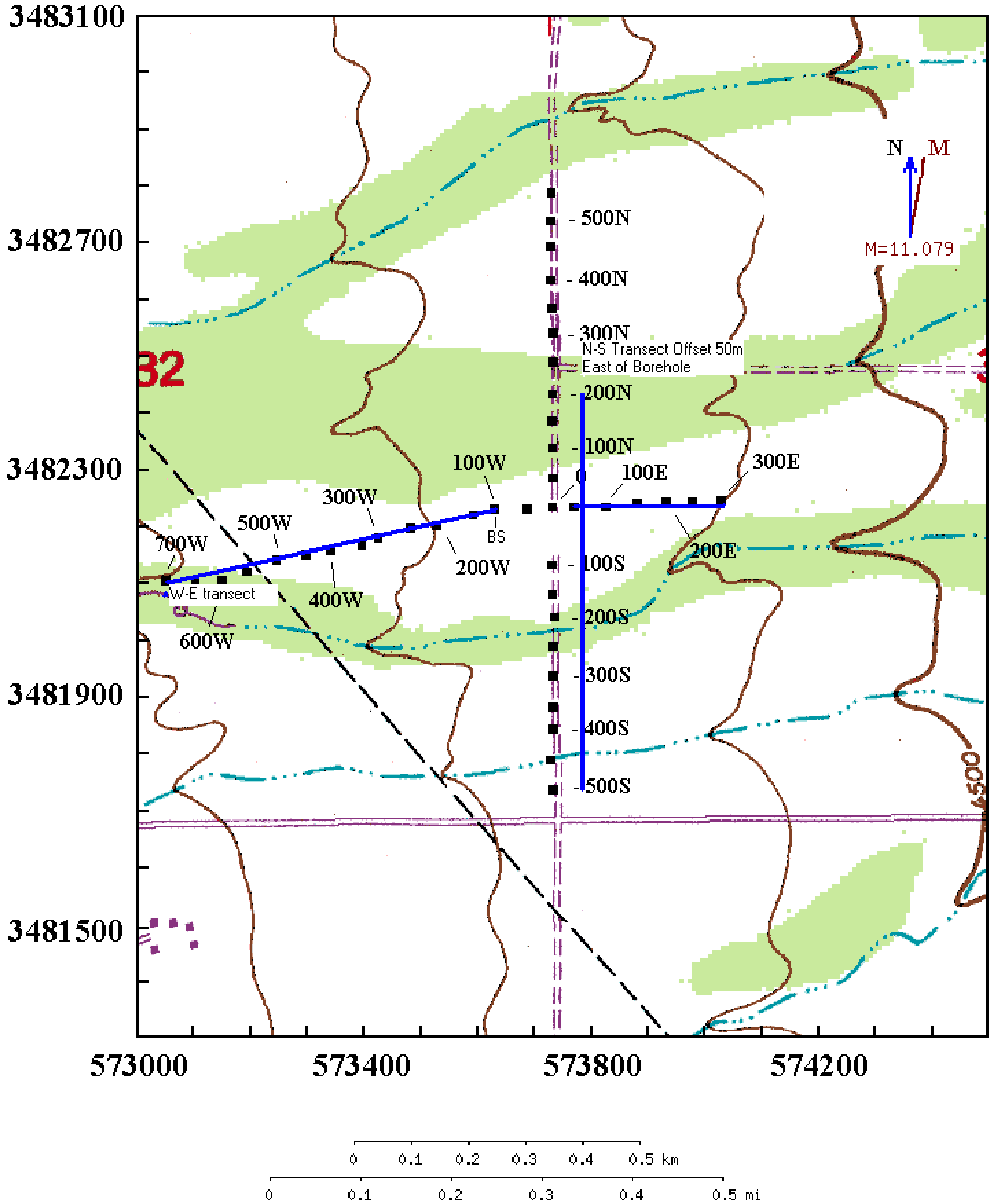

Figure 6.2. Basin Floor 1 location map for magnetic, vertical gradient, and VLF surveys.

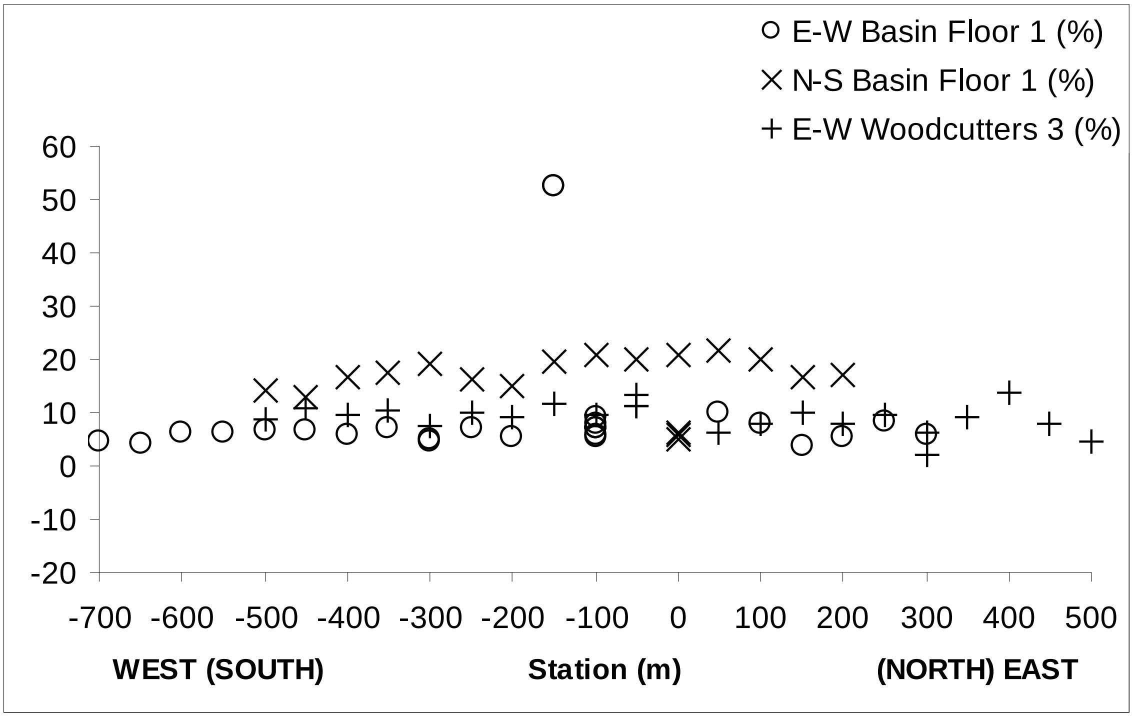

Figure 6.3a. Comparison of the VLF frequency F1 in-phase profiles for the east-west and north-south Basin Floor 1 and east-west Woodcutters 3 sites.

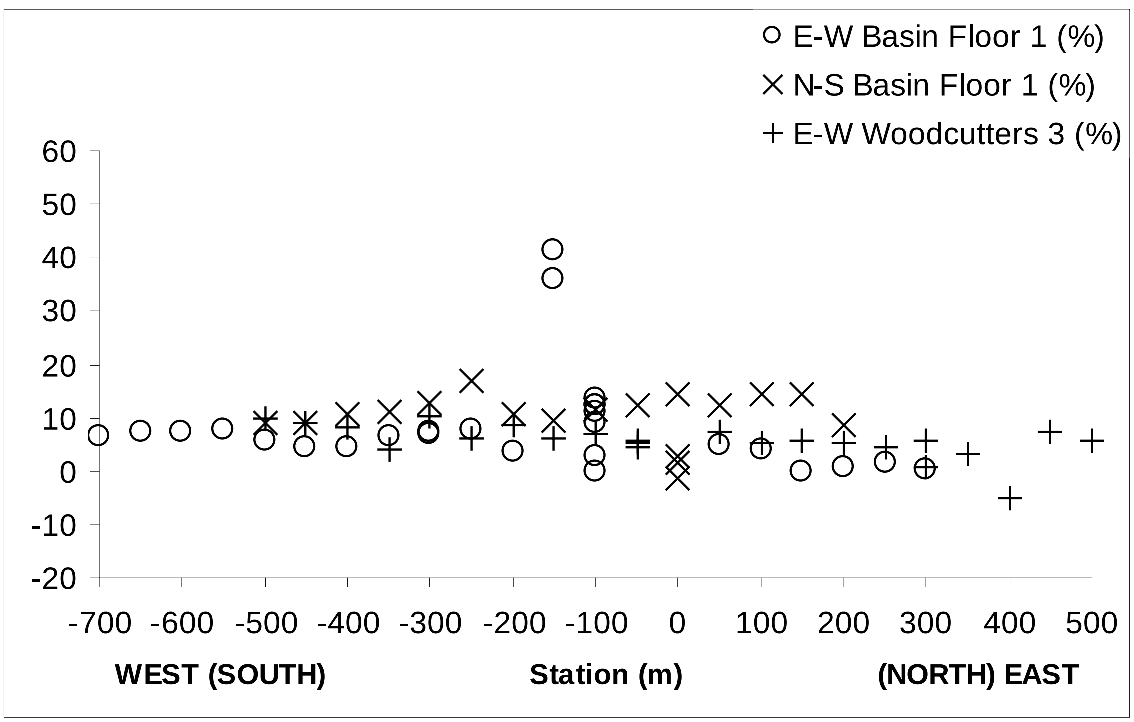

Figure 6.3b. Comparison of the VLF frequency F2 in-phase profiles for the east-west and north-south Basin Floor 1 and east-west Woodcutters 3 sites.

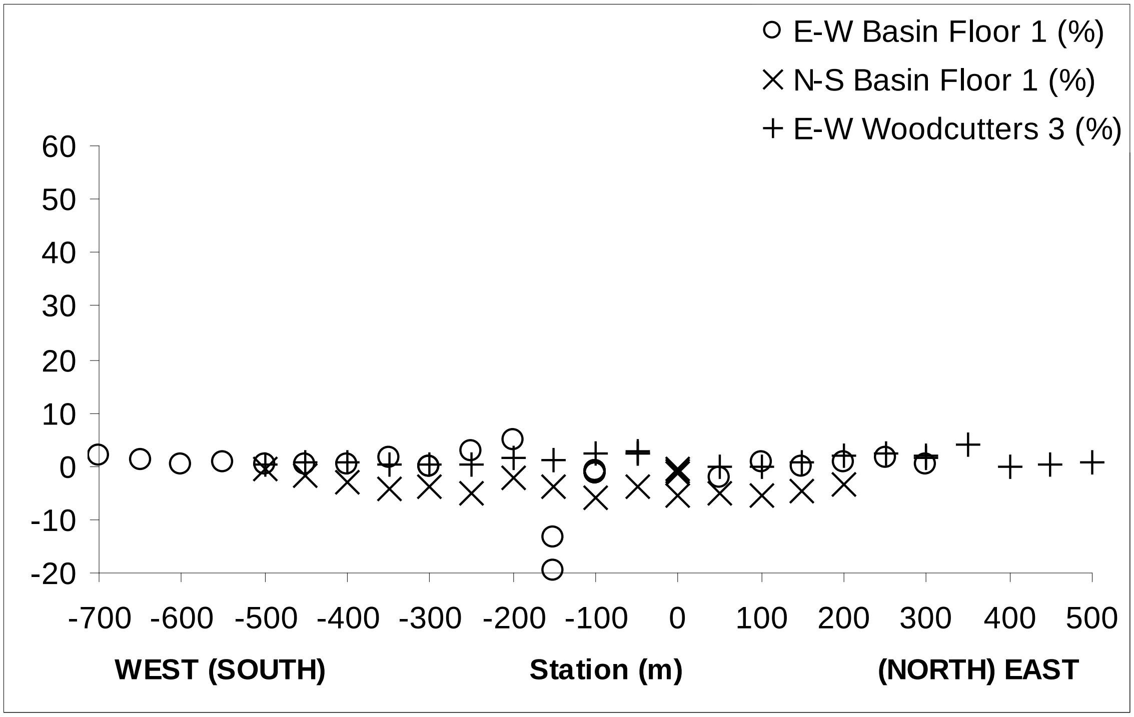

Figure 6.4a. Comparison of the VLF frequency F1 quadrature profiles for the east-west and north-south Basin Floor 1 and east-west Woodcutters 3 sites.

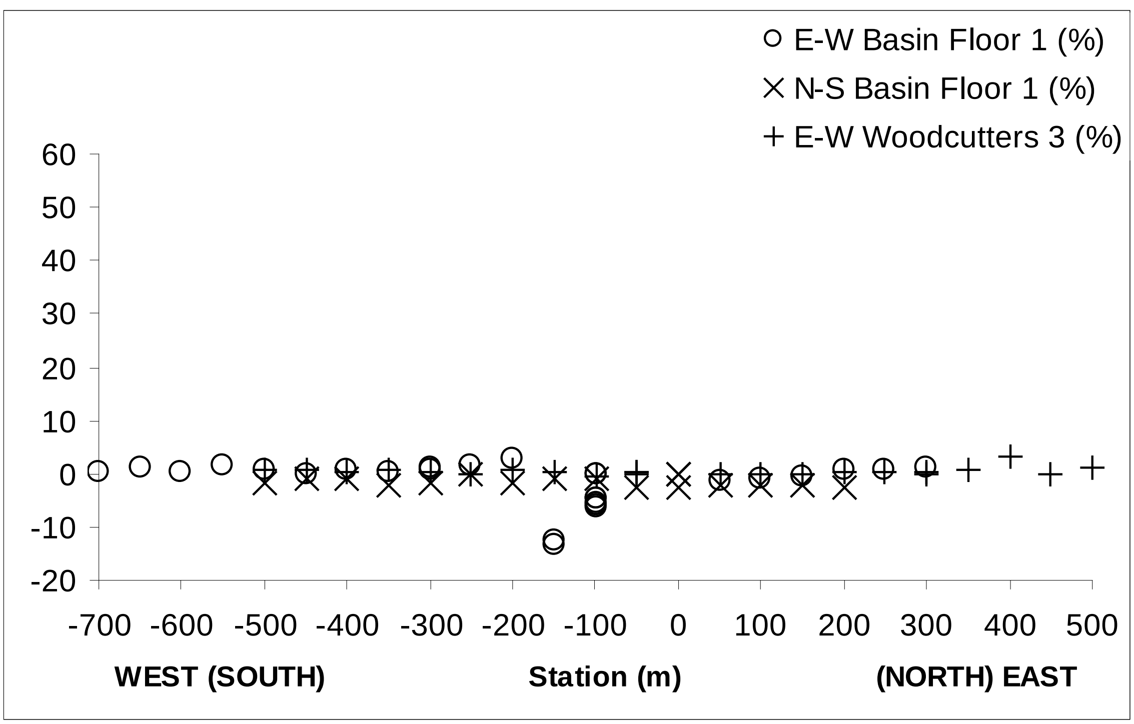

Figure 6.4b. Comparison of the VLF frequency F2 quadrature profiles for the east-west and north-south Basin Floor 1 and east-west Woodcutters 3 sites.

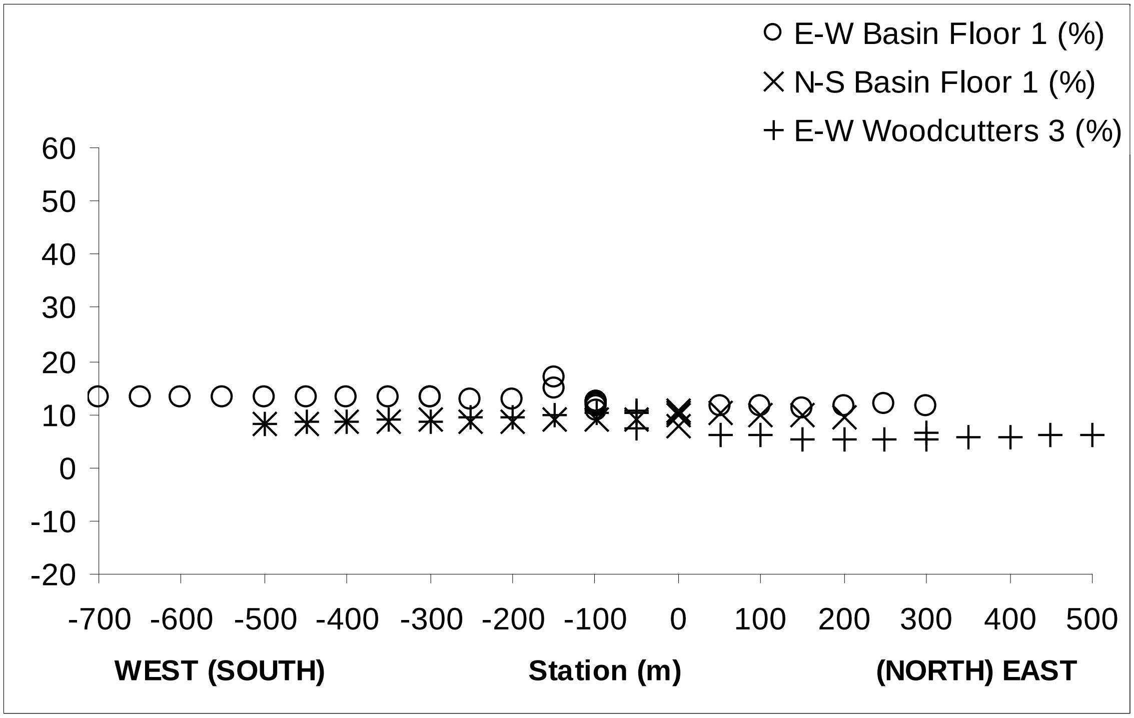

Figure 6.5a. Comparison of the VLF frequency F1 field strength profiles for the east-west and north-south Basin Floor 1 and east-west Woodcutters 3 sites.

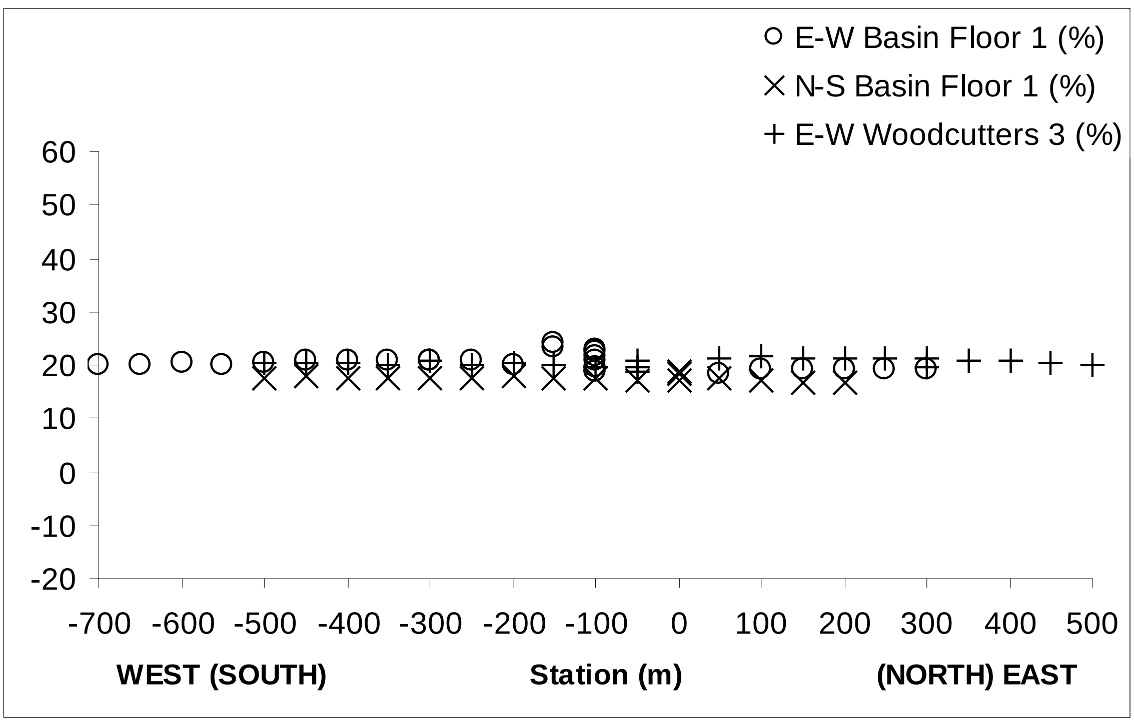

Figure 6.5b. Comparison of the VLF frequency F2 field strength profiles for the east-west and north-south Basin Floor 1 and east-west Woodcutters 3 sites.

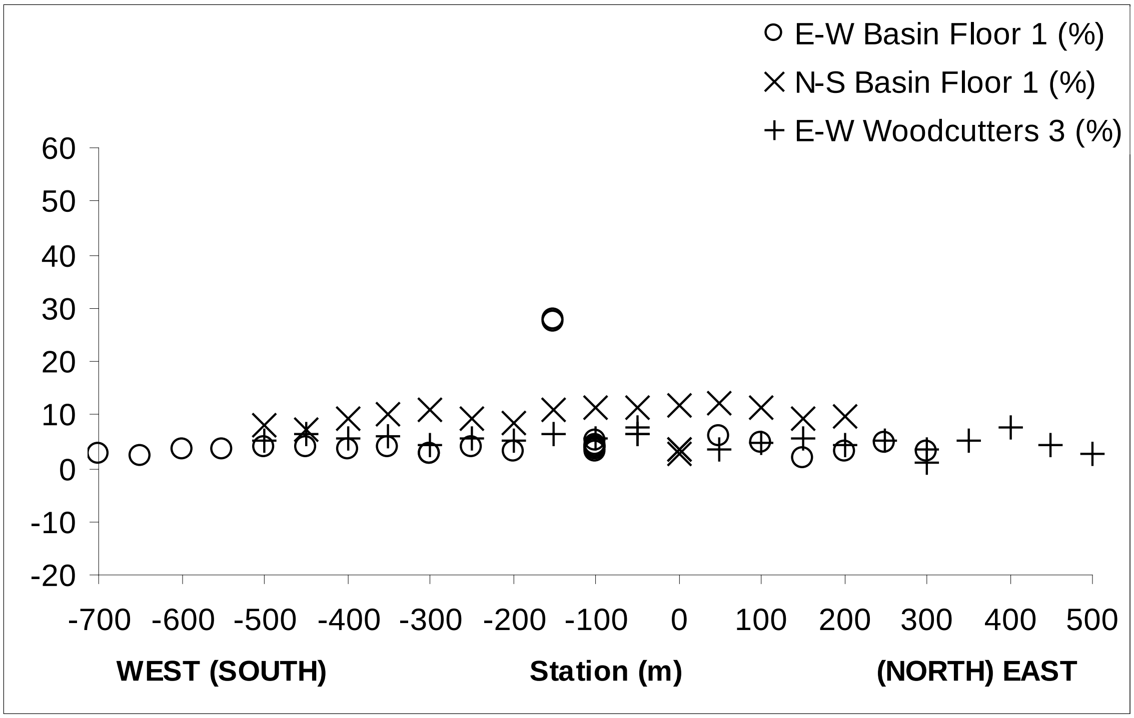

Figure 6.6a. Comparison of the VLF frequency F1 tilt profiles for the east-west and north-south Basin Floor 1 and east-west Woodcutters 3 sites.

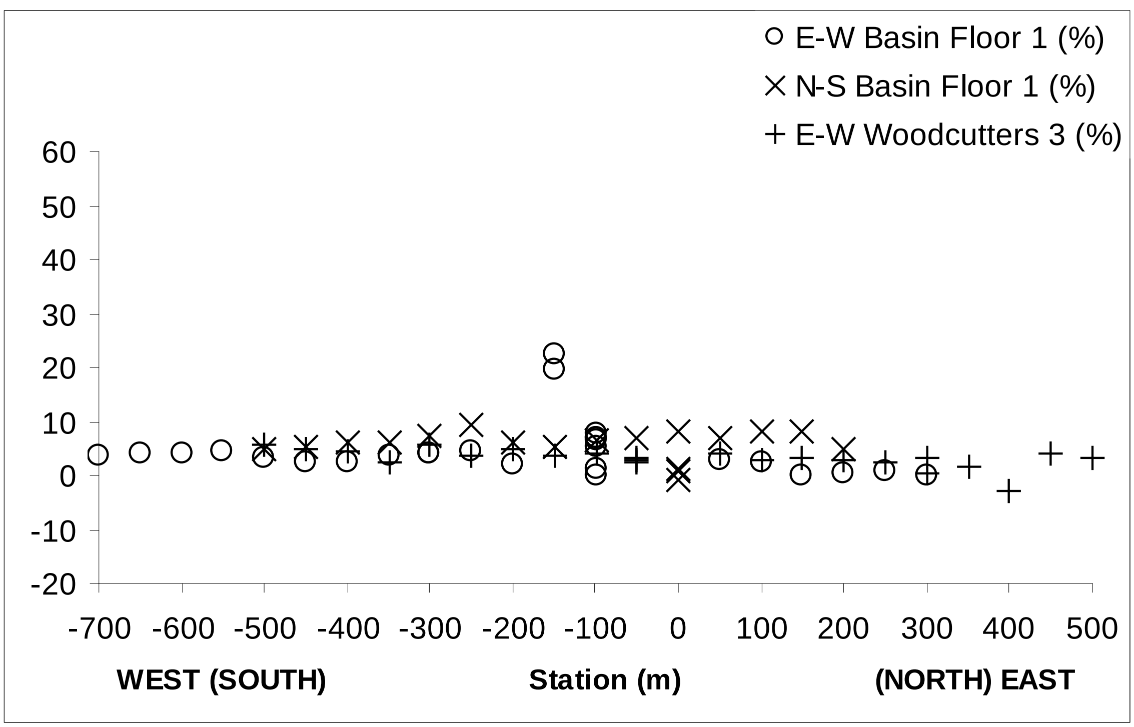

Figure 6.6b. Comparison of the VLF frequency F2 tilt profiles for the east-west and north-south Basin Floor 1 and east-west Woodcutters 3 sites.

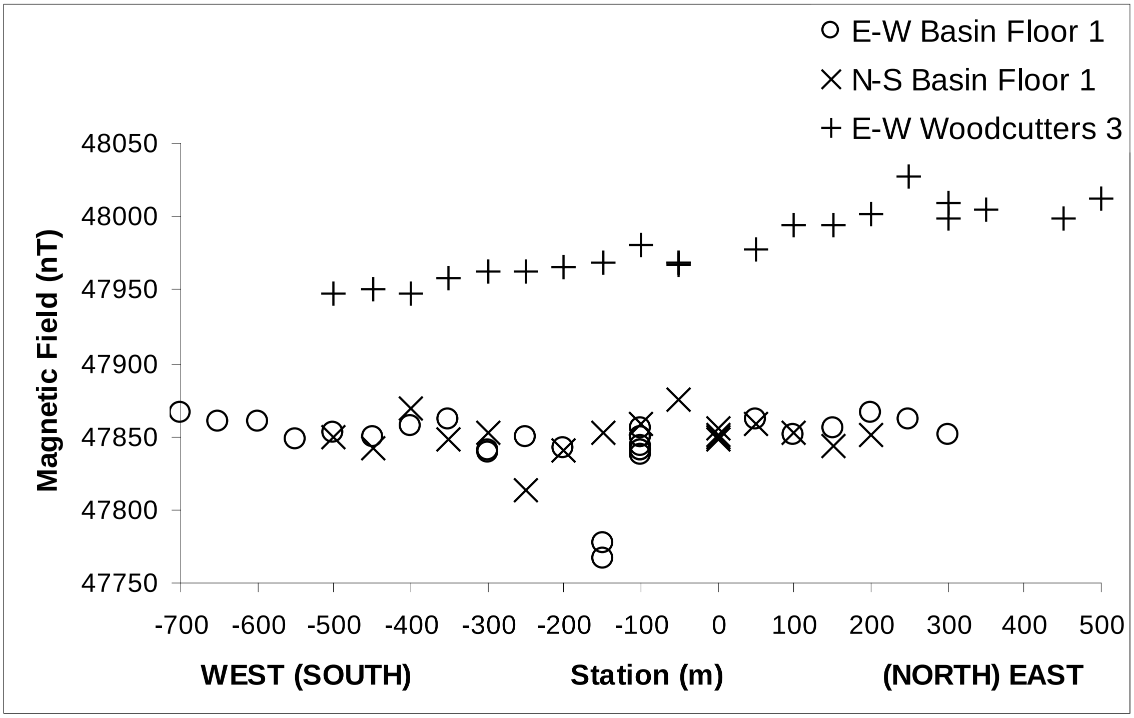

Figure 6.7. Comparison of the magnetic profiles for the east-west and north-south Basin Floor 1 and east-west Woodcutters 3 sites.

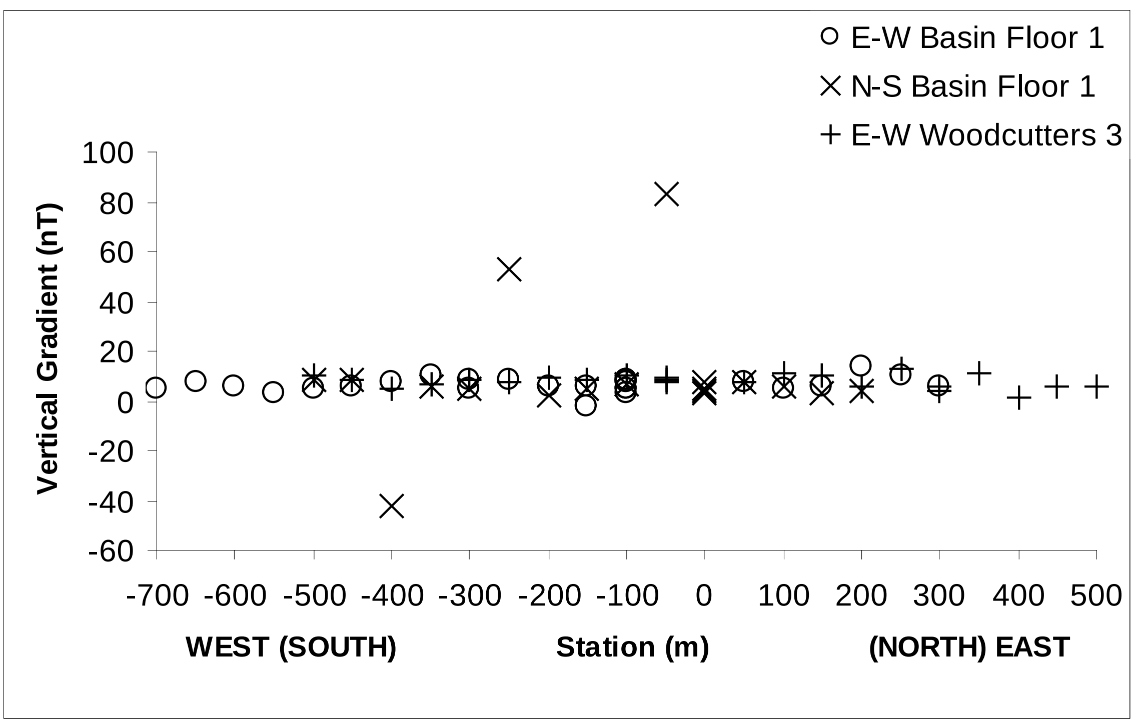

Figure 6.8. Comparison of the vertical gradient profiles for the east-west and north-south Basin Floor 1 and east-west Woodcutters 3 sites.

7. Conclusions

These geophysical surveys served a dual purpose. One, we sought to determine the presence or absence of impermeable clay layers at our sites (Basin Floor 1 and Woodcutters 3), and two, to determine what geophysical methods, if any, could find such clay layers. The geophysical methods employed included TEM, seismic, EM34/31, magnetic, gradient, and VLF.

Seismic data were modeled assuming a two-layer earth. For each layer, the modeled velocities were similar between the two study sites, indicating little difference in material properties between the two sites. For all the modeled velocity profiles, the depth of investigation is less than 5 meters below land surface.

Both the magnetic, VLF, and gradient field profiles only indicated local anomalies. These profiles are not significantly different between the two study sites and each has flat profiles. There is no correlation with any known geologic structures at either site.

Figure 7.1 compares borehole and EM 31 & 34 data collected from the two sites. The borehole data were collected by the U.S. Geological Survey on 2/21/2002 using the slim hole induction tool model number 9512 manufactured by the Century Geophysical Corporation (Callegary, personal communication). The borehole data show that the ground is more conductive at Woodcutters 3 than at Basin Floor 1, at least in the upper 10 meters. The EM34 and EM31 plots agree with the borehole data, in that the values measured at Woodcutters 3 are greater than at Basin Floor 1, which shows ground conductivity is higher at Woodcutters 3. This higher ground conductivity is indicative of higher water content, which may be due to an increased percentage of clay.

The TEM plots seem to support the above conclusion. Looking at the TEM data on Figure 7.2, we see that a highly conductive layer at Basin Floor 1 is more distinct at depth than at Woodcutters 3, but this is at a greater depth than the depth of investigation for either EM34 or 31. The depth of investigation for EM34 as estimated from a coil spacing of 10 meters is approximately 15 meters for the vertical dipole and 7.5 meters for the horizontal dipole (J.D. McNeill, 1980). For EM31, the effective depth is approximately 6 meters for the vertical dipole and 3 meters for the horizontal dipole (J.D. McNeill, 1980). At shallower depths, Woodcutters 3 is actually more conductive than the shallow area at Basin Floor 1, which is in agreement with the relations seen in Figure 7.1.

In most places, we could not directly compare TEM data with EM 31 and 34 data because they were taken along different transects. At one location, however, we could directly compare EM31 and TEM data, as shown in Figure 7.3. Along the east-west transect of Basin Floor 1, we observe a slight rise in the EM31 data near the center point, which correlates with a sharp rise in conductivity seen at Station 1 of the TEM line. EM34 data are plotted in Figure 7.4 along this transect and do not show this rise, as data were collected starting at 50 meters west of the center point. We anticipate that we might have observed a rise in conductivity with EM34 had we collected data east of the center point. However, the EM31 and 34 techniques both have a much shallower depth of investigation than the TEM technique so they may only be observing the rise of the first one or two contours in the TEM plot between Station 2 and 1. Upon closer inspection of Figure 7.4, we can see that the undulations in the EM34 curves roughly emulate undulations seen in the top few contours in the corresponding TEM profile. The data from TEM and EM31 and 34 techniques appear to be self-consistent where they overlap, which increases our confidence in these techniques. However, these techniques have very different effective investigation depths.

Unfortunately, none of the available borehole data show definitive clay layers, and a highly conductive layer seen in TEM, which is a good candidate for a solid clay layer, is much deeper than the nearby borehole. We suggest drilling more and deeper boreholes in these areas to improve ground-truthing for these geophysical methods. Also, EM34 data could be collected with its 20 meter and 40 meter coil spacings to increase its depth of investigation. Long transects are not needed, as absolute values are more indicative of clay content than is lateral variation of quadrature across a transect.

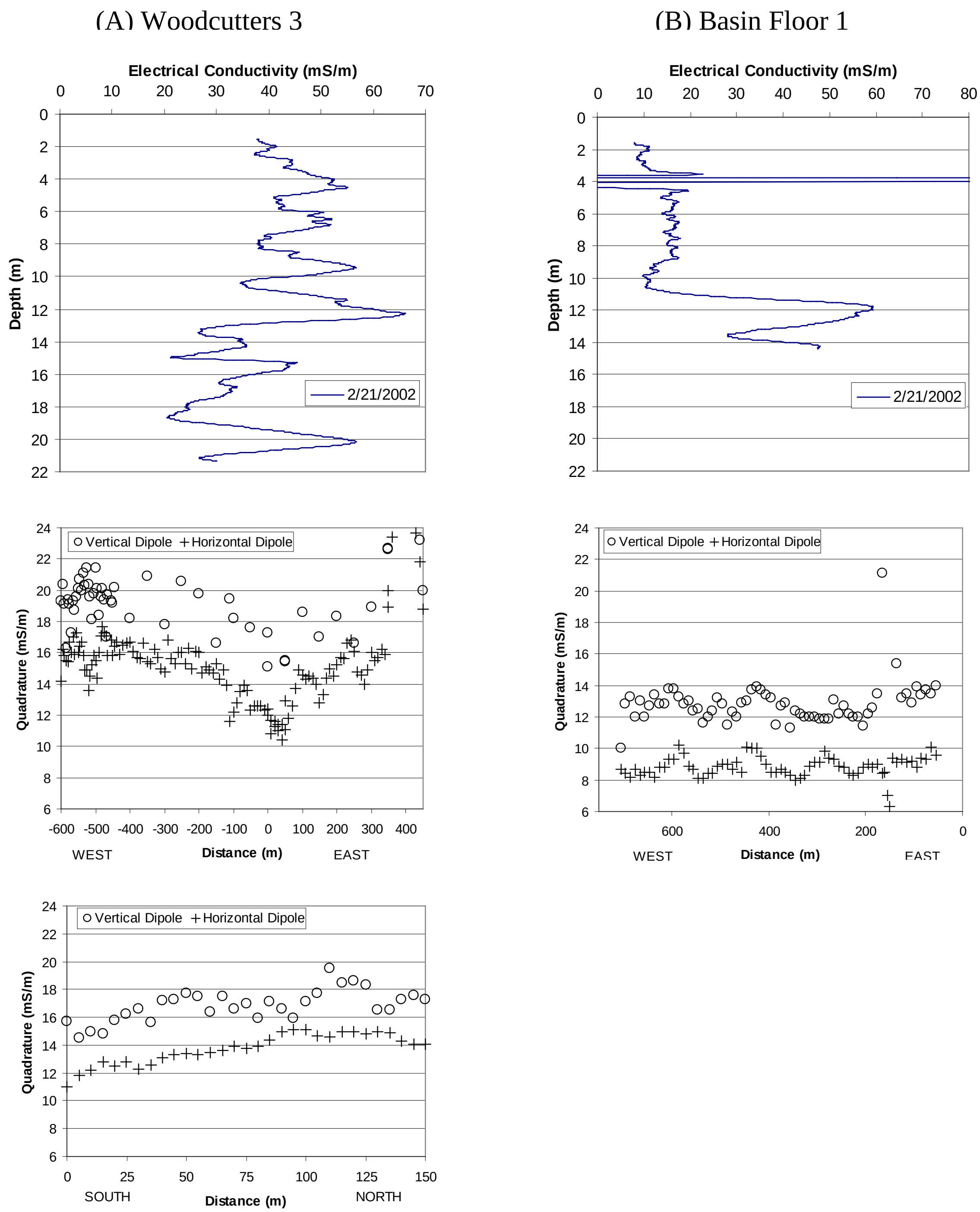

Figure 7.1. Electrical conductivity in mS/m versus depth of core in meters and quadrature in mS/m versus distance in meters for both the horizontal and vertical dipole using EM34 at (A) Woodcutters 3 and (B) Basin Floor 1.

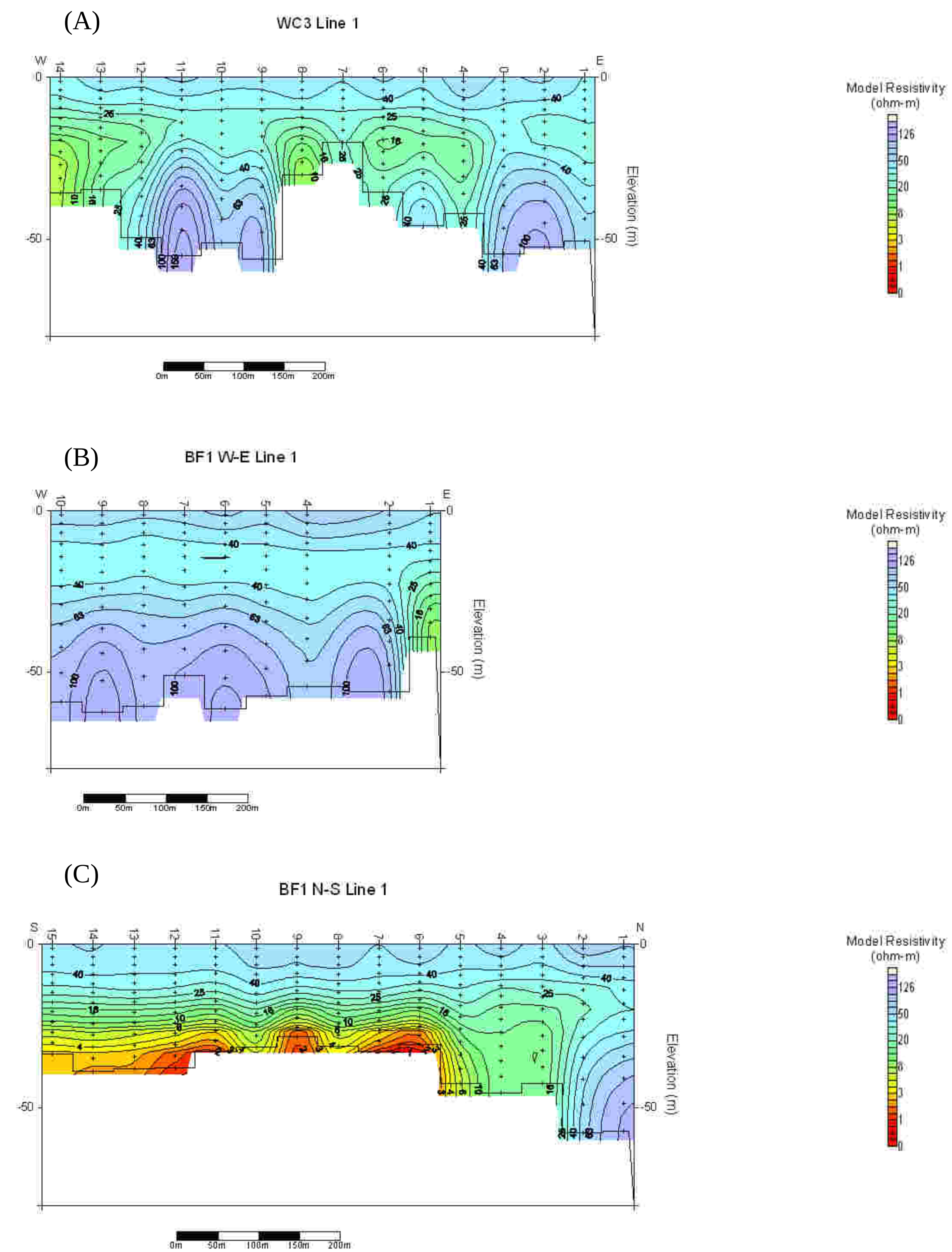

Figure 7.2. TEM smooth model inversion plots for (A) Woodcutters 3 east-west survey, (B) Basin Floor 1 east-west survey, (C) Basin Floor 1 north-south survey.

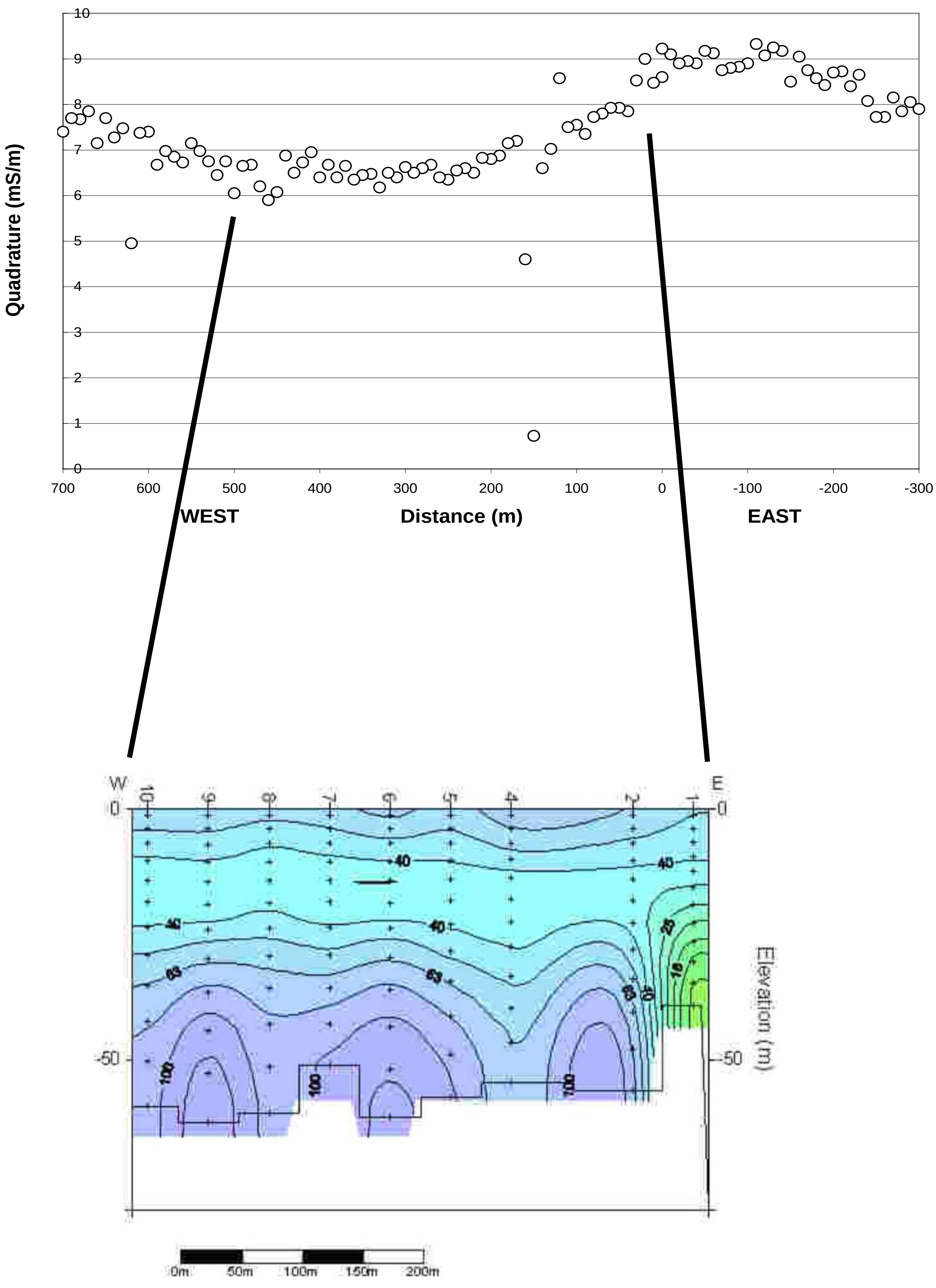

Figure 7.3. EM31 and TEM correlation for Basin Floor 1 west line.

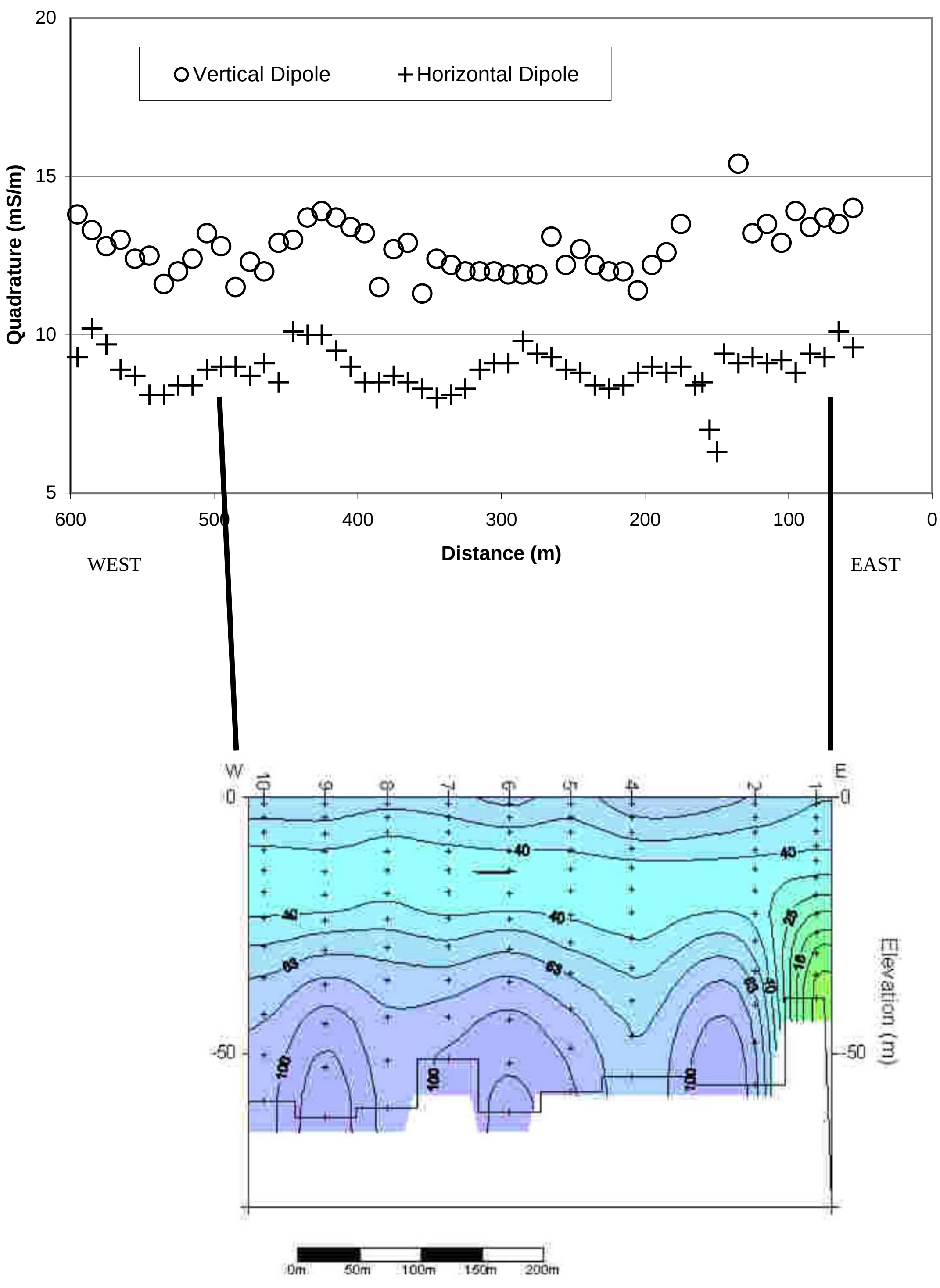

Figure 7.4. EM34 and TEM correlation for Basin Floor 1 west line.

8. References

1.) Pool, D. R. and Coes, A. L. (1999). *Hydrogeologic Investigations of the Sierra Vista Subwatershed of the Upper San Pedro Basin, Cochise County, Southeast Arizona*, U.S. Geological Survey Water-Resources Investigation Report 99-4197, 41 p.

2.) TopoZone maps from Maps a la carte, Inc., web site: http://topozone.com

3.) U.S. Army Corps of Engineers, Engineer Manual 1110-1-1802 (31 August 1995). *Engineering and Design – Geophysical Exploration for Engineering and Environmental Investigations,* Department of the Army, Washington, D.C. 20314 - 1000, pg. 55-57. The manual is on the web site: http://www.usace.army.mil/inet/usace-docs/eng-manuals/em1110-1-1802/toc.htm

4.) McNeill, J.D. (1980). Electromagnetic terrain conductivity measurement at low induction numbers, Geonics Limited LTD, Ontario, Canada, pg. 5-6.

5.) Callegary, J., personal communication, April 27, 2004.

9. Acknowledgements

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The United States Army, Fort Huachuca, Arizona and the United States Geological Survey, Water Resources Division, Tucson, Arizona for their financial support of this survey.

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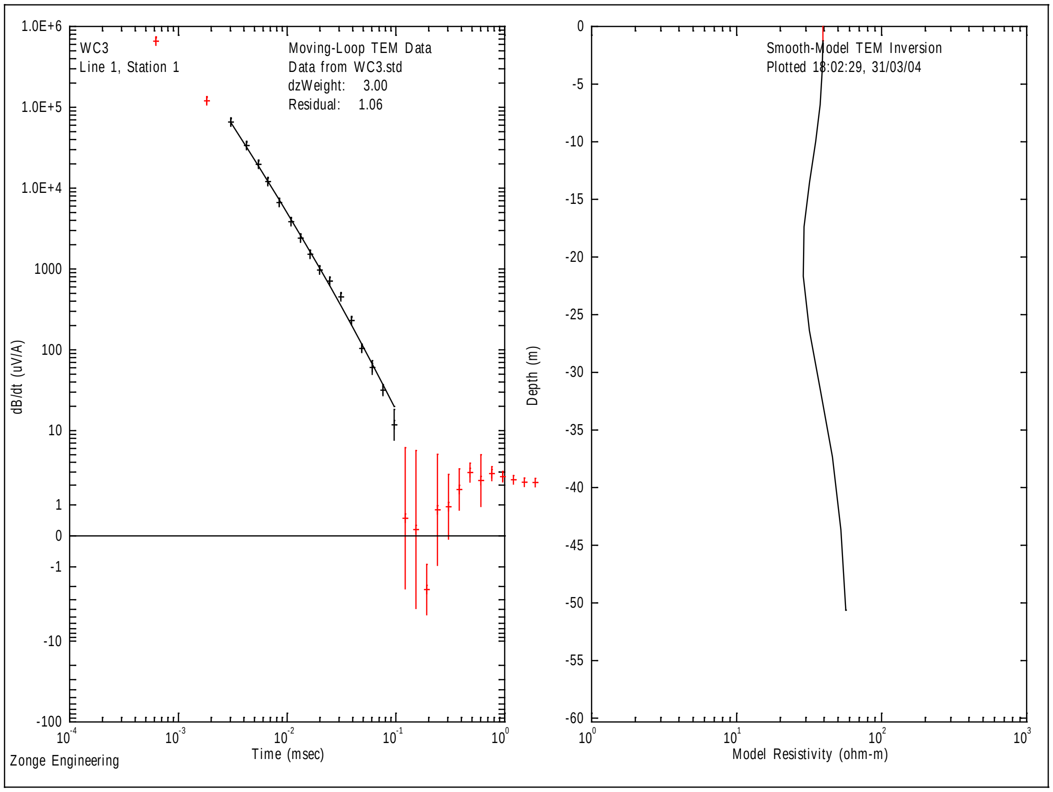
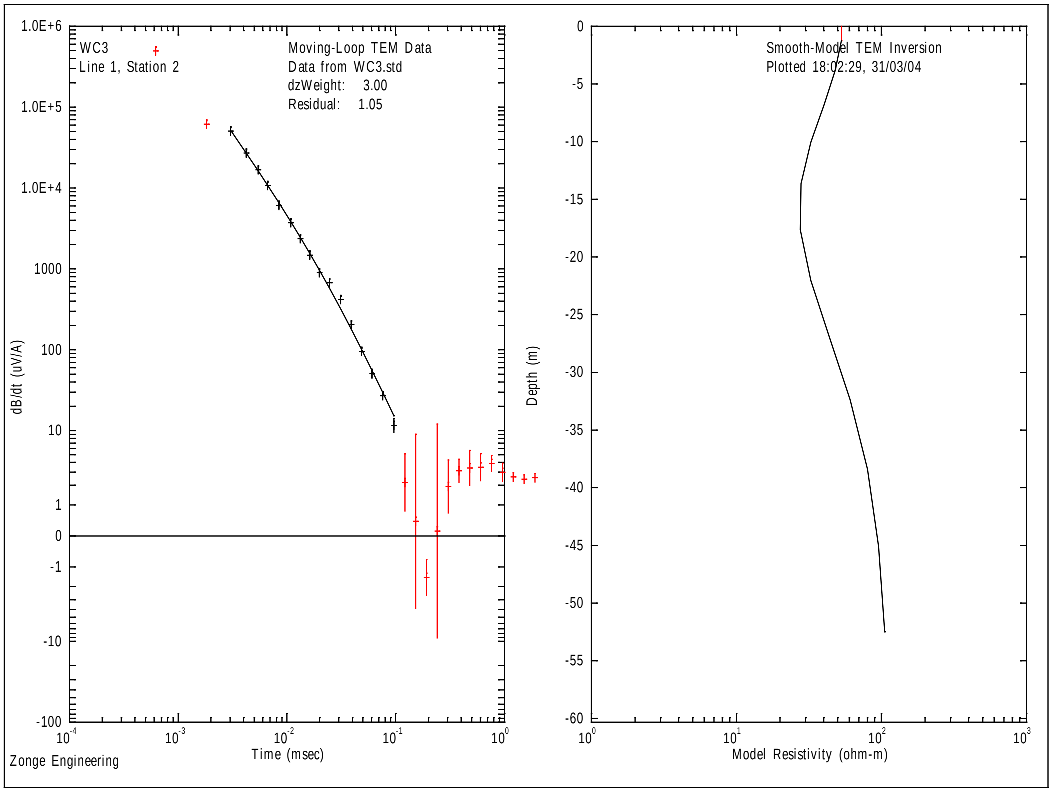
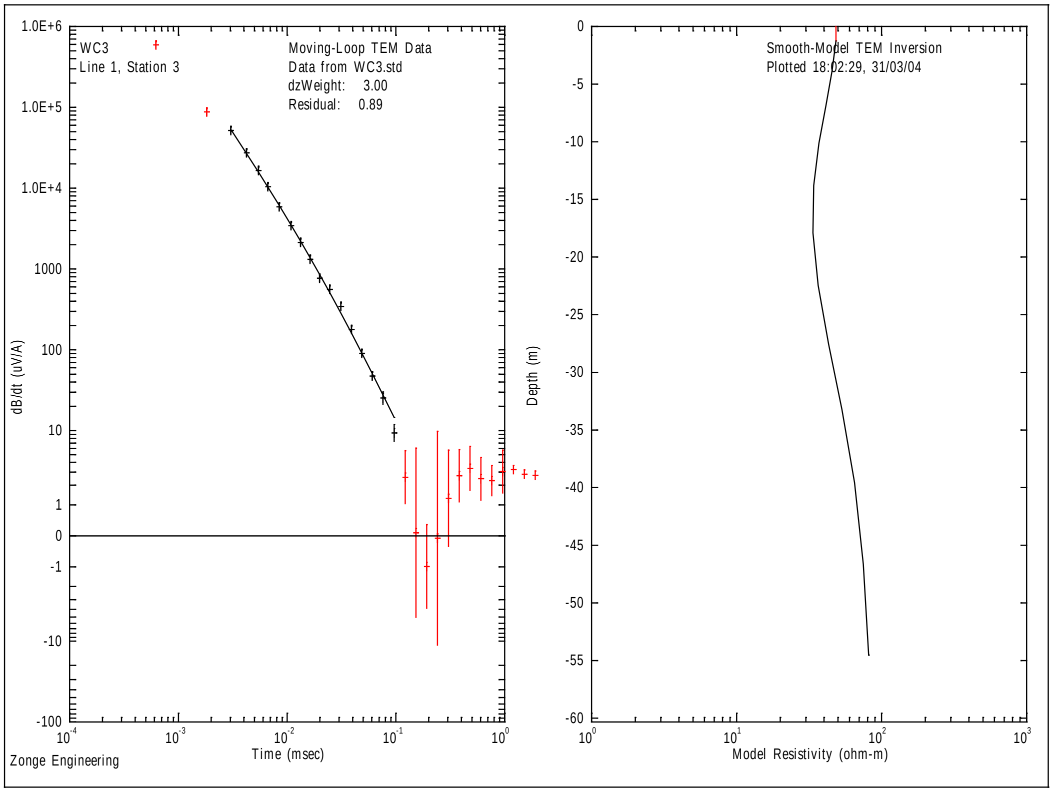
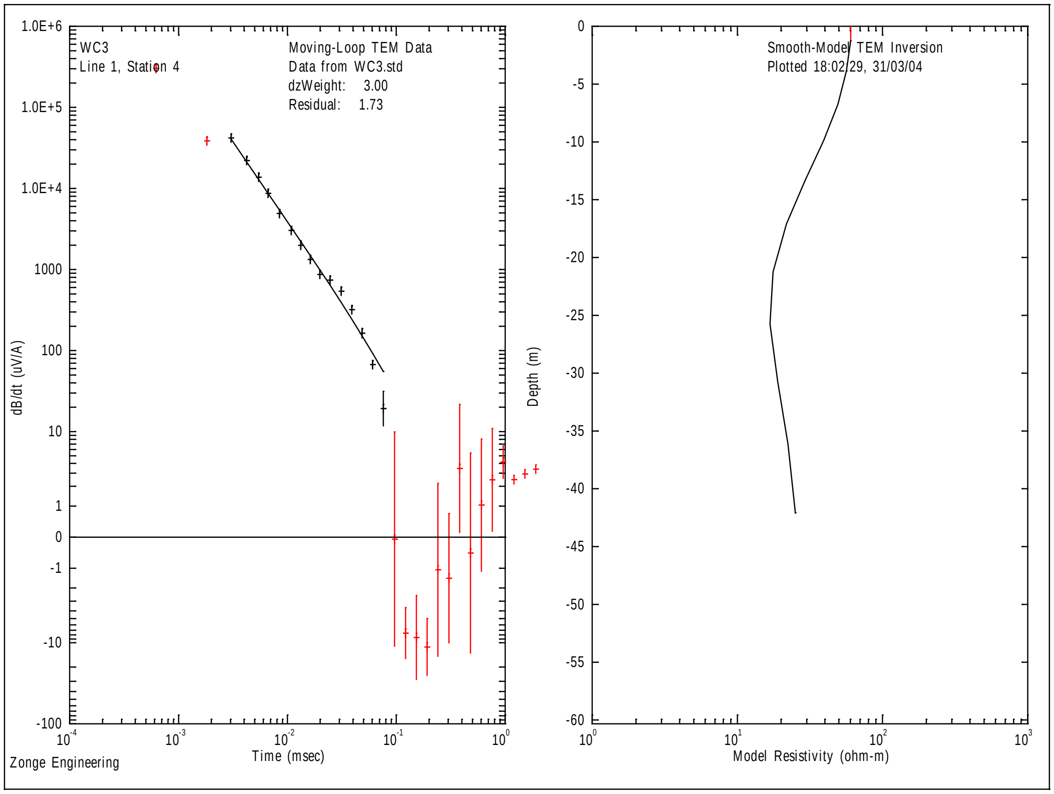
Appendix A

TEM Transient-Decay Plots


WC3
Line 1, Station 1
Moving-Loop TEM Data
Data from WC3.std
dzWeight: 3.00
Residual: 1.06
dB/dt (uV/A)
Time (msec)
Zonge Engineering
Smooth-Model TEM Inversion
Plotted 18:02:29, 31/03/04
Depth (m)
Model Resistivity (ohm-m)


WC3
Line 1, Station 2
Moving-Loop TEM Data
Data from WC3.std
dzWeight: 3.00
Residual: 1.05
dB/dt (uV/A)
Time (msec)
Zonge Engineering
Smooth-Model TEM Inversion
Plotted 18:02:29, 31/03/04
Depth (m)
Model Resistivity (ohm-m)


WC3
Line 1, Station 3
Moving-Loop TEM Data
Data from WC3.std
dzWeight: 3.00
Residual: 0.89
dB/dt (uV/A)
Time (msec)
Zonge Engineering
Smooth-Model TEM Inversion
Plotted 18:02:29, 31/03/04
Depth (m)
Model Resistivity (ohm-m)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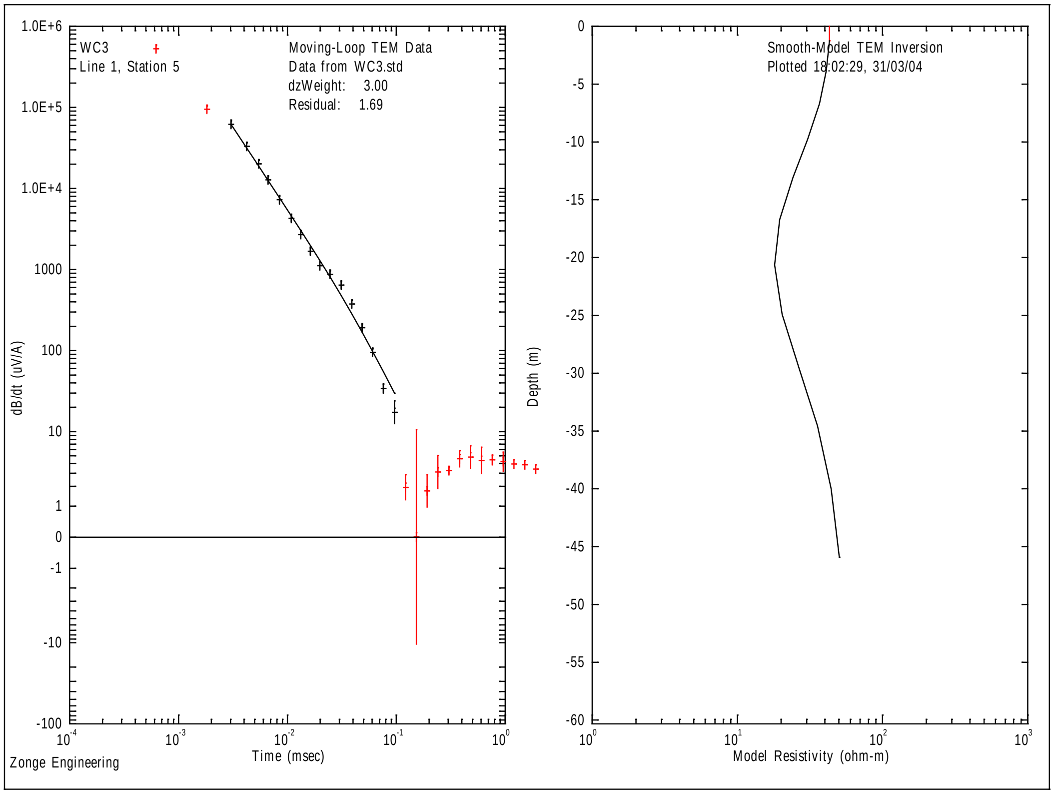
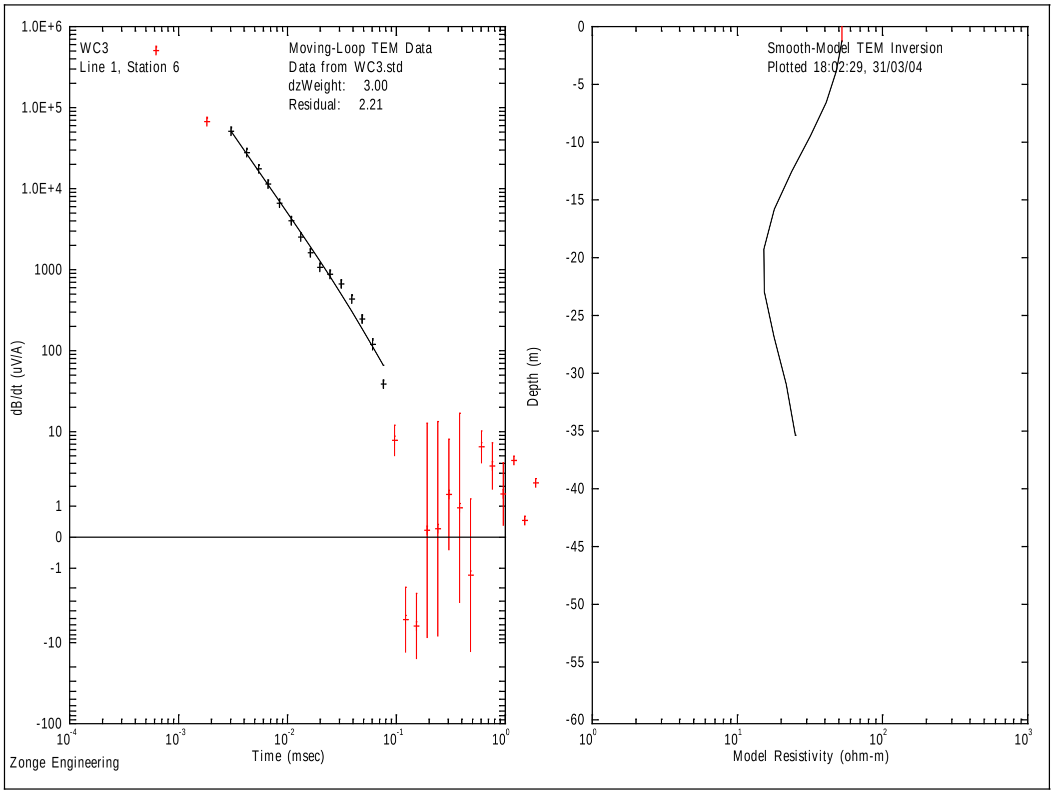
Line 1, Station 4
Moving-Loop TEM Data
Data from WC3.std
dzWeight: 3.00
Residual: 1.73
dB/dt (uV/A)
Time (msec)
Zonge Engineering
Smooth-Model TEM Inversion
Plotted 18:02:29, 31/03/04
Depth (m)
Model Resistivity (ohm-m)


WC3
Line 1, Station 5
Moving-Loop TEM Data
Data from WC3.std
dzWeight: 3.00
Residual: 1.69
dB/dt (uV/A)
Time (msec)
Zonge Engineering
Smooth-Model TEM Inversion
Plotted 18:02:29, 31/03/04
Depth (m)
Model Resistivity (ohm-m)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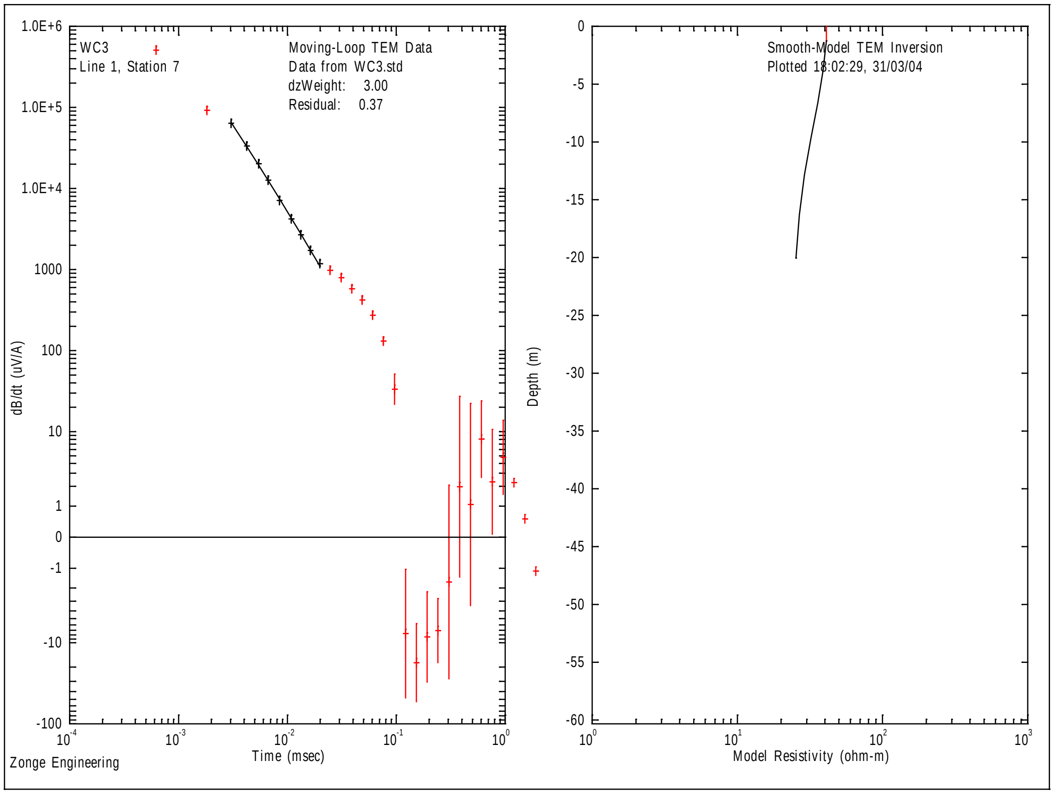
Moving-Loop TEM Data
Data from WC3.std
dzWeight: 3.00
Residual: 2.21
dB/dt (uV/A)
Time (msec)
Zonge Engineering
Smooth-Model TEM Inversion
Plotted 18:02:29, 31/03/04
Depth (m)
Model Resistivity (ohm-m)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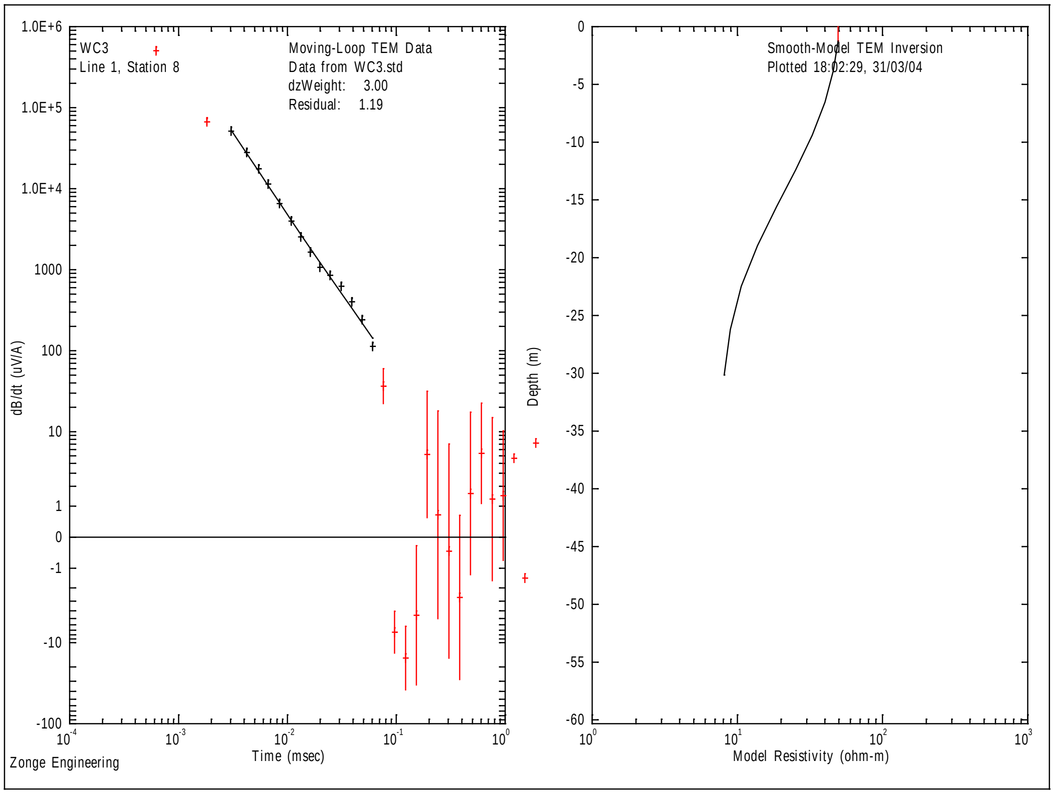
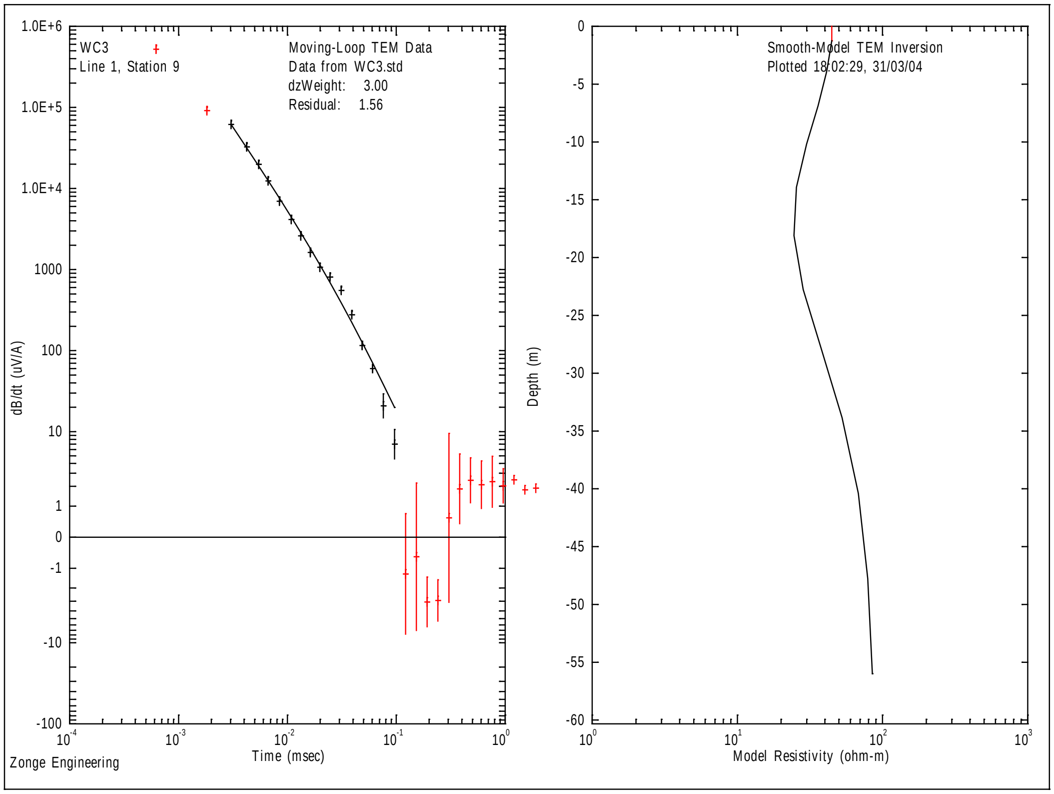
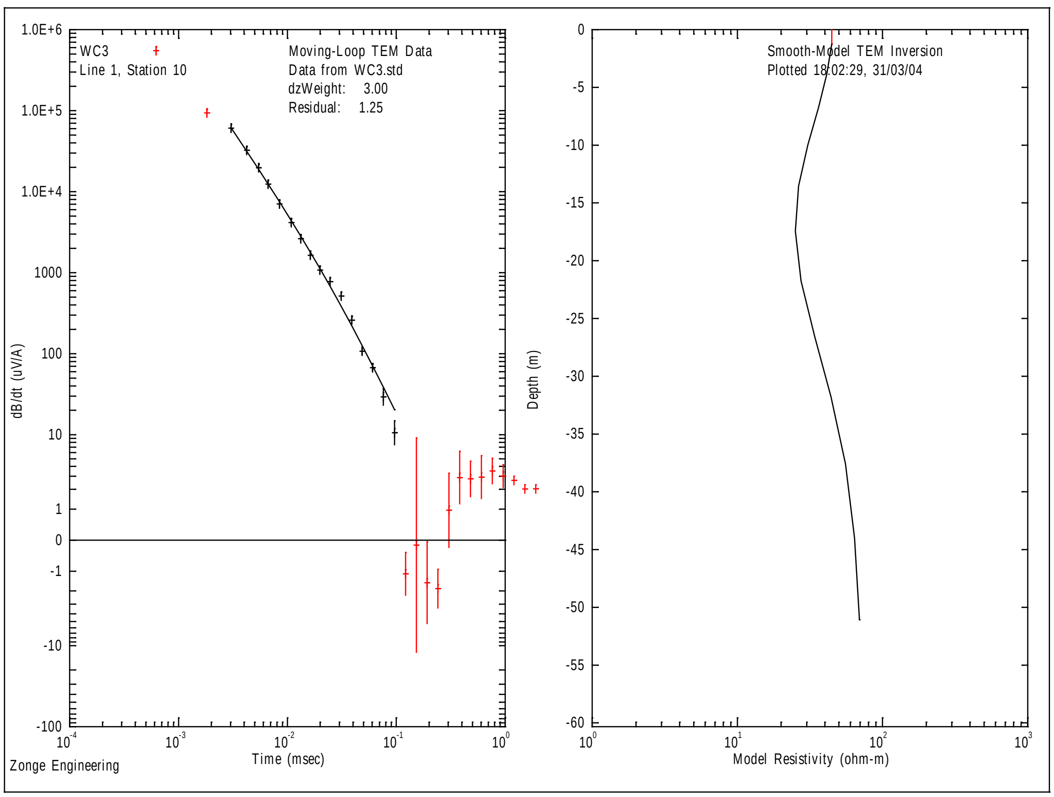
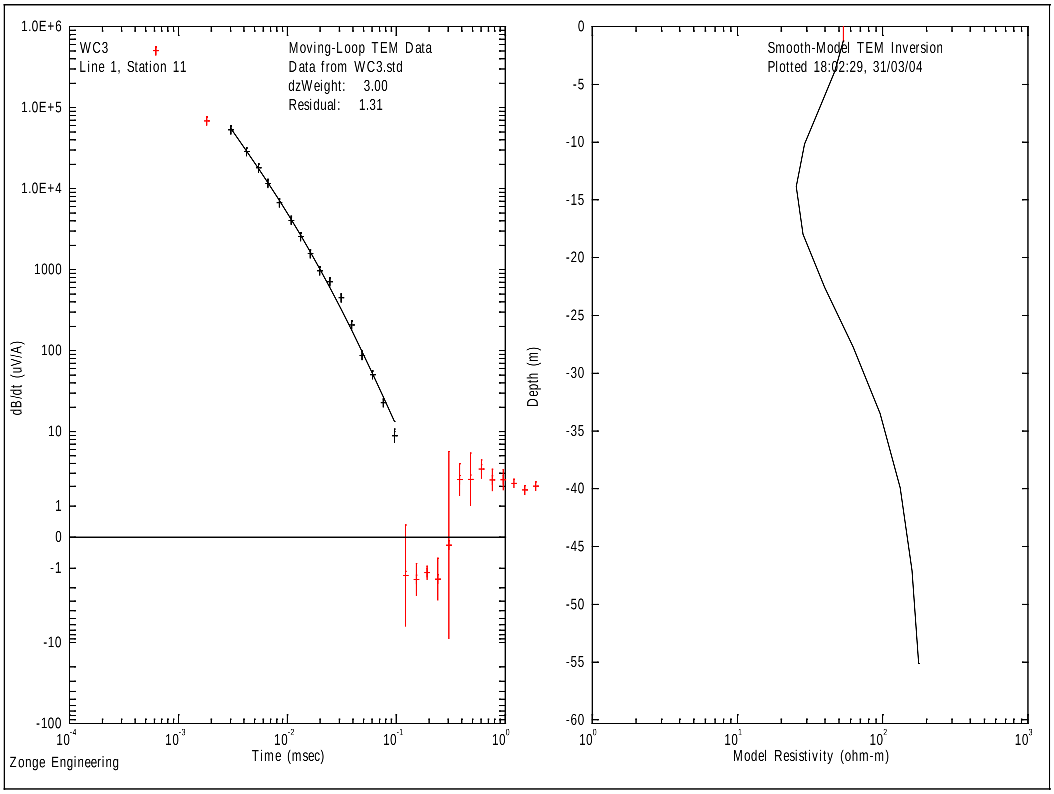
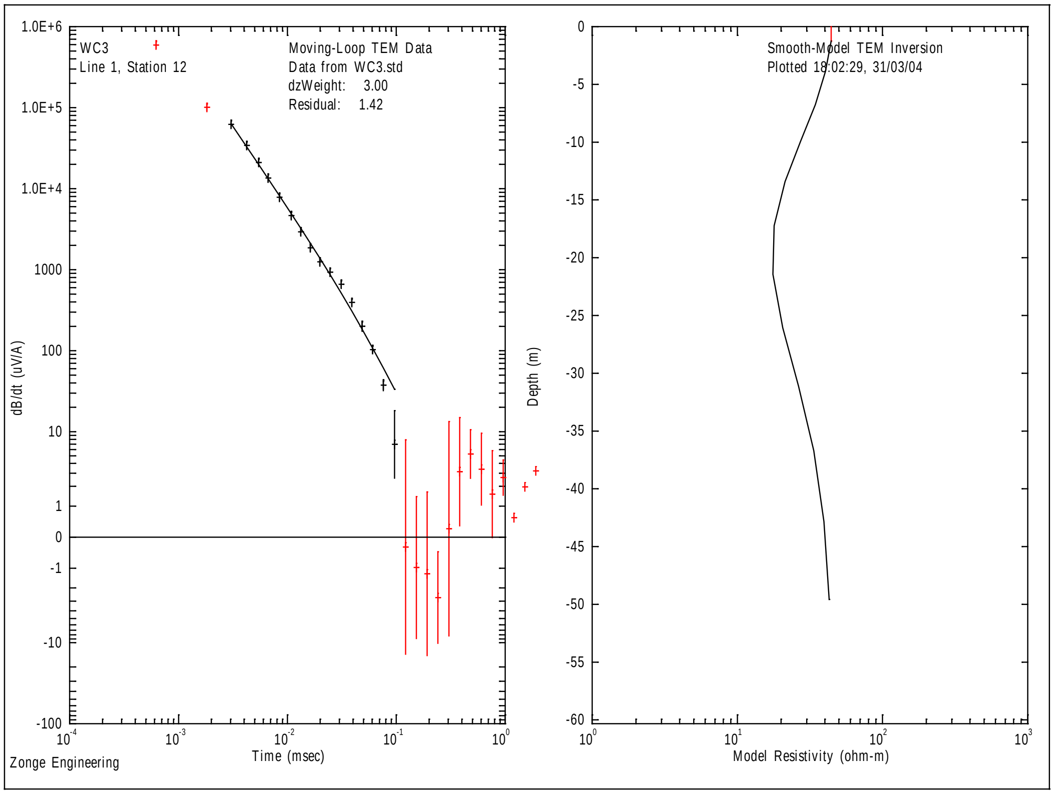
Residual: 0.37
dB/dt (uV/A)
Time (msec)
Zonge Engineering
Smooth-Model TEM Inversion
Plotted 18:02:29, 31/03/04
Depth (m)
Model Resistivity (ohm-m)

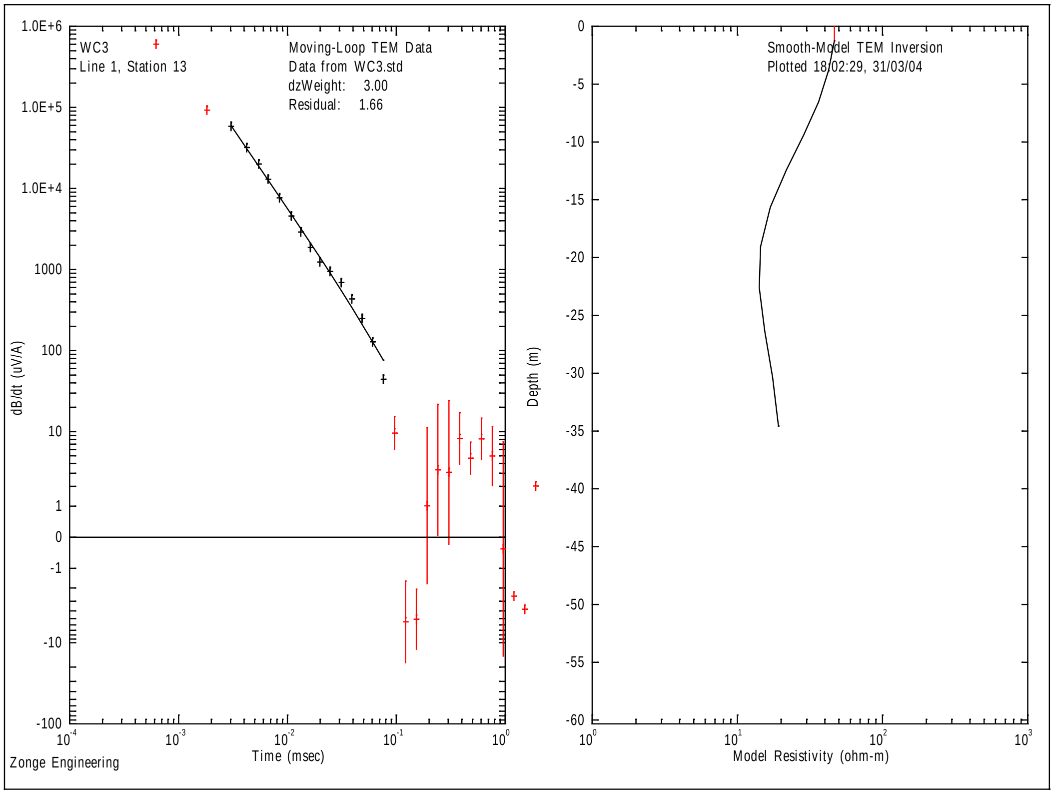

WC3
Line 1, Station 8
Moving-Loop TEM Data
Data from WC3.std
dzWeight: 3.00
Residual: 1.19
dB/dt (uV/A)
Time (msec)
Zonge Engineering
Smooth-Model TEM Inversion
Plotted 18:02:29, 31/03/04
Depth (m)
Model Resistivity (ohm-m)


WC3
Line 1, Station 9
Moving-Loop TEM Data
Data from WC3.std
dzWeight: 3.00
Residual: 1.56
dB/dt (uV/A)
Time (msec)
Zonge Engineering
Smooth-Model TEM Inversion
Plotted 18:02:29, 31/03/04
Depth (m)
Model Resistivity (ohm-m)

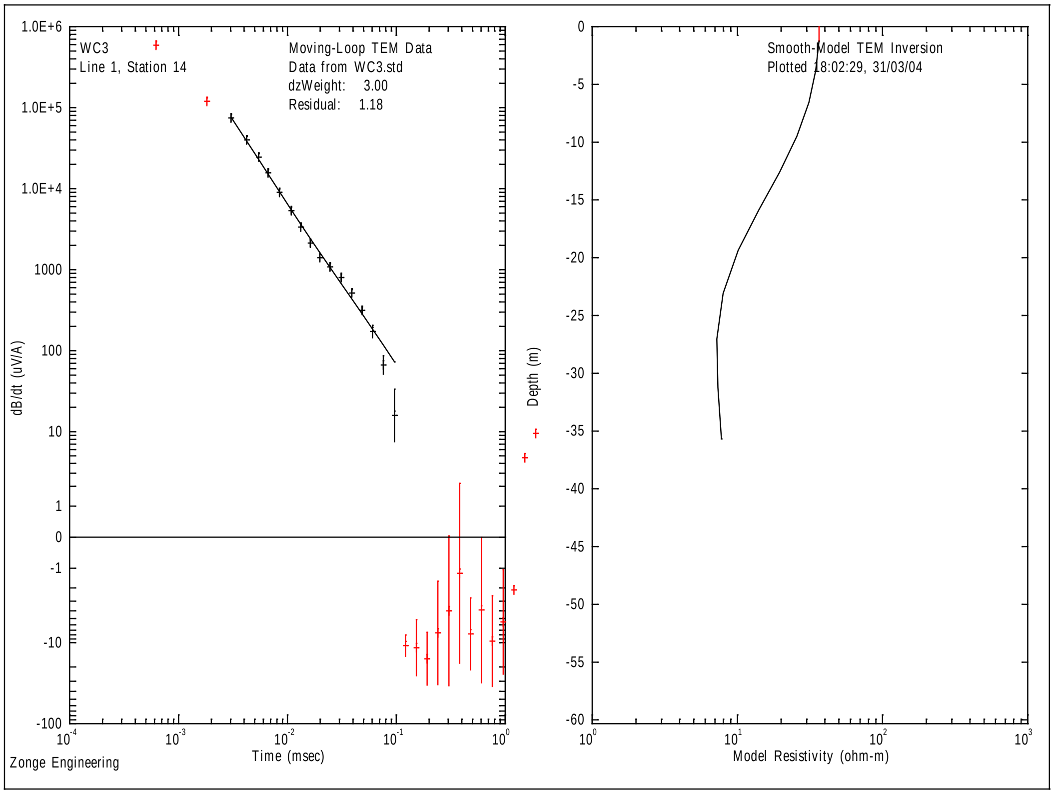

WC3
Line 1, Station 10
Moving-Loop TEM Data
Data from WC3.std
dzWeight: 3.00
Residual: 1.25
dB/dt (uV/A)
Time (msec)
Zonge Engineering
Smooth-Model TEM Inversion
Plotted 18:02:29, 31/03/04
Depth (m)
Model Resistivity (ohm-m)


WC3
Line 1, Station 11
Moving-Loop TEM Data
Data from WC3.std
dzWeight: 3.00
Residual: 1.31
Smooth-Model TEM Inversion
Plotted 18:02:29, 31/03/04
dB/dt (uV/A)
Time (msec)
Depth (m)
Model Resistivity (ohm-m)
Zonge Engineering

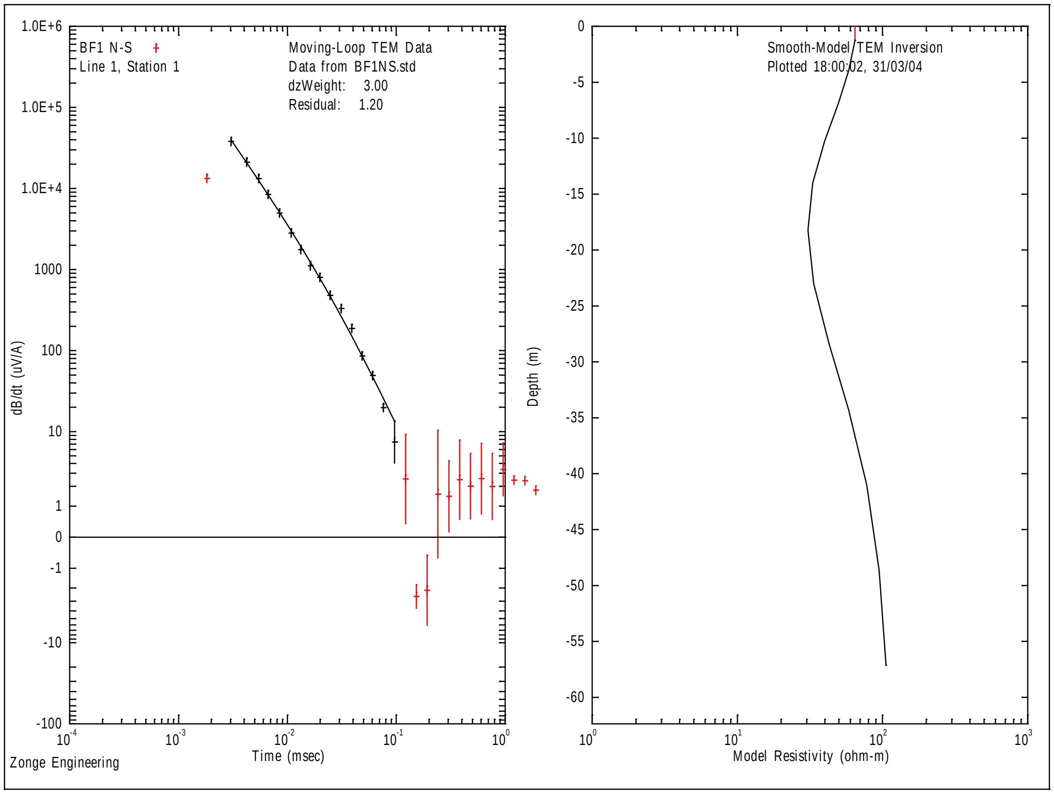

WC3
Line 1, Station 12
Moving-Loop TEM Data
Data from WC3.std
dzWeight: 3.00
Residual: 1.42
Smooth-Model TEM Inversion
Plotted 18:02:29, 31/03/04
dB/dt (uV/A)
Time (msec)
Depth (m)
Model Resistivity (ohm-m)
Zonge Engineering

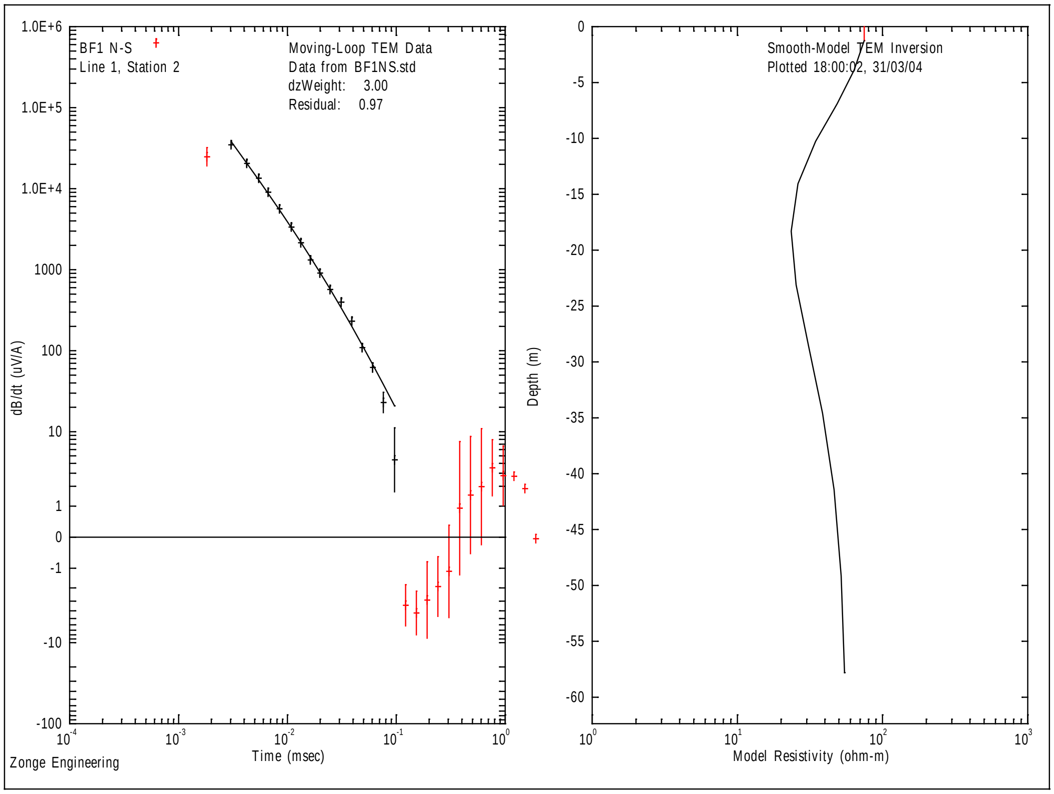


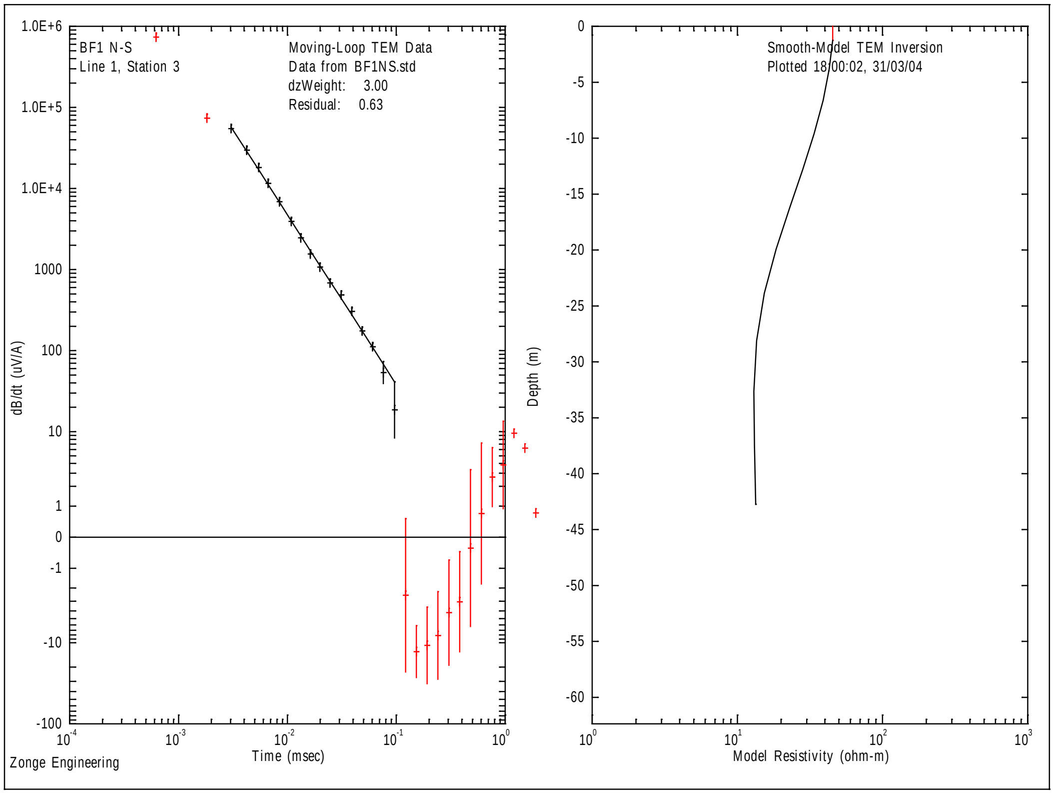
WC3
Line 1, Station 13
Moving-Loop TEM Data
Data from WC3.std
dzWeight: 3.00
Residual: 1.66
dB/dt (uV/A)
Time (msec)
Zonge Engineering
Smooth-Model TEM Inversion
Plotted 18:02:29, 31/03/04
Depth (m)
Model Resistivity (ohm-m)



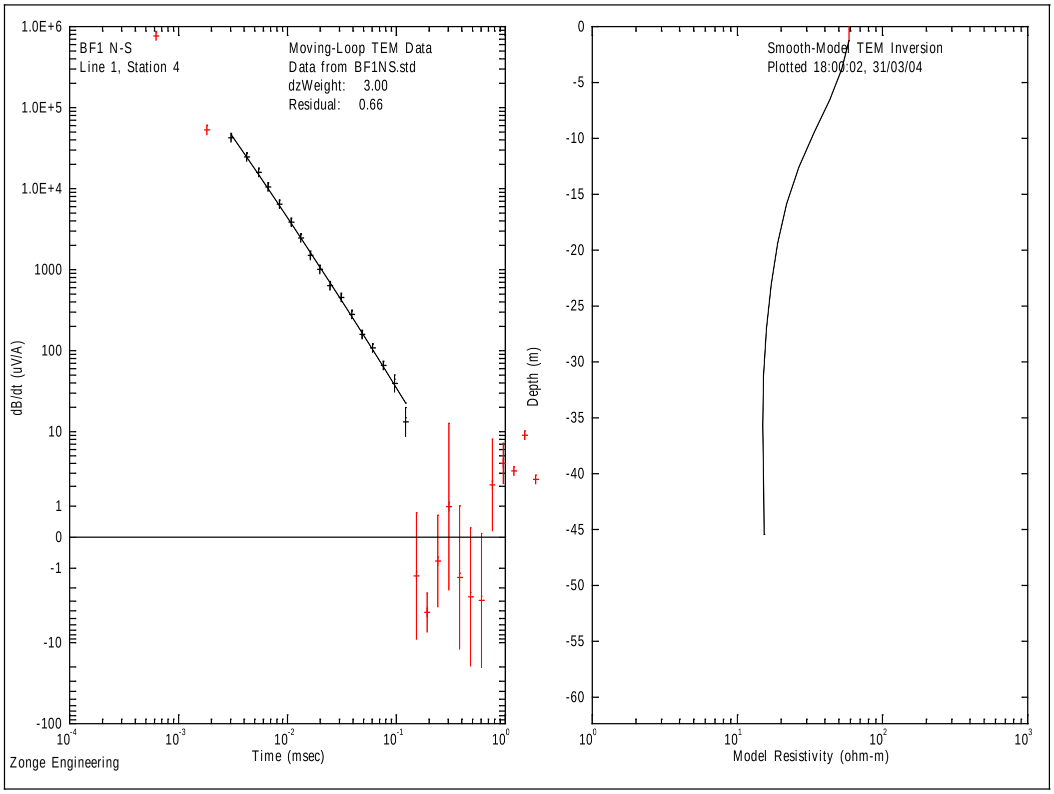
WC3
Line 1, Station 14
Moving-Loop TEM Data
Data from WC3.std
dzWeight: 3.00
Residual: 1.18
dB/dt (uV/A)
Time (msec)
Zonge Engineering
Smooth-Model TEM Inversion
Plotted 18:02:29, 31/03/04
Depth (m)
Model Resistivity (ohm-m)


BF1 N-S
Line 1, Station 1
Moving-Loop TEM Data
Data from BF1NS.std
dzWeight: 3.00
Residual: 1.20
Smooth-Model TEM Inversion
Plotted 18:00:02, 31/03/04
dB/dt (uV/A)
Time (msec)
Depth (m)
Model Resistivity (ohm-m)
Zonge Engineering

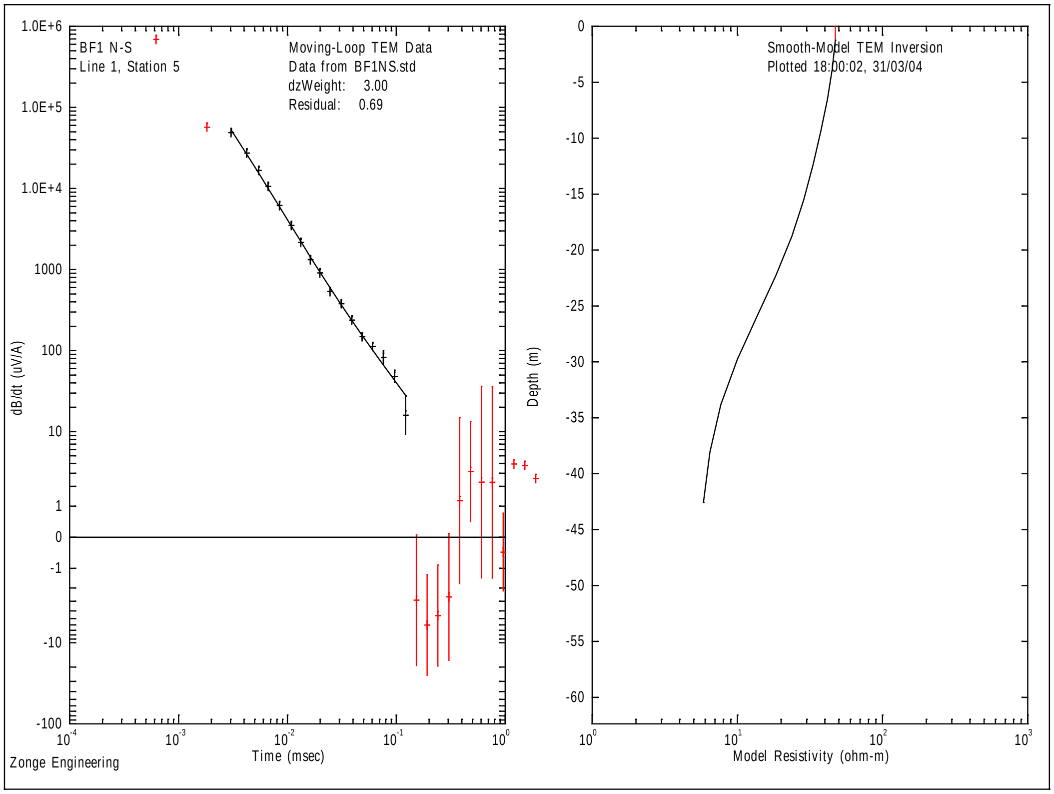

BF1 N-S
Line 1, Station 2
Moving-Loop TEM Data
Data from BF1NS.std
dzWeight: 3.00
Residual: 0.97
Smooth-Model TEM Inversion
Plotted 18:00:02, 31/03/04
dB/dt (uV/A)
Time (msec)
Depth (m)
Model Resistivity (ohm-m)
Zonge Engineering

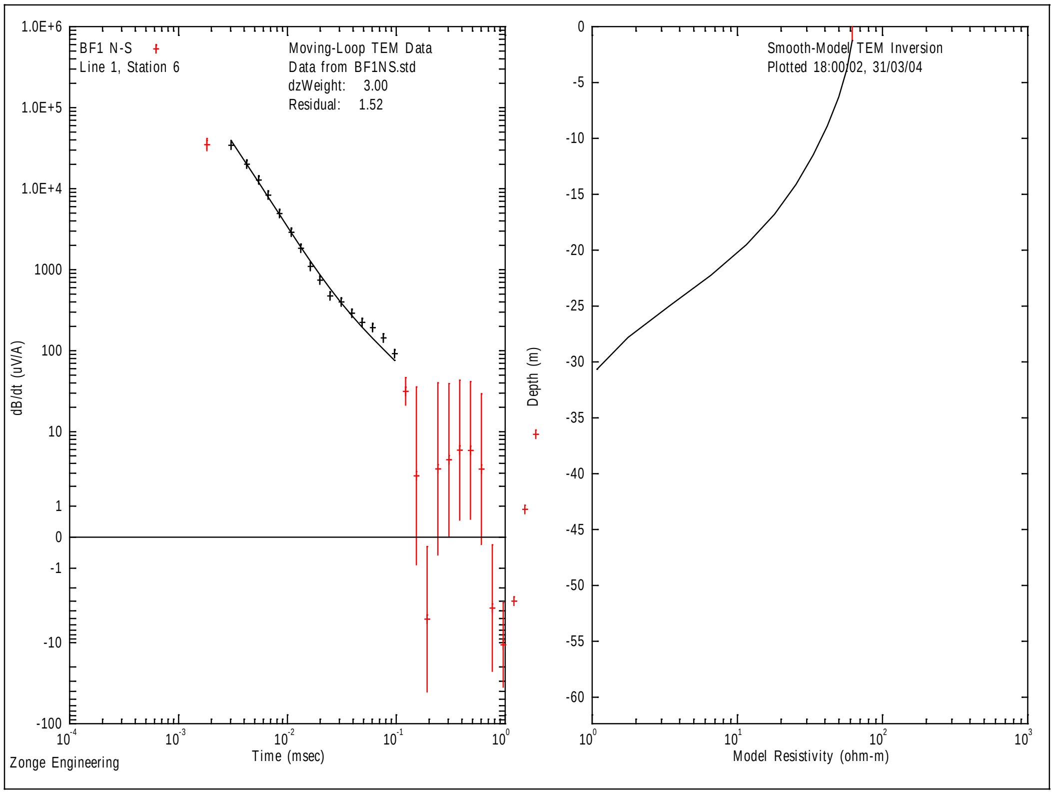


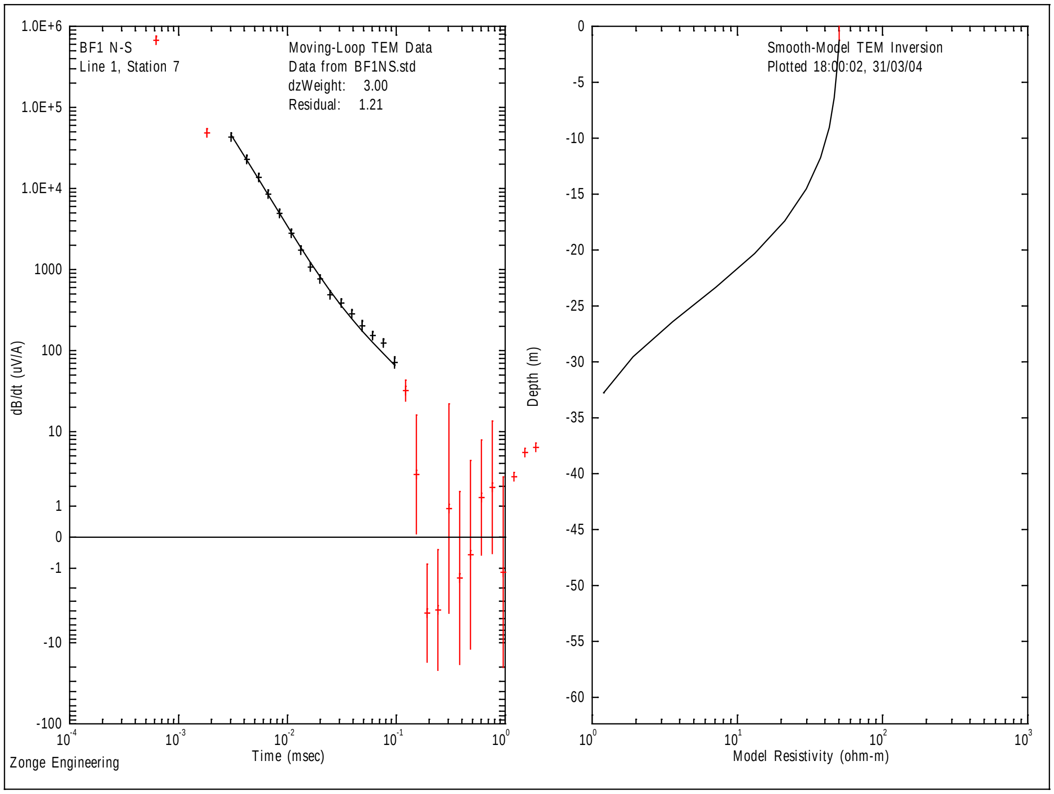
BF1 N-S
Line 1, Station 3
Moving-Loop TEM Data
Data from BF1NS.std
dzWeight: 3.00
Residual: 0.63
dB/dt (uV/A)
Time (msec)
Zonge Engineering
Smooth-Model TEM Inversion
Plotted 18:00:02, 31/03/04
Depth (m)
Model Resistivity (ohm-m)

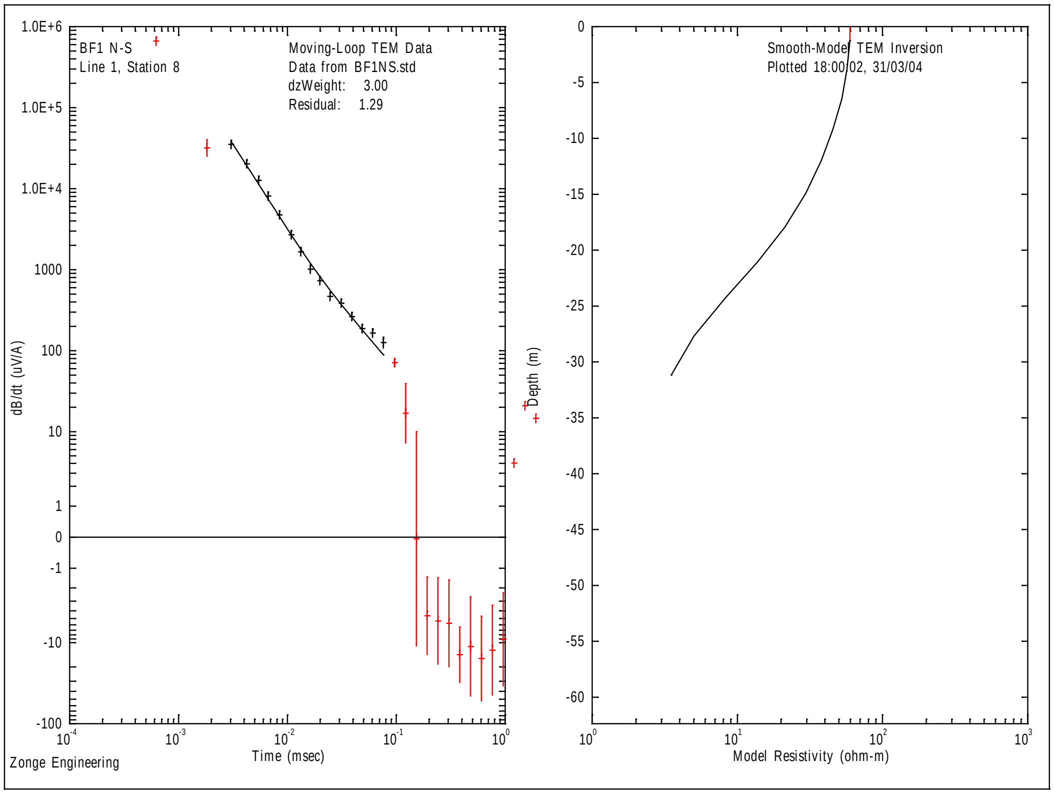


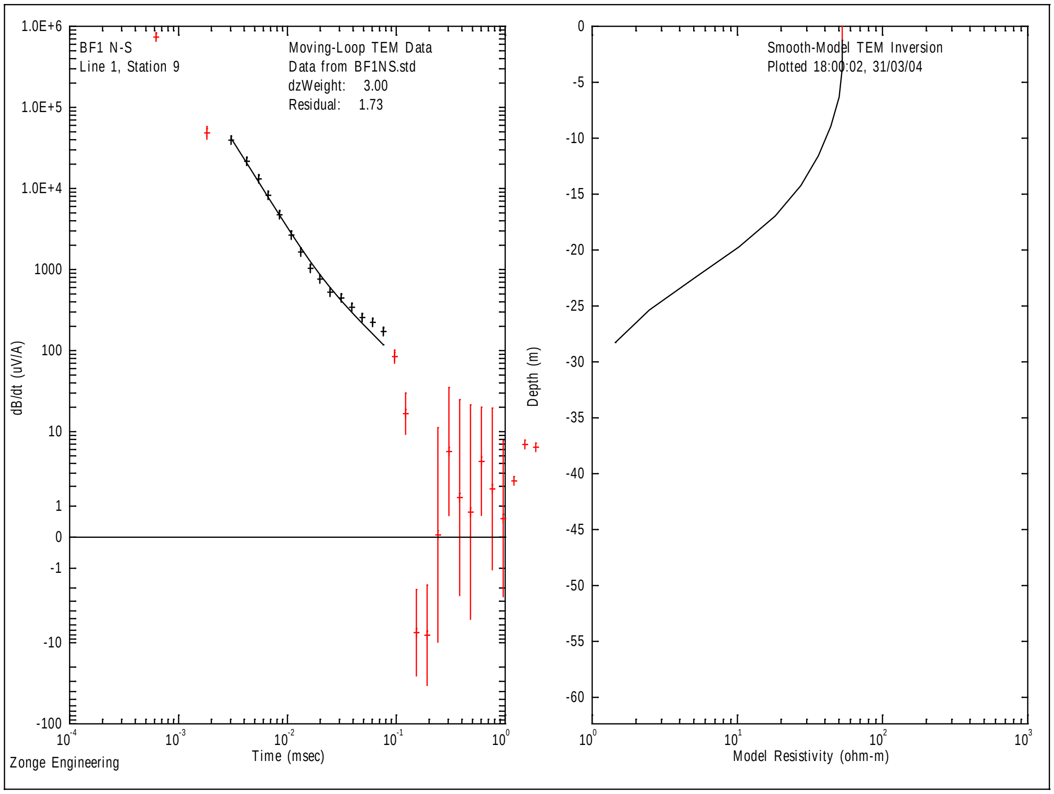
BF1 N-S
Line 1, Station 4
Moving-Loop TEM Data
Data from BF1NS.std
dzWeight: 3.00
Residual: 0.66
dB/dt (uV/A)
Time (msec)
Zonge Engineering
Smooth-Model TEM Inversion
Plotted 18:00:02, 31/03/04
Depth (m)
Model Resistivity (ohm-m)


BF1 N-S
Line 1, Station 5
Moving-Loop TEM Data
Data from BF1NS.std
dzWeight: 3.00
Residual: 0.69
dB/dt (uV/A)
Time (msec)
Zonge Engineering
Smooth-Model TEM Inversion
Plotted 18:00:02, 31/03/04
Depth (m)
Model Resistivity (ohm-m)

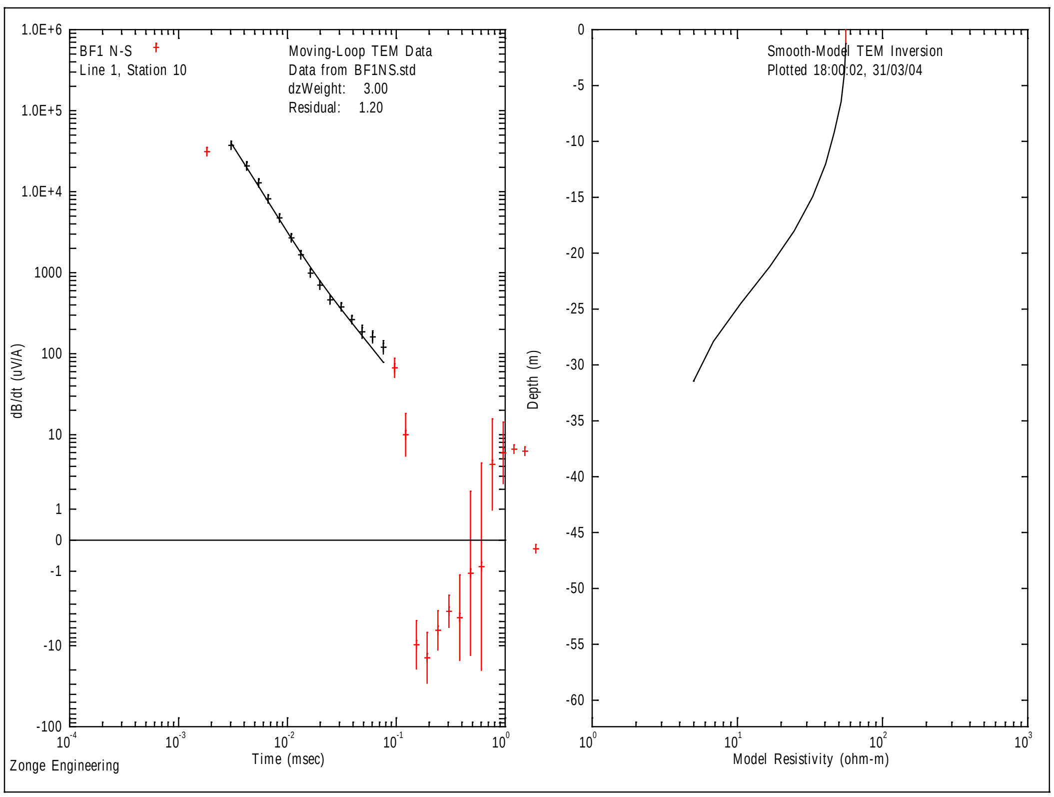

BF1 N-S
Line 1, Station 6
Moving-Loop TEM Data
Data from BF1NS.std
dzWeight: 3.00
Residual: 1.52
dB/dt (uV/A)
Time (msec)
Zonge Engineering
Smooth-Model TEM Inversion
Plotted 18:00:02, 31/03/04
Depth (m)
Model Resistivity (ohm-m)


BF1 N-S
Line 1, Station 7
Moving-Loop TEM Data
Data from BF1NS.std
dzWeight: 3.00
Residual: 1.21
dB/dt (uV/A)
Time (msec)
Zonge Engineering
Smooth-Model TEM Inversion
Plotted 18:00:02, 31/03/04
Depth (m)
Model Resistivity (ohm-m)

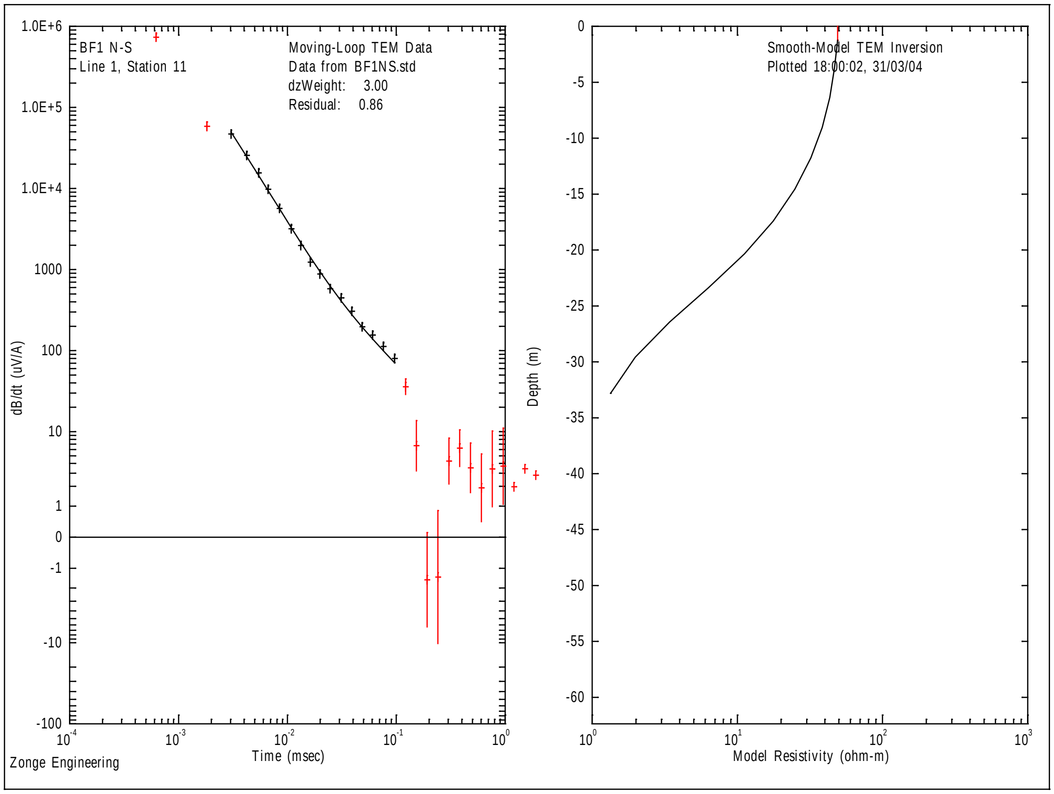

BF1 N-S
Line 1, Station 8
Moving-Loop TEM Data
Data from BF1NS.std
dzWeight: 3.00
Residual: 1.29
dB/dt (uV/A)
Time (msec)
Zonge Engineering
Smooth-Model TEM Inversion
Plotted 18:00:02, 31/03/04
Depth (m)
Model Resistivity (ohm-m)

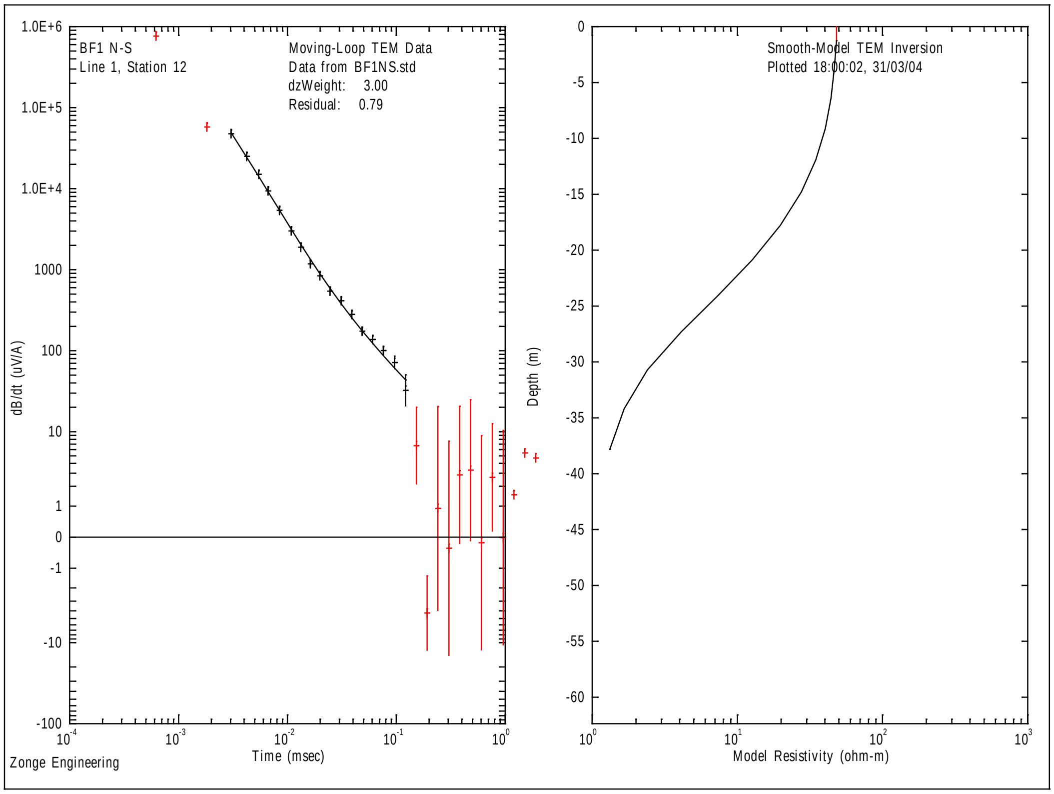


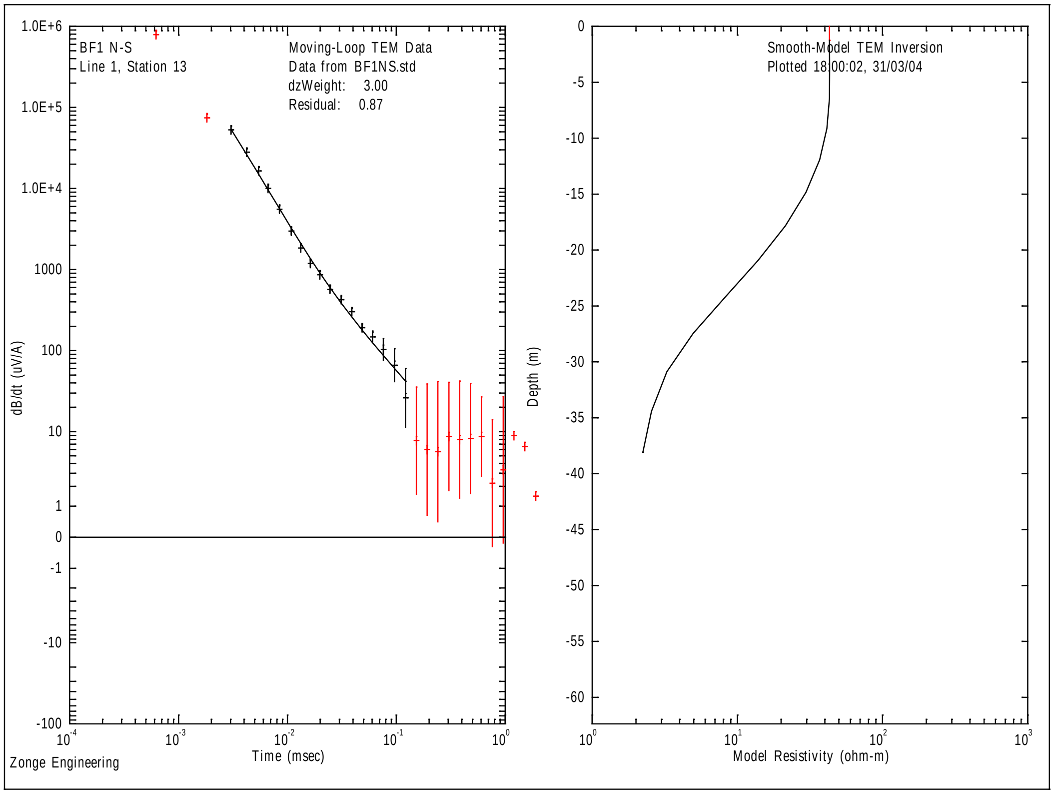
BF1 N-S
Line 1, Station 9
Moving-Loop TEM Data
Data from BF1NS.std
dzWeight: 3.00
Residual: 1.73
Smooth-Model TEM Inversion
Plotted 18:00:02, 31/03/04
dB/dt (uV/A)
Time (msec)
Depth (m)
Model Resistivity (ohm-m)
Zonge Engineering

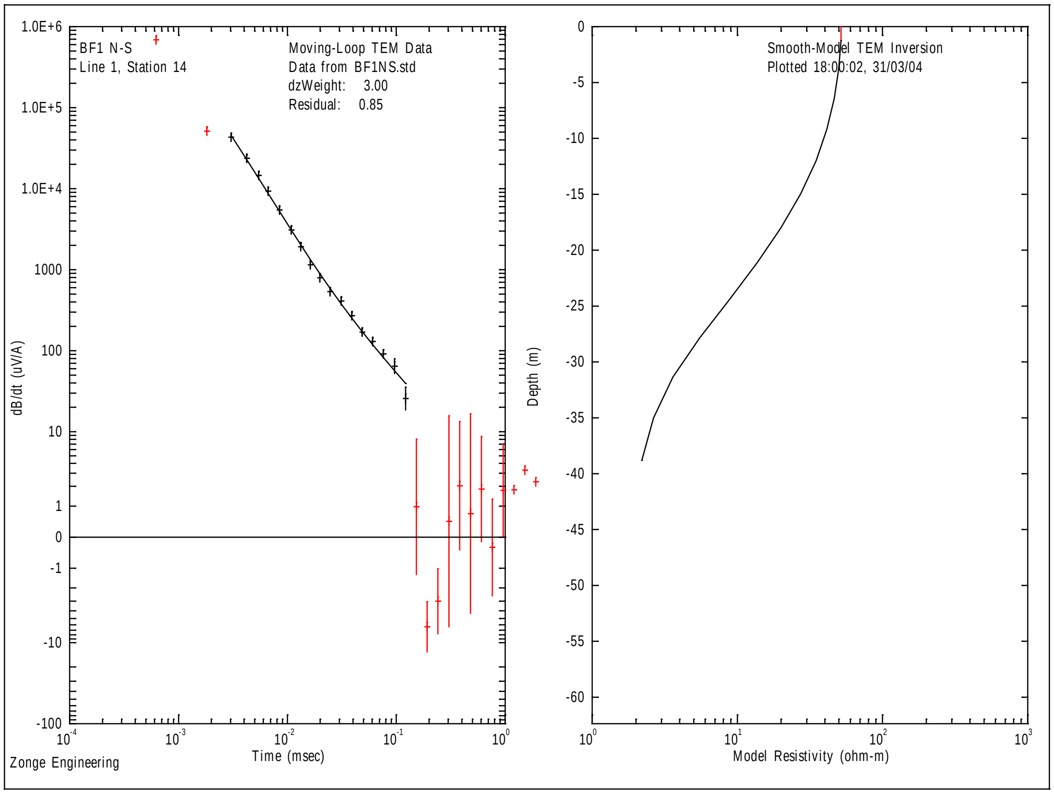


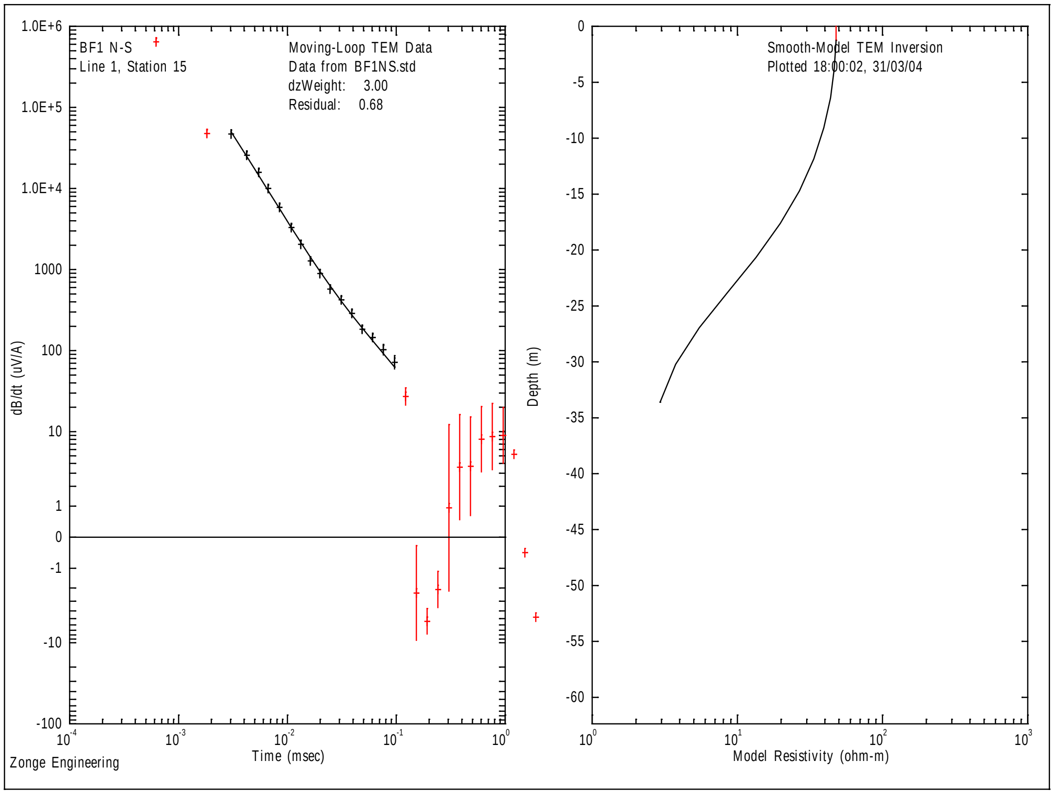
BF1 N-S
Line 1, Station 10
Moving-Loop TEM Data
Data from BF1NS.std
dzWeight: 3.00
Residual: 1.20
Smooth-Model TEM Inversion
Plotted 18:00:02, 31/03/04
dB/dt (uV/A)
Time (msec)
Depth (m)
Model Resistivity (ohm-m)
Zonge Engineering

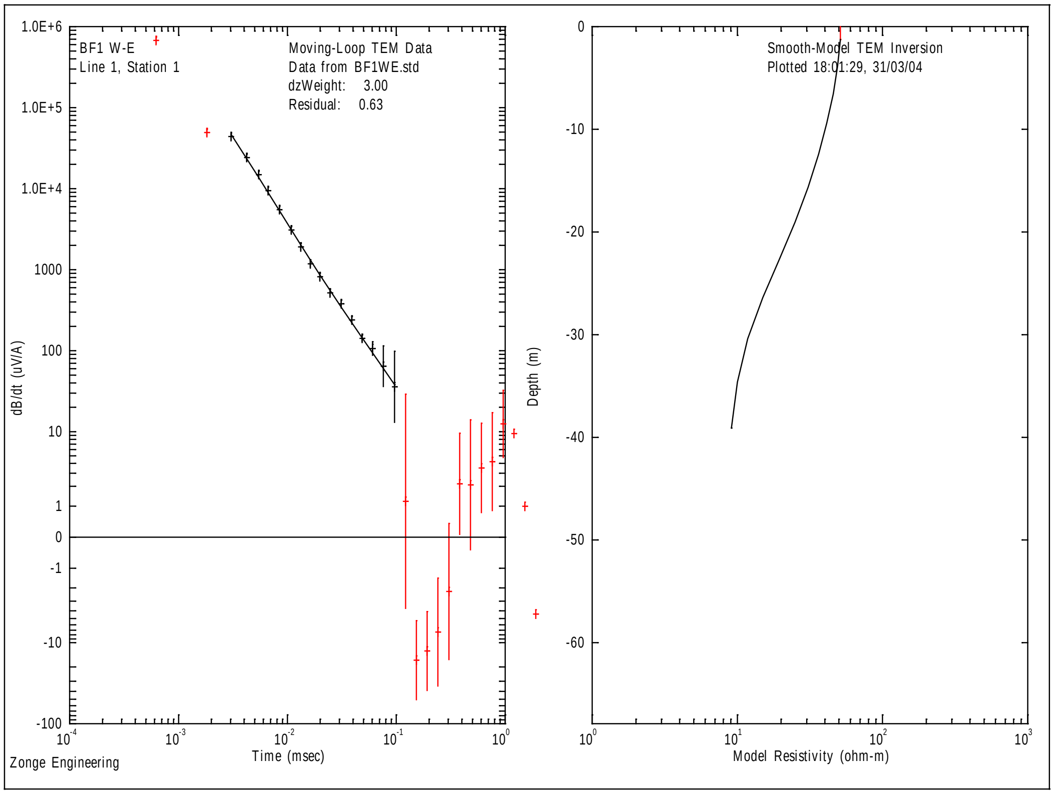

BF1 N-S
Line 1, Station 11
Moving-Loop TEM Data
Data from BF1NS.std
dzWeight: 3.00
Residual: 0.86
Smooth-Model TEM Inversion
Plotted 18:00:02, 31/03/04
dB/dt (uV/A)
Time (msec)
Depth (m)
Model Resistivity (ohm-m)
Zonge Engineering

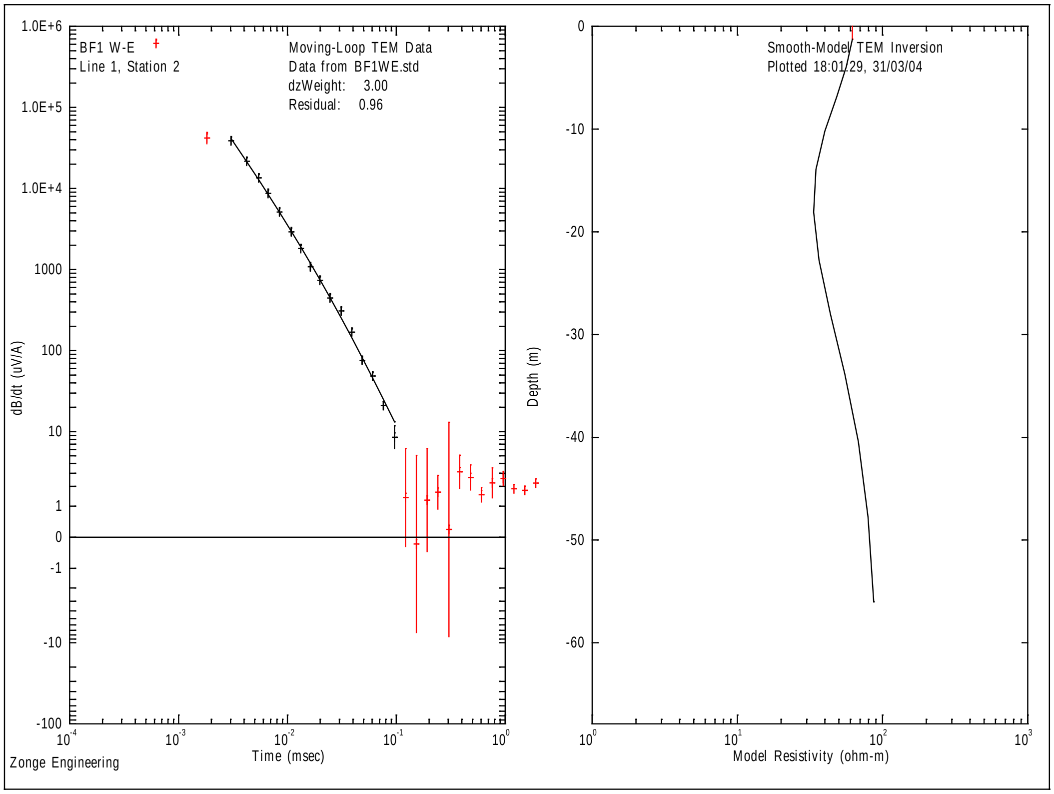

BF1 N-S
Line 1, Station 12
Moving-Loop TEM Data
Data from BF1NS.std
dzWeight: 3.00
Residual: 0.79
Smooth-Model TEM Inversion
Plotted 18:00:02, 31/03/04
dB/dt (uV/A)
Time (msec)
Depth (m)
Model Resistivity (ohm-m)
Zonge Engineering

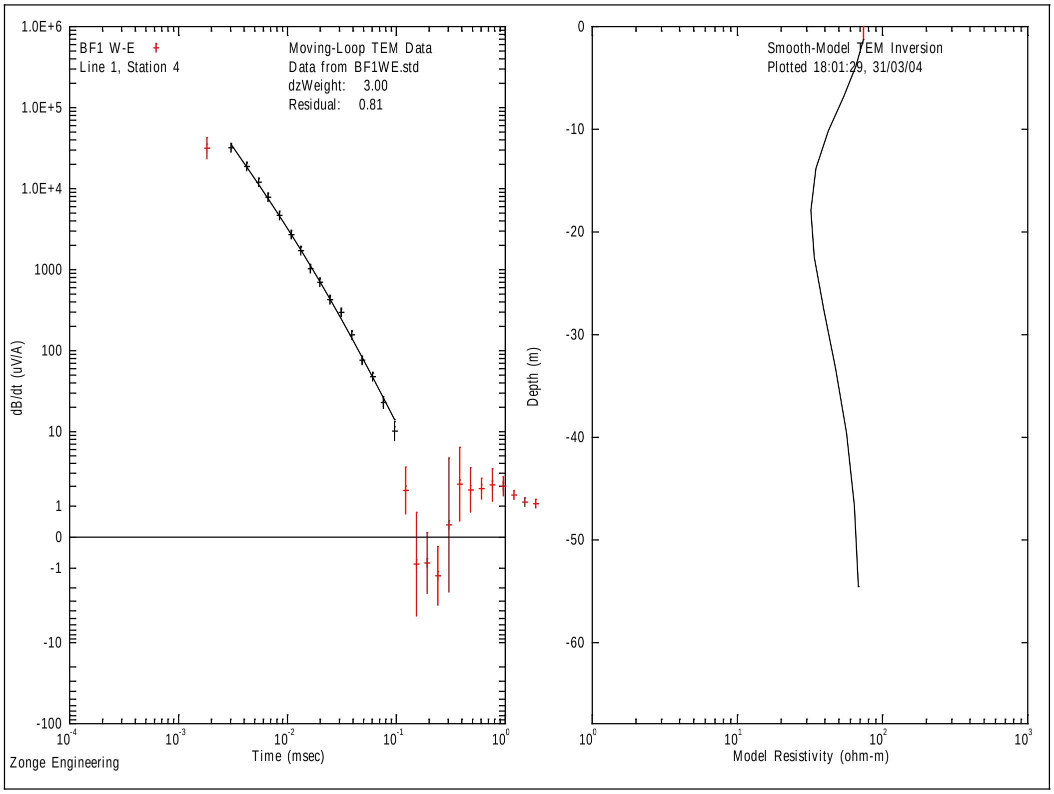

BF1 N-S
Line 1, Station 13
Moving-Loop TEM Data
Data from BF1NS.std
dzWeight: 3.00
Residual: 0.87
Smooth-Model TEM Inversion
Plotted 18:00:02, 31/03/04
dB/dt (uV/A)
Time (msec)
Depth (m)
Model Resistivity (ohm-m)
Zonge Engineering

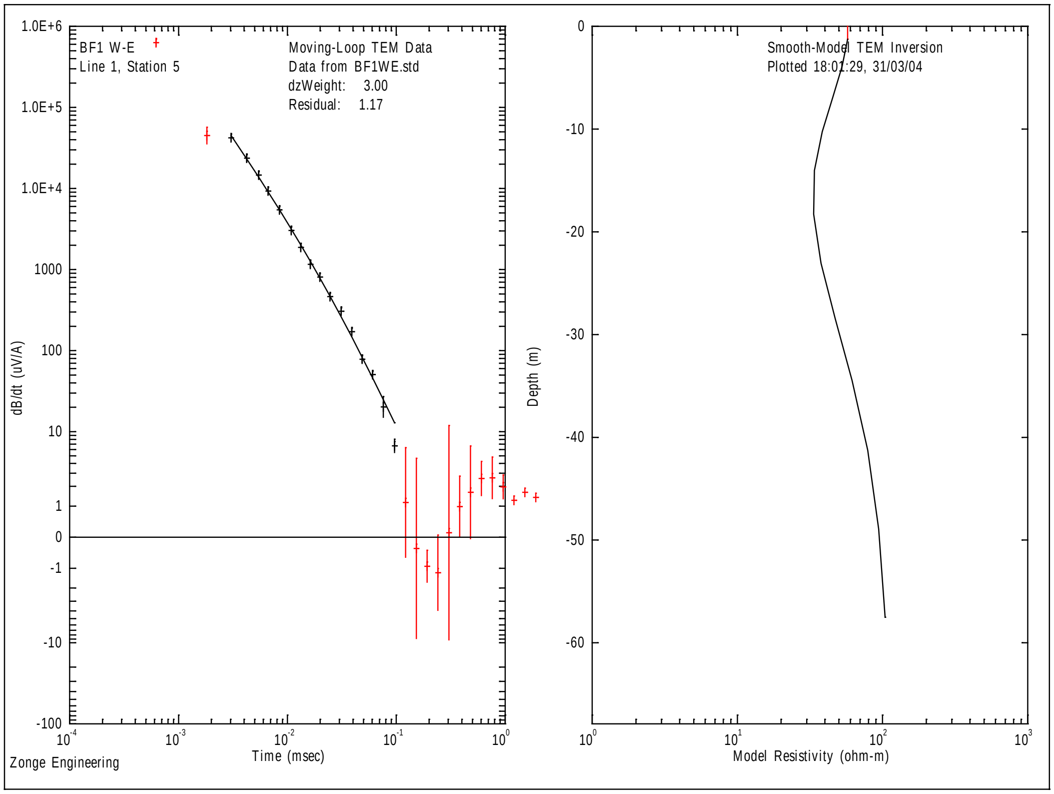

BF1 N-S
Line 1, Station 14
Moving-Loop TEM Data
Data from BF1NS.std
dzWeight: 3.00
Residual: 0.85
Smooth-Model TEM Inversion
Plotted 18:00:02, 31/03/04
dB/dt (uV/A)
Time (msec)
Depth (m)
Model Resistivity (ohm-m)
Zonge Engineering

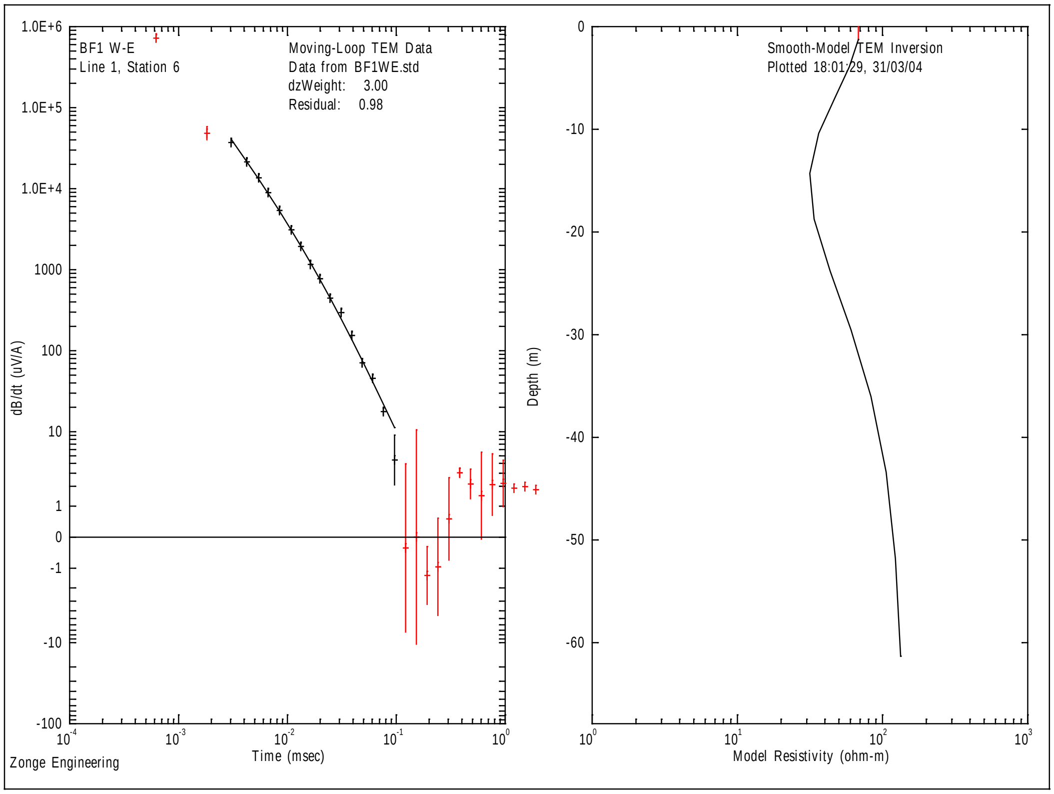

BF1 N-S
Line 1, Station 15
Moving-Loop TEM Data
Data from BF1NS.std
dzWeight: 3.00
Residual: 0.68
Smooth-Model TEM Inversion
Plotted 18:00:02, 31/03/04
dB/dt (uV/A)
Time (msec)
Depth (m)
Model Resistivity (ohm-m)
Zonge Engineering

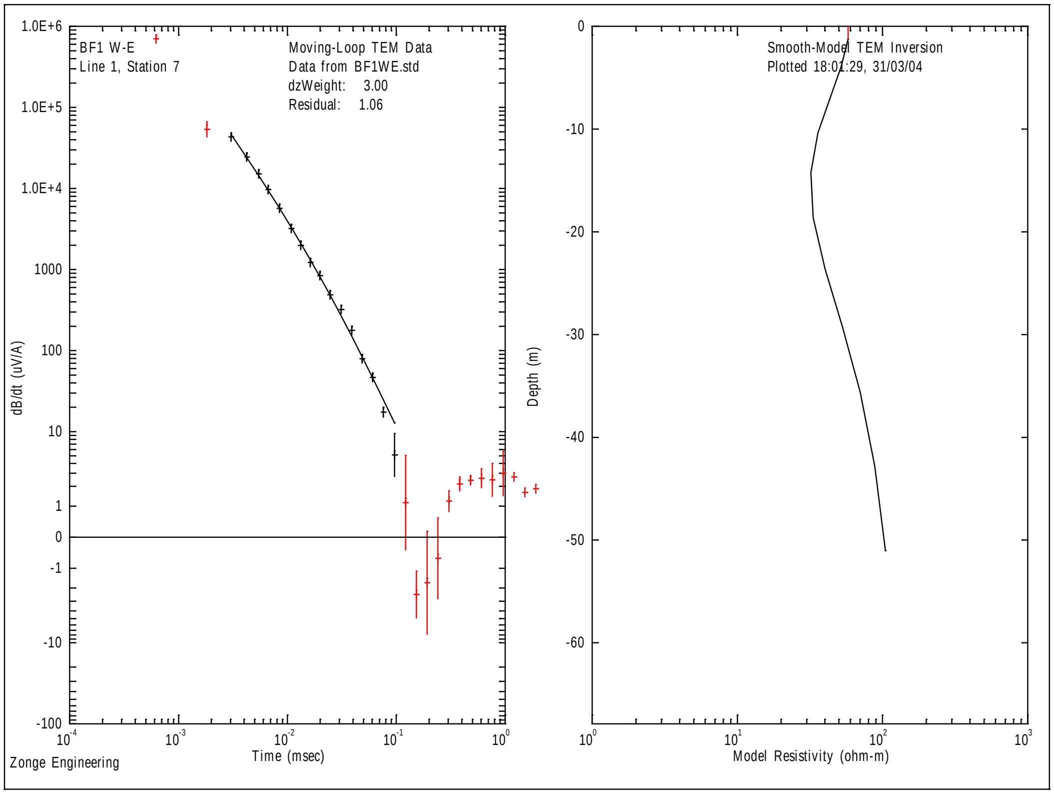

BF1 W-E
Line 1, Station 1
Moving-Loop TEM Data
Data from BF1WE.std
dzWeight: 3.00
Residual: 0.63
Smooth-Model TEM Inversion
Plotted 18:01:29, 31/03/04
dB/dt (uV/A)
Time (msec)
Depth (m)
Model Resistivity (ohm-m)
Zonge Engineering

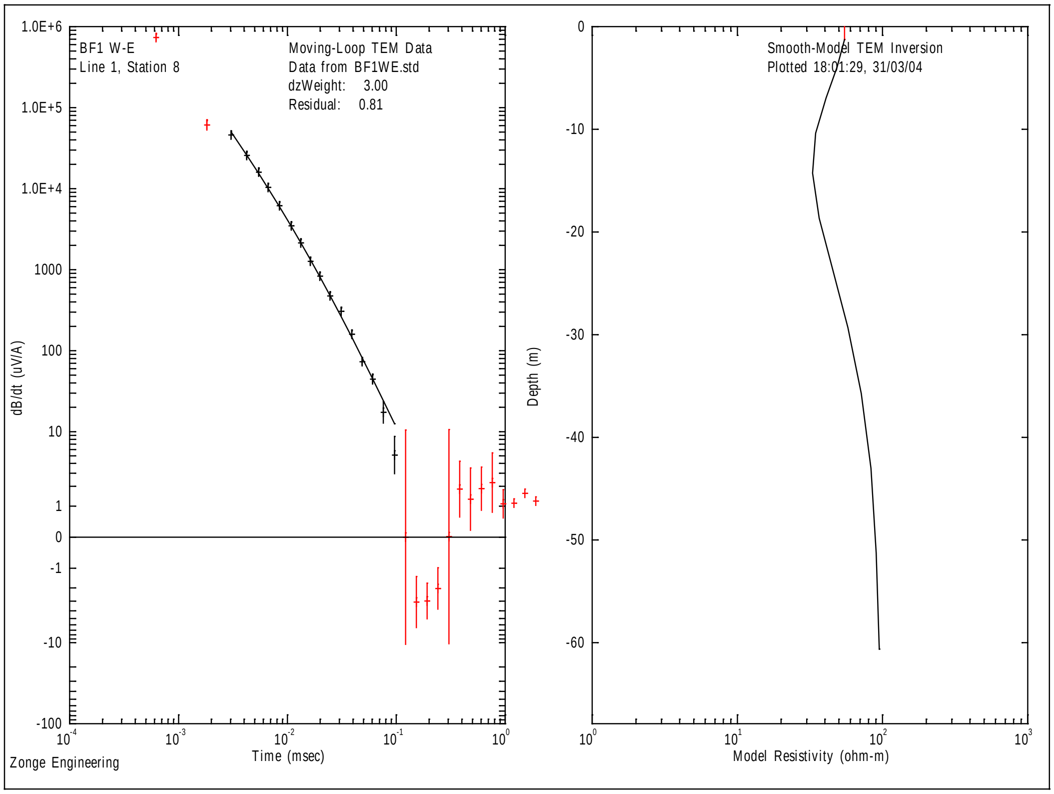

BF1 W-E
Line 1, Station 2
Moving-Loop TEM Data
Data from BF1WE.std
dzWeight: 3.00
Residual: 0.96
dB/dt (uV/A)
Time (msec)
Zonge Engineering
Smooth-Model TEM Inversion
Plotted 18:01:29, 31/03/04
Depth (m)
Model Resistivity (ohm-m)

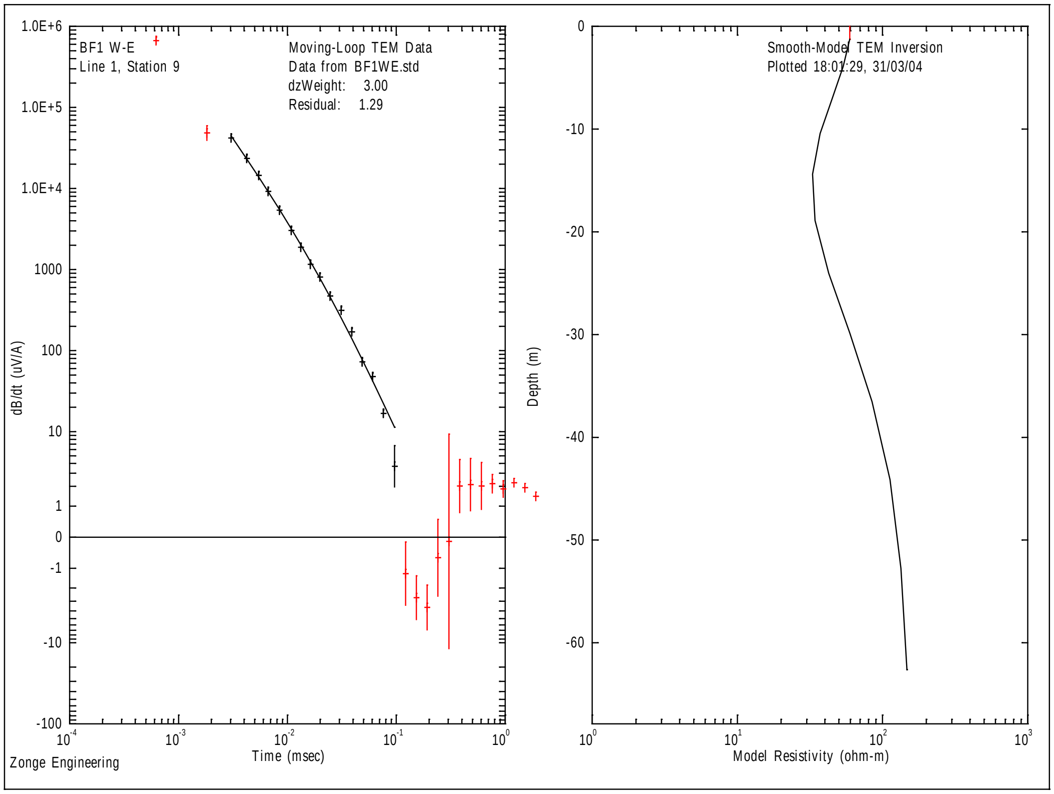

BF1 W-E
Line 1, Station 4
Moving-Loop TEM Data
Data from BF1WE.std
dzWeight: 3.00
Residual: 0.81
dB/dt (uV/A)
Time (msec)
Zonge Engineering
Smooth-Model TEM Inversion
Plotted 18:01:29, 31/03/04
Depth (m)
Model Resistivity (ohm-m)

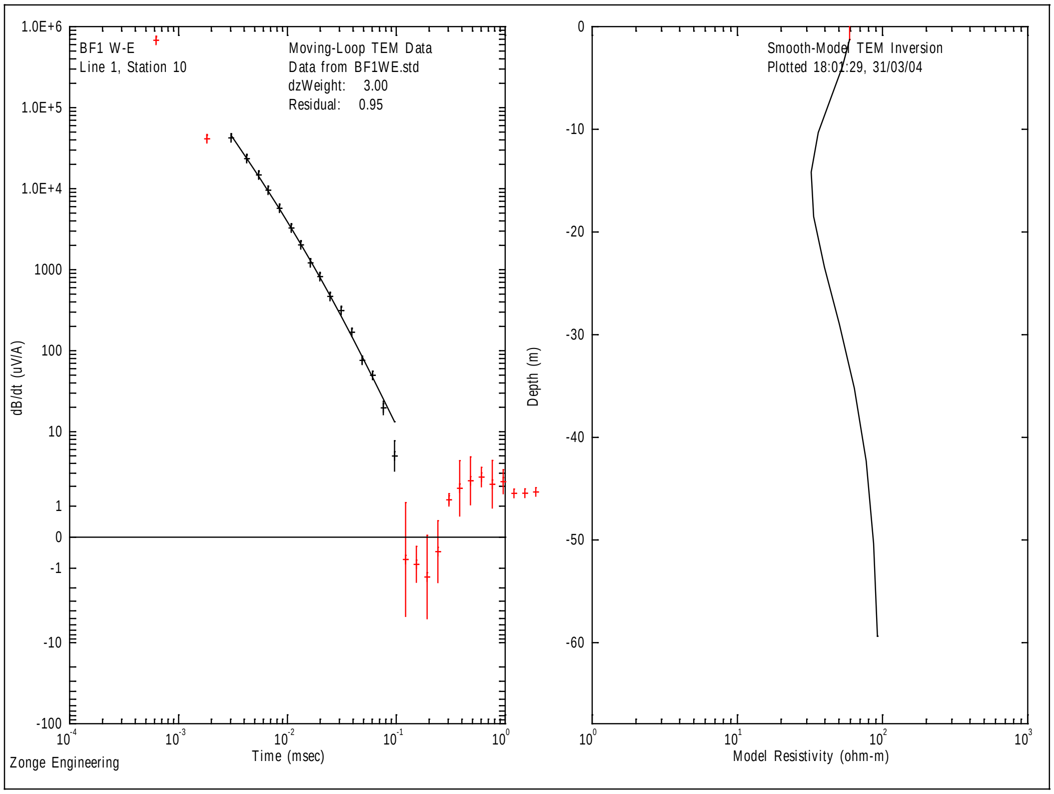

BF1 W-E
Line 1, Station 5
Moving-Loop TEM Data
Data from BF1WE.std
dzWeight: 3.00
Residual: 1.17
dB/dt (uV/A)
Time (msec)
Zonge Engineering
Smooth-Model TEM Inversion
Plotted 18:01:29, 31/03/04
Depth (m)
Model Resistivity (ohm-m)

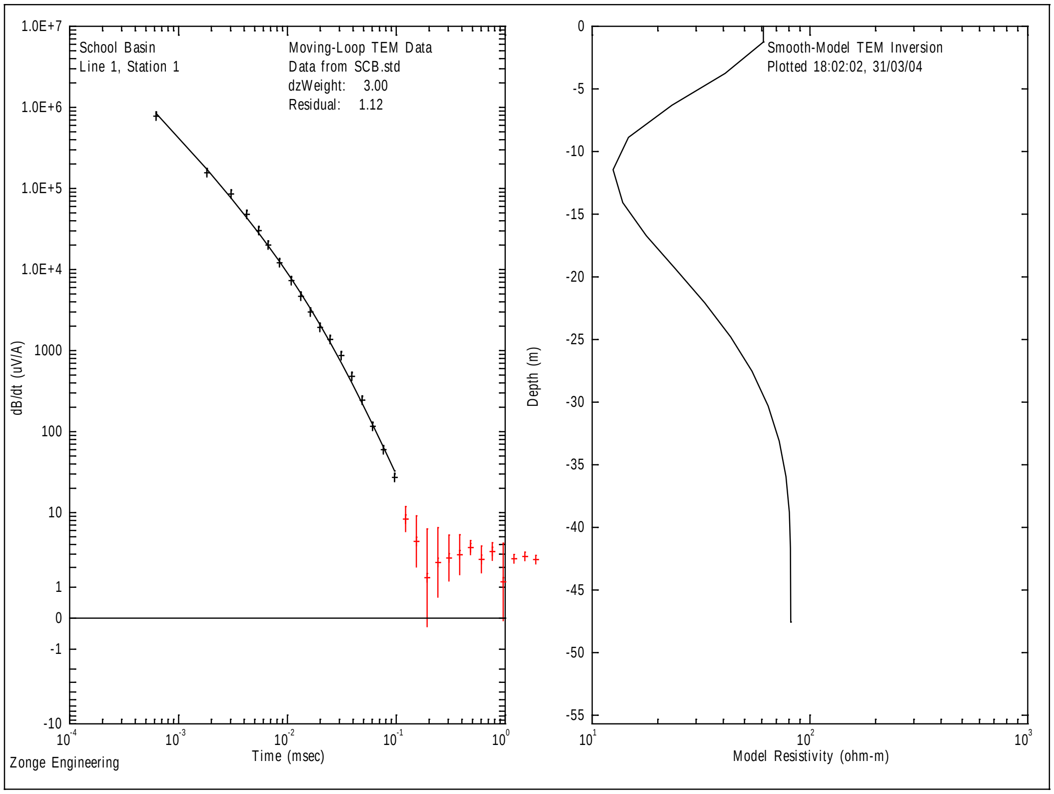

BF1 W-E
Line 1, Station 6
Moving-Loop TEM Data
Data from BF1WE.std
dzWeight: 3.00
Residual: 0.98
dB/dt (uV/A)
Time (msec)
Zonge Engineering
Smooth-Model TEM Inversion
Plotted 18:01:29, 31/03/04
Depth (m)
Model Resistivity (ohm-m)

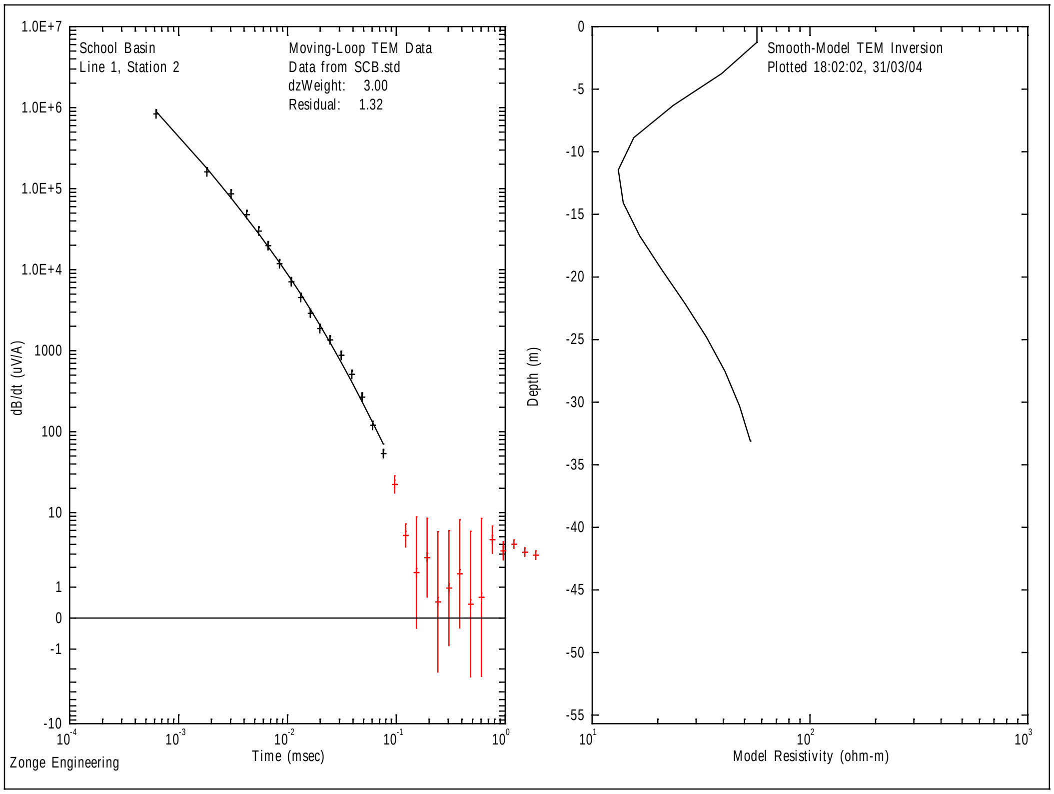

BF1 W-E
Line 1, Station 7
Moving-Loop TEM Data
Data from BF1WE.std
dzWeight: 3.00
Residual: 1.06
dB/dt (uV/A)
Time (msec)
Zonge Engineering
Smooth-Model TEM Inversion
Plotted 18:01:29, 31/03/04
Depth (m)
Model Resistivity (ohm-m)

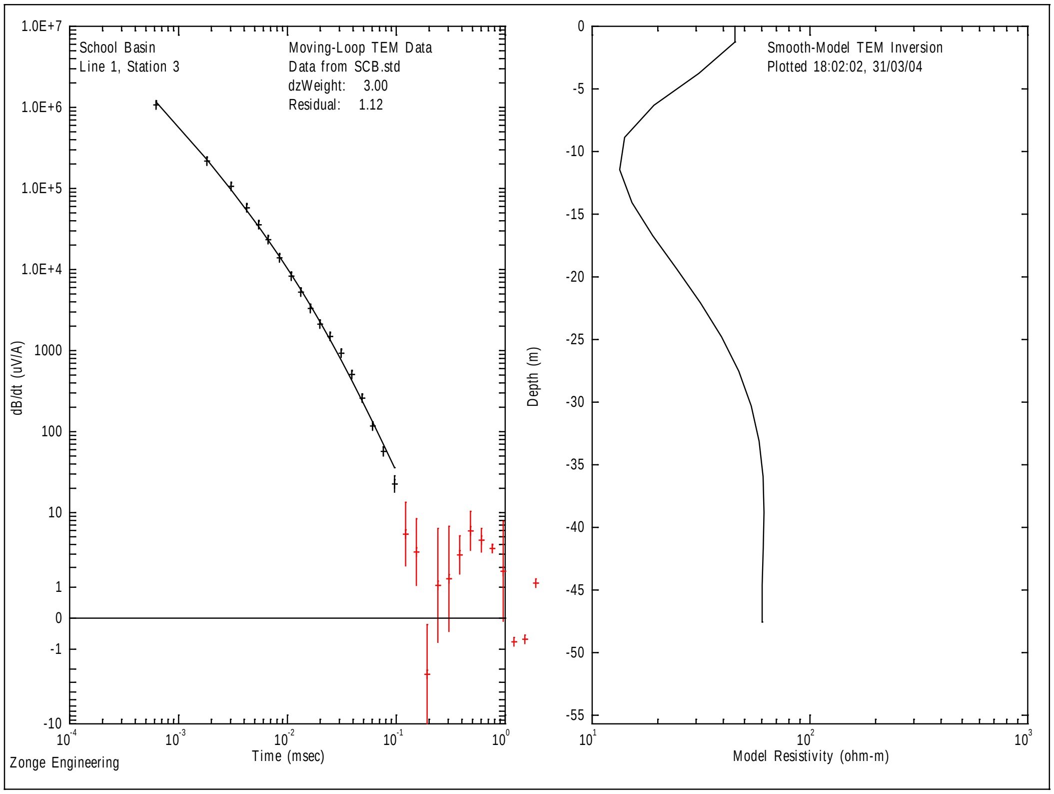

BF1 W-E
Line 1, Station 8
Moving-Loop TEM Data
Data from BF1WE.std
dzWeight: 3.00
Residual: 0.81
dB/dt (uV/A)
Time (msec)
Zonge Engineering
Smooth-Model TEM Inversion
Plotted 18:01:29, 31/03/04
Depth (m)
Model Resistivity (ohm-m)

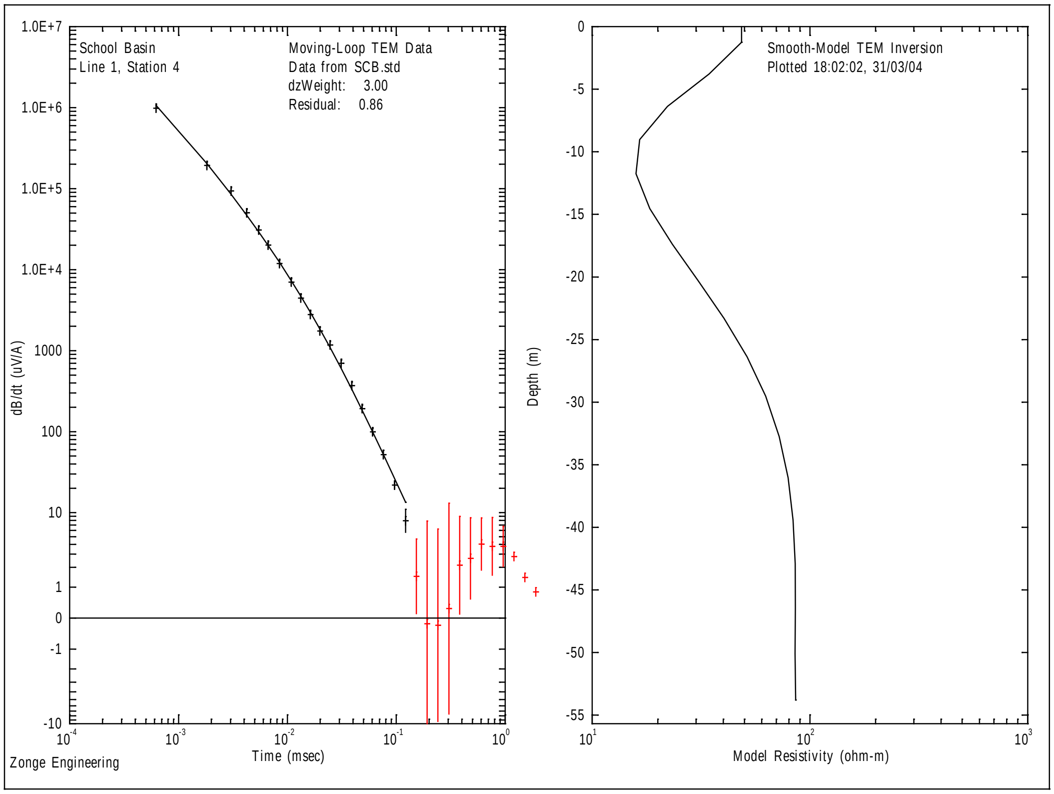

BF1 W-E
Line 1, Station 9
Moving-Loop TEM Data
Data from BF1WE.std
dzWeight: 3.00
Residual: 1.29
dB/dt (uV/A)
Time (msec)
Zonge Engineering
Smooth-Model TEM Inversion
Plotted 18:01:29, 31/03/04
Depth (m)
Model Resistivity (ohm-m)

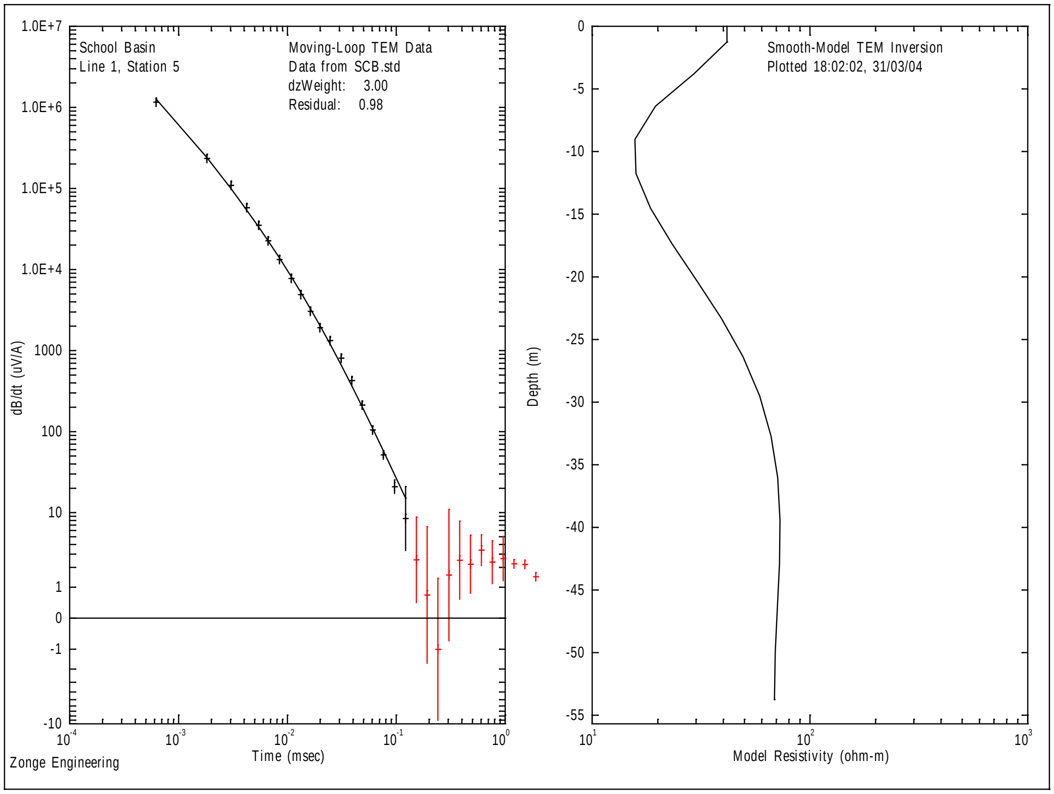

BF1 W-E
Line 1, Station 10
Moving-Loop TEM Data
Data from BF1WE.std
dzWeight: 3.00
Residual: 0.95
dB/dt (uV/A)
Time (msec)
Zonge Engineering
Smooth-Model TEM Inversion
Plotted 18:01:29, 31/03/04
Depth (m)
Model Resistivity (ohm-m)


School Basin
Line 1, Station 1
Moving-Loop TEM Data
Data from SCB.std
dzWeight: 3.00
Residual: 1.12
dB/dt (uV/A)
Time (msec)
Zonge Engineering
Smooth-Model TEM Inversion
Plotted 18:02:02, 31/03/04
Depth (m)
Model Resistivity (ohm-m)


School Basin
Line 1, Station 2
Moving-Loop TEM Data
Data from SCB.std
dzWeight: 3.00
Residual: 1.32
dB/dt (uV/A)
Time (msec)
Zonge Engineering
Smooth-Model TEM Inversion
Plotted 18:02:02, 31/03/04
Depth (m)
Model Resistivity (ohm-m)


School Basin
Line 1, Station 3
Moving-Loop TEM Data
Data from SCB.std
dzWeight: 3.00
Residual: 1.12
Smooth-Model TEM Inversion
Plotted 18:02:02, 31/03/04
dB/dt (uV/A)
Time (msec)
Depth (m)
Model Resistivity (ohm-m)
Zonge Engineering


School Basin
Line 1, Station 4
Moving-Loop TEM Data
Data from SCB.std
dzWeight: 3.00
Residual: 0.86
Smooth-Model TEM Inversion
Plotted 18:02:02, 31/03/04
dB/dt (uV/A)
Time (msec)
Depth (m)
Model Resistivity (ohm-m)
Zonge Engineering



School Basin
Line 1, Station 5
Moving-Loop TEM Data
Data from SCB.std
dzWeight: 3.00
Residual: 0.98
dB/dt (uV/A)
Time (msec)
Zonge Engineering
Smooth-Model TEM Inversion
Plotted 18:02:02, 31/03/04
Depth (m)
Model Resistivity (ohm-m)

Appendix B

EM31 and 34 Survey Data

Table B.1
Instrument: EM34
Site: Basin Floor 1
Transect: West line
Coil Spacing: 10 meters
Error: 0.5

Coil Midpoint Distance* (m)	Vertical Dipole Quadrature (mS/m)	Horizontal Dipole Quadrature (mS/m)	Coil Midpoint Distance* (m)	Vertical Dipole Quadrature (mS/m)	Horizontal Dipole Quadrature (mS/m)
55	14	9.6	375	12.7	8.7
65	13.5	10.1	385	11.5	8.5
75	13.7	9.3	395	13.2	8.5
85	13.4	9.4	405	13.4	9
95	13.9	8.8	415	13.7	9.5
105	12.9	9.2	425	13.9	10
115	13.5	9.1	435	13.7	10
125	13.2	9.3	445	13	10.1
135	15.4	9.1	455	12.9	8.5
145	36.3	9.4	465	12	9.1
150	-73	6.3	475	12.3	8.7
155	-89.1	7	485	11.5	9
160	49.3	8.5	495	12.8	9
165	21.1	8.4	505	13.2	8.9
175	13.5	9	515	12.4	8.4
185	12.6	8.8	525	12	8.4
195	12.2	9	535	11.6	8.1
205	11.4	8.8	545	12.5	8.1
215	12	8.4	555	12.4	8.7
225	12	8.3	565	13	8.9
235	12.2	8.4	575	12.8	9.7
245	12.7	8.8	585	13.3	10.2
255	12.2	8.9	595	13.8	9.3
265	13.1	9.3	605	13.8	9.3
275	11.9	9.4	615	12.8	8.8
285	11.9	9.8	625	12.8	8.8
295	11.9	9.1	635	13.4	8.2
305	12	9.1	645	12.7	8.5
315	12	8.9	655	12	8.5
325	12	8.3	665	13	8.3
335	12.2	8.1	675	12	8.7
345	12.4	8	685	13.3	8.2
355	11.3	8.3	695	12.8	8.4
365	12.9	8.5	705	10	8.7

* coil midpoint distance measured west from 0-meter station

Table B.2
Instrument: EM34
Site: Woodcutters 3
Transect: North line
Coil Spacing: 10 meters
Error: 0.5

Coil Midpoint Distance* (m)	Vertical Dipole Quadrature (mS/m)	Horizontal Dipole Quadrature (mS/m)
0	15.7	11
5	14.5	11.8
10	15	12.2
15	14.8	12.8
20	15.8	12.5
25	16.2	12.8
30	16.6	12.3
35	15.6	12.6
40	17.2	13.1
45	17.3	13.3
50	17.7	13.4
55	17.5	13.3
60	16.4	13.5
65	17.5	13.6
70	16.6	13.9
75	17	13.8
80	15.9	13.9
85	17.1	14.4
90	16.6	15
95	15.9	15.1
100	17.1	15.1
105	17.7	14.7
110	19.5	14.6
115	18.5	15
120	18.6	15
125	18.3	14.8
130	16.5	15
135	16.5	14.9
140	17.3	14.3
145	17.6	14.1
150	17.3	14.1

* coil midpoint distance measured north from 0-meter station

Table B.3
Instrument: EM34
Site: Woodcutters 3
Transect: West line
Coil Spacing: 10 meters
Error: 0.5

Coil Midpoint Distance* (m)	Vertical Dipole Quadrature (mS/m)	Horizontal Dipole Quadrature (mS/m)	Coil Midpoint Distance* (m)	Vertical Dipole Quadrature (mS/m)	Horizontal Dipole Quadrature (mS/m)
600	19.3	14.2	370		15.6
595	20.4	16.2	360		16.6
590	19.1	15.8	350	20.9	15.4
585	16.3	15.5	340		15.3
580	19.4	15.4	330		16.2
575	19.1	16.7	320		15.7
570	17.3	16	310		15
565	19.3	17	300	17.8	14.8
560	18.7	15.9	290		16.8
555	19.6	17.3	280		15.6
550	20.1	16	270		15.3
545	20.7	16.4	260		16
540	20	16.7	250	20.6	16
535	21.1	15.8	240		15.3
530	20.3	14.9	230		16.3
525	21.4	14.9	220		15
520	20.4	13.6	210		16.1
515	19.6	14.5	200	19.8	16
510	18.1	15.2	190		14.7
505	19.8	15.8	180		15.1
500	21.4	15.5	170		14.9
495	20.1	14.4	160		14.7
490	18.4	16	150	16.6	15.3
485	19.6	17.1	140		14.3
480	20.1	17.7	130		14.9
475	19.4	17.3	120		13.9
470	17	17.1	110	19.47	11.6
465	19.7	15.8	100	18.2	12.2
455	19.3	16.8	90		12.8
450	19.2	15.8	80		13.5
445	20.2	16.4	70		13.9
440		16.7	60		13.6
430		15.9	50	17.6	12.3
420		16.5	40		12.6
410		16.6	30		12.6
400	18.2	16.7	20		12.6
390		16.1	10		12.3
380		15.7	0	17.3	12.4

* coil midpoint distance measured west from 0-meter station

Table B.4
Instrument: EM34
Site: Woodcutters 3
Transect: East line
Coil Spacing: 10 meters
Error: 0.5

Coil Midpoint Distance* (m)	Vertical Dipole Quadrature (mS/m)	Horizontal Dipole Quadrature (mS/m)	Coil Midpoint Distance* (m)	Vertical Dipole Quadrature (mS/m)	Horizontal Dipole Quadrature (mS/m)
0	15.1	12	210		15.7
10		10.8	220		15.6
10		11.7	230		16.6
20		11.3	240		16.8
20		11.6	250	16.6	16.1
30		11	260		14.8
30		11.4	270		14.6
40		10.4	280		14
40		11.4	290		14.9
50	15.4	12.9	300	18.9	16
50	15.5	11.1	310		15.5
60		11.8	320		15.7
70		12.6	330		16.2
80		13.7	340		15.9
90		14.9	350	22.6	18.9
100	18.6	14.6	350	22.7	20
110		14.3	360	27	23.4
120		14.5	370	25.3	27.3
130		14.4	380	86.8	29.4
140		14	390	161.7	31
150	17	12.8	400	118	31.2
160		13.3	410	45	27.1
170		14.4	420	30.4	24.9
180		15	430	25.7	23.7
190		14.5	440	23.2	21.8
200	18.3	15.2	450	20	18.8

* coil midpoint distance measured east from 0-meter station

Table B.5
Instrument: EM31
Site: Basin Floor 1
Transect: West line

Date: 2/29/04
Time: 15:31:45
Operator: Peggy
In-phase: -20.47

Orientation: SV10-parallel RV20-perpendicular

Station (m)	Orient.	Quadrature (mS/m)	Station (m)	Orient.	Quadrature (mS/m)
0	SV10	8.6	200	SV10	6.8
0	RV20	8.225	200	RV20	7
10	SV10	8.475	210	SV10	6.825
10	RV20	8.575	210	RV20	6.7
20	SV10	9	220	SV10	6.5
20	RV20	8.625	220	RV20	7.075
30	SV10	8.525	230	SV10	6.6
30	RV20	8.225	230	RV20	6.55
40	SV10	7.85	240	SV10	6.55
40	RV20	8.2	240	RV20	6.7
50	SV10	7.925	250	SV10	6.35
50	RV20	7.85	250	RV20	6.475
60	SV10	7.925	260	SV10	6.4
60	RV20	8.1	260	RV20	6.35
70	SV10	7.8	270	SV10	6.675
70	RV20	8	270	RV20	6.875
80	SV10	7.725	280	SV10	6.6
80	RV20	7.8	280	RV20	6.85
90	SV10	7.35	290	SV10	6.5
90	RV20	7.65	290	RV20	7.075
100	SV10	7.55	300	SV10	6.625
100	RV20	7.675	300	RV20	6.675
110	SV10	7.5	310	SV10	6.4
110	RV20	7.425	310	RV20	6.7
120	SV10	8.575	320	SV10	6.5
120	RV20	7.45	320	RV20	6.025
130	SV10	7.025	330	SV10	6.175
130	RV20	6.975	330	RV20	6.275
140	SV10	6.6	340	SV10	6.475
140	RV20	6.55	340	RV20	6.85
150	SV10	0.725	350	SV10	6.45
150	RV20	13.65	350	RV20	6.725
160	SV10	4.6	360	SV10	6.35
160	RV20	6.3	360	RV20	6.15
170	SV10	7.2	370	SV10	6.65
170	RV20	7.525	370	RV20	6.4
180	SV10	7.15	380	SV10	6.4
180	RV20	7.175	380	RV20	6.3
190	SV10	6.875	390	SV10	6.675
190	RV20	6.925	390	RV20	6.225

Station (m)	Orient.	Quadrature (mS/m)
400	SV10	6.4
400	RV20	6.2
410	SV10	6.95
410	RV20	6.675
420	SV10	6.725
420	RV20	6.65
430	SV10	6.5
430	RV20	6.475
440	SV10	6.875
440	RV20	6.6
450	SV10	6.075
450	RV20	6.45
460	SV10	5.9
460	RV20	6.575
470	SV10	6.2
470	RV20	6.2
480	SV10	6.675
480	RV20	5.9
490	SV10	6.65
490	RV20	6.4
500	SV10	6.05
500	RV20	6.625
510	SV10	6.75
510	RV20	6.75
520	SV10	6.45
520	RV20	6.775
530	SV10	6.75
530	RV20	7
540	SV10	6.975
540	RV20	6.875
550	SV10	7.15
550	RV20	6.95
560	SV10	6.725
560	RV20	6.4
570	SV10	6.85
570	RV20	6.85
580	SV10	6.975
580	RV20	6.8
590	SV10	6.675
590	RV20	6.7

Station (m)	Orient.	Quadrature (mS/m)
600	SV10	7.4
600	RV20	7.3
610	SV10	7.375
610	RV20	7.425
620	SV10	4.95
620	RV20	7.45
630	SV10	7.475
630	RV20	6.1
640	SV10	7.275
640	RV20	7.375
650	SV10	7.7
650	RV20	7.7
660	SV10	7.15
660	RV20	7.3
670	SV10	7.85
670	RV20	7.475
680	SV10	7.675
680	RV20	7.7
690	SV10	7.7
690	RV20	7.35
700	SV10	7.4
700	RV20	7.5

Table B.6
Instrument: EM31
Site: Basin Floor 1
Transect: East line

Date: 3/21/04
Time: 15:10:32
Operator: Don
In-phase: -20.47

Orientation: SV10-parallel RV20-perpendicular

Station (m)	Orient.	Quadrature (mS/m)
-300	SV10	7.9
-290	SV10	8.05
-280	SV10	7.85
-270	SV10	8.15
-260	SV10	7.725
-250	SV10	7.725
-240	SV10	8.075
-230	SV10	8.65
-220	SV10	8.4
-210	SV10	8.725
-200	SV10	8.7
-190	SV10	8.425
-180	SV10	8.575
-170	SV10	8.75
-160	SV10	9.05
-150	SV10	8.5
-140	SV10	9.175
-130	SV10	9.25
-120	SV10	9.075
-110	SV10	9.325
-100	SV10	8.9
-90	SV10	8.825
-80	SV10	8.8
-70	SV10	8.75
-60	SV10	9.125
-50	SV10	9.175
-40	SV10	8.9
-30	SV10	8.95
-20	SV10	8.9
-10	SV10	9.1
0	SV10	9.225

Table B.7
Instrument: EM31
Site: Woodcutters 3
Transect: East-West line

Date: 3/21/04
Time: 10:38:28
Operator: Chalwe
In-phase: -20.47

Orientation: SV10-parallel RV20-perpendicular RV10-parallel
RH10-parallel RH20-perpendicular

Station (m)	Orient.	Quadrature (mS/m)	Station (m)	Orient.	Quadrature (mS/m)
210	RH10	5.125	140	RH10	6.55
330	RH10	5.85	10	RH10	6.55
340	RH10	5.4	90	RH10	7.5
350	RH10	5.175	20	RH10	5.2
430	RH10	3.825	70	RH10	5.175
440	RH10	3.7	210	RH20	5.35
450	RH10	4.8	370	RH20	3.65
150	RH10	6.075	180	RH20	6.85
160	RH10	6.45	240	RH20	4.25
170	RH10	6.925	260	RH20	6.95
180	RH10	6.725	300	RH20	5.525
190	RH10	5.875	330	RH20	7.15
200	RH10	6.55	360	RH20	4.8
220	RH10	6.225	400	RH20	-15.899
230	RH10	6.425	420	RH20	12.025
240	RH10	7.725	430	RH20	4.35
250	RH10	5.425	150	RH20	6.925
260	RH10	6.475	160	RH20	5.675
270	RH10	5.425	170	RH20	6.55
280	RH10	5.975	190	RH20	7.05
290	RH10	6.35	200	RH20	6.875
300	RH10	4.125	220	RH20	5.7
310	RH10	4.425	230	RH20	5.75
320	RH10	6.15	250	RH20	7.225
360	RH10	5.225	270	RH20	7.1
370	RH10	3.1	280	RH20	5.7
380	RH10	1.525	290	RH20	6.3
390	RH10	-2.575	320	RH20	7.175
400	RH10	-11.35	340	RH20	8.025
410	RH10	-9.325	350	RH20	3.175
420	RH10	-7	380	RH20	4.075
30	RH10	5	390	RH20	-10.375
110	RH10	6.7	410	RH20	-13.25
60	RH10	5.95	440	RH20	2.775
100	RH10	6.975	450	RH20	4.425
130	RH10	7.15	310	RH20	6.1
80	RH10	6.95	100	RH20	6.1
120	RH10	6.05	140	RH20	6.975
40	RH10	6.25	20	RH20	5.75
50	RH10	7.15	50	RH20	7

Station (m)	Orient.	Quadrature (mS/m)	Station (m)	Orient.	Quadrature (mS/m)
110	RH10	7.125	0	RV20	6.925
40	RH10	6.2	60	RV20	6
120	RH10	5.475	80	RV20	6.125
10	RH10	5.775	90	RV20	5.875
80	RH10	7.475	100	RV20	5.25
130	RH10	6.025	120	RV20	6.325
30	RH10	6.475	40	RV20	5.85
60	RH10	6.2	50	RV20	6.625
70	RH10	6.375	130	RV20	6.2
90	RH10	6.45	10	RV20	6.125
0	RH10	6.475	440	SV10	3
0	RV10	7.575	120	SV10	6.125
210	RV20	4.675	140	SV10	5.6
350	RV20	4.375	210	SV10	5.2
140	RV20	6.25	390	SV10	-0.475
180	RV20	5.625	50	SV10	7.075
370	RV20	3.475	180	SV10	5.4
150	RV20	6.175	240	SV10	2.425
160	RV20	5.625	450	SV10	3.95
170	RV20	5.775	60	SV10	6.8
190	RV20	5.3	170	SV10	5.9
200	RV20	5.675	200	SV10	5.475
220	RV20	5.3	290	SV10	5.2
230	RV20	5.275	340	SV10	3.475
240	RV20	6.925	30	SV10	5.7
250	RV20	5.9	40	SV10	6.1
260	RV20	5.275	90	SV10	6.025
270	RV20	4.875	100	SV10	6.075
280	RV20	5.25	110	SV10	6.1
290	RV20	5.525	160	SV10	6.3
300	RV20	5.7	190	SV10	5.525
310	RV20	5.7	230	SV10	4.75
320	RV20	4.65	330	SV10	3.8
330	RV20	5.4	380	SV10	1.5
340	RV20	2.125	410	SV10	-1.65
360	RV20	3.4	420	SV10	29.225
380	RV20	-5.15	80	SV10	6.35
390	RV20	-13.024	130	SV10	5.7
400	RV20	-5.125	150	SV10	5.725
410	RV20	2.175	250	SV10	6.2
420	RV20	-8.149	260	SV10	5.05
430	RV20	2.3	270	SV10	5.125
440	RV20	3.9	300	SV10	4.6
450	RV20	3.525	350	SV10	4.65
30	RV20	5.9	360	SV10	4.275
20	RV20	6	10	SV10	5.775
110	RV20	5.2	20	SV10	5.8
70	RV20	6.425	70	SV10	5.875

Station (m)	Orient.	Quadrature (mS/m)
220	SV10	5.225
280	SV10	5.375
310	SV10	5.475
320	SV10	4.35
370	SV10	4.125
400	SV10	0.975
430	SV10	2.125
0	SV10	7.7

Appendix C

Magnetic, Vertical Gradient, and VLF Survey Data

TABLE C.1: Mag/Grad EAST-WEST SURVEY DATA - Basin Floor 1 site, Sunday 2/29/04

Operator: Nchimunya Hazwezwe
Distances measured from benchmark stake, West negative, East positive
Base station is 100W

East-West Line

Station Name	Distance (m)	Time (hours: minutes)	Δt (minutes)	Magnetic Field (nT)	Vertical Gradient (nT)
100W	-100	11:00	0	47843.3	7.8
150W	-150	11:03	3	47777.8	-2.0
100W	-100	11:08	8	47839.7	4.6
100W	-100	11:22	22	47837.3	5.1
150W	-150	11:25	25	47766.0	5.4
200W	-200	11:28	28	47842.2	6.1
250W	-250	11:32	32	47849.1	8.1
300W	-300	11:36	36	47838.8	5.2
100W	-100	11:41	41	47840.9	7.2
300W	-300	11:49	49	47840.2	8.2
350W	-350	11:52	52	47861.0	10.3
400W	-400	11:56	56	47857.2	7.4
450W	-450	11:59	59	47850.2	6.0
500W	-500	12:02	62	47853.2	5.0
550W	-550	12:04	64	47847.3	3.5
600W	-600	12:07	67	47859.3	6.0
650W	-650	12:10	70	47860.8	7.9
700W	-700	12:13	73	47866.3	5.3
100W	-100	12:25	85	47849.1	8.5
100W	-100	13:03	123	47849.5	8.6
50E	50	13:07	127	47862.0	7.8
100E	100	13:16	136	47851.1	4.7
150E	150	13:19	139	47855.3	6.1
200E	200	13:22	142	47866.7	13.7
250E	250	13:24	144	47861.0	10.2
300E	300	13:27	147	47850.6	5.8
100W	-100	13:37	157	47855.4	3.3

TABLE C.2: Mag/Grad NORTH-SOUTH SURVEY DATA - Basin Floor 1 site, Sunday 2/29/04

Operator: Nchimunya Hazwezwe
Distances measured from benchmark stake, West negative, East positive
Base station is 100W

North-South Line (offset 20 meters East from benchmark stake)

Station Name	Distance (m)	Time (hours: minutes)	Δt (minutes)	Magnetic Field (nT)	Vertical Gradient (nT)
100W	0	13:37	157	47855.4	3.3
0N0S20E	0	13:50	170	47848.3	3.9
50N	50	13:53	173	47858.8	7.6
100N	100	13:56	176	47852.9	5.8
150N	150	13:59	179	47843.8	3.2
200N	200	14:02	182	47851.4	3.9
100W	0	14:08	188	47850.1	4.7
50S	-50	14:15	195	47874.9	83.3
100S	-100	14:19	199	47859.1	6.7
150S	-150	14:22	202	47852.2	5.3
200S	-200	14:25	205	47840.1	2.3
250S	-250	14:30	210	47813.0	52.5
300S	-300	14:33	213	47852.8	4.7
350S	-350	14:36	216	47847.4	6.0
400S	-400	14:40	220	47869.4	-42.3
450S	-450	14:43	223	47842.1	8.3
500S	-500	14:46	226	47849.5	8.1
100W	0	15:00	240	47850.3	7.3

TABLE C.3: Mag/Grad EAST-WEST SURVEY DATA – Woodcutters 3 site, Saturday 2/28/04

Operator: Chalwe Musosha
Distances measured from benchmark stake, West negative, East positive
Base station is 50W

East-West Line

Station Name	Distance (m)	Time (hours: minutes)	Δt (minutes)	Magnetic Field (nT)	Vertical Gradient (nT)
50W	-50	14:03	0	47969.2	9.4
100W	-100	14:13	10	47981.3	10.5
50W	-50	14:20	17	47969.1	8.5
150W	-150	14:31	28	47967.9	8.3
200W	-200	14:37	34	47965.8	8.9
250W	-250	14:43	40	47962.6	7.6
300W	-300	14:51	48	47962.5	8.2
350W	-350	14:55	52	47957.6	7.0
400W	-400	15:00	57	47947.0	5.0
450W	-450	15:04	61	47950.7	8.7
500W	-500	15:09	66	47947.4	10.5
50W	-50	15:29	86	47966.7	7.2
50E	50	15:42	99	47978.0	7.8
100E	100	15:50	107	47994.8	11.0
150E	150	16:00	117	47994.5	10.0
200E	200	16:04	121	48002.3	6.2
250E	250	16:10	127	48027.1	12.9
300E	300	16:14	131	47999.0	6.2
350E	350	16:20	137	48005.3	11.2
400E	400	16:30	147	48161.8	1.2
450E	450	16:35	152	47998.7	5.8
500E	500	16:40	157	48011.9	6.2
300E	300	16:45	162	48009.8	4.1

TABLE C.4: VLF Frequency F1 EAST-WEST SURVEY DATA - Basin Floor 1 site, Sunday 2/29/04

Operator: Nchimunya Hazwezwe
Distances measured from benchmark stake, West negative, East positive
Base station is 100W

East-West Line

Frequency F1: Cutler, MA @ 24.0kHz

Station Name	Distance (m)	Time (hours: minutes)	Δt (minutes)	Vertical In-Phase (%)	Vertical Quadrature (%)	Total Field Strength (nT)	Vertical Dip Angle (tilt) (degrees)
100W	-100	11:00	0	7.8	-1.2	11.99	4.5
150W	-150	11:03	3	52.4	-13.2	14.87	27.6
100W	-100	11:08	8	7.2	-1.2	12.16	4.1
100W	-100	11:22	22	7.0	-1.1	12.20	4.0
150W	-150	11:25	25	52.5	-19.4	17.01	27.7
200W	-200	11:28	28	5.4	4.7	12.54	3.1
250W	-250	11:32	32	7.0	2.6	12.87	4.0
300W	-300	11:36	36	4.7	0.0	13.02	2.7
100W	-100	11:41	41	7.0	-1.1	12.26	4.0
300W	-300	11:49	49	4.8	-0.2	13.11	2.7
350W	-350	11:52	52	7.0	1.5	13.06	4.0
400W	-400	11:56	56	5.9	0.4	13.22	3.4
450W	-450	11:59	59	6.8	0.2	13.21	3.9
500W	-500	12:02	62	6.7	0.5	13.18	3.8
550W	-550	12:04	64	6.1	0.7	13.04	3.5
600W	-600	12:07	67	6.1	0.5	13.23	3.4
650W	-650	12:10	70	4.2	1.1	13.23	2.4
700W	-700	12:13	73	4.6	1.9	12.98	2.6
100W	-100	12:25	85	9.0	-1.5	11.76	5.1
100W	-100	13:03	123	5.5	-1.0	11.33	3.1
50E	50	13:07	127	10.2	-2.2	11.36	5.8
100E	100	13:16	136	7.9	0.8	11.48	4.7
150E	150	13:19	139	3.6	0.1	11.24	2.0
200E	200	13:22	142	5.5	0.6	11.44	3.2
250E	250	13:24	144	8.2	1.4	11.91	4.7
300E	300	13:27	147	5.7	0.2	11.59	3.2
100W	-100	13:37	157	5.8	-1.2	10.84	3.3

TABLE C.5: VLF Frequency F2 EAST-WEST SURVEY DATA - Basin Floor 1 site, Sunday 2/29/04

Operator: Nchimunya Hazwezwe
Distances measured from benchmark stake, West negative, East positive
Base station is 100W

East-West Line

Frequency F2: Jim Creek, WA @ 24.8kHz

Station Name	Distance (m)	Time (hours: minutes)	Δt (minutes)	Vertical In-Phase (%)	Vertical Quadrature (%)	Total Field Strength (nT)	Vertical Dip Angle (tilt) (degrees)
100W	-100	11:00	0	12.5	-6.1	22.71	7.1
150W	-150	11:03	3	35.9	-12.7	23.19	19.7
100W	-100	11:08	8	13.4	-5.6	22.33	7.6
100W	-100	11:22	22	12.4	-4.5	21.45	7.0
150W	-150	11:25	25	41.3	-13.4	24.10	22.4
200W	-200	11:28	28	3.5	2.8	20.11	2.0
250W	-250	11:32	32	7.7	1.6	20.74	4.4
300W	-300	11:36	36	7.2	1.1	20.82	4.1
100W	-100	11:41	41	11.2	-4.5	20.87	6.4
300W	-300	11:49	49	6.9	0.8	20.71	3.9
350W	-350	11:52	52	6.6	0.4	20.75	3.8
400W	-400	11:56	56	4.6	0.7	21.02	2.6
450W	-450	11:59	59	4.3	-0.3	20.71	2.5
500W	-500	12:02	62	5.6	0.8	20.44	3.2
550W	-550	12:04	64	7.9	1.5	20.09	4.5
600W	-600	12:07	67	7.4	0.4	20.29	4.2
650W	-650	12:10	70	7.4	1.0	20.16	4.2
700W	-700	12:13	73	6.5	0.5	19.89	3.7
100W	-100	12:25	85	9.1	-6.2	19.76	5.2
100W	-100	13:03	123	0.1	-0.2	18.65	0.1
50E	50	13:07	127	5.0	-1.5	18.38	2.9
100E	100	13:16	136	4.0	-1.0	19.08	2.3
150E	150	13:19	139	-0.2	-0.5	19.04	-0.1
200E	200	13:22	142	0.8	0.7	19.29	0.5
250E	250	13:24	144	1.7	0.7	19.21	0.9
300E	300	13:27	147	0.2	1.0	19.37	0.1
100W	-100	13:37	157	2.6	0.1	18.61	1.4

TABLE C.6: VLF Frequency F1 NORTH-SOUTH SURVEY DATA - Basin Floor 1 site, Sunday 2/29/04

Operator: Nchimunya Hazwezwe
Distances measured from benchmark stake, West negative, East positive
Base station is 100W

North-South Line (offset 20 meters East from benchmark stake)

Frequency F1: Cutler, MA @ 24.0kHz

Station Name	Distance (m)	Time (hours: minutes)	Δt (minutes)	Vertical In-Phase (%)	Vertical Quadrature (%)	Total Field Strength (nT)	Vertical Dip Angle (tilt) (degrees)
100W	0	13:37	157	5.8	-1.2	10.84	3.3
0N0S20E	0	13:50	170	20.7	-5.5	10.27	11.7
50N	50	13:53	173	21.7	-4.9	10.16	12.2
100N	100	13:56	176	20.2	-5.4	10.01	11.4
150N	150	13:59	179	16.5	-4.8	9.74	9.4
200N	200	14:02	182	17.0	-3.5	9.54	9.6
100W	0	14:08	188	4.8	-1.1	9.84	2.7
50S	-50	14:15	195	20.0	-3.9	9.19	11.3
100S	-100	14:19	199	20.9	-5.7	9.15	11.5
150S	-150	14:22	202	19.6	-3.9	8.94	11.1
200S	-200	14:25	205	14.9	-2.3	8.69	8.4
250S	-250	14:30	210	16.2	-5.1	8.63	9.2
300S	-300	14:33	213	19.3	-3.9	8.89	10.9
350S	-350	14:36	216	17.5	-4.2	8.51	9.9
400S	-400	14:40	220	16.6	-3.1	8.78	9.4
450S	-450	14:43	223	12.9	-1.8	8.37	7.3
500S	-500	14:46	226	14.3	-0.4	8.16	8.1
100W	0	15:00	240	6.2	-0.7	7.77	3.5

TABLE C.7: VLF Frequency F2 NORTH-SOUTH SURVEY DATA - Basin Floor 1 site, Sunday 2/29/04

Operator: Nchimunya Hazwezwe
Distances measured from benchmark stake, West negative, East positive
Base station is 100W

North-South Line (offset 20 meters East from benchmark stake)

Frequency F2: Jim Creek, WA @ 24.8kHz

Station Name	Distance (m)	Time (hours: minutes)	Δt (minutes)	Vertical In-Phase (%)	Vertical Quadrature (%)	Total Field Strength (nT)	Vertical Dip Angle (tilt) (degrees)
100W	0	13:37	157	2.6	0.1	18.61	1.4
0N0S20E	0	13:50	170	14.2	-2.4	17.24	8.0
50N	50	13:53	173	12.3	-2.0	17.44	7.0
100N	100	13:56	176	14.6	-2.2	17.30	8.3
150N	150	13:59	179	14.5	-2.0	16.84	8.2
200N	200	14:02	182	8.4	-2.4	16.86	4.8
100W	0	14:08	188	1.5	0.0	18.38	0.9
50S	-50	14:15	195	12.2	-2.4	16.92	6.9
100S	-100	14:19	199	11.4	-0.9	17.38	6.5
150S	-150	14:22	202	9.6	-0.8	17.51	5.5
200S	-200	14:25	205	10.6	-1.6	17.84	6.0
250S	-250	14:30	210	16.7	-0.3	17.48	9.5
300S	-300	14:33	213	12.8	-1.7	17.48	7.3
350S	-350	14:36	216	10.9	-2.2	17.53	6.2
400S	-400	14:40	220	10.5	-1.0	17.44	6.0
450S	-450	14:43	223	9.1	-1.0	17.77	5.2
500S	-500	14:46	226	9.0	-1.8	17.49	5.1
100W	0	15:00	240	-1.2	0.1	18.90	-0.7

TABLE C.8: VLF Frequency F1 EAST-WEST SURVEY DATA - Woodcutters 3 site, Saturday 2/28/04

Operator: Chalwe Musosha
Distances measured from benchmark stake, West negative, East positive
Base station is 50W

East-West Line

Frequency F1: Cutler, MA @ 24.0kHz

Station Name	Distance (m)	Time (hours: minutes)	Δt (minutes)	Vertical In-Phase (%)	Vertical Quadrature (%)	Total Field Strength (nT)	Vertical Dip Angle (tilt) (degrees)
50W	-50	14:03	0	13.2	2.5	10.73	7.5
100W	-100	14:13	10	9.6	2.4	10.19	5.5
50W	-50	14:20	17	11.1	2.3	10.08	6.3
150W	-150	14:31	28	11.5	1.2	9.85	6.5
200W	-200	14:37	34	9.0	1.6	9.59	5.1
250W	-250	14:43	40	9.8	0.5	9.32	5.5
300W	-300	14:51	48	7.7	0.5	8.79	4.4
350W	-350	14:55	52	10.6	0.2	8.96	6.0
400W	-400	15:00	57	9.6	0.6	8.80	5.5
450W	-450	15:04	61	11.0	0.6	8.49	6.2
500W	-500	15:09	66	8.9	0.3	8.39	5.0
50W	-50	15:29	86	11.2	2.6	7.49	6.4
50E	50	15:42	99	6.1	-0.1	5.95	3.5
100E	100	15:50	107	8.1	0.1	5.99	4.6
150E	150	16:00	117	9.8	0.8	5.17	5.6
200E	200	16:04	121	7.8	2.1	5.19	4.5
250E	250	16:10	127	9.4	2.5	5.10	5.3
300E	300	16:14	131	1.9	2.0	5.08	1.1
350E	350	16:20	137	9.0	4.1	5.54	5.1
400E	400	16:30	147	13.8	0.0	5.50	7.8
450E	450	16:35	152	7.9	0.2	6.09	4.5
500E	500	16:40	157	4.7	0.7	6.24	2.7
300E	300	16:45	162	6.4	1.7	6.36	3.7

TABLE C.9: VLF Frequency F2 EAST-WEST SURVEY DATA - Woodcutters 3 site, Saturday 2/28/04

Operator: Chalwe Musosha
Distances measured from benchmark stake, West negative, East positive
Base station is 50W

East-West Line

Frequency F2: Jim Creek, WA @ 24.8kHz

Station Name	Distance (m)	Time (hours: minutes)	Δt (minutes)	Vertical In-Phase (%)	Vertical Quadrature (%)	Total Field Strength (nT)	Vertical Dip Angle (tilt) (degrees)
50W	-50	14:03	0	5.1	0.2	18.92	2.9
100W	-100	14:13	10	6.8	-0.4	19.70	3.9
50W	-50	14:20	17	4.4	0.0	19.76	2.5
150W	-150	14:31	28	6.1	0.5	20.00	3.5
200W	-200	14:37	34	8.5	0.7	20.32	4.8
250W	-250	14:43	40	6.3	0.0	20.19	3.6
300W	-300	14:51	48	10.4	0.3	20.74	5.9
350W	-350	14:55	52	4.2	0.6	19.86	2.4
400W	-400	15:00	57	8.1	0.5	20.26	4.6
450W	-450	15:04	61	9.1	0.6	20.52	5.1
500W	-500	15:09	66	10.0	0.6	20.42	5.7
50W	-50	15:29	86	5.6	0.3	20.77	3.2
50E	50	15:42	99	7.3	-0.1	21.14	4.2
100E	100	15:50	107	5.1	0.1	21.63	2.9
150E	150	16:00	117	5.8	0.0	21.07	3.3
200E	200	16:04	121	5.1	0.4	21.30	2.9
250E	250	16:10	127	4.3	0.5	21.14	2.4
300E	300	16:14	131	5.6	0.4	21.20	3.2
350E	350	16:20	137	3.1	0.7	20.82	1.8
400E	400	16:30	147	-5.0	3.4	20.95	-2.9
450E	450	16:35	152	7.4	-0.2	20.43	4.2
500E	500	16:40	157	5.8	1.0	20.13	3.3
300E	300	16:45	162	0.9	0.1	19.67	0.5

Appendix D

GPS Location Data

Table D.1: GPS LOCATION - Woodcutters 3, Saturday 2/28/2004

Universal Transverse Mercator (UTM) Coordinates
UTM Zone: 12R
Coordinate Datum = WGS84

Station	Easting	Northing
0	569519.1576	3492134.525
50W	569468.7914	3492128.836
100W	569415.8758	3492123.725
150W	569370.6165	3492115.693
200W	569321.7895	3492108.232
250W	569281.1359	3492096.663
300W	569224.1749	3492087.364
350W	569171.2985	3492076.309
400W	569127.0729	3492065.906
450W	569075.6841	3492060.807
500W	569026.8606	3492052.753
550W	568984.1543	3492043.550
600W	568932.3193	3492028.935
50N	569523.3575	3492191.636
150N	569528.7189	3492227.348
200N	569542.1622	3492272.629
50S	569514.4047	3492083.951
100S	569498.9683	3492032.116
150S	569474.8369	3491986.169
200S	569454.7624	3491942.628
250S	569437.7743	3491894.351
300S	569421.7764	3491850.243
350S	569405.7585	3491809.108
400S	569384.7048	3491759.614
50E	569566.4411	3492144.355
100E	569620.3988	3492145.906
150E	569667.8736	3492127.196
200E	569716.8120	3492118.011
250E	569765.7586	3492107.636
300E	569814.7332	3492093.100
350E	569862.6578	3492083.314
400E	569910.1133	3492067.579
450E	569958.0861	3492050.658
500E	570005.5540	3492033.139

Table D.2: GPS LOCATION - Basin Floor 1, Sunday 2/29/2004

Universal Transverse Mercator (UTM) Coordinates
UTM Zone: 12R
Coordinate Datum = WGS84

Station	Easting	Northing
50W	573687.8051	3482230.217
100W	573630.2121	3482231.000
150W	573593.0911	3482219.440
200W	573528.4979	3482201.146
250W	573483.1770	3482196.069
300W	573425.7052	3482179.610
350W	573397.2639	3482165.733
400W	573341.7717	3482157.613
450W	573297.4907	3482149.572
500W	573247.1027	3482140.298
550W	573194.2418	3482120.305
600W	573151.5394	3482105.140
650W	573104.1504	3482104.213
700W	573051.6570	3482104.439
50E	573770.8445	3482234.372
100E	573827.4183	3482233.584
150E	573882.4044	3482241.108
200E	573932.8462	3482242.655
250E	573979.2281	3482241.795
300E	574029.1561	3482243.933
0	573733.6396	3482234.704
50N	573734.8151	3482284.659
100N	573733.4216	3482337.570
150N	573732.0701	3482384.534
200N	573733.2624	3482432.112
250N	573733.8778	3482489.199
300N	573734.0299	3482539.742
350N	573731.6803	3482583.726
400N	573729.8025	3482633.066
450N	573730.4010	3482692.531
500N	573730.0856	3482737.125
550N	573731.2652	3482786.486
0	573733.1426	3482232.916
50S	573733.0367	3482175.833
100S	573732.3287	3482131.827
150S	573733.1958	3482081.291
200S	573736.0382	3482039.688
250S	573734.8710	3481988.544

300S	573734.2135	3481937.402
350S	573734.0949	3481882.103
400S	573733.8587	3481843.451
450S	573729.6547	3481789.312
500S	573734.1017	3481737.018
550S	573735.4952	3481684.107

Table D.3: GPS LOCATION - School Basin TEM Survey, Saturday 3/20/2004

Universal Transverse Mercator (UTM) Coordinates
UTM Zone: 12R
Coordinate Datum = WGS84

Station	Easting	Northing
waypoint 105	570334	3491592